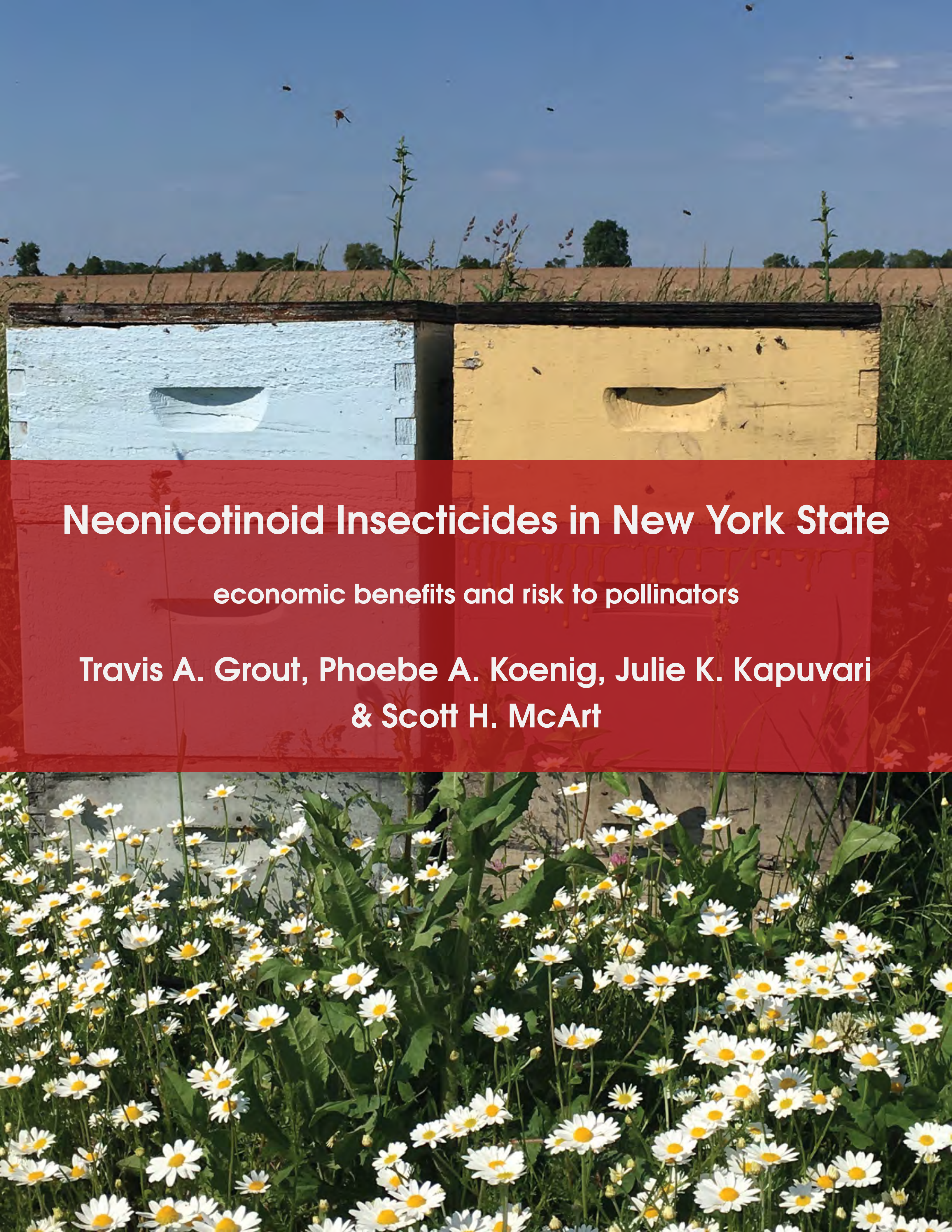

Neonicotinoid Insecticides in New York State

economic benefits and risk to pollinators

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1. Executive Summary

Insecticides are effective tools for controlling pests and therefore provide aesthetic, economic, agricultural, or conservation benefits to farmers, land managers, and other stakeholders. For some insect pests, chemical insecticides are currently the only practical, economical means of control. At the same time, insecticides can harm non-target organisms. This includes pollinators, some of which are currently experiencing range contractions and population declines. The scientific consensus is that, along with loss of habitat, climate change, parasites/disease, and inadequate management practices, insecticides and other pesticides are contributing to pollinator declines.

Since neonicotinoid insecticides first became commercially available in the early 1990s, they have become the most widely used class of insecticides in the world. Neonicotinoids are used as foliar sprays, soil drenches, trunk injections, and applied as seed coatings before planting. As with any pest management product or practice, the use of neonicotinoids has both benefits and risks. They are highly effective at controlling many types of insect pests and exhibit relatively low toxicity to humans, including pesticide applicators. All neonicotinoids are systemic, meaning they absorb into plant tissues and spread throughout the plant, providing continuous protection for a length of time. On the other hand, neonicotinoids can persist in the environment, accumulate in pollen and nectar, and are highly toxic to many non-target organisms, including insect pollinators.

In August 2018, with funding provided through the Environmental Protection Fund to research potential adverse impacts of pesticides, such as neonicotinoids, Cornell began developing a risk-benefit analysis of neonicotinoid insecticide usage in New York State with the following three goals: 1) Estimate the pest control and plant protection benefits of neonicotinoid insecticides under current usage in New York, 2) Estimate the risk from neonicotinoids to pollinators, and 3) Evaluate the relative benefits and risks of likely neonicotinoid substitutes (i.e., other insecticides or pest control strategies) compared to neonicotinoids. This report summarizes the research undertaken to address those goals.

As the scope of this report is limited to direct economic benefits to users and risk to pollinators, it is intended to complement existing studies and risk assessments, particularly the comprehensive reviews of neonicotinoid active ingredients conducted by the U.S. Environmental Protection Agency (USEPA) and New York State Department of Environmental Conservation (NYSDEC). At the same time, this risk assessment is unique in that it summarizes new analyses and quantifies benefits to users and risk to pollinators in a side-by-side manner for five major application contexts: field crops (corn, soybean, wheat), fruit crops (e.g., apple, strawberry, blueberry), vegetable crops (e.g., squash, pumpkin); ornamentals, turf, & landscape management (e.g., golf courses, ornamental plant nurseries), and conservation & forestry.

While this risk assessment is intended to support evidence-based decisions, we make no recommendations or policy prescriptions. Instead, this document aims to clarify the trade-offs between benefits to users and risk to pollinators that may be inherent to policy decisions or regulatory actions regarding neonicotinoid insecticides.

Value of neonicotinoids in New York State

Neonicotinoid products used outdoors[1] in New York contain the active ingredients acetamiprid, clothianidin, dinotefuran, imidacloprid, or thiamethoxam. These active ingredients are available in many formulations and labelled for use against numerous agricultural and landscape/ornamental pests, including aphids, adelgids, leafhoppers, flies, whiteflies, borers, leaf-feeding beetles, and white grubs. Neonicotinoids are also widely used for managing invasive forest pests such as hemlock woolly adelgid, emerald ash borer, and Asian longhorned beetle.

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[1] Though not addressed in this report, neonicotinoids are also used in some veterinary (e.g., flea treatments) and household (e.g., control of bed bugs) applications.

While alternative insecticides or pest control strategies exist for nearly all relevant target pests, switching from neonicotinoids usually entails a direct or indirect cost to users. Farmers and pesticide applicators choose products with care. When they use a neonicotinoid insecticide, it is typically because that product is the best option when considering price, efficacy, safety, insecticide rotation pattern, and other factors. The value of a neonicotinoid to users is the expected increase in benefits from using the neonicotinoid product instead of the best available non-neonicotinoid pest control product or technique. Many neonicotinoid-based products have important advantages that are difficult to quantify with existing data (e.g., safety for pesticide applicators, or the "insurance value" of preventive products that protect against unpredictable pests).

To assess the direct economic value of neonicotinoid insecticides for users, this report draws on data from over 5,000 paired field trials that compare the performance of a neonicotinoid-based insecticide to that of a chemical or non-chemical alternative. For many applications, the data show that neonicotinoids consistently increase net income, reduce crop damage, or provide superior pest control compared to likely substitutes. For other applications, the benefit to New York users is small or ambiguous.

For many New York fruit and vegetable crops, soil- and foliar-applied neonicotinoid products provide consistent benefits for farmers and are important components of insecticide rotations. For a handful of important pests, such as root-form phylloxera (grape), root weevils (berries), boxwood leafminer (ornamentals), and thrips and Swede midge (cabbage), there are few or no effective chemical alternatives available in New York. In cases where there are effective alternatives, they may be more expensive, require greater safety protection for applicators, or need to be applied more frequently. Even if there are effective, affordable substitutes for neonicotinoid products, farmers benefit from access to insecticides with diverse modes of action. The removal of any one insecticide from a rotation increases the risk of developing insecticide-resistant pest populations and increasing long-term pest management costs to farmers. In some foliar applications, products based on the neonicotinoid acetamiprid, which has relatively low toxicity to beneficial insects including pollinators, can be an effective alternative to those based on the nitroguanidine neonicotinoids imidacloprid and thiamethoxam.

In contrast to neonicotinoid applications in fruit and vegetable crops, routine use of neonicotinoid-treated seeds does not consistently increase net income for New York field corn or soybean producers.

Treated seeds are commonly used as a preventative measure rather than in response to site-specific risk from pests. While seed treatments benefit farmers when there is high early-season pest pressure, these benefits are limited to a small proportion of fields. Specifically, 87-93% of field trials find no increase (or a decrease) in corn yield compared to chemical alternatives or untreated controls when neonicotinoid-treated seeds are used in corn fields within the state, region, or North America. Even when compared to plots using no insecticides, 89% of field trials observe no increase in corn yield when neonicotinoid-treated seeds are used. Similarly, 82-89% of field trials find no increase (or a decrease) in soybean yield compared to chemical alternatives or untreated controls when neonicotinoid-treated seeds are used in soybean fields within the state, region, or North America. Nevertheless, neonicotinoid-treated seeds are used by nearly all conventional field corn farmers and, likely, the majority of soybean producers in New York. In part, this is due to the insurance value of neonicotinoid-treated seeds. Even if routine use of neonicotinoid-treated seeds does not increase expected net income, such preventative pest control products protect growers against unpredictable, potentially severe, losses from early-season pests. Incentives and policies to reduce usage of neonicotinoid-treated seeds may benefit from recognizing their value as inexpensive crop insurance as well as a pest management tool.

Risk of neonicotinoids to pollinators in New York State

Neonicotinoid insecticides potentially pose a risk to pollinators due to their high toxicity, systemic activity in plants (i.e., they spread throughout the entire plant, contaminating pollen and nectar, which are food sources for pollinators), and relatively lengthy persistence in the environment. A recent worldwide meta-analysis of in-hive pesticide residue studies found that, under current use patterns, five insecticides pose substantial risk to bees: thiamethoxam, phosmet, chlorpyrifos, imidacloprid, and clothianidin. Three of those five insecticides are neonicotinoids (thiamethoxam, imidacloprid, and clothianidin).[2] However, this study and others suggest that risk to pollinators from neonicotinoid insecticides varies greatly with the conditions of their use. Thus, to assess when and where neonicotinoids pose substantial risk to bees, we conducted a systematic review of over 400 peer-reviewed studies, performed a quantitative risk assessment based on the literature review, and conducted new research with honey bees and bumble bees in New York to assess exposure and risk in multiple settings.

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[2] Phosmet and chlorpyrifos are organophosphate insecticides.

The analysis shows that neonicotinoids can, but do not always, result in risk to bees in New York and elsewhere. The most comprehensive data come from field crops settings, particularly in and near corn and soybean fields. Data from ninety-six exposure assessments indicate that 74% of neonicotinoid exposures are likely to impact honey bee physiology, 58% of exposures are likely to impact honey bee behavior, and 37% of exposures are likely to impact honey bee reproduction. Exposures were often found at over 100 times the concentration known to impact pollinators. Furthermore, exposures in field crops settings occurred months and even years after neonicotinoids were used, indicating widespread contamination in and near corn and soybean fields. Particularly concerning is the ubiquity soils containing neonicotinoids at levels known to be toxic to pollinators. These contaminated soils pose a threat to ground-nesting bees, which comprise 54% of New York's 417 species of bees.

In addition to risk in field crops settings, the data indicate that neonicotinoids used on cucurbits and turf containing weedy flowers result in exposures that are likely to impact honey bee reproduction in 85% and 100% of cases, respectively. The USEPA has recently recognized the high risk of neonicotinoids in cucurbits, issuing a recommendation to prohibit use of imidacloprid-, clothianidin-, and thiamethoxam-based products on cucurbits between vining and harvest to protect pollinators. Our analysis extends this window before the vining stage, since applications before or during planting (i.e., treatments applied to soils before seeding or at the time of transplanting) result in exposures known to impact honey bee reproduction. In turfgrass settings, a simple and effective risk mitigation strategy exists: mowing turf before spray applications of imidacloprid is known to reduce concentrations in weedy flowers by 98%. In addition, use of the anthranilic diamide chlorantraniliprole as a substitute for imidacloprid results in much less risk to bees while providing similar control against important turfgrass pests.

Less comprehensive pollinator exposure data exists for other application contexts, limiting what can be inferred regarding risk from neonicotinoids in these contexts. This surprising knowledge gap is an important finding of this report. Specifically, aside from cucurbits, only four exposure assessments for pollinators (all from sunflower) have been conducted for other vegetable crops. Similarly, only eighteen exposure assessments have been conducted for ornamental plants, and only twenty-four exposure assessments exist for fruit crops. From these assessments, the data indicate that risk to bees can be high; 89% of neonicotinoid exposures in ornamentals are likely to impact honey bee physiology, 83%

of exposures are likely to impact honey bee behavior, and 61% of exposures are likely to impact honey bee reproduction.[3] The data from fruit crops also indicate that risk to bees can be high, but is lower than other application contexts; 50% of neonicotinoid exposures in fruit crops are likely to impact honey bee physiology, 38% of exposures are likely to impact honey bee behavior, and 17% of exposures are likely to impact honey bee reproduction. Additional studies focusing on neonicotinoid exposures to pollinators in vegetable crops, fruit crops, and ornamentals contexts would be helpful for understanding whether the limited data to date are representative of overall patterns.

Finally, it is important to emphasize that neonicotinoid usage does not always result in risk to pollinators, nor are neonicotinoids the only pesticides contributing to risk. For example, our own data from New York apple orchards and strawberry plantings during bloom shows that applications of acetamiprid result in the greatest insecticide exposures to bees in these crops. However, this neonicotinoid poses low risk to bees due to its low toxicity compared to the two nitroguanidine neonicotinoids (imidacloprid and thiamethoxam) and other non-neonicotinoid insecticides (e.g., chlorpyrifos and indoxacarb) that are currently used in New York fruit crops. In addition, risk to pollinators is likely negligible following trunk injections for invasive forest pests such as hemlock woolly adelgid, emerald ash borer, and Asian longhorned beetle, simply because pollinators are not likely to be exposed to neonicotinoids in those contexts. Thus, specific neonicotinoid active ingredient and application context are key considerations when evaluating risk from neonicotinoids and other pesticides to pollinators.

Relative benefits and risk of neonicotinoids compared to likely substitutes in New York State

Neonicotinoid insecticide applications in New York State have real benefits for insecticide users and real risks for insect pollinators. However, those benefits and risks vary greatly among common application contexts.

For some application contexts, the quantifiable benefits of neonicotinoids are minor or confined to a small number of users. Notably, neonicotinoid-treated corn and soybean seeds do not consistently increase expected net income compared to untreated seeds or pyrethroid insecticide alternatives.[4] At the

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[3] These summary values are only for ornamentals, while the summary values in Figures 6.6 & 6.7 also include turfgrass exposures.

[4] There is stronger evidence of net income benefits for neonicotinoid-treated seeds in vegetable crops, and field crops

same time, widespread use of neonicotinoid-treated seeds incurs risks for insect pollinators. In studies of neonicotinoid exposures in field crops, 37-74% of known exposures are predicted to have adverse impacts on honey bee behavior, physiology, or reproduction. Because pyrethroids are not systemic in plants and are less environmentally persistent, these alternatives likely pose less risk to pollinators compared to neonicotinoid-treated seeds. In addition, the anthranilic diamides chlorantraniliprole and cyantraniliprole show promise as alternative systemic insecticide seed treatments for corn and soybean, respectively, though they are currently more expensive than neonicotinoids. Finally, a main reason why preventative seed treatments are used so extensively in field crops is due to the unpredictable nature of early-season pest outbreaks. Further work to improve the predictability of such outbreaks via degree-day modeling that includes site-specific characteristics, or to control early-season pests with non-synthetic chemical insecticides (e.g., biocontrols, biopesticides or RNA-based approaches), will increase the sustainability and security of field crops production in New York.

In other application contexts, a shift away from neonicotinoids will likely place a greater burden on farmers and pesticide applicators. As noted above, there are few or no effective chemical alternatives to neonicotinoids for several important agricultural pests (e.g., root-form phylloxera, root weevils, boxwood leafminer, Swede midge). Even when effective substitutes are available, the loss of neonicotinoids from insecticide rotations would be problematic for some New York crops. Long-term control of the Colorado potato beetle and other important pests may be difficult without access to insecticides with several different modes of action, including neonicotinoids. If treated repeatedly with a single class of insecticide, pest populations can develop resistance more rapidly. That said, chemical insecticides are not the only means of controlling the vast majority of agricultural and non-agricultural insect pests in New York. Integrated Pest Management (IPM) that includes pest monitoring, non-synthetic chemical insecticides, and new technologies that are rapidly emerging in the digital and precision agriculture fields, provide multiple tools for farmers and pesticide applicators to control insect pests. Again, greater development and adoption of these non-synthetic chemical pest control options will increase the sustainability and security of New York agriculture, while also reducing risk to non-target organisms in non-agricultural contexts such as turf/ornamentals and conservation/forestry.

For a few application contexts, restrictions on neonicotinoids could have negative environmental

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growers do benefit from the insurance value of neonicotinoid-treated seeds.

consequences. Most importantly, New York relies on neonicotinoid-based products to contain and control hemlock woolly adelgid. There are currently no effective, affordable alternatives for slowing progress of this pest, which kills almost 100% of infested trees. Hemlocks are the third most common tree in New York, and are an ecologically important foundation species, so ending control of hemlock woolly adelgid with neonicotinoids could have severe consequences for New York forests. Because pollinators are not known to interact extensively with wind-pollinated hemlocks, risk to pollinators is likely negligible following trunk injections with neonicotinoids in this context.

Overall, this report aims to summarize current knowledge regarding the direct economic benefits of neonicotinoid insecticides to users and risk to pollinators in New York. The report does not assess other environmental risks or indirect economic impacts associated with usage of neonicotinoid insecticides. We suggest a key contribution of the report is showing that benefits and risks of neonicotinoids vary based on numerous factors such as neonicotinoid type, crop or pest system, application method and timing, and landscape context. Furthermore, it is essential to consider risk from neonicotinoids in relation to their likely substitutes. No pest management product or technique is risk-free, and several likely alternatives to neonicotinoid products pose risks of their own. To this end, we make note of contexts in which IPM approaches, non-synthetic chemical insecticides, and other pest control technologies are likely to be effective. A key recognition of this report is the need for continual, science-based, adaptive approaches to IPM through investment in research and extension of that research to farmers and other pesticide applicators in New York. With new technologies rapidly emerging in digital and precision agriculture, along with more biologically-based solutions, there is an ongoing need for pest control tools that are effective while also being environmentally sustainable. Farmers and other pesticide applicators will adopt environmentally sustainable solutions when such solutions are easy to use, relatively inexpensive, safe and effective.

As outlined above and throughout the report, while this risk assessment is intended to support evidence-based decisions, we make no recommendations or policy prescriptions. Finding the “best policy” or “best policies” for neonicotinoid insecticides in New York will require thoughtful choices between competing priorities.

2. Scope and Methods

The goal of this report is to summarize the benefits and risks of neonicotinoid insecticides and their alternatives in New York State, **focusing specifically on direct economic benefits to users and risk to non-target insect pollinators**. Given this limited scope, we do not attempt to capture all benefits and risks associated with neonicotinoid insecticides and their alternatives. Rather, this report is written to complement existing studies and risk assessments. This chapter lays out the scope of this work, the methods used, and the key assumptions underlying our analysis.

For our estimates of economic benefits, we quantify changes in insecticide purchase costs, application costs, and (for agricultural uses) crop yield over a single growing season when switching from a neonicotinoid product to an alternative. We do not predict how changing products would influence longer-term farm or landscape management decisions, nor do we quantify indirect economic effects from such decisions. A farmer switching from a neonicotinoid product to an alternative might change other farm practices, such as cover cropping, manure use, and crop rotation patterns. Similarly, non-agricultural neonicotinoid users might change some landscape management practices if switching to non-neonicotinoid alternatives[1]. However, there is insufficient data to predict how a shift away from

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Photo by Ohio Department of Health, Consumer Protection Lab.

[1] For example, insecticide-treated seeds have made it easier for farmers to adopt cover cropping by reducing the risk of damage from insect pests overwintering in cover crops. Some New York farmers may forgo cover crops if neonicotinoid-treated seeds are more expensive or unavailable. Others may continue to plant cover crops, but could change other management

neonicotinoids would influence these decisions. This report does, however, note several applications of neonicotinoids in which indirect economic effects may be particularly important.

Similarly, this report focuses specifically on risk to pollinators, not risk to other non-target organisms. Human health risks from neonicotinoid insecticides and their alternatives are briefly described later in this chapter and mentioned throughout the report, but we do not exhaustively synthesize or quantify this topic because it has been addressed extensively in risk assessments by the USEPA and New York State Department of Environmental Conservation (NYSDEC). We also do not quantify the risks of neonicotinoids and their alternatives to other non-target organisms (e.g., aquatic invertebrates, amphibians, non-pollinator terrestrial arthropods, birds). Again, we refer the reader to the peer-reviewed literature and recent analyses by federal and state regulatory agencies addressing these risks.

With these important boundaries of the report clarified, we can set out to assess the direct economic benefits to users and risks to pollinators from neonicotinoid insecticides and their alternatives. However, before doing so, we need to answer three basic questions:

First, what is a neonicotinoid insecticide? We cover this topic in *Chapter 3*, where we describe the chemical properties of the five major neonicotinoid insecticides labeled for use in New York, then outline their development and history.

Second, how are neonicotinoid insecticides currently regulated and used in New York? We cover this topic in *Chapters 3 and 4*, where we first describe federal and state regulation of neonicotinoid insecticides, then describe common application methods (e.g., seed treatments, foliar sprays, trunk injections) and provide extensive information on which pests are targeted by users of neonicotinoid insecticides in different application contexts. Five major contexts are described: field crops (corn, soybean, and wheat), fruit crops (e.g., apples, grapes, berries), vegetable crops (e.g., beans, squash, potatoes), ornamentals, turf, & landscape management (e.g., outdoor ornamental plants, golf courses, private homes and gardens), and conservation & forestry (e.g., hemlock and ash trees). Sources of information and methods describing how current usage patterns in each application context were quantified are outlined below in Section 2.1.

Third, what are the most likely substitutes for neonicotinoid insecticides? We cover this topic in

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practices (potentially increasing costs) to adapt. Still others may continue existing cover crop management. The report addresses this potential effect of neonicotinoid restrictions, but does not attempt to predict the proportion of farmers that will choose a particular response.

Chapter 4, where we outline likely short-term alternatives to neonicotinoids in each application context. This report emphasizes currently-available alternatives to neonicotinoids; the quantitative analyses do not include products that are currently in development, even if they appear promising, because their introduction to the market is uncertain.

In *Chapter 5*, we draw on earlier risk assessments and over 500 additional peer-reviewed studies to quantify the value of the most common uses of neonicotinoids in New York relative to the most likely substitute insecticide(s) or other pest management strategies. For each neonicotinoid use outlined in *Chapter 4*, we estimate how net income and/or pest control costs would change if the state's farmers, businesses, or homeowners no longer had access to neonicotinoid-based products. Methods, assumptions, and limitations for the economic analysis are described below in Section 2.2. In *Chapter 6* we do the same for pollinator risk, first quantifying risk to pollinators from neonicotinoid insecticide usage in each application context outlined in *Chapter 4*, then comparing risk from neonicotinoids to risk from alternatives. Methods describing the pollinator risk assessment protocols are outlined below in Section 2.3. Finally, in *Chapter 7* we summarize the report's findings on benefits and risks of neonicotinoids and their alternatives in a side-by-side manner for each application context. We highlight where important data gaps exist and suggest promising areas for future research.

2.1 Identifying neonicotinoid uses in New York

This report draws on several sources to identify common uses of neonicotinoid insecticides in New York State. The most comprehensive estimates of agricultural neonicotinoid use in New York are those of the U.S. Geological Survey (USGS) Pesticide National Synthesis Project, which published estimates of agricultural pesticide use by crop and state based on user surveys through 2014 [908, 35]. The USGS estimates through 2014 reflect both pesticide applications and the use of pesticide-treated products such as neonicotinoid-treated seeds.[2]. Treated seeds are the dominant use of neonicotinoids, by quantity of active ingredient, in the United States [990, 985]. As discussed further in *Chapter 4*, this is also likely to be true for New York State, where neonicotinoid-treated seeds are widely used when planting corn,

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[2] Planting pesticide-treated seeds is not a pesticide application as defined under federal and state law (see Section 3.1) A facility that applies pesticide treatments to seeds is subject to EPA regulations for pesticide applications, as well as the regulations of the state in which it is located. If a given pesticide is not registered in New York, growers may still purchase and use seeds treated with that pesticide by facilities in other states.

soybean, and several vegetable crops.

New York's Pesticide Sales Use and Reporting (PSUR) database provides valuable data on neonicotinoid insecticide applications made or supervised by commercial applicators and technicians in the state. Under New York State's Pesticide Reporting Law (see Section 3.1),[3] each commercial application of a pesticide must be reported to the NYSDEC. The report includes basic information on the product used, date applied, quantity applied, and location. Data from those reports are available through the PSUR database. The database also includes all sales by in-state vendors of restricted-use pesticides to private applicators, which are reported by law. Pesticide-coated seeds are exempt from these regulations, because planting them is not considered a pesticide application (see Section 3.1). Therefore, New York's pesticide sales and application data do not reflect use of treated seed by New York farmers.

The U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) tracks pesticide use through the Agricultural Chemical Use Program [954]. This program surveys growers of major commodities on a rotating basis. Complementing the PSUR and USGS data, this is a useful tool to identify major uses of neonicotinoids and trends in usage.

Finally, this analysis draws on a variety of academic and extension sources. In particular, we relied on the decades of experience and knowledge of Cornell professors and staff who have formal research and extension responsibilities for the crops and non-agricultural uses evaluated in this report. Additionally, we relied heavily on Cornell Cooperative Extension (CCE) experts and published CCE Guides[4] series of publications on pest management, crop production, and landscape/garden plant maintenance. These sources of information were invaluable in identifying relevant pest management challenges, key neonicotinoid uses, and the trade-offs facing insecticide users.

2.2 Assessing relative value of insecticides

The quantitative economic analysis in this report is based on a partial budgeting model. The partial budgeting approach is appropriate for analyzing the net income effects on a business of changing one aspect of its operations [865]. It does not address overall profitability or viability. In the context of this

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[3] Environmental Conservation Law Article 33, Title 12

[4] CCE Guides include regularly updated volumes covering field crops, grapes, berry crops, tree fruits, vegetable crops, trees and shrubs, greenhouse crops and herbaceous ornamentals, and home pest control.

report, it focuses on the immediate impact of exchanging one insecticide for another on pest control costs and farm revenue. It does not attempt to quantify potential indirect effects on farm operations or planning, though we discuss such potential impacts in the text (see "Limitations" below).

To establish bases for comparison, this report identifies the most likely substitute(s) for neonicotinoids for each of their common uses in New York. For some crops, this report benefits from previous research on farmer's insecticide preferences or changes in pest management strategy following neonicotinoid restrictions (e.g., responses to the EU neonicotinoid ban). In most cases, though, such research either does not exist or is not appropriate to predict behavior in New York. In such cases, we selected the most likely substitutes using CCE guidance, other extension publications, and input from subject matter experts. We used the same process to identify substitutes for commercial landscape and residential applications.

Having identified substitutes for each common neonicotinoid use, we estimated production and pest management costs based on published studies of the relevant neonicotinoid product and likely substitutes. Estimated value of production is based on the ten-year average price received by U.S. farmers for the given commodity, as estimated by the USDA NASS. If the likely substitute would require additional crop scouting[5] and pesticide applications, we estimated additional grower costs using mean values from recent state extension surveys of farm custom work rates[6] [148, 677, 1036, 46, 204, 484, 690, 538]. For foliar insecticides, we assume additional costs of $12.17 per hectare ($4.93/A) for scouting and $21.16 per hectare ($8.57/A) for application. For preventive insecticides applied to the soil at planting, we assume additional planting costs of $3.05 per hectare ($1.24/A).

Our methodology for assessing the value of landscape and residential insecticide uses is, by necessity, different than for agricultural uses. The value of an agricultural pesticide is ultimately determined by its effect on a farm's net income. Quantifying the value of pesticides used in commercial landscaping is not as straightforward. Cosmetic insect damage to landscaping may make a golf course, shopping center, or hotel less appealing to its customers; however, it is difficult to measure this effect directly. Similarly, it is difficult to measure the value of an attractive lawn or garden to residential

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[5] Scouting, here, is the process of checking crops for pests, diseases, and various other indicators of health and growth. Regular and systematic scouting is an important component of integrated pest management.

[6] The cost of hiring a contractor or another farm operator to provide machinery or services on a farm.

pesticide users. For our analysis, we assume that landscape and residential users need to achieve a certain level of pest control, and will choose the most cost-effective insecticide available to do so.

2.2.1 Limitations of the economic analysis

The partial budgeting model described above quantifies the immediate net income effects of replacing a neonicotinoid-based product with a non-neonicotinoid alternative. The data underlying this analysis come from field trials comparing efficacy of a neonicotinoid-based product (measured in terms of yield, crop damage, or pest control) to one or more chemical alternatives or control plots. The quantitative analysis aggregates data from these trials to compare neonicotinoid performance to a given category of alternatives (i.e., those using a particular application method or class of active ingredients). Therefore, it may not capture variations in performance between products or formulations in that category of alternatives. Similarly, while we discuss some non-chemical management options in the text, the quantitative analysis does not distinguish between these options.[7] The benefits analysis also does not consider pest management strategies that would take several seasons to implement (e.g., changes to crop rotations) or pest management options that may become available in the future (e.g., novel insecticides or improved pest forecasting). Over the long term, farms and other insecticide users would adjust to neonicotinoid restrictions in less obvious ways (as, indeed, all businesses respond to changes in the cost and availability of inputs). For example, if neonicotinoid restrictions increased costs or losses for one crop, some operators might shift acreage to another crop, use a more pest-resistant cultivar, or change capital spending plans to adapt. Long term, new insect management technologies and techniques currently under development will be commercialized; other insecticides will leave the market due to regulatory action or unprofitability.

In addition to net income benefits, neonicotinoids are valuable because of their low toxicity to humans. Replacing neonicotinoids with more toxic alternatives (e.g., insecticides in the organophosphate group) could lead to a net increase in injuries and illnesses to pesticide applicators, farm workers, and other exposed individuals. Further work to quantify the relative risks of neonicotinoid and non-neonicotinoid alternatives to pesticide applicators would be useful.

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[7] For example, a comparison plot that used no pest management techniques and a comparison plot timing planting to reduce the risk of pest infestations would both be considered “untreated” in the quantitative analysis.

Table 2.1: **Insecticide Resistance Action Committee (IRAC) mode of action groups for common insecticides**

Group abbreviation, group name, and IRAC number			**Selected active ingredients and products**
NEO	**Neonicotinoids**	**4A**	Acetamiprid, clothianidin, dinotefuran, imidacloprid, thiamethoxam *Actara, Admire, Assail, Cruiser, Gaucho, Merit, Platinum, Poncho*
AND	**Anthranilic diamides**	**28**	Chlorantraniliprole, cyantraniliprole, flubendiamide *Acelepryn, Altacor, Exirel, Ference, Fortenza, Lumivia, Verimark*
AVR	**Avermectins and milbemycins**	**6**	Abamectin, emamectin benzoate *Agri-Mek, Proclaim*
BNZ	**Benzoylureas**	**15**	Novaluron *Rimon*
BPR	**Buprofezin**	**16**	Buprofezin *Applaud*
BT	***Bacillus thuring--iensis* (Bt)**	**11A**	Varieties of the bacterium *Bacillus t.* and its insecticidal proteins *Agree, DiPel, Trident*
CRB	**Carbamates**	**1A**	Aldicarb, carbaryl, methomyl, oxamyl, thiodicarb *Lannate, Sevin*
FLN	**Flonicamid**	**29**	Flonicamid *Aria, Beleaf*
OP	**Organophosphates**	**1B**	Acephate, chlorpyrifos, diazinon, dimethoate, malathion, phorate *Imidan, Lorsban, Orthene, Thimet*
OXD	**Oxadiazines**	**22A**	Indoxacarb *Avaunt, Provaunt*
PAD	**Pyridine azomethine derivatives**	**9B**	Pymetrozine, pyrifluquinazon *Endeavor, Fulfill*
PYR	**Pyrethroids**	**3A**	Bifenthrin, cyfluthrin, cypermethrin, esfenvalerate, tefluthrin *Asana, Baythroid, Brigade, Danitol, Force, Mustang, Pounce, Warrior*
SPN	**Spinosyns**	**5**	Spinetoram, spinosad *Conserve, Delegate, Entrust, Radiant*
TTA	**Tetronic and tetramic acid derivatives**	**23**	Spirotetramat *Movento*
UN	**Unknown or uncertain mode of action**	**UN**	Azadirachtin *Aza-Direct, AzaSol, Molt-X, Neemix*

This table is limited to IRAC groups, active ingredients, and products referred to in this report; it is not a comprehensive list.

This report deals with several other potential economic effects qualitatively. In some applications, the “insurance value” of preventive neonicotinoid products may be more important than their effect on net income. Even if they do not raise yield or lower pest damage for the majority of users, they may make outcomes more predictable and reduce financial risk to users.

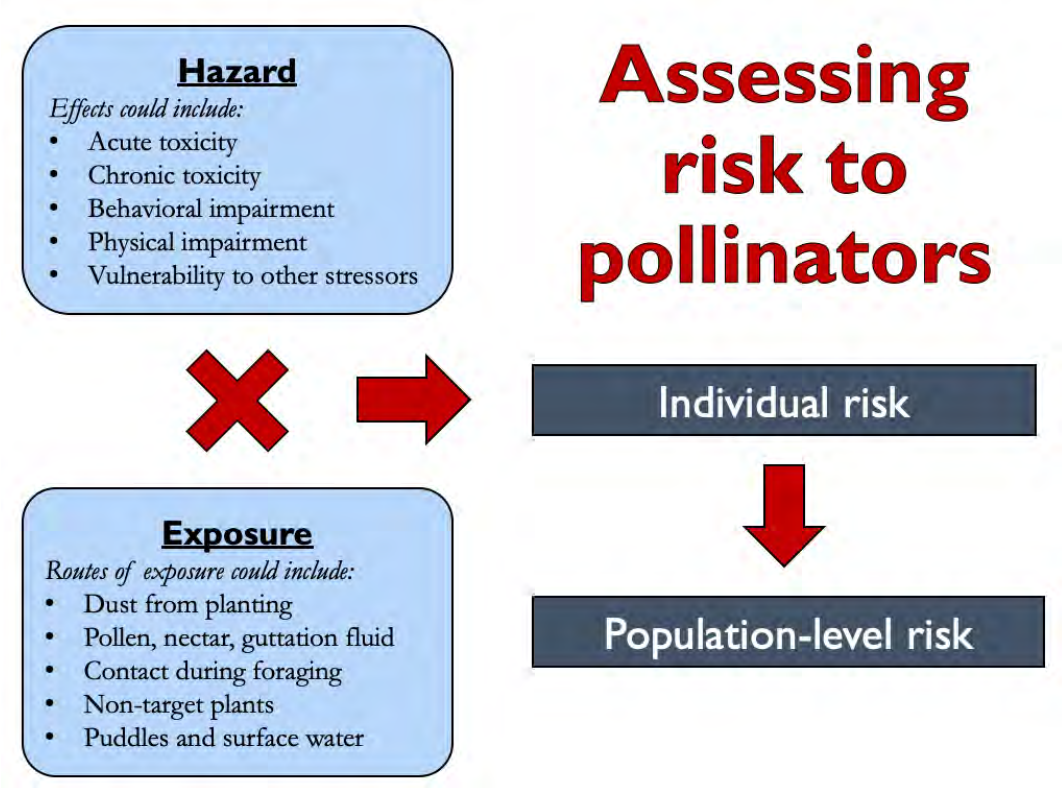
2.3 Assessing risk of insecticides to pollinators

Chapter 6 of this risk assessment synthesizes current knowledge on the magnitude of risk from neonicotinoids as a sole stressor on pollinators. This chapter does not quantify risk from interactions between neonicotinoids and other stresses (e.g., synergisms with fungicides, increased susceptibility to parasites/pathogens) because the scientific community currently lacks robust methods to quantify the magnitude of such risk. Furthermore, this risk assessment does not attempt to assess the relative importance of risk from neonicotinoid insecticides compared to other stressors (e.g., loss of habitat, parasites/pathogens) because this information is rarely known and is likely to be context-dependent. Thus, the scope of *Chapter 6* is to estimate when and where exposure to neonicotinoid insecticides is likely to cause lethal and/or sublethal effects on pollinators.

The environmental risk of a pesticide is a product of hazard and exposure (see Figure 2.1). A hazard is any potentially harmful effect that a pesticide can have on a person, organism, or ecological system of interest. Exposure is the quantity of pesticide that the person, organism, or ecological system contacts or ingests. Risk, therefore, is the likelihood that a hazard will result in harm given the amount and nature of exposure in real-world conditions. Risk can be mitigated by reducing or eliminating exposure to hazards; indeed, mitigating risk is the primary purpose of the USEPA and NYSDEC pesticide registration process. As an example, Figure 2.1 lists several hazards and routes of exposure relevant to evaluating pesticide risk to insect pollinators.

In this report, we use three metrics to assess risk: the Environmental Impact Quotient (EIQ), the Hazard Quotient (HQ), and comparisons of observed insecticide exposure in the field to the Lowest Observed Effect Concentration (LOEC) for the relevant active ingredient. All three metrics are frequently used in risk assessment literature. The EIQ has been evaluated or adapted by numerous researchers for their own risk rating schemes, and values continue to be updated by Cornell University

Figure 2.1: **Example of hazard, exposure, and risk**



via the New York State Integrated Pest Management Program[8]. The HQ and LOEC are both commonly used by regulatory agencies, including the USEPA, when assessing risk to non-target organisms. For risk to pollinators, the USEPA considers HQ and LOEC results during Tier II or III risk assessments [6]. Such assessments are conducted by the USEPA when warranted following Tier I assessment, as has been the case for all neonicotinoid insecticides.

2.3.1 Environmental Impact Quotient (EIQ)

The EIQ was first described in Kovach et al. [459] and the database of EIQ values is maintained and updated by Eshenaur et al. [242]. The EIQ estimates the risk of a pesticide active ingredient per pound applied by combining data on toxicity and likelihood of exposure into a formula consisting of three equally-weighted components: farm worker, ecological, and consumer risk. The underlying data are

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[8] www.nysipm.cornell.edu/publications/eiq/

largely drawn from information submitted during the EPA pesticide registration process. Lower EIQ values generally indicate lower environmental risk. The formula used to determine the EIQ value of a pesticide is given in equation 2.1.

$$\begin{aligned} EIQ = \frac{1}{3} \times \{ &\Big(\; C\times[(DT\times 5)+(DT\times P)] \; \Big) && \leftarrow \textbf{farm worker component}\\ &+\begin{pmatrix} (F\times R)+(D\times \frac{S+P}{2}\times 3)\\ +(Z\times P\times 3)+(B\times P\times 5)\end{pmatrix} && \leftarrow \textbf{ecological component} \\ &+\Big(\; (C\times(\tfrac{S+P}{2}\times SY)+L) \; \Big)\} && \leftarrow \textbf{consumer component}\end{aligned} \tag{2.1}$$

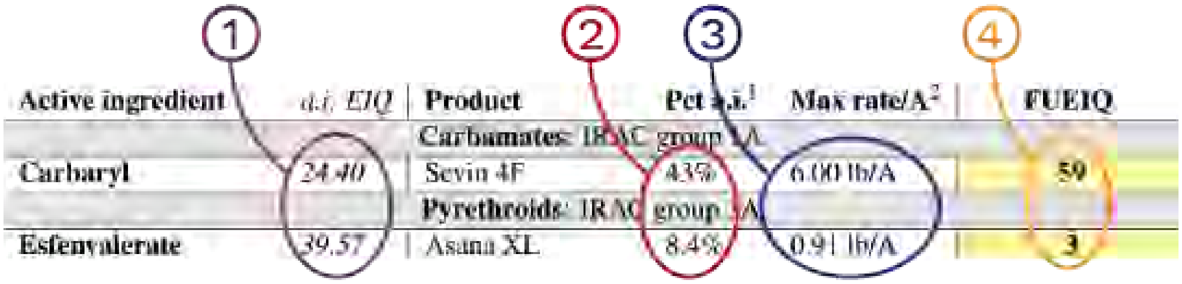
C	chronic toxicity (human)	R	surface loss potential	B	beneficial arthropod toxicity
DT	dermal toxicity (human)	D	bird toxicity	SY	systemicity
P	plant surface half-life	S	soil half-life	L	leaching potential
F	fish toxicity	Z	bee toxicity		

The Field Use Environmental Impact Quotient (FUEIQ), derived from the EIQ, is the estimated risk of a pesticide at a given application rate. It can, therefore, be used to compare the risk of different pesticide applications as they would be used in the field. Therefore, we only report FUEIQ in this document, not EIQ values (which reflect risk per pound of active ingredient). Throughout the report, we compute FUEIQ using the *Calculator for Field Use EIQ* developed by Grant [327]. As an illustration, Table 2.2 lists the FUEIQ of a single application of several insecticides labeled for control of apple maggot (see Section 4.2)), as well as three characteristics needed to calculate the FUEIQ for each product: the base EIQ for its active ingredient, the percent of the product that is active ingredient, and the product's application rate per acre (FUEIQ in this report is calculated using the maximum single-application rate). Figure 2.2 walks through the process of calculating FUEIQ for two non-neonicotinoid products: Sevin 4F and Asana XL.

FUEIQ allows easy comparisons of the estimated risk of different pesticides or management strategies. However, these estimates should be used with caution. FUEIQ calculations do not reflect

Figure 2.2: **Interpreting Field Use Environmental Impact Quotient (FUEIQ)**

Chapter 4 uses FUEIQ to illustrate differences in environmental risks among multiple insecticide products that may be used to control a given pest. This figure, drawing on Table 2.2, illustrates the process used to calculate FUEIQ for two products allowed for use to control apple maggot in New York State: Sevin 4F (with active ingredient carbaryl) and Asana XL (with active ingredient esfenvalerate).



Active ingredient	a.i. EIQ	Product	Pct a.i.[1]	Max rate/A[2]	FUEIQ
		Carbamates: IRAC group 1A			
Carbaryl	*24.40*	Sevin 4F	43%	6.00 lb/A	**59**
		Pyrethroids: IRAC group 3A			
Esfenvalerate	*39.57*	Asana XL	8.4%	0.91 lb/A	**3**

① Environmental impact quotient (EIQ) of the active ingredients

Based solely on the EIQs of their respective active ingredients, one might suppose that a carbaryl (EIQ: 24.40) product like Sevin 4F would have lower risk than an esfenvalerate (EIQ: 39.57) product like Asana XL. However, active ingredients' EIQs do not reflect differences in the quantity of active ingredient used in the field. Product FUEIQs, which take this into account, are more appropriate for comparing the environmental risk of different pesticide products or treatment plans.

② Percent active ingredient

The active ingredient rarely makes up 100% of a pesticide product. Here, note that Sevin 4F contains 43% carbaryl while Asana XL contains 8.4% esfenvalerate.

③ Maximum application rate per acre

FUEIQ calculations in this report use the maximum amount of a given product, per application, that is allowable for use to control a given pest on a given crop. Maximum application rates are listed on product labels, which are legally enforceable. Note that the application rate for Asana XL is much lower than that of Sevin 4F.

④ Product FUEIQ

Finally, we can calculate FUEIQ by multiplying the EIQ by the percent active ingredient and the application rate. The FUEIQs for our two sample products are:

Sevin 4F: 24.40*0.43*6.00 = **58.6**

Asana XL: 39.57*0.084*0.91 = **3.0**

Despite the higher EIQ of esfenvalerate, an application of Asana XL has a much lower FUEIQ than an application of Sevin 4F, as relatively little esfenvalerate is used per acre. Controlling apple maggot with Asana XL has lower estimated environmental risk than controlling that pest with Sevin 4F.

Table 2.2: **Calculating Field Use Environmental Impact Quotient (FUEIQ) for selected foliar sprays used to control apple maggot**

Active ingredient	*a.i. EIQ*	**Product**	**Pct a.i.**[1]	**Max rate/A**[2]	**FUEIQ**
Neonicotinoids (NEO):			IRAC group 4A		
Acetamiprid	*28.73*	Assail 30SG	30%	0.50 lb/A	**4**
Imidacloprid	*36.71*	Admire Pro	42.8%	0.18 lb/A	**3**
Thiamethoxam	*33.30*	Actara 25WDG[3]	25%	0.34 lb/A	**3**
Anthranilic diamides (AND):			IRAC group 28		
Chlorantraniliprole	*20.07*	Altacor[3]	35%	0.28 lb/A	**2**
Cyantraniliprole	*11.7*	Exirel[3]	10.2%	1.28 lb/A	**2**
Carbamates (CRB):			IRAC group 1A		
Carbaryl	*24.40*	Sevin 4F	43%	6.00 lb/A	**59**
Organophosphates (OP):			IRAC group 1B		
Phosmet	*32.82*	Imidan 70W	70%	5.75 lb/A	**109**
Oxadiazines (OXD):			IRAC group 22A		
Indoxacarb	*31.19*	Avaunt 30WDG	30%	0.38 lb/A	**4**
Pyrethroids (PYR):			IRAC group 3A		
Esfenvalerate	*39.57*	Asana XL	8.4%	0.91 lb/A	**3**
Lambda-cyhalothrin	*44.17*	Warrior II	22.8%	0.12 lb/A	**1**
Spinosyns (SPN):			IRAC group 5		
Spinetoram	*28.74*	Delegate WG	25%	0.44 lb/A	**3**

Notes: See Table 2.1 for active ingredient group abbreviations. (1) Percent of the product, by weight or volume, that is the listed active ingredient. (2) Maximum amount of the given product, per acre, that is allowable for use in a single application to apple trees in New York State for control of apple maggot. Growers may make multiple applications per season of some products. For liquid products, the EIQ assumes that 1 fluid ounce weighs one ounce (this introduces slight inaccuracies, as actual specific gravities of liquid pesticides vary). (3) Sale and use prohibited in Nassau and Suffolk Counties. Use outside of these counties permitted with a 2(ee) recommendation.

data gaps and uncertainty,[9] environmental conditions during application, and non-linear relationships between insecticide dose and environmental risks. In order to have comparable underlying data for most pesticides, the EIQ mainly relies on categories of studies that are standard in the USEPA risk assessment process for new active ingredients (see Section 6.1 for more detail on this process). Toxicity ratings used in the EIQ are based on toxicity to the model species used in those studies. Other species coming into contact with a pesticide may be more or less vulnerable than those model species. The EIQ, like any risk assessment tool, was created with implicit value judgements about which types of impacts should be considered and the relative importance of different hazards and routes of exposure included in the EIQ formula. EIQ is a helpful tool, particularly for practitioners comparing pesticide

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[9] Cornell's EIQ database substitutes average values for missing toxicological data points [242].

options. It is not (nor was it intended to be) a definitive measure of total environmental risk.[10]

2.3.2 Hazard Quotient (HQ)

This report uses HQ to estimate risk to honey bees from neonicotinoid insecticides. Unlike FUEIQ, which predicts but does not measure exposure, HQ incorporates measured exposure values into its estimate of risk. Specifically, quantitative levels of pesticide residues in a given exposure matrix (e.g., pollen, nectar, wax) are assessed, then these exposure values are weighted by the hazard of each pesticide residue by dividing by its LD_{50} value for an organism of interest (i.e., the lethal dose for 50% of organisms in a 48-hour laboratory trial). The sum of each residue, divided by its LD_{50} value, thus represents the acute risk from that particular sample, as outlined in equation 2.2:

$$HQ = \sum_{i=1}^{n} (residue_i \div LD_{50i}) \tag{2.2}$$

Several regulatory agencies and peer-reviewed studies use HQ to estimate acute pesticide risk to pollinators. In addition, regulatory agencies such as the USEPA have defined "levels of concern" for acute contact exposure based on an HQ value for a given organism. Thus, a clear benchmark is set by the USEPA that defines when contact exposure to a pesticide is considered an acute risk. This benchmark can be highly useful when considering if a pesticide does or does not pose acute contact risk to a target organism.

At the same time, the HQ metric has some disadvantages. The USEPA does not set official benchmarks for acute oral exposure (this is especially important for neonicotinoid insecticides, which are more toxic to bees via oral exposure than contact exposure). In addition, sublethal effects on organisms (e.g., impacts on physiology or reproduction) are not considered via HQ, nor is risk from chronic exposures. In addition, USEPA's (and this report's) use of HQ to assess risk to pollinators is reliant upon the western honey bee (*Apis mellifera*) being a useful surrogate for all pollinators (see Section 6.6.1). Honey bees are a common model organism in toxicological studies, and there is a

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[10] All FUEIQ calculations in this document are rounded to the nearest unit. Small differences in FUEIQ are not indicative of meaningful differences in environmental risk.

substantial literature quantifying hazards to honey bees from neonicotinoids and alternative insecticides. Relatively few data exist regarding hazard of pesticides to most other invertebrate pollinators. The little that is known suggests other pollinators may be more sensitive to the same concentrations of pesticides when compared to *A. mellifera*. Thus, HQ results presented in this risk analysis are likely to be conservative when considering the full diversity of New York's pollinators, which include 417 bee species. More work is needed to clarify how New York's wild bees and other pollinators differ in their responses to insecticides compared to the western honey bee.

2.3.3 Lowest Observed Effect Concentration (LOEC)

The LOEC is the lowest observed concentration of a substance that produces an adverse, statistically significant effect on a given organism. Unlike the HQ metric, which is useful for estimating acute risk, the LOEC approach estimates risk from sublethal effects and chronic exposures. This approach can be advantageous since it relies on more information than acute short-term hazard studies to inform when a pesticide is likely to have an effect on an organism. This is especially relevant to the current risk assessment since the consensus in the scientific community is that sublethal effects from multiple stressors are responsible for current pollinator declines [83, 197, 326].

To assess risk from sublethal effects and chronic exposure to pesticides, the USEPA and peer-reviewed studies often compare the LOEC to pesticide exposure observed in the field (measured via quantitative levels of pesticide residues in a given exposure matrix such as pollen, nectar, or wax). The LOEC for multiple response categories of interest can be determined (e.g., physiology, behavior, reproduction), then compared to field exposure data to estimate risk that a pesticide will impact each organismal process. This can lead to sophisticated insight for syntheses such as the current risk assessment, especially when a large amount of LOEC data exists for an organism of interest. Such is the case for the western honey bee (*A. mellifera*), as shown in *Chapter 6*. However, as with HQ, this reliance upon *A. mellifera* assumes it is a useful surrogate for all pollinators. While this is certainly not true, the studies that have assessed sublethal effects of neonicotinoid insecticides on other bee species have generally found those other species to be more sensitive. Thus, the LOEC-based results presented in this risk analysis is likely to be conservative when considering the full diversity of New

York's pollinators.

2.4 Neonicotinoids and human health

This risk assessment was commissioned to focus on risk to pollinators from neonicotinoid insecticides and their alternatives. Thus, risk to other non-target organisms, including humans, is not exhaustively synthesized in this report for practical reasons. However, because human health is always an important consideration, here we point the reader to the most up-to-date information from the USEPA. Specifically, risk to human health from neonicotinoid insecticides is summarized in the following references for acetamiprid [971], clothianidin [974], dinotefuran [978], imidacloprid [983], and thiamethoxam [989].

All humans may be exposed to pesticides through ingestion of contaminated water or food, but the risks from pesticides are greater for pesticide applicators and those who work and live near application areas. Neonicotinoids are designed to specifically target insects and are therefore considered less harmful to mammals than most insecticides with older chemistries, such as pyrethroids and organophosphates. As described in Section 3.2, neonicotinoids function by binding with nicotinic acetylcholine receptors (nAChRs) in the insect brain. Neonicotinoids show low affinity for vertebrate nAChRs, so exposure to humans must be substantial to cause acute toxicological effects. Mammals can rapidly metabolize and eliminate neonicotinoids [989, 983, 978, 971, 974]. Furthermore, the USEPA has determined that neonicotinoids are not likely to be carcinogenic[11] [971, 974, 983, 989, 289, 290, 291, 292]. Finally, mammals have a barrier separating circulating blood from the brain and central nervous system, which limits (though does not eliminate) neonicotinoid penetration of the brain [1101, 925, 757].

Tables 2.3, 2.4, and 2.5 show the label safety statements that are required by the USEPA to protect applicators of neonicotinoid and alternative insecticide products used on apple, potato, and turf. The purpose of these tables is *not* to quantitatively compare human health risks from neonicotinoid and alternative insecticides; rather, the purpose is to illustrate how the USEPA considers hazard to applicators among several different insecticide products. Insecticide labels may be required to display a

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[11] We base this statement on several reviews of relevant research. The USEPA classified thiamethoxam, but not other neonicotinoids, as a likely human carcinogen from 2002 based on studies in mice [334, 926, 957]. It revised that decision in 2007 based on subsequent research suggesting that thiamethoxam was unlikely to be carcinogenic in humans [335, 655, 960].

signal word (caution, warning, danger, or danger-poison). They also may be required to state an oral, dermal, inhalation, or eye hazard, and must say what PPE is required to mix and apply the chemical. Additionally, they must state how soon after application the area can be re-entered without PPE, and the PPE required to enter prematurely. Since this report focuses on neonicotinoids and their most likely alternatives, we use one common neonicotinoid product for each crop as a reference. We then indicate whether other pesticide products have greater, lesser, or equal protections in each category for applicators. For each crop, there are alternative insecticide products that require greater applicator protections than the reference neonicotinoid, and products that require fewer protections. It is important to note that these tables denote the hazard, not the risk, of products to applicators. If all protections on the label of an insecticide product are followed, there will be minimal and equal risk for each insecticide as determined by the USEPA.

2.5 Key assumptions of this document

As in any risk assessment, this study makes several assumptions about future behavior by neonicotinoid producers and users:

1. **Consistent insecticide formulations.** In order to estimate and compare impacts, we assume that insecticide formulations and tank mixes will stay the same for the immediate future. This is a potential source of uncertainty, as the inert ingredients and adjuvants applied with insecticides can have a significant impact on efficacy and risks.
2. **Consistent treated area.** This report assumes that New York farmland area, and the acreage devoted to particular crops, will remain the same. There is some evidence that neonicotinoid restrictions in Europe led some growers to switch crops or reduce acreage; however, we cannot forecast likely acreage changes with existing data. In this context, holding the treated area constant allows more useful comparisons.
3. **Consistent insecticide choices and prices.** There are numerous active ingredients that may be viable alternatives to neonicotinoids in specific applications (discussed in *Chapter 4*). However, the most likely substitutes for neonicotinoids fall within a small number of insecticide families. We assume that growers will choose between the same insecticides (and non-chemical pest man-

agement techniques) available to them today. Our analysis cannot account for future restrictions on currently available non-neonicotinoid insecticides or the introduction of new insecticides. We also assume that insecticide product prices and application costs (drawn from agricultural extension publications) will stay constant over time. This analysis does not reflect expected increases in farm labor costs or reductions in the cost of (currently) novel pest control products.

4. **Consistent target pests.** Insect pest challenges facing New York farmers are not constant. Some pests become less damaging over time due to seed producers incorporating insect resistant traits, the success of biological control measures, or the adoption of farm practices that limit the likelihood of infestation or likelihood of economic crop damage. New invasive crop pests periodically arrive, and existing pests may become more damaging. Climate change also affects the pest outlook for New York farmers. In the future, New York is likely to be wetter in the spring, dryer in the fall, and warmer overall than the historical norm [966]. These changes will make New York more hospitable to some insect crop pests. This study takes these changes into account where practical (for instance, by noting emerging insect pests controlled by neonicotinoids). However, we cannot confidently predict long-term pest pressures, and must base our analysis of benefits and risks on existing data. These unpredictable long-term changes may make neonicotinoids more or less effective in New York agriculture.
5. **Consistent commodity prices.** The benefits analysis estimates gross income per hectare based on prices paid to New York farmers in the three most recent USDA survey years. It also assumes that state-level changes in insecticide usage would not substantially change prices paid to producers. Substantially higher or lower commodity prices would change the value of neonicotinoid products relative to alternatives.
6. **Consistent policies outside of New York.** Federal policy or regulatory changes would directly affect the insecticides available to New York growers. Even decisions in other states or foreign countries or restrictions made by produce markets or food processors (on, for instance, acceptable pesticide residues on fresh foods) can change pesticide usage in New York State by making it more or less profitable to produce or use a given active ingredient. As we cannot predict how out-of-state pesticide policy and regulations will change, we assume a constant regulatory

environment.

7. **Negligible risk to pollinators from household pest control and antiparasitic uses.** This report focuses on outdoor use of neonicotinoids to protect plants, and does not consider products that control pests in households (e.g., bedbugs, ants, cockroaches), fleas and ticks on pets, or insect parasites of livestock. Such applications are unlikely to lead to substantial exposure for insect pollinators.

Table 2.3: **Comparison of USEPA label safety statements to protect applicators for selected neonicotinoid-based and alternative insecticide-based products used to control common apple pests.**

Chemical class (IRAC group)	**Active ingredient**	**Product**	**Signal word**	**Oral hazard**	**Dermal hazard**	**Inhalation hazard**	**Eye hazard**	**PPE, mixing**	**PPE, applying**	**Re-entry interval**	**Early-entry PPE**
NEO	Acetamiprid	Assail 30SG	C	H	H	H	MI	G	G	12 hrs	CG
NEO	Imidacloprid	Admire Pro	o	o	o	o	o	o	o	o	o
NEO	Thiamethoxam	Actara 25WDG	o	o	o	o	o	o	o	o	o
AND	Cyantraniliprole	Exirel	o	-	-	-	o	o	o	o	o
AVR	Abamectin	Agri-Mek 8SC	+	+	o	+	o	o	+	o	o
BNZ	Novaluron	Rimon 0.83EC	+	-	o	-	+	+	+	o	+
CRB	Methomyl	Lannate LV 2.4L	+	+	o	o	+	+	+	+	+
CRB	Carbaryl	Sevin XLR Plus	o	o	o	o	-	+	+	o	o
FLN	Flonicamid	Beleaf 50SG	o	o	o	-	o	-	-	o	o
OP	Phosmet	Imidan 70W	+	+	+	+	o	+	+	+	o
OXD	Indoxacarb	Avaunt 30WDG	o	o	o	o	o	o	o	o	o
PYR	Fenpropathrin	Danitol 2.4EC	+	+	o	o	+	+	+	+	+
PYR	Lambda-cyhalothrin	Warrior II	+	+	o	-	o	+	+	+	o
SPY	Spinetoram	Delegate 25WG	o	-	-	-	o	-	-	-	o
TTA	Spirotetramat	Movento 240SC	o	o	o	-	o	+	+	+	+
UN	Azadirachtin	Aza-Direct	o	o	o	o	o	o	o	-	o

Key: **C** = Caution; **CG** = Coveralls and gloves; **G** = Gloves; **H** = Hazard

MI = Moderate irritation; **PPE** = Personal protective equipment

- = Label suggests **lesser** hazard from exposure compared to Assail 30SG;

o = Hazard or PPE language identical or comparable to that of Assail 30SG;

+ = Label suggests **greater** hazard from exposure compared to Assail 30SG.

Notes: As part of the pesticide registration process, the USEPA assesses data about potential effects on human health, wildlife, plants, and surface/ground water. This information is incorporated into the product label in the form of informational statements on how to safely use and handle the product. This table compares product label applicator hazard warnings and protection measures for neonicotinoid (light blue) and non-neonicotinoid (dark blue) insecticides that may be used to control several common pests on apple trees (see Table 4.3). The baseline for this table is the label language used for Assail 30SG, an acetamiprid-based foliar insecticide. Signal words, hazard statements, Personal Protective Equipment (PPE) requirements, and re-entry interval relate to a product's *hazards*, which reflect the harm it might cause [992]. However, higher hazard is not equivalent to higher *risk*, which depends upon both hazard and exposure. A pesticide applicator following all label requirements and using mandated personal protective equipment, which limit the potential for exposure, should not experience elevated risk. See Table 2.1 for active ingredient group abbreviations.

Table 2.4: **Comparison of USEPA label safety statements to protect applicators for selected neonicotinoid-based and alternative insecticide-based products used to control common potato pests.**

Chemical class (IRAC group)	Active ingredient	Product	Signal word	Oral hazard	Dermal hazard	Inhalation hazard	Eye hazard	PPE, mixing	PPE, applying	Re-entry interval	Early-entry PPE
NEO	Acetamiprid	Assail 30SG	C	H	H	H	MI	G	G	12 hrs	CG
NEO	Imidicloprid	Admire Pro	o	o	o	o	o	o	o	o	o
AVR	Abamectin	Agri-Mek SC	+	+	o	o	o	o	o	o	o
BT	Bacillus t. (Bt)	Trident	o	-	o	o	o	+	+	-	+
CRB	Methomyl	Lannate LV	+	+	o	o	+	+	+	+	+
FLN	Flonicamid	Beleaf 50SG	o	o	o	-	o	-	-	o	o
OP	Dimethoate	Dimethoate 400	+	+	o	-	+	+	+	+	o
OXD	Indoxacarb	Avaunt	o	o	o	o	o	o	o	o	o
PAD	Pymetrozine	Fulfill	o	-	o	-	-	o	o	o	o
PYR	Beta-cyfluthrin	Baythroid XL	+	+	o	o	+	+	+	o	+
PYR	Esfenvalerate	Asana XL	+	+	-	+	-	+	+	o	+
SPY	Spinosad	Entrust SC	-	-	-	-	-	-	-	o	-
UN	Azadirachtin	Neemix 4.5	o	o	o	o	-	+	+	-	+

Key: **C** = Caution; **CG** = Coveralls and gloves; **G** = Gloves; **H** = Hazard
MI = Moderate irritation; **PPE** = Personal protective equipment

- = Label suggests **lesser** hazard from exposure compared to Assail 30SG;
o = Hazard or PPE language identical or comparable to that of Assail 30SG;
\+ = Label suggests **greater** hazard from exposure compared to Assail 30SG.

Notes: As part of the pesticide registration process, the USEPA assesses data about potential effects on human health, wildlife, plants, and surface/ground water. This information is incorporated into the product label in the form of informational statements on how to safely use and handle the product. This table compares product label applicator hazard warnings and protection measures for neonicotinoid (light blue) and non-neonicotinoid (dark blue) insecticides that may be used to control several common pests on potato (see Table 4.7). The baseline for this table is the label language used for Assail 30SG, an acetamiprid-based foliar insecticide. Signal words, hazard statements, PPE requirements, and re-entry interval relate to a product's *hazards*, which reflect the harm it might cause [992]. However, higher hazard is not equivalent to higher *risk*, which depends upon both hazard and exposure. A pesticide applicator following all label requirements and using mandated personal protective equipment, which limit the potential for exposure, should not experience elevated risk. See Table 2.1 for active ingredient group abbreviations.

Table 2.5: **Comparison of USEPA label safety statements to protect applicators for selected neonicotinoid-based and alternative insecticide-based products used to control common pests of turfgrass.**

Chemical class (IRAC group)	**Active ingredient**	**Product**	**Signal word**	**Oral hazard**	**Dermal hazard**	**Inhalation hazard**	**Eye hazard**	**PPE, mixing**	**PPE, applying**	**Re-entry interval**
NEO	Imidacloprid	Merit 0.5G	C	H	H	NN	I	WC	WC	NN
NEO	Imidacloprid	Armortech IMD 75	o	o	o	+	o	+	+	+
AND	Chlorantraniliprole	Acelepryn G	-	-	-	o	-	+	+	+
AND	Cyantraniliprole	Ference	-	-	-	o	-	+	+	+
BT	Bacillus t. (Bt)	DiPel Pro DF	o	-	o	+	o	+	+	+
CRB	Carbaryl	Sevin SL	o	o	o	+	+	+	+	+
PYR	Bifenthrin	0.15G ProSect	o	o	o	o	o	o	o	+
PYR	Trichlorfon	Dylox 420SL	o	o	o	o	o	+	+	+
SPY	Spinosad	Conserve SC	-	-	-	o	-	+	+	+
TTA	Indoxacarb	Provaunt WDG	o	o	o	o	o	o	o	+

Key: **C** = Caution; **H** = Hazard; **I** = Irritation; **NN** = None noted;
PPE = Personal protective equipment; **WC** = Work clothes

- = Label suggests **lesser** hazard from exposure compared to Merit 0.5G;
o = Hazard or PPE language identical or comparable to that of Merit 0.5G;
+ = Label suggests **greater** hazard from exposure compared to Merit 0.5G.

Notes: As part of the pesticide registration process, the USEPA assesses data about potential effects on human health, wildlife, plants, and surface/ground water. This information is incorporated into the product label in the form of informational statements on how to safely use and handle the product. This table compares product label applicator hazard warnings and protection measures for neonicotinoid (light blue) and non-neonicotinoid (dark blue) insecticides that may be used to control several common pests of turfgrass (see Table 4.12). The baseline for this table is the label language used for Merit 0.5G, an imidacloprid-based granular insecticide. Signal words, hazard statements, PPE requirements, and re-entry interval relate to a product's *hazards*, which reflect the harm it might cause [992]. However, higher hazard is not equivalent to higher *risk*, which depends upon both hazard and exposure. A pesticide applicator following all label requirements and using mandated personal protective equipment, which limit the potential for exposure, should not experience elevated risk. See Table 2.1 for active ingredient group abbreviations.

3. Introduction to Neonicotinoids

Neonicotinoids are the world's most widely used class of insecticides, making up more than 25% of the global market [852]. Their principal use in the United States generally, and New York specifically, is in seed treatments [908, 35, 211, 201]. Among major New York crops, neonicotinoid-treated seeds are used for the majority of conventional field corn and are common in soybean, snap bean, sweet corn, and cucurbit cultivation [154, 149]. In addition, growers, land managers and other stakeholders use neonicotinoids via foliar sprays, trunk injections, and soil drenches.

Widespread adoption of neonicotinoids occurred quickly: imidacloprid, the first commercially successful neonicotinoid, debuted in 1991 and was the best-selling insecticide in the world (by value) by 1999. Taken together, the six principal neonicotinoid active ingredients were the world's best-selling group of insecticides[1] by 2008. Growers, land managers and other stakeholders adopted neonicotinoids quickly because they have several major advantages relative to older insecticide classes [428, 621, 832, 570]. First, neonicotinoids are effective against a broad range of insect pests, including those that had developed resistance to other insecticides. Second, neonicotinoids are systemic (i.e., they are taken up and spread throughout the plant, protecting all plant tissues) and persistent (potent against pests for an extended period), which reduces the need for repeated insecticide applications and, often,

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Photo by Heping Zhu, USDA Agricultural Research Service.

[1] Insecticides are commonly organized into groups of active ingredients with the same mode of action (see Table 2.1).

the total quantity of insecticide needed for protection. Third, neonicotinoid-treated seeds require less labor to use than alternative flowable or granular insecticides applied at planting. Fourth, and perhaps most importantly, neonicotinoids are often safer for pesticide applicators than older broad-spectrum insecticides such as organophosphates, pyrethroids and carbamates (see Tables 2.3, 2.4, and 2.5 for examples).

However, neonicotinoid use has also attracted significant public, scientific, and regulatory attention over the past two decades due to concerns about environmental impacts and risk to non-target organisms. Some of the very qualities that make neonicotinoids useful for crop protection can be problematic for non-target organisms, including insect pollinators. For example, the systemic activity of neonicotinoids in plants can protect all parts of a plant against target pests, but pollinators may be exposed to neonicotinoids translocated to pollen and nectar. Currently, over 400 peer-reviewed studies have examined hazard or exposure of neonicotinoid insecticides to bees. As discussed in *Chapter 6*, exposures to neonicotinoid concentrations that often occur in the field can negatively impact honey bee physiology, behavior, and reproduction. These findings have prompted concern in the context of broader pollinator declines around the world, as well as our increasing global reliance on pollinators for agricultural production [9].

Around the world, risks to pollinators and other non-target organisms from neonicotinoid insecticides have featured prominently in risk assessments by several regulatory agencies over the past decade. The European Union imposed a moratorium on outdoor uses of the most common neonicotinoids[2] in 2013 [267, 269, 270]. The EU made the moratorium permanent in 2018, justified largely by its assessment of risk to pollinators [271, 272, 273]. Canada considered a similar ban [667, 668, 669], opting instead to phase in new restrictions starting in 2019 [670, 671, 672]. Australia also reviewed environmental risks associated with neonicotinoids, concluding that additional restrictions were not justified [28].

In the United States, the USEPA is in the final stages of registration reviews of five neonicotinoid active ingredients (all pesticide active ingredients undergo routine registration reviews). After releasing

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[2] The moratorium applied to the nitroguanidine neonicotinoids: clothianidin, dinotefuran, imidacloprid, and thiamethoxam. The cyanoamidine neonicotinoid acetamiprid, which is substantially less toxic to pollinators, was not subject to the EU moratorium. Section 3.4 describes the differences between nitroguanidine and cyanoamidine neonicotinoids.

topic-specific risk assessments for all neonicotinoid insecticides from 2016 through 2018 (see Table 6.1), the USEPA published proposed interim decisions for public comment in January 2020. The proposed interim decisions recommend updating standards for some uses of neonicotinoids and additional restrictions on others. We highlight proposed changes that, if accepted, are likely to impact major uses of neonicotinoids in New York State in Section 3.4 below. The USEPA risk assessments have attracted extraordinary public attention, including over 1.4 million public comments.[3]

It is well known that neonicotinoid insecticides are not the only stressor impacting pollinators. Pollinator declines are occurring due to multiple factors, including loss of habitat, parasites/pathogens, invasive species, climate change, inadequate management practices for domesticated bees, and exposure to pesticides [326]. Furthermore, interactions among stressors are important. For example, inadequate nutrition can exacerbate the negative effects of pesticides [739], exposure to pesticides can increase susceptibility to parasites/pathogens [894], and inadequate management practices for domesticated bees such as honey bees and bumble bees can lead to declines in their health as well as parasite/pathogen spillover into the broader pollinator community [330, 331, 16]. In addition, a growing body of evidence suggests interactions between pesticides, especially interactions between fungicides and insecticides (including neonicotinoids), can result in up to 1000-fold increases in toxicity of the blend compared with exposure to each pesticide independently [679, 816, 419, 437]. Research to better understand interactions among stressors is sorely needed since important data gaps exist that can potentially inform actionable risk mitigation strategies by regulatory agencies and the public.

While risks to pollinators from neonicotinoid insecticides exist, economic benefits to users of neonicotinoid insecticides also exist. However, to our knowledge, no risk assessment to date on this topic has conducted a side-by-side synthesis of economic benefits of neonicotinoid insecticides to users and risks to pollinators in the multiple contexts in which neonicotinoids are used. Such an analysis is likely to be useful for policymakers and the public, who may want to consider both factors when deciding whether or not risks of neonicotinoid insecticide usage outweigh benefits, or vice versa, in particular application contexts. In this report, we summarize an effort with this

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[3] Total individual submissions recorded in regulations.gov dockets for FIFRA section 3(g) reviews of acetamiprid (case #7617) clothianidin (case #7620), dinotefuran (case #7441), imidacloprid (#7605), and thiamethoxam (#7614) as of January 14, 2020. This figure would not include all comments submitted by mail, phone, or via third parties, nor any comments submitted during the public comment period starting February 2020.

exact goal in mind. Specifically, we summarize a side-by-side comparison of economic benefits of neonicotinoid insecticides to users and risks to pollinators in five major application contexts: field crops (corn, soybeans, wheat), fruit crops (e.g., apple, strawberry, blueberry), vegetable crops (e.g., squash, pumpkin); ornamentals, turf, & landscape management (e.g., golf courses, ornamental plant nurseries), and conservation & forestry (protecting trees from invasive insect pests). In addition, when data exist, we compare economic benefits and/or risk to pollinators from alternative chemical insecticides.

3.1 Federal and State regulation

Under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA),[4] pesticides distributed or sold in the United States must be registered with the USEPA with few exceptions. USEPA registration requires the registrant to demonstrate that a new pesticide "will not cause unreasonable risk to man or the environment, when used in accordance with widespread and commonly accepted practice, taking into account the economic, social, and environmental costs and benefits of the use of any pesticide" before it can be sold in the United States. Registrants commission studies to evaluate the potential hazard and exposure of a given product to people and the environment, given its expected uses. Applicant-submitted studies and scientific data must meet USEPA methodological standards and undergo peer review. The USEPA is responsible for assessing risk based on all available information, working with the registrant to mitigate risks when necessary, and making regulatory decisions on registration issuance, labelling, and food tolerances.

All registered insecticides must be accompanied by a USEPA-approved label [992]. It is illegal to use a pesticide in a manner inconsistent with its label. Labels may include a wide variety of mandatory statements to manage risk associated with a given product, including provisions related to worker safety (e.g., PPE for pesticide applicators) and environmental protection (e.g., minimum distance between application site and surface water). Insecticides known to be hazardous to bees, including neonicotinoids, include language on pollinator protection. Label requirements may include specific measures to protect pollinators, imposing limits on when and how the product can be used. For example, many insecticides may not be used while the target plant is in bloom (limiting direct exposure

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[4] 7 U.S.C. §136 et seq. (1996)

to foragers). Since 2013, labels of insecticides containing any of four neonicotinoid active ingredients[5] must include a “Pollinator Protection Box” highlighting those products’ hazards to bees and application restrictions for pollinator safety [962].

Section 2(ee) of FIFRA allows use of a pesticide against target pests not specified on the label, as long as the label does not specifically limit usage to named pests. In New York, any 2(ee) exceptions must be approved by the NYSDEC. “Special Local Need” provisions, in Section 24(c) of FIFRA, allow states to request limited exceptions to USEPA-approved uses of a pesticide, either permitting a local use that was not part of the USEPA registration or imposing additional restrictions on local uses. As of February 12, 2020, the New York State Pesticide Administration Database (NYSPAD) listed 37 FIFRA 2(ee) recommendations and 6 Special Local Need labels for neonicotinoid-based products.

The NYSDEC regulates pesticides at the state level. Among other responsibilities, the NYSDEC oversees state pesticide registration, enforces relevant laws, and approves 2(ee) recommendations. Any pesticide that requires USEPA registration must also be registered with the NYSDEC prior to sale or use in New York State. New York prohibits or otherwise restricts numerous USEPA-registered pesticide uses, including some uses of neonicotinoid insecticides (see Section 5.3). The NYSDEC also oversees certification requirements for pesticide applicators and technicians. Under federal and state law, any person who applies or supervises the application of a restricted use pesticide (a category which includes some products based on or containing neonicotinoids) must be certified as either a private or commercial applicator. Private applicator certification is for growers: the pesticide must be used for agricultural production on land owned or rented by the applicator or his/her employer. In New York, commercial applications of pesticides can be made only by certified commercial applicators, certified commercial technicians, or trained apprentices working under the direct supervision of a certified commercial applicator; certified technicians must also be under the direct supervision of a certified commercial applicator when applying restricted-use pesticides.

New York State law requires that pesticide technicians and applicators who are seeking certification must meet initial training requirements and pass a certification exam specific to the applicable pesticide category (applicators, but not technicians, may be certified in multiple categories). Pollinator protection

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[5] Specifically, the nitroguanidine neonicotinoids: clothianidin, dinotefuran, imidacloprid, or thiamethoxam (see Section 3.4.

is part of the certification training and exam for the agricultural plants category. Certified pesticide applicators must meet continuing education requirements or pass recertification exams to maintain their certification. Training manuals (on which certification exams are based) developed by Cornell Cooperative Extension's Pesticide Management Education Program cover pollinator protection, as do numerous training events that count toward continuing education credits.

The USEPA applies FIFRA's Treated Article Exemption[6] to seeds treated with pesticides before planting.[7] As such, seeds treated with pesticides do not need to be registered as pesticides provided that (1) the pesticide used is already registered with the USEPA and (2) the treatment is "for the protection of the seed itself" [999]. Planting treated seeds is, therefore, not a pesticide use. In the context of New York, planting pesticide-coated seeds does not trigger state pesticide use reporting, and New York's pesticide sales and application data do not reflect treated seed use. In practical terms, NYSDEC registration decisions for pesticide seed coatings only constrain New York seed treatment facilities. Such businesses can only use active ingredients registered with the NYSDEC, but New York farmers are free to purchase seeds treated in other states. By and large, NYSDEC registration decisions do not affect the availability and prices of treated seed products for New York farmers.

Specifically related to pollinators (and more specifically using the honey bee, *Apis mellifera*, as a model organism), the USEPA has conducted risk assessments for all five neonicotinoids used in New York: acetamiprid [970], clothianidin [985], dinotefuran [976], imidacloprid [965], and thiamethoxam [985]. In their risk assessments, USEPA reviews required tests from registrants as well as the peer-reviewed literature; the latter includes studies on sublethal hazards from neonicotinoid insecticides and exposures in specific application contexts. We draw on data from these USEPA risk assessments throughout the report.

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[6] 40 CFR § 152.25

[7] This interpretation of federal law has attracted some controversy. In 2018, for instance, the USEPA sought public comment on a petition to re-interpret the Treated Article Exemption to exclude planted seeds treated with systemic insecticides [109, 993].

3.2 Mode of action

Neonicotinoids are synthetic insecticides, similar to nicotine but designed to specifically target insects.[8] Neonicotinoids act as agonists in organisms with a central nervous system by binding to nAChR receptors, which prevents nAChRs from accepting neurotransmitters [31, 428]. Since nAChRs play an essential role in transmitting nerve impulses, this inhibits normal neuromuscular functions. Neonicotinoids are highly selective to insect pests, binding readily and irreversibly to insect nAChRs, but infrequently and weakly to vertebrate nAChRs [239]. Mammals, including humans, do not readily absorb neonicotinoids through the skin or mucus membranes [757]. Neonicotinoid-based insecticides are thus relatively safe for people to handle and use [926].

All neonicotinoids have systemic properties. The active ingredients are moderately water-soluble, allowing them to be taken up by plants and translocated to all parts of the plant [428]. Once inside a plant systemic insecticides tend to degrade more slowly and provide longer-lasting protection than non-systemic products exposed to rain, wind, and sun [239]. Neonicotinoids also have translaminar properties. Plants can also absorb neonicotinoids applied to fruits, leaves, flowers, or stems [280], albeit less efficiently than soil- or seed-applied neonicotinoids [568]. After penetrating the cuticle, the active ingredient can circulate to other parts of the plant. A single neonicotinoid application or neonicotinoid-treated seed may protect a plant for weeks [779]. Neonicotinoid applications to protect trees from invasive forest pests can be effective for a year or more [160]. Systemic insecticides can be applied as a precautionary measure to protect against a large number of sucking and biting insect pests for a predictable period. These are important advantages for many growers, reducing labor and increasing predictability of pest control [570, 621, 832, 590].

3.3 Development and history

Nicotine has been used to control insect pests since at least 1690 [545], but was never an ideal commercial insecticide due to its toxicity to humans and therefore applicators. Following the development of synthetic organic insecticides in the 1940s, chemists made several attempts to find more effective and

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[8] Nicotine, in contrast, is more toxic to mammals than to insects. Historically, nicotine was used as an organic insecticide, but is no longer available commercially due to its risks to users [1108, 757].

Table 3.1: **Major neonicotinoids' year of introduction**

Active Ingredient	**Developer(s)**	**U.S. patent**[1]	**First sales**[2]	**USEPA registration**[3]
Imidacloprid	Bayer CropScience	1985	1991	1994
Acetamiprid	Nippon Soda	1988	1995	2002
Clothianidin	Bayer CropScience & Sumitomo	1989	2001	2003
Thiamethoxam	Syngenta	1992	1997	1999
Dinotefuran	Mitsui Chemicals	1993	2002	2004

Notes: (1) Year of U.S. patent priority; (2); Year of first commercial sales in the world; (3) Year of initial U.S. pesticide registration.

selective compounds using nicotine's mode of action [906].

Shell Development Company discovered the first neonicotinoid in 1970, ultimately commercialized as nithiazine [456]. Despite its promising qualities, nithiazine was consigned to niche livestock applications and household pest control because it breaks down quickly in sunlight [10]. Bayer finally cleared the photo-stability hurdle in the 1980s. Its new insecticide, imidacloprid, was effective and selective like nithiazine, but also persistent under field conditions. Bayer launched its first imidacloprid-based insecticides in 1991 and secured USEPA registration in 1994. The NYSDEC issued the first state-level registrations for imidacloprid-based insecticides in March 1995 [599]. By 1999, imidacloprid (under its various trade names) was the most popular single insecticide in the world [1108, 896].

Several of Bayer's competitors developed effective neonicotinoids in the late 1980s and early 1990s, but imidacloprid was well-established before any rivals made it to market. The USEPA approved the second neonicotinoid, Syngenta's thiamethoxam, for commercial use in 1999. Acetamiprid, thiacloprid, clothianidin, and dinotefuran were on the U.S. market by 2004.

Neonicotinoids rapidly gained market share, even as the overall insecticide market shrank [115, 1033]. According to a study by Jeschke et al. [428], neonicotinoids represented 24% of global insecticide sales by 2008. Imidacloprid alone was 10% of insecticide sales by value. Demand for some older, more toxic insecticide classes had declined since the introduction of imidacloprid in 1991. From 1990 to 2008, organophosphates' global market share declined from 43% to 14%, carbamates' from 16% to 11%, and pyrethroids' from 18% to 16%. Studies in the United States also suggest a strong correlation between increased neonicotinoid use and decreased applications of organophosphates and carbamates [398, 95]. While neonicotinoids made a major splash in the broader insecticide market, they revolutionized insecticidal seed coatings [349, 211, 35]. The market for such seed treatments grew by more than 600% between 1990 and 2008, with neonicotinoids making up 80% of sales [428].

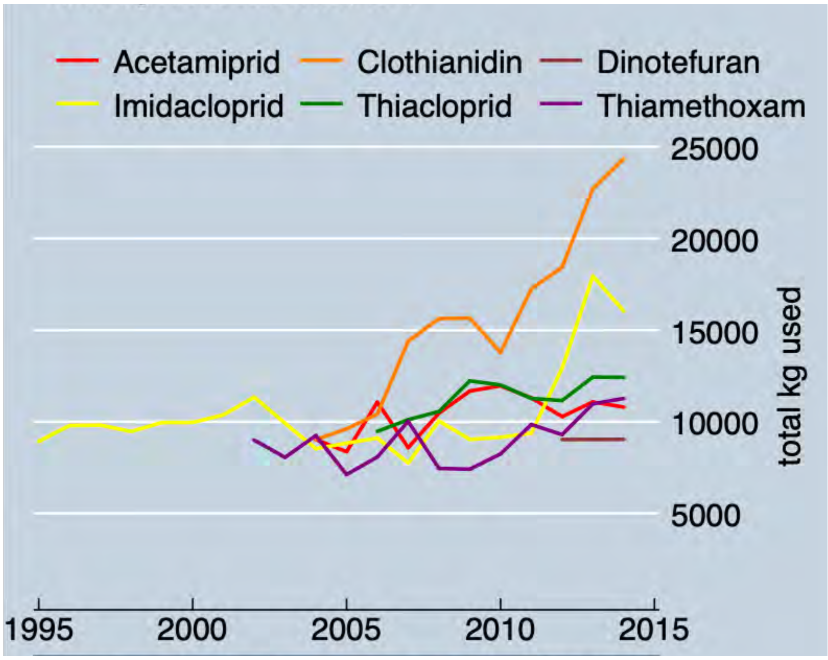
Despite restrictions on their use in some countries, most notably in the EU after 2013, neonicotinoids have largely maintained their global market position. They made up more than 25% of global insecticide sales in 2014 [44], roughly the same as in 2008. In the United States, nearly all conventional field corn is planted with a neonicotinoid-based seed treatment. Such seed treatments are also common for soybean, cotton, canola, sorghum, wheat, and several vegetable crops [571]. As required for all pesticide active ingredients by the Food Quality Protection Act, the USEPA is undertaking its regularly scheduled registration reviews of five neonicotinoids and, after releasing topic-specific risk assessments from 2016 through 2018, published proposed interim decisions in January 2020 [995, 996, 997, 998].

3.4 Neonicotinoids used in New York

Five neonicotinoids are commonly used in New York State. While each have unique characteristics, there are significant differences in the hazards posed by the four *N*-nitroguanidine (nitro-substituted) neonicotinoids and the *N*-cyanoamidine (cyano-substituted) acetamiprid. Most of the controversy surrounding neonicotinoids has focused on members of the nitroguanidine group. The EU's "neonicotinoid ban," in fact, affects only nitroguanidines; the European Food Safety Authority (EFSA) decided against new restrictions on the cyanoamidine neonicotinoid acetamiprid. Compared to the cyanoamidine group, nitroguanidine neonicotinoids (clothianidin, dinotefuran, imidacloprid, and thiamethoxam) are more common, better studied, and more acutely toxic to pollinators. In New York, many uses of nitroguanidine neonicotinoids require a licensed applicator; acetamiprid is not a restricted use pesticide (see Table 3.2). Nevertheless, cyanoamidine neonicotinoids also present environmental risks.

We do not address several uncommon or novel neonicotinoid active ingredients in this study. Nitenpyram is primarily used for fast-acting, short duration flea and tick control. It is most familiar to consumers as the active ingredient in Capstar products for cats and dogs, and has some livestock applications. Novel neonicotinoids include cycloxaprid, imidaclothiz, and paichongding. None are commonly used in the United States, and are not considered in this risk assessment.

Figure 3.1: **Neonicotinoid use in New York, 1995-2014**



USGS low estimate of annual agricultural usage, 1995-2014 [908]. USGS high estimates of annual agriculture usage were, for these active ingredients in New York, an average of 4% higher than the low estimates. Includes neonicotinoid-treated seeds planted in New York. Thiacloprid is included in this chart, but thiacloprid-based products are no longer sold in the United States.

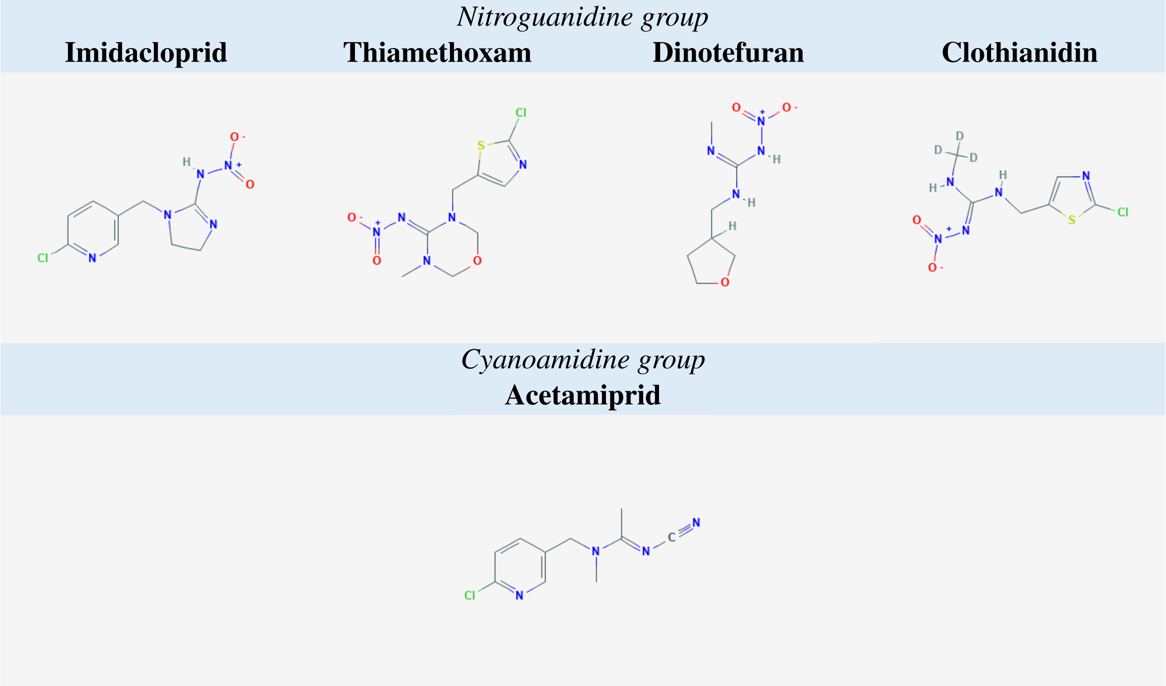
3.4.1 Nitroguanidine neonicotinoids

Nitroguanidine neonicotinoids are more acutely toxic to bees (by 2-3 orders of magnitude) than the cyanoamidines [282]. Nitroguanidines are relatively difficult for bees to metabolize, and the principal metabolites are themselves toxic [419]. New York State imposes county-specific restrictions on nitro-substituted neonicotinoids on Long Island, primarily due to concerns about groundwater contamination [607].

Imidacloprid

The first commercially-successful neonicotinoid, imidacloprid is still popular for a wide range of applications. Though originally developed by Bayer, several of its trademarks have since been acquired by other companies. In addition, many companies have started to produce generic or “authorized generic” imidacloprid-based formulations since the patent on imidacloprid expired in 2006.

Figure 3.2: **Chemical structure of common neonicotinoids**



As collected in PubChem, the National Institutes of Health open chemistry database [448].

As of March 26, 2019, 416 products containing imidacloprid had active registrations for use in New York State[9] [613]. Imidacloprid-treated seeds are commonly used in soybean and, less often, in corn and large-seeded vegetable crops. Between 2004 and 2013, seed treatments represented approximately 56% of imidacloprid used in the United States [990]. An average 20% of U.S. soybean acres used imidacloprid-treated seeds over that decade (up to 33% in some years). Imidacloprid-treated corn makes up less than 5% of U.S. acres.

Soil- and foliar-applied imidacloprid is commonly used in several major New York crops. In 2013, the USEPA estimated that U.S. farmers applied imidacloprid to 30% of apple acres, 25% of cabbage, 30% of grapes, 5% of green beans, 35% of potatoes, and 15% of squash [963]. Imidacloprid is also frequently used for turfgrass management and outdoor ornamentals, applied as a standalone insecticide or mixed with fertilizer. For parks and conservation agencies, imidacloprid plays an important role in controlling Asian longhorned beetle, emerald ash borer, and hemlock woolly adelgid. Popular insecticides based on imidacloprid alone include Merit, Nuprid, and Wrangler. Several others

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[9] This total includes 135 products for use on domestic animals for fleas and tick control.

contain imidacloprid and a second insecticide. Brigadier, Swagger, and BiThor, for instance, combine imidacloprid with the pyrethroid insecticide bifenthrin.

As part of its routine registration review of neonicotinoid active ingredients, the USEPA issued a proposed interim decision for imidacloprid in early 2020 [998]. This document proposed restrictions on or changes to several uses of imidacloprid that are currently common in New York State. If adopted, the proposed maximum annual application rates for foliar and soil-applied imidacloprid would fall by between 0.04 and 0.1 pounds of active ingredient per acre for many crops (a 10-25% reduction). Major New York crops affected would include apple (20% reduction), berries (20% reduction), cabbage (13% reduction), and snap beans (15% reduction). Among non-agricultural uses, the maximum annual application rate of imidacloprid to turf and commercial ornamentals would fall from 0.4 to 0.3 pounds per acre.[10] For cucurbits, USEPA proposed a prohibition on use between vining and harvest to reduce exposure to pollinators. The USEPA also proposed application rate reductions for several individual uses of imidacloprid-based products. Farmers using imidacloprid-based foliar sprays would also need to maintain a 10-foot vegetative filter strip between application sites and waterbodies.[11] To mitigate risk from spray drift, applicators would need to observe new restrictions, including limits on windspeed, spray droplet size, release height, and distance to waterbodies. The proposed interim decision also recommends new label language emphasizing the importance of picking up spilled imidacloprid-treated seeds to protect birds and mammals.

Thiamethoxam

Syngenta's thiamethoxam is most widely used as a seed treatment under the Cruiser name. Nationwide, approximately 80% of thiamethoxam used in agriculture is applied as a seed treatment, the majority in soybean and field corn [986]. In New York, thiamethoxam is also a common seed treatment for sweet corn, snap bean, and cucurbits and a common seed piece treatment for potato. A metabolite of thiamethoxam, clothianidin, is used as an insecticide in its own right (see below).

As of March 26, 2019, 43 products containing thiamethoxam were registered for use in New York

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[10] The USEPA recommended cancelling registrations of imidacloprid-based products for residential turf sprays. Such products are already restricted in New York State. Granular formulations, imidacloprid-treated fertilizer mixes, and other non-spray formulations of imidacloprid would not be affected.

[11] Some imidacloprid products already have this requirement.

State [613]. Actara and Platinum brand flowable insecticides are registered for a variety of foliar and soil applications in major New York crops. In 2017, the USEPA estimated that thiamethoxam-based insecticides are applied to an average 5% of U.S. apple acres, 15% of potatoes, and 5% of squash [986]. The patent on thiamethoxam expired in 2012, and several generics are available.

The USEPA's 2020 proposed interim decision for clothianidin recommends changes that would affect several uses of thiamethoxam in New York State [996]. If adopted as written, the maximum annual application rates for thiamethoxam would fall from 0.188 to 0.15 pounds of active ingredient per year for berry crops, a 20% reduction. The proposed interim decision recommends crop stage-based restrictions for apple (bud-break to petal fall) and cucurbits (vining to harvest) to protect pollinators. As with imidacloprid, use of thiamethoxam foliar sprays in agricultural would require a 10-foot vegetative filter strip between application sites and waterbodies, and applicators would be subject to new restrictions (windspeed, spray droplet size, release height, and distance to waterbodies, among others). The proposed interim decision also recommends new label language emphasizing the importance of picking up spilled thiamethoxam-treated seeds to protect birds and mammals.

Dinotefuran

Dinotefuran was the last major neonicotinoid to reach the U.S. market, earning its initial USEPA approval in 2004. In New York, dinotefuran is registered for specific outdoor uses (direct application to tree bark and tree injection) in conjunction with Special Local Need labeling. Dinotefuran-based insecticides are crucial for chemical control of several invasive pests: hemlock woolly adelgid, emerald ash borer, and spotted lanternfly [610, 387, 176, 496, 940]. In the immediate future, there are no obvious alternatives to dinotefuran and imidacloprid for the systemic control of hemlock woolly adelgid.

As of March 26, 2019, 52 products containing dinotefuran were registered for use in New York State, nearly all for indoor or veterinary uses [613]. The NYSDEC declined applications from Valent to register Safari and Venom insecticides for a wide variety of vegetable, fruit, and ornamental crops. Scorpion 35SL, another dinotefuran-based product by Gowan, also labeled on the same crops as Venom and Safari, is not permitted for use in New York State. The NYSDEC found "potential for unacceptable risks to non-target organisms and groundwater resources" [604].

The USEPA issued a proposed interim decision for its routing registration review of dinotefuran in January 2020. The USEPA recommended label changes for several agricultural and commercial applications of dinotefuran products. However, given that dinotefuran is not widely used in New York State, the changes proposed by the USEPA are unlikely to have a major impact in the state.

Clothianidin

Over 95% of clothianidin used in the United States is applied to seeds, and over 95% of those seed treatments are applied to field corn [981]. Between 2005 and 2014, approximately 45% of U.S. corn acres were planted with clothianidin-based seed coatings (up to 65% in some years) [985]. The USEPA has registered clothianidin-based products for over 140 agricultural applications by foliar spray or chemigation. They have also approved some landscape and residential uses (e.g., turfgrass, ornamentals). Despite approval at the federal level, clothianidin-based products are not registered for outdoor use in New York State (as discussed below, this does not affect planting of clothianidin-treated seeds). In 2005, Bayer withdrew an application to register its Poncho 600 seed treatment in the state. The NYSDEC acknowledgement of that withdrawal notes that its modeling suggested substantial potential for groundwater contamination [601]. In 2007, NYSDEC denied an application for registration of four clothianidin-based insecticides,[12] again citing risks to groundwater as well as fish and wildlife. The registrant, Arysta LifeScience, did not submit several requested studies that would have allowed the NYSDEC to assess risk [603]. At present, the only clothianidin-based products registered in New York are labeled for bedbug and roach control [605, 613].

Although clothianidin-based treatments cannot be *applied* to seeds in New York State (as those treatments do not have NYSDEC registration), New Yorkers may purchase and use seeds treated with clothianidin in other states. Under Federal law, pesticide-treated products, including seeds, are not regulated as pesticides themselves.

New York farmers planted treated seed bearing an estimated 24,000 kg (53,000 lb) of clothianidin in 2014; this is more than any other neonicotinoid used on farms, whether as a coating on treated seeds or applied as a pesticide (see Figure 3.1). Nearly all clothianidin used in New York is in field corn seed treatments.

In 2020, the USEPA released a proposed interim decision recommending some changes to uses

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[12] Arena 50 WDG, Arena 0.5 G, Clutch 50 WDG, and Celero 16 WSG

Table 3.2: **New York Restricted Use Pesticide (RUP) status of neonicotinoid insecticides**

Active Ingredient	Treated seeds	Agricultural Use	Commercial Use	Homeowner Use
Acetamiprid	*Not applicable*	Not restricted	Not restricted	Not restricted
Clothianidin	Not restricted	*No outdoor uses*	*No outdoor uses*	*No outdoor uses*
Dinotefuran	*Not applicable*	RUP statewide	RUP statewide	*No outdoor uses*
Imidacloprid	Not restricted	RUP statewide	RUP statewide & county restrictions[1]	County restrictions[2]
Thiamethoxam	Not restricted	*Foliar* restrictions[3]	*Foliar* restrictions[3]	*No outdoor uses*

Notes: New York state restrictions as of December 15, 2018 [611, 613]. (1) No soil injection applications in Nassau and Suffolk Counties; (2) Prohibited on Long Island; (3) Foliar applications prohibited in Nassau and Suffolk Counties and statewide limits on foliar applications per acre.

and labeling of clothianidin [996]. Most of those recommendations will not affect New York State, as insecticide-treated corn is the only major use of clothianidin in the state. However, the USEPA document did propose new advisory statements for clothianidin products registered for seed treatment to encourage collection of spilled seeds.

3.4.2 Cyanoamidine neonicotinoids

Only one cyanoamidine neonicotinoid is in common use in New York: acetamiprid. The NYSDEC previously approved a flowable insecticide (Bayer's Calypso) based on thiacloprid, another cyanoamidine neonicotinoid, for several agricultural uses [602]. However, Bayer voluntarily cancelled all USEPA registrations of thiacloprid-based products during an USEPA registration review in 2014 [968]. With the exception of some existing stocks, Bayer did not sell or distribute Calypso in the United States after that point. The New York State registration was suspended by the registrant as of December 31, 2017.

As noted above, the acute toxicity of cyanoamidine neonicotinoids to bees is much lower than that of the nitroguanidine neonicotinoids. Indeed, acetamiprid is considered a reduced-risk insecticide. As such, many regulations that apply to clothianidin, imidacloprid, dinotefuran, and thiamethoxam do not apply to acetamiprid. Acetamiprid is not subject to the EU's "neonicotinoid ban" or Canada's proposed restrictions.

Acetamiprid

Developed by Nippon Soda, acetamiprid entered the U.S. market in 2002. Acetamiprid is typically sold in flowable formulations for foliar, soil, and injection applications in a wide variety of crops.

Acetamiprid is frequently used with fresh fruit and vegetable crops due to its low toxicity. Major brands include Assail, Intruder, and TriStar. Since Nippon Soda's patent expired in 2008, several competitors have entered the market. Loveland's Anarchy, Helena's Omni, Atticus Quasar, and Tacoma's Anniston are among the 34 acetamiprid-based products registered for use in New York State [613].

The USEPA's 2019 proposed interim decision for acetamiprid (see Section 3.1) recommends additional PPE for landscape basal bark applications of acetamiprid, additional requirements for spray drift mitigation, and new advisory language on insecticide resistance, hazard to pollinators, and best practices for water soluble packaging [995]. The proposed pollinator advisory language identifies acetamiprid as "moderately toxic to bees and other pollinating insects" exposed directly or through residues on blooming plants. If adopted, new spray drift mitigation measures would apply to aerial and ground applications of acetamiprid-based products. Among other provisions, this would impose new windspeed requirements, prohibit applications during temperature inversions, require medium or coarser spray droplet size, and require minimum buffers for spraying near water bodies.

3.5 Common application methods

Neonicotinoid manufacturers, formulators, and distributors make their products available in a wide variety of formulations appropriate for different crops and applications. Active ingredients are commonly delivered as liquids, granules, powders, baits, seed coatings, or as components of fertilizer or growing media. As described in Section 3.1, insecticide users must follow product-specific instructions for safe handling and application.

Table 3.3: **Percent of U.S. field crop acres planted with neonicotinoid-treated seeds, USEPA estimates**

	Percent of U.S. acres, annual							
	Clothianidin		Imidacloprid		Thiamethoxam		**Totals**	
Crop	Avg.	Max	Avg.	Max	Avg.	Max	**Avg.**	**Max**
Corn	45%	65%	<5%	<5%	25%	45%	**<75%**	**<100%**
Soybean	<2.5%	<2.5%	20%	33%	15%	25%	**<37.5%**	**<60.5%**
Wheat	<2.5%	<2.5%	10%	30%	5%	15%	**<17.5%**	**<47.5%**

Estimates from U.S. Environmental Protection Agency [990, 987, 985]. Estimates from 2005-2014 for clothianidin and thiamethoxam, 2004-2013 for imidacloprid.

3.5.1 Seed treatment

By quantity of active ingredient, seed treatments[13] represent the most significant use of neonicotinoids in the United States [987, 990, 985]. Neonicotinoid-treated seeds represent the great majority of field corn planted in the United States, and are commonly used in the cultivation of soybean, cotton, canola, wheat, potato, sorghum, and several other crops [852]. Usage in New York followed national trends through 2014, the last year for which USGS data are available [889]. However, adoption may have increased since then among farmers growing soybean and large-seeded vegetables (see Section 4.1). As noted in Section 2.1, there is no publicly-available data on how and where neonicotinoid-treated seeds are used in New York State after 2014. Insecticide-treated seeds are not pesticide products under Federal law, and planting such seeds does not trigger pesticide reporting requirements. The assumptions in this report about neonicotinoid-treated seed usage are based on trends through 2014, estimates of nationwide usage in USEPA risk assessments and prior studies, and advice from Cornell professors and staff.

Figure 3.3: **Coated soybean seeds**

Uncoated (left) and coated (right) soybean seeds. Photo by Kathy Eystad, USDA Agricultural Research Service.

Farmers typically select seed treatments at the same time as the seeds themselves, months before planting. They must, therefore, decide whether anticipated pest pressure justifies an on-seed insecticide with relatively little or no information about weather and pest conditions the following spring. Seed dealers often offer an insecticide as one of several components in a seed treatment and deliver the product with the coating already in place. Bayer's Acceleron corn treatment, for example, combines the neonicotinoid clothianidin with three fungicides (metalaxyl, prothioconazole, and fluoxastrobin) and an optional nematicide (*Bacillus firmus*) [50].

Less commonly, some growers arrange for seed treatment application themselves, allowing them to combine products not packaged together by their vendor. In 2018, 9% of New York corn acres

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[13] In this report, we use "seed treatment" at a catch-all term encompassing many types of dressing, coating, or pelleting that may be applied prior to sowing seeds, cuttings, tubers, etc.

were planted with seeds that were treated *after* purchase with insecticides, fungicides, herbicides, and/or nematicides. Nationally, seeds treated after purchase represented 24% of U.S. corn acres and 33% of U.S. soybean acres [953]. The seed itself may also have insect resistant traits such as incorporated genes from *Bacillus thuringiensis* (Bt), a bacterium that produces proteins toxic to many insect species. Depending on local pest pressures, these traits may complement active ingredients used in seed treatments. In 2018, 82% of field corn planted in the United States contained at least one Bt gene [952], and nearly all Bt corn is also treated with a neonicotinoid before planting. Some pests (notably corn rootworm larvae) are primarily targeted by appropriate Bt seeds, but damage is further reduced when the seeds are treated with neonicotinoids. Corn borers and fall armyworm are controlled by Bt genes but not neonicotinoid seed treatments; the reverse is true for seedcorn maggot and wireworms [149, 926].

Once farmers receive treated seeds, they are expected to follow product-specific instructions for safe handling and use. Under the Federal Seed Act, vendors must provide customers of chemically treated seeds with a USEPA-approved label. Neonicotinoid-treated seed labels include warnings and instructions related to product toxicity to wildlife, personal protective equipment requirements for workers handling treated seed, disposal restrictions, and maximum per-acre application rates for the relevant active ingredient. These label requirements are legally enforceable.

For planting, farmers typically combine treated seeds with a seed lubricant in the hopper of their planter. Seed lubricants reduce abrasion of seeds and seed coatings, help to ensure consistent planting, and reduce dust emissions. Talc- and graphite-based lubricants are the most common (and least expensive), though newer products like Bayer's Fluency Agent Advanced offer performance benefits. As described in Chapter 6, planter design and the choice of seed lubricant can have a significant impact on the environmental risks associated with neonicotinoid-treated seeds.

As noted above, seed treatments offer many benefits to users compared to older pest management products. Treated seeds protect against a range of pests without requiring scouting, mixing, or repeated foliar applications, saving growers time and effort. A seed coating provides a more consistent dose of insecticide than in-furrow granules or soil treatments, and ensures that insecticide is delivered to the seed itself. Neonicotinoid-treated seeds are safer for humans to handle and use than seed treatments using older organophosphate or pyrethroid insecticides, let alone granules or flowable insecticides using those active ingredients. In surveys, users place a higher value on seed treatments than yield alone would justify, likely due to such non-monetary considerations [410, 832].

3.5.2 Foliar sprays

Foliar pesticides are formulated for spray application to leaves and other aboveground plant structures (we discuss basal bark sprays separately: see below). Neonicotinoids applied to fruits, leaves, flowers, or stems may be absorbed by and translocated within target plants, providing long-lasting protection against postemergence crop pests. Neonicotinoid-based foliar sprays are commonly used in many New York agricultural commercial applications, including soybean (against soybean aphid), fruits, vegetables, floriculture, nursery production, and landscape plants. Acetamiprid-based sprays are also available for non-commercial users in New York State.

Figure 3.4: **Foliar application of a pesticide**

Air-curtain orchard sprayer in an apple orchard. Photo by Keith Weller, USDA Agricultural Research Service.

3.5.3 Soil treatments and chemigation

Soil-applied neonicotinoids can control early-season pests at planting, provide systemic protection later in the season when taken up through the roots, or can be used outside of the growing season to attack pests overwintering in soil. Neonicotinoids are highly versatile, and may be applied to the soil as granules, as a drench or drip, through chemigation (pesticide applied through an irrigation system), or as a component of a fertilizer or seed mix. When used to control early-season pests, soil treatments typically require a greater quantity of active ingredient per acre than treated seeds but can be used for applications where seed treatments are unavailable or impractical [239]. New York pesticide sales and usage data suggest that imidacloprid soil treatments are popular for landscaping and turfgrass management [614]. Imidacloprid-based soil treatments are also marketed directly to consumers for lawn and garden uses[14] [609].

3.5.4 Trunk injection and basal application

Figure 3.5: **Insecticidal trunk injection (left) and bark basal spray (right)**

Photos by Mark Whitmore, Cornell University.

Several formulations of imidacloprid and dinotefuran are intended for injection into trees' vascular systems. Several techniques and products are commercially available, each with unique advantages [151]. Trunk injection greatly reduces off-target pesticide contamination relative to crown spraying or soil treatments while simultaneously increasing the translocation of active ingredients within the tree [1013]. Depending on the tree and target pest, trunk-injected neonicotinoids may provide protection for multiple seasons, though with great variation in the concentrations available in different parts of the plant [586, 542]. Neonicotinoid trunk injections are effective against several invasive forest pests, notably emerald ash borer and hemlock woolly adelgid [235, 566, 891].

Other woody species can be treated by applying an appropriately-formulated insecticide to the lower trunk, root collar, and exposed roots: a basal spray. Imidacloprid and dinotefuran can penetrate

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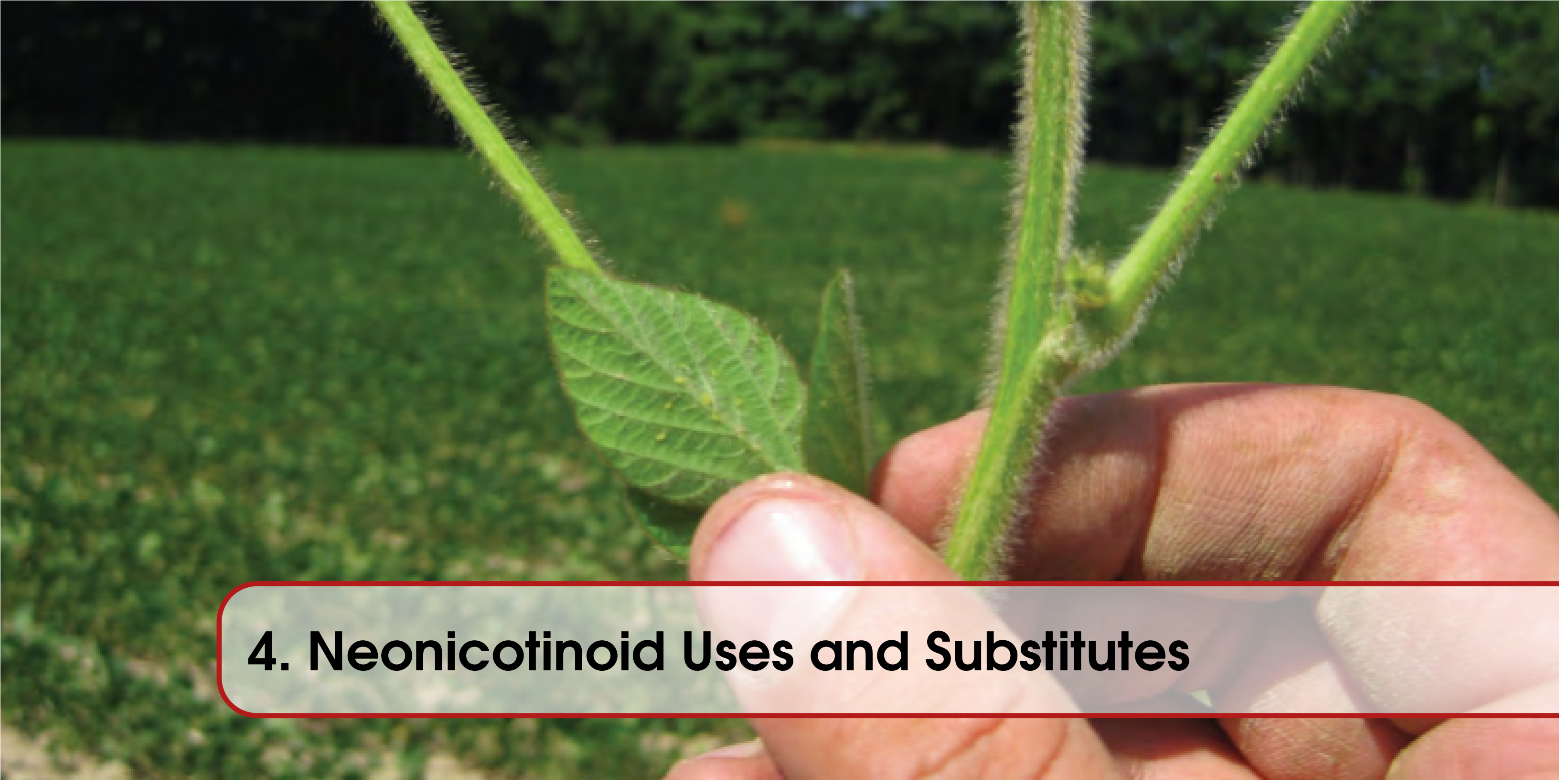
[14] Sale and use of imidacloprid-based products is restricted on Long Island.

the basal bark of many species and move throughout the plant [160, 161]. Trees take up basal sprays faster than soil-applied insecticides, are less costly to apply, and avoid tree wounding health risks associated with drilling holes for injection [387]. In New York, basal bark application is the now the dominant application method for treating forest pests like hemlock woolly adelgid. This technique also reduces environmental exposure relative to soil-applied insecticides.



4. Neonicotinoid Uses and Substitutes

To assess the benefits and risks of neonicotinoid insecticides and their alternatives, it is important to understand the specific contexts in which neonicotinoids are used and what alternatives, if any, exist on a case-by-case basis. This chapter describes the most common uses of neonicotinoids in New York State and the alternatives available to growers and other users.

A pesticide's efficacy in controlling target pests is important, but growers consider other factors as well when choosing between pest management products or strategies. Other considerations include cost, ease of use, application time and labor, and potential health or environmental risks. The neonicotinoid alternatives discussed in this report are rarely perfect substitutes for neonicotinoid products. Insecticide users choose products with care, so switching from a preferred neonicotinoid to the "next best" product would likely entail some loss of value for users. The best non-neonicotinoid replacement for a given use may also differ depending on the priorities of the customer. The most likely substitute for a neonicotinoid product is not necessarily the option best at controlling pests or the option with the least environmental risk, but may simply be the lowest-priced substitute that provides acceptable performance. The active ingredients and products discussed in this chapter are not *recommended* substitutes for neonicotinoids; they are merely *likely* substitutes.

Photo by Derek Zerkowski, Cornell University.

4.1 Field crops

At present, New York corn, soybean, and wheat farmers use neonicotinoid seed treatments, but rarely use neonicotinoid-based foliar or soil-applied insecticides. Seed treatments are often the only insecticidal products used in a field. Just 5% of New York and 13% of U.S. corn acres were treated with another insecticide in 2018. Comparable New York figures for soybean and wheat are not available, but 16% of U.S. soybean and 6% of U.S. winter wheat acres were treated with a non-seed insecticide in 2018 and 2017, respectively. Neonicotinoid foliar sprays made up a small percentage of insecticides applied to these crops [953].

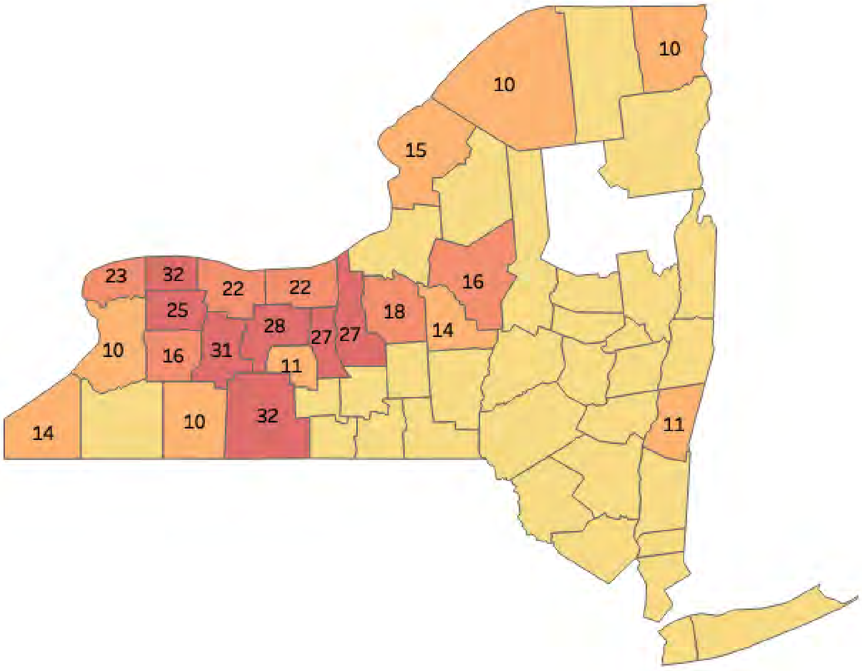
Preventive use of neonicotinoid-treated seeds is not necessarily related to relative pest pressure or infestation risk in a given field. In soybean grower surveys from 2004 through 2012, 65% of neonicotinoid seed treatment users were not targeting any specific pest [591]. Since seeds are typically ordered months in advance of planting, most farmers cannot choose between insecticide-treated and untreated seeds on the basis of conditions at the time of planting. It is also important to note that neonicotinoids are usually just one of several seed protection products applied in a coating, and that neonicotinoid treatment costs are a small part of total seed and planting costs [167]. Many suppliers include a neonicotinoid in seed coatings by default or bundle it with other seed treatment components.

Growers do not necessarily expect a financial return from neonicotinoid-treated seeds. They are valuable, in part, as a way to reduce risk. Even treated seeds do not increase average expected yield relative to no treatment, they may reduce the risk of an unlikely, but severe loss from unpredictable pest infestations. In this context, insecticide-treated seeds may be considered a form of crop insurance. Neonicotinoid-treated seeds may also entail less risk of pesticide exposure to farmworkers relative to soil-applied insecticides that need to be handled, stored, and prepared for use. Similarly, loading treated seeds into a planter requires less labor than applying a soil-applied or foliar insecticide.

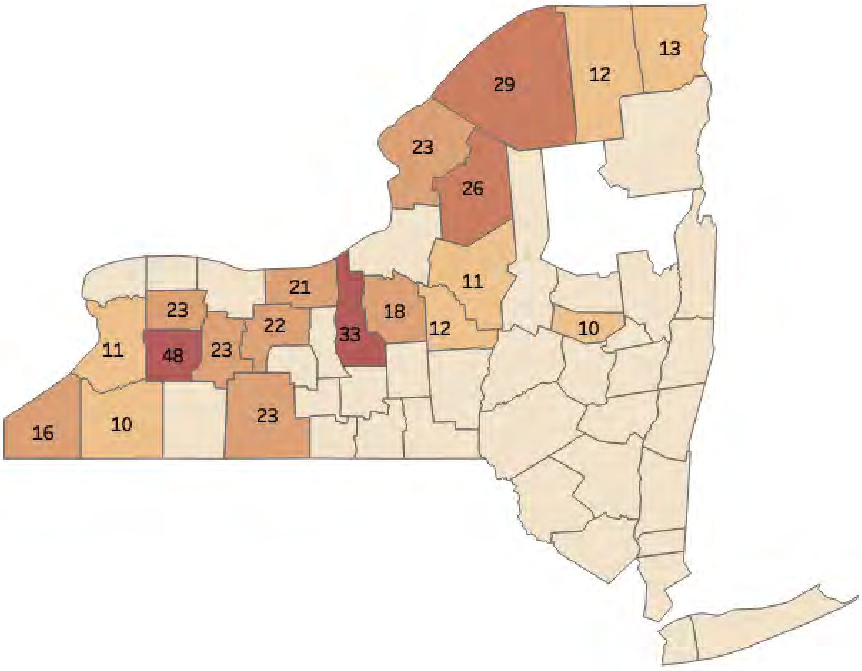
In several respects, the use of neonicotinoid-treated seeds has influenced how corn and soybean are grown in New York State. Field crop growers in New York have increased their use of cover crops over the last two decades [946, 949], and neonicotinoid-treated seeds likely contributed to this trend. Cover crops can increase farm sustainability and long-term productivity by increasing nutrient availability, preventing erosion, increasing resilience to droughts and floods, controlling weeds, and

Figure 4.1: **Acres of field corn harvested in New York counties (in thousands), 2017**

Harvested for grain



Harvested for silage



Excludes counties with fewer than 10,000 acres harvested in 2017 [949].

providing habitat for beneficial fauna [105]. However, cover crops can also increase the risk of certain early-season pests [777, 477]. In New York corn, cover crops are used more widely today than two decades ago. While cover crops offer benefits to farmers such as suppressing weeds and improving soil health, they can also increase the risk posed by seedcorn maggot. This risk varies depending on which cover crop is used. Some farmers have reported that seed treatments have made the adoption of cover cropping easier [410]; if corn growers stopped using insecticidal seed treatments (neonicotinoids or substitutes), it could discourage cover cropping for some farmers. In a similar vein, insecticide-treated seeds are well suited for reduced tillage systems; unincorporated crop residues can also harbor early-season pests. For many field crop growers, the benefits of cover crops and/or reduced tillage would make these practices worthwhile with or without insecticide-treated seeds. All else being equal, however, one would expect restrictions on neonicotinoid seed treatments to have a negative impact (to some degree) on adoption of cover crops and reduced tillage in field crops. As noted in *Chapter 2*, this report does not attempt to quantify the effects that neonicotinoid restrictions would have on farm management.

4.1.1 Corn

Corn is the major field crop of New York State, with roughly 1.1 million acres harvested in 2018. Of this total, 645,000 acres were harvested for grain. Corn grain production was worth $420 million. In the same year, New York farmers produced approximately 8.5 million tons from the 445,000 acres of corn harvested for silage, worth approximately $350 million at $41/ton [945]. Corn silage is also an important input for the $2.5 billion New York dairy industry [951], providing nutritious feed for many dairy farmers at a significantly lower price than commercial feed or hay.

In New York, corn seed treatments based on clothianidin (Poncho) or, less often, thiamethoxam (Cruiser) primarily protect against losses from seedcorn maggot (bean seed fly: *Delia platura*). Neonicotinoid-treated seeds also protect against early-season damage from corn rootworms (cucumber beetles: *Diabrotica virgifera* and, less often, *Diabrotica longicornis*), wireworms (click beetles: primarily *Agriotes*, *Limonius*, and *Melanotus* spp.), and white grubs (scarab beetles: *Popillia japonica*, *Amphimallon majale*, and *Phyllophaga* spp.) [845, 1096]. Neonicotinoids are effective against seedcorn maggot, wireworm, and white grubs at a low application rate. A higher application rate is used if corn rootworm, a primarily mid-season pest, is of concern. Seed treatments are not effective at controlling other major insect pests of New York corn: cutworms (*Agrotis ipsilon* and *Striacosta albicosta*), European corn borer (*Ostrinia nubilalis*), armyworm (*Spodoptera frugiperda*), or corn earworm (*Helicoverpa zea*) [1096, 1095].

Table 4.1: **Target pests and FUEIQ for selected field corn seed treatments and alternatives**

		Representative product			***Representative pests***			
Group	**Active ingredient**	**Product**	**Rate**	**FUEIQ[1]**	**SCM**	**CRW**	**WW**	**WG**
Seed-applied products								
NEO	Clothianidin	Poncho (low rate)	0.25 mg ai/seed	1	X	-	X	X
NEO	Clothianidin	Poncho (high rate)	1.25 mg ai/seed	3	X	X	X	X
AND	Chlorantraniliprole	Lumivia (low rate)	0.25 mg ai/seed	<0.5	X	-	X	X
AND	Chlorantraniliprole	Lumivia (high rate)	0.75 mg ai/seed	1	X	-	X	X
PYR	Tefluthrin	Force ST	1 mg ai/seed	2	X	-	X	X
Soil-applied products								
OP	Phorate	Thimet 20G Smartbox	6.5 lb/A	43	X	X	X	X
PYR	Bifenthrin	Capture LFR (high rate)	17 fl oz/A	8	X	X	X	-
PYR	Tefluthrin	Force EVO (high rate)	20 fl oz/A	8	X	X	X	X
Genetic traits								
-	Bt corn seeds	Various[2]	-	-	-	X	-	-

Target pests: **SCM**: seedcorn maggot; **CRW**: corn rootworms (cucumber beetles, northern & western); **WW**: wireworms (click beetles, several species); **WG**: white grubs (scarab beetles, several species)

Notes: (1) FUEIQ calculations for seed treatments assume a planting rate of 30,000 seeds per acre; (2) Seeds containing certain Agrisure, Herculex, and YieldGard traits target corn rootworm.

FUEIQ is the estimated risk of a product, adjusted to application rate. It consists of three equally weighted components: consumer, farm worker, and ecological. Please see the introduction to EIQ in Chapter 2 for a description of its uses and limitations. In this report, FUEIQ values were calculated based on the maximum labelled application rate for a given pest, unless otherwise stated.

Seedcorn maggot

Seedcorn maggot (*Delia platura*) is a sporadic pest of large-seeded crops, present in all 50 states and every inhabited continent [226, 133, 395, 650]. In New York, pupae of the species overwinter in the soil, emerging as adult flies once temperatures reach roughly 7°C (45°F) in the spring [776, 149]. The adults mate and then lay eggs shortly thereafter, favoring sites with abundant organic matter [1016, 354, 1011]. The first generation of seedcorn maggot in New York usually hatches in late April to early May, with a second generation emerging in mid May to mid June. This coincides with corn sowing, which begins in late April and is mostly complete by June 1. Field corn is vulnerable to harm from seedcorn maggot between planting and seedling emergence: a period of 1-2 weeks in New York State [225, 913]. This vulnerability is longer, and damage is most likely, in years with cool spring weather and slow initial growth after planting [228, 776].

Early-season infestations can cause major stand losses in field corn [810]. Such severe infestations are currently uncommon, but unpredictable. By the time growers detect seedcorn maggot damage (often because many seedlings failed to emerge), the only available management option is replanting. However, replanting is seldom recommended in New York due to the short growing season, lower expected yield from late planted corn, and the seed and labor costs associated with replanting [149, 810].[1]

Some fields have increased risk of seedcorn maggot infestation due to management factors that attract adults in the early spring or shelter overwintering pupae. Infestation risk is increased in fields where live cover crops or animal manure have been incorporated in the two weeks before planting, where corn is in continuous cultivation, where corn is grown after alfalfa or another grassy crop, and where corn is replacing conservation plantings [353, 354, 49, 149, 90]. As such, several non-chemical management techniques can reduce the likelihood of seedcorn maggot infestation. Early incorporation of manure and cover crops, reduced tillage, some crop rotations, and/or reduced seed planting depth significantly reduce risk [300, 408, 354, 285, 650]. Some farmers may delay corn planting until seedcorn maggots have entered their (non-damaging) pupal stage. Both crop and insect development are dependent on temperature. Within certain bounds, it is possible to forecast when seedcorn maggots will be *most* dangerous to crops and to time planting or insecticide treatment accordingly. Degree-

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[1] According to CCE personnel, May stand losses need to exceed approximately 30% and June stand losses need to exceed approximately 40% for replanting to be economically viable.

day models can predict "maggot-free" dates in other U.S. corn growing regions.[2] However, models developed for other states are less reliable in New York conditions, and would need to be modified to be useful for New York farmers [913]. In addition, a farmer waiting for maggot-free planting dates would likely plant later in the spring than the current standard. Later planting dates are associated with lower average yields [149]. However, none of these strategies entirely eliminate the risk of infestation [285, 650].

Prevalence of seedcorn maggot

No recent studies have quantified seedcorn maggot prevalence or crop damage in New York State or the United States. Since seed treatments provide inexpensive, reliable control of seedcorn maggot, this pest has not been a major focus of research and extension work in the last two decades. Across the United States, seedcorn maggot is not a primary driver of pest management decisions in corn: just 0.8% of growers actively manage for the pest [776]. Thus, it is not obvious how prevalent seedcorn maggots are today, how likely infestations would become in the absence of neonicotinoid-treated seeds, or how frequently such infestations would cause significant damage.

In this context, the results of a recent study in Quebec provide some insight. Similar to New York State, neonicotinoid-treated seeds have been used in almost 100% of Quebec's corn acres (mostly clothianidin) and 60% of its soybean acres (mostly thiamethoxam) in recent years to prevent damage from seedcorn maggot, wireworms, and white grubs. Quebec shares some characteristics with New York that may increase its susceptibility to seedcorn maggot. A significant portion of its corn acreage is devoted to silage rather than grain,[3] supporting Quebec's dairy industry. Quebec uses significantly more manure, per acre of cropland, than New York.[4] Quebec's growing season is comparable to northern New York and slightly shorter than in the principal corn-growing counties of Western New York, limiting the timing of when manure can be applied in advance of planting. Given these conditions and constraints, one would expect seedcorn maggot pressure in Quebec's corn-growing regions to be at

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[2] Degree day models predict periods of high risk of crop damage based on temperatures in a given season. Using a 39 degree base, the first generation of seedcorn maggot typically pupates from 781-1051 degree days after January 1 [772, 300, 415, 810].

[3] Approximately 40% of New York's corn acreage is devoted to silage, compared to 15.2% of Quebec's [945, 418].

[4] In 2017, manure application acreage in New York was 22% of cropland acreage. According to Canada's 2016 Census of Agriculture, manure application area in Quebec was equivalent 46% of land in crops [949, 872].

least as high as in New York.

Between 2013 and 2015, Labrie et al. [482] measured insect pressure in 84 corn and soybean fields around Quebec, selected to represent a range of conditions and preexisting pest risk factors. Each field was planted with alternating strips of treated seed and untreated seed. Researchers measured the number of soil pests captured in soil traps, plant stand, seedling damage, and crop yield. Seedcorn maggot was present in nearly every field, and corn seedlings from treated seeds were significantly less likely to have some pest damage than those from untreated seeds.[5] However, most damage to seedlings was minor. Indeed, there was no significant difference in corn plant stand or yield between treated and untreated strips. Despite the widespread presence of seedcorn maggots, the great majority of corn plantings experienced little early-season damage or were able to compensate for that damage over the course of a season. Neonicotinoid-treated seeds did not produce better outcomes.

In addition, it may be useful to consider research and pest management guidance published before the U.S. introduction of imidacloprid in 1994. At least two major studies examined seedcorn maggot prevalence and damage prior to the introduction of neonicotinoid-treated seeds. Neither of the studies included data New York, so whether the results are indicative of the specific situation in New York, including its use of high organic content fertilizers, cannot be known. A 1975 study concluded that seedcorn maggot losses averaged less than 1% in the U.S. Corn Belt [595]. In 1987, pest management guidance by the University of Illinois estimated that the likelihood of a cornfield in the state experiencing some damage from seedcorn maggot ranged from a low of 0.7% for corn following soybean to a high of 10% in corn following alfalfa [477]. These studies and contemporary extension guidance characterize seedcorn maggot as a pest capable of causing serious losses, but unlikely to cause economic damage in any given corn planting [1016, 564, 224, 300, 362, 394, 409].

Providing a contrasting view, a group of experts associated with CCE and the Western New York Crop Management Association provided an informal estimate of seedcorn maggot risk in New York. Based on their experience, they expect that seedcorn maggot risk in the absence of routine, preventive seed treatment would be "very high" for approximately 20% of New York corn acres grown for silage (100,000 acres), "high" for 80% of silage acres (400,000 acres), and "moderate" or lower for continuous

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[5] In treated strips, the average number of seedlings damaged by wireworm or seedcorn maggot was 7.0%, 0.6%, and 7.4% in 2013, 2014, and 2015, respectively. In untreated corn strips, 13.0%, 1.6%, and 12.1% of seedlings were damaged.

corn grown without the application of animal manure before planting, without a cover crop, and in rotation with soybean (up to 500,000 acres) [842]. This estimate assumes that corn silage yield is less likely to recover from early-season damage than corn grain yield.

Further research to quantify the likelihood of seedcorn maggot damage to conventional corn in New York State, and the effectiveness of management techniques to reduce risk, would be useful. In addition, surveying organic farmers, who do not use seed treatments, about losses from seedcorn maggot could provide useful data from within New York. Since New York currently ranks first in the nation in terms of acres of certified for organic field crops and hay, a large but currently untapped knowledge base exists in the state on this particular topic.

Corn rootworms

Western corn rootworms (and, rarely, northern corn rootworms) are significant mid-season pests and occasional early-season pests of corn in New York State. Corn rootworms threaten fields that have been used for corn for two or more consecutive seasons, with the likelihood of economic damage increasing with each year of corn cultivation. Nationally, corn rootworms are the most destructive insect pest of U.S. corn. In a 2014 survey, 54% of corn growers nationwide cited rootworms as the most important pest of their crops [410]. The annual cost of corn rootworm damage and treatment to U.S. farmers is over $1 billion [917]. Rootworm eggs can overwinter in New York, with larvae hatching to feed on corn roots in late May and June. However, the majority of feeding damage occurs after larvae molt into their final instar in July [149].

New York field corn growers control rootworm primarily by planting genetically modified corn hybrids that express an appropriate Bt toxin.[6] Neonicotinoid-treated seeds may be used to control corn rootworm in lieu of planting Bt corn or, if applied to Bt corn seeds, as a complementary measure. Corn rootworms can still damage Bt corn if the local population has developed resistance to the relevant Bt toxin(s) or if rootworm pressure is unusually high. When used, treated seeds are only a component of season-long corn rootworm management. Neonicotinoid-treated seeds are only effective against corn rootworms for 2-4 weeks following planting, and do not reduce mid-season damage. In

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[6] Four commercialized Bt genes are effective (to varying degrees) against corn rootworm, and farmers may "stack" certain Bt traits to protect against later-season pests as well [96, 411].

neonicotinoid-treated seeds, the labelled application rate for corn rootworm control[7] is higher than for control of seedcorn maggot, wireworm, or white grub[8]. Both seed treatment application rates are used by New York corn growers, but publicly available data do not permit us to estimate the proportion of farmers using the high rate.[9]

High-rate seed treatments may become more common in New York if Bt resistance becomes more widespread in corn rootworm populations. Some western corn rootworm[10] populations have developed resistance to the toxins produced by each of the four Bt genes and, in some cases, resistance to multiple Bt toxins [310, 846, 97, 309, 96]. Bt resistance appeared first and is more widely distributed in the Midwest, likely due to higher rootworm pressure in the Midwest Corn Belt [843], but it has become a pressing issue in New York as well [844]. The first Bt-resistant corn rootworm population in New York State was discovered near Ithaca in 2013 [274]. Corn growers dealing with Bt resistance may need to switch to a hybrid using multiple (stacked) Bt genes or apply insecticides to control rootworms during the growing season.[11]

Scouting for adult corn rootworm beetles during or shortly after pollination can help to identify fields that are likely to harbor many eggs and are therefore at risk of infestation the following spring. Growers can predict corn rootworm with greater confidence than seedcorn maggot. If a grower finds adult populations at the economic threshold,[12] they should take action before planting the following year to prevent a damaging infestation [1099, 720, 149].

Many New York corn farmers also use annual crop rotations, in part, to reduce the risk of corn rootworm damage. In their larval stage, corn rootworms do not feed on other crops and cannot move between fields, making annual corn-soybean or corn-haylage rotations an effective means of control[13]

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[7] 1.25 mg and 1.34 mg active ingredient per seed for clothianidin and imidacloprid, respectively

[8] 0.25 mg and 0.60 mg active ingredient per seed for clothianidin and imidacloprid, respectively.

[9] The net income analysis in the following chapter makes the (conservative) assumption that most New York corn growers use seeds with the lower application rate, which are less expensive.

[10] Field-evolved Bt resistance in *northern* corn rootworm was first reported in specimens collected from North Dakota in 2016 [97].

[11] Corn rootworm resistance has also been documented to carbamates, organophosphates, and pyrethroids [866, 563].

[12] A pest population is said to be above the **economic injury level** when its expected damage to a crop exceeds the cost of treatment. It represents the financial break-even point for treatment. The **economic threshold** is a closely related concept, representing the pest density that should trigger treatment. Detecting pest density at the economic threshold should allow time for action before pest populations reach the economic injury level [393].

[13] Some populations of corn rootworms in the Midwest have adapted to survive corn-soybean rotations through delayed egg hatching (northern corn rootworm) or by laying eggs in crops rotated with corn (western corn rootworm), allowing them to attack first year corn [642]. However, but this adaptation has not yet been reported in New York [149].

[145, 939]. Annual corn-soybean rotations are more practical for operations growing corn for grain as a cash crop. Fields supporting dairy production often grow silage corn for 2-3 consecutive years before rotating to another silage crop (e.g., alfalfa), small grains, or pasture [762, 348, 948, 149].

Other corn pests controlled with neonicotinoid-treated seeds

Wireworms are the larval stage of click beetles, and an occasional pest of corn in New York. The susceptibility of wireworms to insecticides and the potential for economic damage varies considerably from species to species [1006, 1017, 1007]. Like seedcorn maggot, wireworms cause damage to corn in the first few weeks after planting by feeding on corn seeds and roots [40]. Neonicotinoid seed treatments are the main way of controlling wireworms in conventional New York State corn, and there is currently no effective rescue treatment for a severe wireworm infestation. At field-realistic concentrations, neonicotinoids do not usually kill wireworms or prevent their reproduction, but rather reduce wireworm activity and feeding [1019, 581]. Neonicotinoid soil treatments are not effective against all wireworm species, or if wireworm populations are particularly high. In these situations, growers may employ soil-applied insecticides or non-neonicotinoid seed treatments [932, 580].

"White grub" is the common name for the larval stage of scarab beetles, including the European chafer beetle, Japanese beetle, May beetles, and June bugs. They cause damage to corn and other crops through direct feeding on roots and tunneling through the root zone [145]. Problems with white grubs can arise in corn-alfalfa crop rotations, and rescue treatments are not effective after planting [426].

For fields at risk of wireworm or white grub infestations, corn farmers have several non-chemical control options. If crop rotation is considered, it must be tailored to the lifecycle of the species of greatest concern, since weedy grass from previous plantings can increase risk of pest problems [145, 932]. Weedy grass control and removal of plant debris can significantly reduce overwintering habitat for pests and the number of eggs in mid summer [94, 302]. Late planting can reduce damage from some pests, but reduces the length of the growing season and, therefore, crop yield [40].

Chemical alternatives to neonicotinoid-treated seeds in corn

In the short term, growers seeking non-neonicotinoid seed treatments for corn may turn to products based on anthranilic diamides, a relatively new class of systemic insecticides that act against ryanodine receptors in insect nervous systems [143]. The USEPA and NYSDEC have registered seed treatment products based on the active ingredients chlorantraniliprole and cyantraniliprole for use in field corn to protect against wireworms, white grubs, cutworms, and seedcorn maggot. While not an exact substitute for neonicotinoid-treated seeds, seeds treated with products like DuPont's Lumivia and Syngenta's Fortenza offer similar functionality to farmers currently using neonicotinoid-treated seeds and do not require changes to management techniques. Chlorantraniliprole-treated seeds have been used in the United States since 2013, and in Canada since 2017 [666, 715]. Following restrictions on neonicotinoids in Ontario, field corn seed vendors have emphasized chlorantraniliprole-based treatments as the principal replacement [60, 941, 863]. At present, however, chlorantraniliprole products are more expensive than neonicotinoids in the United States. In field trial data collected for this report, mean yields and estimated financial returns were also lower for corn plots planted with chlorantraniliprole-treated seeds than for plots using neonicotinoid-treated seeds (see *Chapter 5*), though this analysis is based on relatively few paired observations.

The pyrethroid tefluthrin (as Force ST) is also registered with the USEPA as a seed treatment for field and sweet corn[14]. At its "high" application rate, it is labeled for control of seedcorn maggot, rootworms, wireworms, and white grubs [1050, 240]. Though introduced in 1995, tefluthrin seed treatments failed to capture a significant share of the market [211]. Tefluthrin is not systemic, so operates only as a contact insecticide in the soil around a germinating seed and offers a shorter window of protection than systemic neonicotinoids or anthranilic diamides. Though they are rarely used at present, they could be more widely adopted if restrictions were imposed on neonicotinoid-treated seeds. Thus, we include tefluthrin-treated corn seeds in the quantitative analysis in *Chapter 5*.

Several other insecticides applied to the soil at planting act effectively against insect pests currently controlled with neonicotinoid-treated seeds, though all have financial, health, and/or environmental drawbacks. Soil-applied anthranilic diamides (chlorantraniliprole or cyantraniliprole) are available to farmers outside of Long Island, albeit at a higher per-acre cost than neonicotinoids or non-neonicotinoid alternatives. Before widespread adoption of neonicotinoid seed treatments, many New York corn farmers applied organophosphate or pyrethroid insecticides at planting to protect against corn rootworm,

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[14] A different pyrethroid, permethrin, was registered for corn seed treatment from 1998 to 2010 under the name Pounce 25 STD [211].

wireworms, white grubs, and seedcorn maggot [224, 225, 228, 652, 145, 146, 365, 35]. Lindane, an organochlorine, was widely used as well [225, 1018]. It is no longer registered, due to environmental risks and pest resistance [720]. Commonly-used organophosphates included chlorpyrifos (i.e., Lorsban 50W, applied as a slurry in the planter box), diazinon (various brands, applied as a dust in the planter box), and phorate (in Thimet 20-G granules). Pyrethroid-based treatments included products based on tefluthrin (Force) and permethrin (Kernel Guard Supreme) [365, 35]. As of February 2020, all of these organophosphate- and pyrethroid-based treatments are still registered for use in New York State.[15] However, Governor Cuomo recently directed the NYSDEC to have regulations in place to ban chlorpyrifos for all uses, except spraying apple tree trunks, by December 2020. Chlorpyrifos will be banned for all uses in New York by July 2021 [129].

Switching from neonicotinoid-treated seeds to a soil-applied preventive insecticide would be difficult for some New York corn growers. Neonicotinoid-treated seeds have been widely available for more than two decades, and growers have invested in agricultural equipment and cropping systems appropriate for that technology. For instance, applying insecticides while planting requires planter attachments or other equipment not needed to use pre-treated seeds. Other costs associated with a shift to soil-applied insecticides could include additional labor costs associated with pesticide storage and use and greater health risks to farm workers who handle insecticides.

4.1.2 Soybean

In 2018, New York soybean production was worth $141 million, harvested from 325,000 acres of New York farmland [945]. Annual New York soybean production, in bushels, has increased by more than 300% since 1998 (see Figure 4.2). After field corn, it is the most valuable crop in New York State using neonicotinoid-treated seeds.

Historically, soybean farmers in the Northeast[17] used neonicotinoid-treated seeds on a smaller proportion of acres than soybean farmers elsewhere in the U.S. This may be attributable to relatively low pest pressure or other factors. Between 2008 and 2012, soybean farmers in the Northeast planted an

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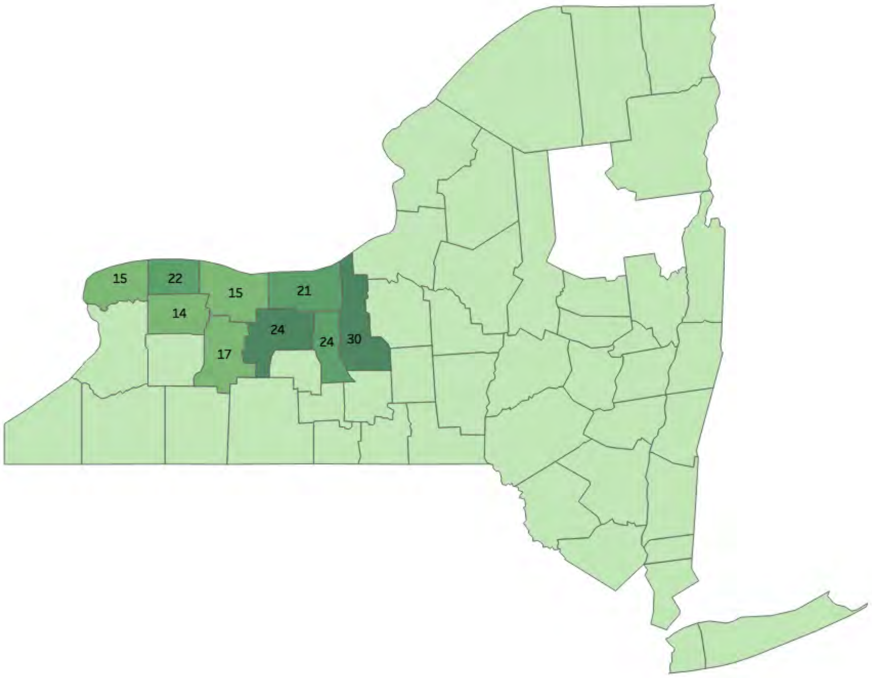
[15] Corteva Agriscience, which makes Lorsban-branded products and is the principal U.S. producer of chlorpyrifos, intends to stop manufacturing and selling chlorpyrifos at the end of 2020 [52]. Chlorpyifos-based insecticides from other companies are currently available in New York,[16] but are not available for all of the uses and modes of application offered by Lorsban.

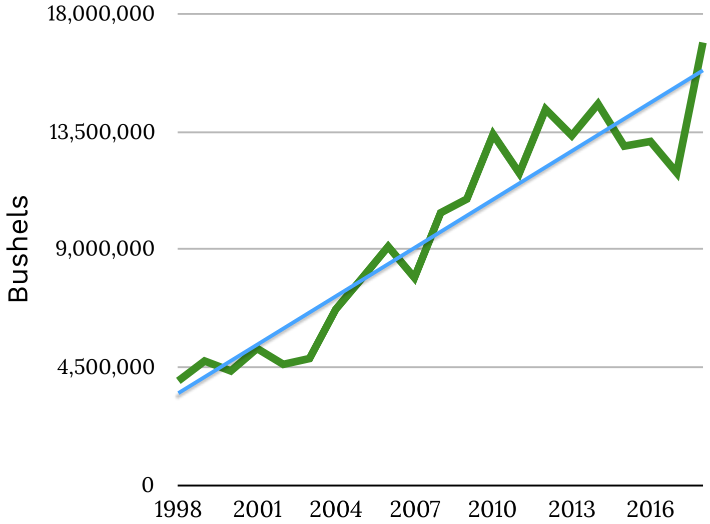
[17] USDA Farm Production Region including Delaware, Maryland, New Jersey, New York, Pennsylvania, and the New England states. New York represented about 12% of regional soybean production in 2017 [949].

Figure 4.2: **New York soybean production**

Acres of soybean harvested in New York counties[1] (in thousands), 2017



Annual soybean harvest in New York State, 1998-2018



Notes: (1) Excludes counties with fewer than 10,000 acres of soybean harvested in 2017 [949].

average 16% of acres with neonicotinoid-treated seeds compared to 28-32% in the rest of the country [591]. Nationwide, a majority of soybean farmers likely used neonicotinoid-treated seeds by 2013 [243, 410, 987, 990, 985]. Imidacloprid and thiamethoxam[18] are commonly used in U.S. soybean seed coatings. Clothianidin is also registered for soybean seed treatment, but made up less than 5% of this market in 2014 [591, 985]. No data exist on treated seed usage in New York after 2014.

Preventive use of neonicotinoid-treated seeds effectively control three occasional, early-season insect pests: seedcorn maggot, wireworms, and white grubs. Of these, seedcorn maggot is the most important. While seedcorn maggots can colonize almost any large-seeded crop, some research suggests soybean may be more susceptible to colonization and more vulnerable to damage than corn[19] [1016, 776, 49].

As in corn, a recent study of seedcorn maggot prevalence and damage in Quebec by Labrie et al. [482] may be useful in assessing risks to New York soybeans from this pest. The study measured soybean plant stand, seedling damage, numbers of soil pests, and soybean yield in alternating strips planted with neonicotinoid-treated seed and untreated seed. Researchers measured the number of soil pests captured in soil traps, plant stand, and seedling damage. Seedcorn maggots were present in nearly every field, but caused little damage. In 16 soybean trials, there was no difference in soil insect damage, plant stand, or yield between treated and untreated plots; only two sites identified any seedlings damaged by wireworm or seedcorn maggot.

The soybean aphid is the insect pest most often economically damaging to New York soybeans [149, 1094]. Seed treatments slow early-season aphid population growth, but there is little evidence that this decreases season-long pest damage or leads to an increase in yield [540, 436, 822, 33, 462]. Nevertheless, neonictoinoid-treated seeds are widely used for soybean aphid control. Indeed, according to a 2014 soybean grower survey, it is the primary soybean pest targeted with neonicotinoid-treated seeds [567]. Field trials that evaluate the effectiveness of soybean insecticidal products regularly compare neonicotinoid-treated seeds to neonicotinoid and non-neonicotinoid foliar products that are

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[18] Primarily under the Cruiser and Gaucho brands, respectively

[19] Based on field trials in New York State, Vea et al. [1016] estimated that seedcorn maggot populations could reach 20 maggots per soybean seed before causing significant stand reductions; the estimated threshold for field corn was 40 maggots per seed. Though this study is still useful to demonstrate the relative susceptibility of field corn and soybean, specific economic thresholds calculated today would be quite different than in 1975. Commodity prices and farming costs have substantially changed. There is no currently accepted economic threshold for seedcorn maggot.

also labeled for control of soybean aphid.[20] Early-season soybean aphid can be managed with scouting and a timely foliar insecticide application, which can be a neonicotinoid or a non-neonicotinoid alternative.

Alternatives to neonicotinoid-treated seeds in soybean

If neonicotinoid-treated seeds were to stop being available or increase in price, some soybean growers would use other insecticidal seed treatments. The USEPA and NYSDEC have registered two products with the active ingredient cyantraniliprole (an anthranilic diamide) for soybean seed treatment: DuPont's Lumiderm and Syngenta's Fortenza.[21] At present, these products are significantly more expensive than neonicotinoid seed treatments. However, switching from neonicotinoid-treated seeds to cyantraniliprole-treated seeds would not require major changes in equipment or management.

Compared to field corn, fewer insecticides are labelled for control of seedcorn maggot, wireworm, and white grub in soybean. Soil-applied pyrethroids available for control of all three pests in soybean include bifenthrin (Brigade, Capture) and permethrin (Arctic). The organophosphate phorate (Thimet) is also registered for these uses. There are many more options for growers primarily concerned with soybean aphid.[22] The latest CCE Integrated Pest Management (IPM) Guidelines (CCE Guidelines) for soybean list two organophosphate active ingredients (chlorpyrifos and dimethoate) and three pyrethroids (beta-cyfluthrin, lambda-cyhalothrin, and zeta-cypermethrin) labelled for control of soybean aphid [149]. NYSDEC has also registered products based on active ingredients from several other Insecticide Resistance Action Committee (IRAC) groups for use against this pest in New York State: carbamates (methomyl), butenolides (flupyradifurone), anthranilic diamides (cyantraniliprole), and flonicamid (flonicamid).

Growers can reduce the risk of a seedcorn maggot infestation with several non-chemical management practices: no-till farming, later planting, and allowing a gap between cover crop incorporation and planting[23] [355, 650, 399]. Higher seeding rates (greater planting density) may partially compensate

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[20] Recent examples include Hodgson and VanNostrand [402, 403, 404], Dierks [203], and Cook et al. [141]

[21] These products are labelled for control of white grubs and wireworms on soybean. They are not currently registered for treatment of seedcorn maggot on soybean. However, Fortenza is labelled for control of seedcorn maggot in corn, and is approved for use against seedcorn maggot in soybean in Canada and other countries.

[22] As previously noted, neonicotinoid seed treatments do not provide season-long control of aphids.

[23] Manure application is a major risk factor in corn, but manure is seldom applied to soybeans since they fix nitrogen.

for early-season pest damage. The most recent version of the CCE Guide for pest management in field crops recommends planting 7-15% more seeds per acre higher if not using insecticide-treated seeds [149]. However, none of these techniques entirely eliminate risk from seedcorn maggot [390], and all impose costs on growers using them. There can be serious consequences to “guessing wrong” about seedcorn maggot risk for individual farmers. In the 2019 season, the pest caused visible stand reductions in at least two New York soybean fields planted without neonicotinoid-treated seeds [1093].

4.1.3 Wheat

Between 2010 and 2012, an average of 18% of winter wheat acres nationwide were planted with neonicotinoid-treated seeds [571], likely concentrated in the Southeast and West, where Hessian fly and wireworms, respectively, are a greater threat to wheat than in New York [391]. 30,600 acres of winter wheat were planted in New York in 2017, about 3% of the acreage devoted to corn. Armyworm, cereal leaf beetle, and Hessian fly are occasional pests of winter wheat in New York State; neonicotinoid-treated seeds are labelled for control of only Hessian fly [284, 809]. The CCE guidelines for wheat note that insecticides are not normally justified for Hessian fly. Growers may control this pest with mechanical control after harvesting infested crops and planting winter wheat only after the local fly-free date [149].

4.2 Fruit crops

In fruit crops, neonicotinoids (acetamiprid, imidacloprid, and thiamethoxam) are primarily used in foliar sprays, with some soil-applied products. New York State fruit growers deal with a wide range of potential insect pests, with pest pressures varying significantly by season, location, and many other factors. The “key pests” for a given grower may be different than those for a fruit crop in New York as a whole. Therefore, the description of pest pressures below is somewhat simplified. Furthermore, this report focuses on New York fruit crops with an annual production value of $10 million or more. It does not go into detail on minor fruit crops. Melons are addressed with the other cucurbits in Section 4.3.5.

4.2.1 Apples and tree fruits

New York was the nation's second-largest producer of apples by weight (688,400 tons) and third-largest by value ($262 million) in 2018. The state harvests approximately 40,000 acres of apple orchards. Two other tree fruits, peach and cherry, accounted for another $14 million in 2018 production [945]. New York tree fruits also contribute to the New York agritourism and craft beverage industries [812].

Neonicotinoid-based products are widely used to control tree fruit pests in New York, partially displacing older and more toxic broad-spectrum organophosphates and carbamates [363, 150, 1077]. The *2019 Pest Management Guidelines for Commercial Tree Fruit Production* lists several neonicotinoid-based products that provide "good" control of the common tree fruit pests, which are included in Table 4.2 [150]. Popular neonicotinoid foliar sprays include Actara (thiamethoxam), Admire Pro (imidacloprid), and Assail (acetamiprid), as well as several pre-mixed products that combine neonicotinoids with other active ingredients.[24] Growers may also apply Admire Pro as a soil treatment to combat the woolly apple aphid. Though the technique is not yet widely used, equipment and insecticide formulations for neonicotinoid trunk injection are now available. These show promise for controlling apple pests with lower environmental and user risk than foliar application methods. [5, 1086].

Dozens of insect pests can decrease fruit yields or make the harvest unsaleable on the fresh market. However, a relatively small number of pests drive the majority of insecticide applications in orchards [592]. Important pests sometimes controlled with neonicotinoids include the apple maggot (*Rhagoletis pomonella*), several aphid species, and fruit-feeding caterpillars (the internal lepidopteran pest complex). Acetamiprid sprays, in particular, are valuable tools for protecting against pests that burrow into the fruit itself: apple maggot, codling moth, oriental fruit moth, and lesser appleworm. Acetamiprid can penetrate the skin of tree fruit and persist for weeks. At the same time, acetamiprid has very low toxicity to consumers; residues in the fruit are unlikely to cause harm [280, 172].

In the absence of neonicotinoids, most tree fruit growers would likely switch to a different chemical insecticide. Table 4.2 lists chemical alternatives to neonicotinoids for major tree fruit pests. Biopesticides containing codling moth granulosis virus, *Chromobacterium subtsugae*, or Bt are also effective against particular pests, as are some non-insecticide management strategies [126]. However, grow-

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[24] e.g., Agri-Flex, Endigo, and Leverage.

Table 4.2: **Tree fruits: selected target pests of neonicotinoids and alternatives**

IRAC group[1]	*Active ingredient*	Apple maggot	Aphids[2]	European apple sawfly	Internal lepidopterans[3]	Leafhoppers	Plum curculio	Pear psylla	Spotted tentiform leafminer
NEO	Acetamiprid	**X**	**X**	x	**X**	**X**	x	x	**X**
NEO	Imidacloprid		**X**			**X**		x	**X**
NEO	Thiamethoxam		**X**	**X**		**X**	**X**	**X**	x
CRB	Carbamates	*CAR, MET*	*MET, OXA*		***MET***	***CAR, MET***	*CAR, MET, OXA*		***MET, OXA***
OP	Organophosphates	***DIA, PHO***		***PHO***	***PHO***		***PHO***		
PYR	Pyrethroids	***CYF, ESF, FEN, LCY, PER***	*CYF, ESF, FEN, PER, LCY*	*CYF, ESF, FEN, PER, LCY*	***CYF, ESF, FEN, LCY***	***CYF, ESF, FEN, PER, LCY***	*CYF, ESF, FEN, PER, LCY*	*ESF, FEN, PER, LCY*	***CYF, ESF, FEN, PER, LCY***
SPY	Spinosyns	*STM, SPD*		*SPD*	***SPM, SPD***		*SPM*	***SPM, SPD***	***SPM***
AVR	Avermectins				*EMA*	***ABA***		***ABA***	***AMA, EMA***
PAD	Pyriproxyfen				*PFN*			***PFN***	*PFN*
BNZ	Benzoylureas				***NOV***	*NOV*			***NOV***
16	Buprofezin					*BPR*		***BPR***	
OXD	Oxadiazines	*IND*		*IND*	*IND*	***IND***	***IND***		*IND*
TTA	Tetronic acids		***SPI***					***SPI***	
AND	Anthranilic diamides[4]	*CHL, CYA*		***CHL, CYA***	***CHL, CYA***	***CYA***	***CYA***	***CYA***	***CYA***
FLN	Flonicamid		***FLN***						
UN	Azadirachtin		*AZA*		*AZA*	*AZA*			***AZA***

Ratings for the control of common pome fruit pests from Cornell Cooperative Extension [150]. Active ingredients offering "good" control are highlighted in green; those offering "fair" control are highlighted in yellow. This table only lists the most effective insecticides of a given class (i.e., "fair" performers are not included if there is a "good" insecticide of that class). Gray highlights indicate that a class of insecticides has not been studied for control of the given pest(s), that it is ineffective, or that it provides only "poor" control.

Notes: (1) The Insecticide Resistance Action Committee (IRAC) groups active ingredients by mode of action; (2) includes apple, spirea, and rosy apple aphids; (3) includes codling moth, oriental fruit moth, and lesser appleworm; (4) sale and use prohibited in Nassau and Suffolk Counties.

Key to insecticides:

1A	Carbamates	CAR=carbaryl, MET=methomyl, OXA=oxamyl
OP	Organophosphates	DIA=diazinon, DIM=dimoethoate, PHO=phosmet
PYR	Pyrethroids	CYF=cyfluthrin, ESF=esfenvalerate, FEN=fenpropatrin, LCY=lambda-cyhalothrin, PER=permethrin
SPN	Spinosyns	STM=spinetoram, SPD=spinosad
AVR	Avermectins	ABA=abamectin, EMA=emamectin benzoate
PAD	Pyriproxyfen	PFN=pyriproxyfen
BNZ	Benzoylureas	NOV=novaluron
BPR	Buprofezin	BPR=buprofezin
OXD	Oxadiazines	IND=indoxacarb
TTA	Tetronic acids	SPI=spirotetramat
AND	Anthranilic diamides	CHL= chlorantraniliprole, CYA=cyantraniliprole
FLN	Flonicamid	FLN=flonicamid
UN	Azadirachtin	AZA=azadirachtin

ers often need to control multiple pests simultaneously. In the absence of a neonicotinoid (or other broad-spectrum insecticide), multiple active ingredients may be needed to control the same pests. Some alternatives are more toxic to beneficial field insects or pesticide applicators (see Table 2.2) [126].

4.2.2 Grapes

New York grape growers harvested 187,000 tons of grapes in 2017 (three-quarters for juice), earning $69 million at the year's average price of $369 per ton [945]. However, the sales value of New York grapes grossly understates the importance of viticulture to the state. According to an industry study, New York wineries earned $553 million in 2012 and led to another $401.5 million in wine-related tourism spending [879]. The direct economic impact of New York grapes, grape juice, wine, and related products may be over $5.5 billion per year [433].

The most significant arthropod pest of New York grapes is the grape berry moth (*Paralobesia viteana*), which is widespread in all of the state's grape-growing regions and poses a persistent economic threat [511, 1038]. Adult moths lay eggs directly on grape berries. Upon hatching, the moth larvae burrow into the fruit to feed, causing both direct damage to the crop and making grapes more vulnerable to late season rots [1038]. Growers typically rely on insecticide sprays targeting larvae[25] [1040]. An acetamiprid-based foliar spray (Assail) is registered for use against grape berry moth in New York,

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[25] There is a well-established protocol for predicting grape berry moth laying. Pest forecasts and a degree-day calculator are available at `http://newa.cornell.edu`.

Table 4.3: **Apples: selected neonicotinoid uses, alternatives, and FUEIQ**

	Representative products		***FUEIQ at max rate for representative pests***				
Group	**Active ingredient**	**Product**	**RAA**	**EAS**	**WAL**	**PC**	**STLM**
NEO	Acetamiprid	Assail 30SG	2		2		1
NEO	Imidacloprid	Admire Pro	10		10		3
NEO	Thiamethoxam	Actara 25WDG	2	3	1	3	3
AND	Cyantraniliprole	Exirel	2	1	1	2	1
AVR	Abamectin	Agri-Mek 8SC			1		1
BNZ	Novaluron	Rimon 0.83EC					3
CRB	Methomyl	Lannate LV 2.4L	19		19		19
CRB	Carbaryl	Sevin XLR Plus		66	33	66	
FLN	Flonicamid	Beleaf 50SG	1				
OP	Phosmet	Imidan 70W		132		132	
OXD	Indoxacarb	Avaunt 30WDG		4	4	4	
PYR	Fenpropathrin	Danitol 2.4EC		10	10	10	10
PYR	Lambda-cyhalothrin	Warrior II		2	2	2	2
SPY	Spinetoram	Delegate 25WG					3
TTA	Spirotetramat	Movento 240SC	5				
UN	Azadirachtin	Aza-Direct	1		1		1

Target pests: **RAA**: rosy apple aphid; **EAS**: European apple sawfly; **WAL**: white apple leafhopper; **PC**: plum curculio; **STLM**: spotted tentiform leafminer

Products assessed to provide "good" control of the given pest in Cornell Cooperative Extension [150] are highlighted in green; those offering "fair" control are highlighted in yellow. See Table 2.1 for active ingredient group abbreviations.

FUEIQ is the estimated risk of a product, adjusted to application rate. It consists of three equally weighted components: consumer, farm worker, and ecological. Please see the introduction to EIQ in Chapter 2 for a description of its uses and limitations. FUEIQ values in this table were calculated based on the maximum labelled application rate for a given pest.

and there is some evidence that mid-season chemigation with imidacloprid can reduce grape berry moth infestation [1010]. However, neonicotinoids are not as effective against grape berry moth as several alternative insecticides [532]. The relevant CCE Guidelines list insecticides with Bt, carbamate, organophosphate, pyrethroid, spinosyn, or anthranilic diamide active ingredients for grape berry moth control [1040].

Neonicotinoid-based sprays are highly effective against grape leafhoppers (*Erythroneura* spp.) and Japanese beetle, which frequently damage the leaves of grapes from mid-season [532, 370]. There are well-established monitoring protocols and economic thresholds for both of these pests. When needed, growers often apply products containing both a neonicotinoid and another insecticide (e.g., Brigadier, Leverage) to target grape leafhoppers and/or Japanese beetles at the same time as the grape berry

Table 4.4: **Grapes: selected neonicotinoid uses, alternatives, and FUEIQ**

	Representative products		***FUEIQ at max rate for representative pests***			
					Grape phylloxera	
Group	**Active ingredient**	**Product**	Leafhoppers	Japanese beetle	*Leaf-form*	*Root-form*
NEO	Acetamiprid	Assail 30SG	**3**	**3**	**3**	
NEO	Imidacloprid	Admire Pro	**1**	**1**[1]	**5**	**14**
NEO	Thiamethoxam	Actara 25WDG	**3**	**3**		
NEO	Thiamethoxam	Platinum 75SG[2]		**9**	**9**	**9**
AND	Chlorantraniliprole	Altacor[2]		**2**		
BPR	Buprofezin	Applaud[2]	**18**			
CRB	Carbaryl	Sevin XLR Plus	**40**	**40**		
OP	Phosmet	Imidan 70W WSP		**49**		
OXD	Indoxacarb	Avaunt 30WDG	**4**	**4**		
PYR	Bifenthrin	Brigade WSB	**4**	**4**		
PYR	Fenpropathrin	Danitol 2.4EC	**5**	**10**	**10**	
TTA	Spirotetramat	Movento 240EC			**4**	**4**

Notes: (1) with 2(ee) recommendation; (2) sale and use prohibited in Nassau and Suffolk Counties.
FUEIQ is the estimated risk of a product, adjusted to application rate. It consists of three equally weighted components: consumer, farm worker, and ecological. Please see the introduction to EIQ in Chapter 2 for a description of its uses and limitations. FUEIQ values in this table were calculated based on the maximum labelled application rate for a given pest. See Table 2.1 for active ingredient group abbreviations.

moth [511]. Foliar neonicotinoids are also used to control several secondary pests of grape, including mealybugs, rose chafer, leaf form grape phylloxera, potato leafhopper, spotted wing drosophila, and multicolored Asian lady beetle [1040].

Soil-applied imidacloprid is effective against two historic insect pests of grape that are becoming more relevant in New York: grape rootworm (*Fidia viticida*) and root-form grape phylloxera (*Phylloxera vitifoliae*). Grape rootworm was a major pest in the early 1900s, but was easily controlled from mid-century through the application of broad-spectrum insecticides targeting multiple pests. Grape rootworm damage is becoming more common, however, as growers have moved toward narrower-spectrum insecticides that target other grape pests with a high specificity [1039]. Root-form grape phylloxera was once the major obstacle to growing *Vitis vinifera* grapes in North America, but the pest is now largely controlled by hybridization or by grafting susceptible *V. vinifera* scion onto phylloxera-resistant rootstock. For some purposes, however, vineyards may need to use ungrafted, non-resistant vines. Even for resistant cultivars, root-form phylloxera can reduce productivity. Soil-applied neonicotinoids can reduce damage from grape phylloxera and substantially increase yields for susceptible cultivars

[609, 1040]. In the absence of neonicotinoids, grape growers would have just one active ingredient effective against root-form phylloxera control: spirotetramat [511].

A new invasive insect, the spotted lanternfly (*Lycorma delicatula*), is likely to threaten New York grapes and berry crops in the coming years. The pest is established in southeast Pennsylvania and is causing serious damage. Dinotefuran- and imidacloprid-based sprays will be an important tool for lanternfly control if, as expected, this invasive planthopper expands into New York [943, 176].

4.2.3 Berries

New York produced $19 million of berries in 2017 ($10 million of which were strawberries) [945]. Many of the insect pests that affect grapes also attack berry crops. The patterns of insecticide use in berry crops are somewhat similar to those in grapes.

Spotted wing drosophila

Spotted wing drosophila (*Drosophila suzukii*) were first detected in New York in 2011, and have since become a significant New York berry pest. To a lesser extent, they also feed on stone fruits and grapes. Spotted wing drosophila larvae feed inside ripening fruit, and even a mild infestation can make it difficult for farmers to sell their crop [719, 752]. The effect on usable yield can be dramatic; when the pest first arrived in California, farmers growing susceptible crops suffered 20% average losses [68]. Regular monitoring[26] can consistently detect the presence of adult spotted wing drosophila in time for treatment, allowing targeted rather than preventive spraying [1032, 512]. Once the pest is detected, however, farmers often have little recourse but to apply insecticides weekly through harvest. Monitoring is rendered more difficult by the short generation time; growers often have only a few days to identify the problem and apply insecticide [153].

Acetamiprid is one of several insecticides to receive 2(ee) recommendation approvals for control of spotted wing drosophila in New York. However, acetamiprid is less effective against spotted wing drosophila than several other insecticides of the organophosphate, carbamate, pyrethroid, spinosyn, and diamide IRAC groups.[27] [81, 1091, 750, 513] Anecdotal evidence suggests that neonicotinoid sprays

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[26] On-farm monitoring is most effective when informed by regional reporting. The New York State IPM program coordinates spotted-wing drosophila reporting in New York.

[27] Imidacloprid- and thiamethoxam-based products have also been tested for control of spotted wing drosophila, though

may therefore be declining in popularity among U.S. berry farmers, as farmers shift insecticide rotations to favor active ingredients that are fully effective against drosophila as well as other late-season pests [751].

Cultural and physical control can substantially reduce spotted wing drosophila risk. Early season cultivars (i.e., June-bearing strawberries) have thus far escaped damage by this pest in New York [153]. Frequent harvests can reduce losses to drosophila (and the risk of spreading infestations), as does chilling and sanitizing harvested fruit [769, 153]. Removing rotting, overripe, and infested fruit is also important for controlling infestations [369]. Where practical, netting is effective in blueberries and raspberries [444, 144, 20, 495], and even high tunnels can reduce rates of infestation [86, 754]. Mass trapping with an insecticidal bait can reduce adult fly numbers, but trials have produced inconsistent results [369, 20]. Biological controls are under investigation; native insectivores and introduced parasitoids may be part of long-term solution [303, 26, 369]. At present, cultural and physical controls alone cannot replace regular application of chemical insecticides for spotted wing drosophila.

Other notable strawberry pests

New York strawberry growers may encounter well over a dozen other arthropod pests, but neonicotinoid-based soil treatments and/or foliar sprays are perhaps most notable for their role in controlling root weevils (*Otiorhynchus* spp.) and the strawberry sap beetle (*Stelidota geminata*). These pests are not the most common or economically important for New York berry farmers, but they are difficult to control with insecticides [153, 544]. For both, the only insecticides listed in the *2019 Cornell Pest Management Guidelines for Berry Crops* are based on neonicotinoids (thiamethoxam for root weevils; acetamiprid for strawberry sap beetle) or the pyrethroid bifenthrin. Root weevil grubs feed on the roots of strawberries, potentially stunting plants and reducing yields [867]. In addition to chemical insecticides, entomopathogenic nematodes (*Heterorhabditis* spp.) and fungi (*Beauveria bassiana* or *Isaria fumosorosea*) can offer effective control. Crop rotation also reduces root weevil populations [153]. Strawberry sap beetles, both adults and larvae, attack ripe and over-ripe strawberries and occasionally other fruit crops. Sap beetles are becoming more common in New York. Though they

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they are not labeled for this target pest in New York State. These products seem to perform somewhat better than acetamiprid but not as well as the best-performing insecticides from other IRAC groups [81].

Table 4.5: **Berries: selected neonicotinoid uses, alternatives, and FUEIQ**

Representative products			*FUEIQ at max rate for representative pests*			
Group	**Active ingredient**	**Product**	Spotted wing drosophila[1]	Root weevils (strawberry)	Sap beetle (strawberry)	Blueberry maggot (blueberry)
NEO	Acetamiprid	Assail 30SG	**3**		**4**	**3**
NEO	Imidacloprid	Admire Pro				**3**
NEO	Thiamethoxam	Actara 25WDG		**2**		
NEO	Thiamethoxam	Platinum 75SG		**6**		
AND	Cyantraniliprole	Exirel[5]	**2**[6]			**2**
CRB	Carbaryl	Sevin 4F				**39**
OP	Malathion	Malathion 5EC	**44**[2]			**14**
PYR	Fenpropathrin	Danitol 2.4EC	**8**			**5**
PYR	Bifenthrin	Brigade WSB	**4**	**9**	**9**	**4**
SPY	Spinetoram	Delegate WG	**3**[3,4]			**3**
SPY	Spinosad	Entrust	**1**			
UN	Azadirachtin	AzaSol				**< 0.5**

Notes: (1) Spotted wing drosophila recommendations are insecticides with "good" or "excellent" probable efficacy in Loeb et al. [513]. Insecticides for other pests are listed in the most recent CCE Guide for berry crops [153]. (2) FUEIQ based on maximum rate in strawberries (3.2 pt/A); FUEIQ for maximum rate in raspberries and blackberries (3 pt/A) is 40 and in blueberries (2 pt/A) is 27. (3) use permitted with a 2(ee) recommentation. (4) labelled for use in blueberries, raspberries, and blackberries; Delegate WG is another spinetoram-based insecticide with a 2(ee) recommendation for use against spotted wing drosophila in strawberries (up to 10 fl oz/A, FUEIQ: 2). (5) sale and use prohibited in Nassau and Suffolk Counties; (6) labeled for use on strawberries and blueberries.

FUEIQ is the estimated risk of a product, adjusted to application rate. It consists of three equally weighted components: consumer, farm worker, and ecological. Please see the introduction to EIQ in Chapter 2 for a description of its uses and limitations. FUEIQ values in this table were calculated based on the maximum labelled application rate for a given pest. See Table 2.1 for active ingredient group abbreviations.

rarely cause economic damage, severe infestations can be difficult to control. Growers can reduce sap beetle risk by harvesting ripe fruit regularly, keeping fields free of dropped fruit, and choosing strawberry cultivars that tend to hold fruit off of the ground [517].

Other strawberry pests controlled in part by neonicotinoid-based products include the greenhouse whitefly (*Trialeurodes vaporariorum)*), potato leafhopper (*Empoasca fabae*), Japanese beetle (*Popillia japonica*), aphids, and the white grub pest complex. In addition to neonicotinoids, each of these pests can be controlled with insecticides from several other classes [153].

Other notable blueberry pests

Blueberry maggot (*Rhagoletis mendax*), cranberry fruitworm (*Acrobasis vaccinia*), and cherry fruitworm (*Grapholita packardi*) are significant pests of blueberry in New York. The larvae of all three species tunnel into and feed on fruit. An infestation both depresses yield and makes it difficult for farmers to sell their crop [364, 808]. Acetamiprid- and imidacloprid-based sprays and insect traps are effective controls, and can be timed with monitoring and a well-established degree-day model [29, 1087, 808]. Chemical alternatives for blueberry maggot are described in Table 6.4. Fruitworms can be controlled with acetamiprid-based foliar sprays, other chemical insecticides,[28] or biopesticides containing *Bacillus thuringiensis* or *Chromobacterium substsugae*. Aggressive weed control and removal of infested fruit can slow population growth [808].

Neonicotinoids are also effective against many secondary pests of blueberry, including Japanese beetle, aphids, and leafhoppers. A thiamethoxam-based insecticide (Actara) has received a 2(ee) recommendation for a potentially important emerging pest, the brown marmorated stink bug (*Halymorpha halys*) [153].

4.3 Vegetable crops

4.3.1 Cabbage and other crucifers

Cabbage is New York's most valuable vegetable crop. New York also produces more cabbage, by value, than any state except California and Florida: approximately $54 million harvested from 10,000 acres in 2018 [945]. Cabbage is closely related to kale, broccoli, cauliflower, and the other cole vegetables; all of these crops are cultivars of a single species, *Brassica oleracea*. Other crops within the family Brassicaceae, known collectively as crucifers or brassicas, include turnips, canola, arugula, and radish. The production value of non-cabbage crucifers in New York is much lower than cabbage, so they are not discussed separately, but they are susceptible to many of the same pests.

In crucifers, neonicotinoid foliar sprays and soil treatments are commonly used to control flea beetles (*Phyllotreta* spp.), aphids (*Brevicoryne brassicae*, *Myzus persicae*, and others), onion thrips (*Thrips tabaci*), and Swede midge (*Contarinia nasturtii*) [154]. Prior to the introduction of neonicotinoids, producers largely relied on repeated applications of organophosphates and pyrethroids [875]. Table 4.6 lists neonicotinoid-based and alternative insecticides effective against these target pests.

Flea beetles are a crucifer pest from planting through July, as they feed on almost all exposed

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[28] Insecticides listed in the CCE Guidelines for control of fruitworm in blueberry include active ingredients in the carbamate (1A), organophosphate (1B), pyrethroid (3A), spinosyn (5), pyrifroxyfen (7C), diacylhydrazine (18B), oxadiazine (22), and tetronic acid (28) IRAC groups [153]

Table 4.6: **Crucifers: selected neonicotinoid uses, alternatives, and FUEIQ**

	Representative products		*FUEIQ: representative pests*			
Group	**Active ingredient**	**Product**	Flea beetles	Aphids	Onion thrips	Swede midge
NEO	Acetamiprid	Assail 30SG		**2**	**2**	**2**
NEO	Imidacloprid	Admire Pro	**3**	**10**	**10**	**10**
NEO	Thiamethoxam	Actara	**2**	**2**		
NEO	Thiamethoxam	Platinum 75SG	**6**	**6**	**6**	
AND	Cyantraniliprole	Exirel[1]	**2**	**2**	**2**	**2**[1]
CRB	Carbaryl	Sevin XLR Plus	**10**			
FLN	Flonicamid	Beleaf 50SG		**1**		
OP	Acephate	Orthene 97		**24**		
OP	Chlorpyrifos	Lorsban 75WG				**27**[2]
PAD	Pymetrozine	Fulfill		**2**		
PYR	Beta-cyfluthrin	Baythroid XL	**1**		**< 0.5**	
PYR	Bifenthrin	Brigade 2EC	**5**			
PYR	Esfenvalerate	Asana XL			**2**	
PYR	Lambda-cyhalothrin	Warrior II	**1**		**1**	**1**[2]
PYR	Zeta-cypermethrin	Mustang MAXX	**1**	**1**	**1**	
SPY	Spinetoram	Radiant SC			**2**	
SPY	Spinosad	Entrust SC	**1**		**2**	
TTA	Spirotetramat	Movento		**3**	**3**	**3**

Notes: (1) Sale and use prohibited in Nassau and Suffolk Counties; (2) use permitted with 2(ee) recommendation. Pest and insecticide combinations highlighted in green are listed in the most recent Cornell pest management guide [154]. With the exception of the FUEIQ for cyantraniliprole (calculated by the authors), calculated FUEIQ is from the same source. FFUEIQ is the estimated risk of a product, adjusted to application rate. It consists of three equally weighted components: consumer, farm worker, and ecological. Please see the introduction to EIQ in Chapter 2 for a description of its uses and limitations. FUEIQ values in this table were calculated based on the maximum labelled application rate for a given pest. See Table 2.1 for active ingredient group abbreviations.

parts of the plant[29] [651]. Frequent monitoring is necessary, as movement from wild hosts can trigger reinfestation even after successful insecticide treatment [154]. Early infestations can stunt or kill seedlings (especially in direct-seeded fields). Later in the season, flea beetles can cause severe foliar damage, lowering crop yield and quality [824]. Flea beetles also vector crucifer diseases, including alternaria leaf spot [324]. Row covers are highly effective against flea beetles, but generally impractical in conventional production. Crop rotation, aggressive weed control, and trap cropping may reduce flea beetle populations, but are not reliable methods of control [94, 154].

Cabbage and green peach aphids can be significant pests for cabbage growers after mid-June. Several groups of insecticide active ingredients are effective against aphids; neonicotinoid-based

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[29] Flea beetle larvae feed on crucifers belowground as well, but this damage is rarely economically significant [651].

products include acetamiprid, imidacloprid, and thiamethoxam foliar sprays [154]. Regular weeding and clearing crop debris after harvest can also reduce aphid pressure in some instances, but is not a substitute for chemical control [154]. Native predatory insects often keep aphid populations below the economic thresholds, but aphid predators are vulnerable to many insecticides. It can be challenging for growers to simultaneously protect aphid predators and treat for non-aphid pests. Growers may experience a spike in aphid populations after applying insecticides that (unintentionally) kill predatory insects [938].

Onion thrips feed on cabbage leaves and can discolor and cause raised bumpy areas on leaves. This results in decreased marketable yield and higher processing costs for growers [833]. Though a significant pest of cabbage, onion thrips rarely damage other crucifers in New York [154]. Onion thrips are difficult to control once inside a cabbage head, even with repeated insecticide applications. A long window for infestation makes the management challenge greater. Multiple waves of thrips can arrive over a season, so growers use a preventive management approach by applying insecticides at planting or shortly thereafter. Some cabbage cultivars are thrips-resistant, and usually have much less damage [118, 834]. The risk of thrips infestations can also be decreased by weeding, planting further from cover crops and small grains, planting later, and/or harvesting earlier [154]. Neonicotinoid soil drenches have become standard practice for controlling thrips on susceptible cabbage varieties. This has the added benefit of controlling Swede midge (see below), for which few effective insecticides and other strategies are available.

Swede midge larvae can cause severe damage by feeding on growing tips of crucifers. Pest damage can be difficult to diagnose, as the larvae are difficult to spot, adults are indistinguishable from native midges, and it is difficult to distinguish between Swede midge damage and abnormalities from other causes [447, 117, 152]. New York cabbage producers rely heavily on acetamiprid- and imidacloprid-based products for Swede midges. Removing neonicotinoids from insecticide rotations would increase the cost and difficulty of Swede midge control. Non-chemical management techniques to reduce Swede midge damage include crop rotation, early planting, and frequent control of cruciferous weeds [94, 154].

4.3.2 Potatoes

New York farmers harvested 230,600 tons of potatoes in 2018, worth roughly $50 million [945]. The Colorado potato beetle, (*Leptinotarsa decemlineata*), is the most damaging insect pest of potatoes in New York, with aphids (several genera), and potato leafhopper (*Empoasca fabae*) posing significant threats as well [848, 609]. Many New York farmers apply neonicotinoid insecticides to their potato seed pieces immediately before planting, while others apply them to the soil at planting or to foliage as a spray.

Table 4.7: **Potatoes: selected neonicotinoid uses, alternatives, and FUEIQ**

	Representative products		*FUEIQ at max rate for representative pests*		
Group	**Active ingredient**	**Product**	Colorado potato beetle	Potato leafhopper	Aphids
NEO	Imidacloprid	Admire Pro (soil)	**7**	**7**	**7**
NEO	Thiamethoxam	CruiserMaxx Potato	**3**	**3**	**3**
NEO	Imidacloprid	Admire Pro (foliar)	**1**	**1**	**1**
NEO	Acetamiprid	Assail 30SG	**2**	**2**	**2**
AND	Cyantraniliprole	Verimark	**2**		
AVR	Abamectin	Agri-Mek SC	**1**		
BT	Bacillus t. (Bt)	Trident	**23**		
CRB	Methomyl	Lannate LV		**19**	**19**
FLN	Flonicamid	Beleaf 50SG			**1**
OP	Dimethoate	Dimethoate 400		**15**	**15**
OXD	Indoxacarb	Avaunt	**4**		
PAD	Pymetrozine	Fulfill			**3**
PYR	Beta-cyfluthrin	Baythroid XL	**1**	**<0.5**	**1**
PYR	Esfenvalerate	Asana XL	**2**	**2**	**2**
SPY	Spinosad	Entrust SC	**2**		
UN	Azadirachtin	Neemix 4.5	**1**	**1**	**<0.5**

FUEIQ is the estimated risk of a product, adjusted to application rate. It consists of three equally weighted components: consumer, farm worker, and ecological. Please see the introduction to EIQ in Chapter 2 for a description of its uses and limitations. FUEIQ values in this table were calculated based on the maximum labelled application rate for a given pest. See Table 2.1 for active ingredient group abbreviations.

The Colorado potato beetle feeds on foliage, frequently damaging potatoes and reducing tuber yields. It has an extraordinary propensity to adapt to insecticides. Resistant populations of the beetle have been reported for 52 different active ingredients, including all major neonicotinoids [22]. U.S. potato farmers adopted imidacloprid (and, later, thiamethoxam) seed piece treatments and foliar sprays quickly after they were introduced to the market in the mid-1990s. Neonicotinoid resistance (to varying degrees) is now common among Colorado potato beetle populations in the Eastern United States [66, 893, 412]. As early as 2003, the average lethal dose of imidacloprid for beetles captured on Long Island was 309-fold higher than for beetles from populations not exposed to imidacloprid. The Long Island population also displayed cross-resistance to other neonicotinoids that had not been used in their area, likely because all neonicotinoids have similar modes of action [587]. For the time being, thiamethoxam and other neonicotinoids are at least partially effective against Colorado potato beetles on some farms and are often useful as part of a multi-year insecticide rotation [609]. The CCE Guidelines for potato production list several neonicotinoid-based seed piece treatments and in-furrow products. Growers are encouraged to apply neonicotinoids (or any other insecticide mode of action) no more than once every two years in order to slow the spread of resistant traits through the population and reserve neonicotinoids for control of the Colorado potato beetle [412]. Although potato growers have access to a range of other insecticides that can be applied in-furrow, as a soil drench, or as a foliar spray[30] to control the Colorado potato beetle, effective chemical management must take local insecticide resistance into account [154]. Cyantraniliprole-based Verimark is the only non-neonicotinoid insecticide available to New York farmers that can be applied at planting as either an in-furrow drench or seed piece treatment [154]. However, Verimark is several times as expensive as neonicotinoid-based products, precluding its widespread use in this application. In addition, cyantraniliprole may not be used on Long Island, which contained 13% of New York's potato acreage in 2017 [945].

Effective scouting, the use of economic thresholds, and crop rotation can significantly reduce insecticide applications for Colorado potato beetle. Potatoes are resilient to leaf damage, with some cultivars tolerating 20% foliage loss after emergence or 60% foliage loss after late bloom without affecting financial returns [1117]. Where practical, rotating potatoes to fields at least 0.5 mile away from the previous year's potatoes can reduce early-season beetle numbers by 90% [154].

Several species of sap-feeding aphids and the potato leafhopper feed on potato plants in New York. Economically significant damage typically takes place late in the season. Leafhopper feeding locally disrupts the plant's respiration and photosynthesis [589]. Aphids can also vector serious plant diseases.[31] The aphid-transmitted potato leafroll virus can reduce potato yields by 50% [680]. Aphids

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[30] The CCE Guidelines for potato list insecticides from the pyrethroid (IRAC group 3), spinosyn (5), avermectin (6), oxadiazine (22), and anthranilic diamide (28) groups, as well as organic products based on azadirachtin, Bt, or cryolite [154]

[31] Insecticides have less impact on damage from insect-borne diseases than on direct feeding damage. Insecticides rarely

also transmit the damaging potato virus Y. Insecticide foliar sprays, including neonicotinoid-based products, are the principal means of managing these pests. Growers who have planted neonicotinoid-treated seed pieces in the current or preceding season should use foliar products with a different mode of action.[32] Fortunately, there are suitable alternative insecticides from several other IRAC groups [154]. Several cultural and physical control techniques can decrease the risk of aphid damage, including regular weeding, clearing crop debris, and creating favorable conditions for natural predators [154].[33] Well-established monitoring procedures and economic thresholds allow targeted application of insecticides for aphids and leafhoppers [154].

4.3.3 Snap bean

In 2018, New York farmers produced approximately $42 million in snap beans, beans that are grown for fresh market and for processing [945]. The category includes string beans, wax (yellow) beans, and runner beans, but not dry bean cultivars, shell peas, lima beans, or edamame (soybean). The major insect pests of snap bean controlled with neonicotinoids are seedcorn maggot and potato leafhopper[34] [154].

Seedcorn maggot is a sporadic early-season pest of large-seeded crops in New York State (see Section 4.1 for more information on this pest and its management). It is present throughout the state and, depending on weather and conditions, colonizes snap bean fields sown before mid-June [154]. Growers cannot scout for or reliably predict seedcorn maggot infestations [14]. While there is significant variation between snap bean cultivars [1015], laboratory and field trials with multiple crops suggest that snap beans are particularly vulnerable to seedcorn maggot damage [224, 225, 228, 1114, 409, 408]. Heavy infestations can cause high stand and yield losses. The Cornell Pest Management Guide lists

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kill instantly, and often kill the target pest after it has started to feed. This delay gives ample opportunity for viruses, bacteria, and fungal spores to spread from the insect to the plant.

[32] Repeated applications of insecticides with the same mode of action increase the likelihood of insecticide resistance in the target population.

[33] Leafhopper-resistant potato cultivars exist, but are no longer grown in New York State [589].

[34] The invasive soybean aphid (*Aphis glycines*) was first spotted in New York in 2001, and was immediately considered a major pest of New York snap and dry beans [768]. Curiously, this pest is incapable of reproducing on snap bean, so the crop was only damaged when large populations of adults would infest seedling-stage crops. Neonicotinoid-treated seeds used for managing seedcorn maggot and potato leafhopper also protected seedlings against soybean aphid. Large populations of soybean aphid have not been encountered in snap bean fields since 2009; since then, no significant damage from this pest has been reported in the state [154]. The cause of this decline is unclear; contributing factors could include unfavorable weather, an abundance of natural predators, neonicotinoid-treated seeds on soybean, or effective IPM.

Table 4.8: **Snap beans: selected neonicotinoid uses, alternatives, and FUEIQ**

	Representative products		***FUEIQ at max rate for representative pests***	
Group	**Active ingredient**	**Product**	Seedcorn maggot	Potato leafhopper
NEO	Thiamethoxam	Cruiser 5FS	**1**[1]	**1**[1,2]
NEO	Acetamiprid	Assail 30SG		**3**
AND	Cyantraniliprole	Exirel[3]	**2**	
CRB	Carbaryl	Sevin 4F		**20**
CRB	Methomyl	Lannate		**19**
OP	Dimethoate	Dimethoate 400		**15**
OP	Phorate	Thimet 20G Smartbox[3]	**74**	**74**
PYR	Bifenthrin	Brigade WSB	**4**	**4**
PYR	Lambda-cyhalothin	Warrior II		**1**
PYR	Zeta-cypermethrin	Mustang MAXX		**1**
UN	Azadirachtin	Molt-X	**<0.5**	**<0.5**

Notes: (1) FUEIQ calculated assuming 80 pounds of seed per acre; (2) Effective for early-season infestations; (3) sale and use prohibited in Nassau and Suffolk Counties.

FUEIQ is the estimated risk of a product, adjusted to application rate. It consists of three equally weighted components: consumer, farm worker, and ecological. Please see the introduction to EIQ in Chapter 2 for a description of its uses and limitations. FUEIQ values in this table were calculated based on the maximum labelled application rate for a given pest. See Table 2.1 for active ingredient group abbreviations.

only thiamethoxam-based seed treatments (Cruiser 5FS) as an effective preventive insecticide for this pest in snap bean [154]. Prior to the introduction of neonicotinoid seed treatments, New York snap bean growers used chlorpyrifos (Lorsban) seed treatments or in-furrow treatments based on phorate (Thimet) or lindane[35] (Isotox). About 20% of snap bean acres were affected by seedcorn maggot in a given season [225, 228, 877, 598].

The potato leafhopper is another principal snap bean pest controlled with neonicotinoids. It is very common in New York snap beans [877]. Fields planted with thiamethoxam-treated seed are at low risk of early-season damage from leafhoppers, but may require a foliar insecticide application after bloom [154]. Insecticides listed for this use in the CCE Guidelines for snap bean are in Table 4.8. Farmers not using an insecticidal seed treatment may require an early-season foliar spray as well [850]. Economic thresholds and scouting protocols inform whether and when applications are needed [154].

If thiamethoxam-treated seeds were no longer available, most growers would likely use an in-furrow insecticide at planting to reduce the risk of seedcorn maggot infestation.[36] Insecticides in the

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[35] No longer registered for seed treatment use.

[36] Alternative seed treatments are not currently available for this crop. Anthranilic diamide (chlorantraniliprole and cyantraniliprole), spinosyn (spinosad), pyrethroid (tefluthrin), and organophosphate (diazinon) seed treatments have performed

organophosphate, pyrethroid, and anthranilic diamide groups are registered for control of seedcorn maggot in New York snap beans. Some of these products are also effective against early-season potato leafhopper, but additional foliar sprays might be needed after planting. Later-season infestations of potato leafhopper may be treated with foliar insecticides from several IRAC groups.

Cultural management techniques can reduce, but not eliminate, seedcorn maggot risk [850, 810]. For example, the risk of seedcorn maggot damage can be reduced by not planting into fields that have recently received animal manure or had a cover crop incorporated. Plantings of snap bean in July and early August are going to have lower infestation risk because seeds will germinate quickly in warmer soils and therefore escape seedcorn maggot damage. Beans planted after the first generation of maggots has pupated are much less likely to suffer damage. As noted in the corn section above, "maggot-free" dates can be estimated with a degree-day model in other states[37] [851]. However, models developed for other states are less reliable in New York conditions, and would need to be modified to be useful for New York farmers [913]. Non-chemical pest management techniques are of limited use against leafhoppers.

4.3.4 Sweet corn

In addition to field corn, New York harvested 26,600 acres of sweet corn in 2018 with a total value of $36 million [945]. Clothianidin- and thiamethoxam-based seed treatments are very common for sweet corn grown in New York, controlling many of the same early-season pests that trouble field corn farmers (see Section 4.1), notably seedcorn maggot [154]. Some sweet corn varieties are more susceptible to early-season Stewart's wilt, a bacterial infection vectored by the corn flea beetle (*Chaetocnema pulicaria*). Corn flea beetle (and, therefore, Stewart's wilt) can be controlled with neonicotinoid-treated seeds [588, 656, 472, 657]. Neonicotinoids are not effective against the primary pests affecting sweet corn ears: corn earworm, fall armyworm, western bean cutworm, and European corn borer[38] [205]. However, the CCE Guidelines for sweet corn lists acetamiprid-based foliar sprays for several secondary

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well against seedcorn maggot in snap bean field trials [228, 811, 413, 240, 1000]. However, these products are not currently labeled for snap bean.

[37] Cornell University, in partnership with Network for Environment and Weather Applications (NEWA), maintains a degree-day calculator and pest forecasts at `http://newa.cornell.edu`.

[38] These, as well as corn rootworm, are now largely controlled by planting Bt hybrid corn. The popularity of Bt field corn has reduced the regional population of both pests [205].

late-season pests: corn leaf aphid (*Rhapolosiphum maidis*), picnic (sap) beetle, Japanese beetle, and the adult stage of corn rootworms [154]. The economic threshold for insecticide applications in fresh-market sweet corn is, in general, much lower than for field corn due to low customer tolerance for insect damage.

Table 4.9: **Sweet corn: selected neonicotinoid uses, alternatives, and FUEIQ**

	Representative products		***FUEIQ at max rate for representative pests***			
Group	**Active ingredient**	**Product**	Flea beetle	Seedcorn maggot	Picnic beetle	Corn leaf aphid
NEO	Clothianidin	Poncho 600 (seed treatment)	**1**	**<0.5**		
NEO	Thiamethoxam	Cruiser Extreme (seed treatment)	**2**	**2**		
NEO	Acetamiprid	Assail 30SG (foliar spray)	**3**		**3**	**2**
CRB	Methomyl	Lannate LV (foliar spray)	**10**		**10**	**10**
OP	Malathion	Malathion 57EC (foliar spray)			**20**	
PYR	Bifenthrin	Capture LFR (soil-applied)		**7**		
PYR	Tefluthrin	Force EVO (soil-applied)		**4**		
PYR	Lambda-cyhalothrin	Warrior II (foliar spray)	**1**		**1**	**1**

FUEIQ is the estimated risk of a product, adjusted to application rate. It consists of three equally weighted components: consumer, farm worker, and ecological. Please see the introduction to EIQ in Chapter 2 for a description of its uses and limitations. FUEIQ values in this table were calculated based on the maximum labelled application rate for a given pest. See Table 2.1 for active ingredient group abbreviations.

In the absence of neonicotinoid seed treatments, most sweet corn growers would likely use a soil-applied pyrethroid insecticide at planting. Such treatments, as well as pyrethroid-treated seeds, were common in New York sweet corn prior to the introduction of neonicotinoid seed treatments [225, 227]. Soil-applied alternatives include formulations based on bifenthrin (Capture LFR) and tefluthrin (Force) [154]. Though not currently in production, a tefluthrin-based product (Force ST) is also labelled for use as a seed treatment to control seedcorn maggot, corn rootworms, wireworms, and white grub in sweet corn. None of these alternatives effectively control flea beetle; users would have to rely on identifying problems through scouting and applying foliar sprays as needed.

Several non-chemical pest management techniques used in field corn to reduce the risk of damage by early-season seedcorn maggot, corn rootworms, wireworms, and white grubs (see Section 4.1) are also effective for sweet corn. Disease-resistant cultivars are the principal non-chemical means for growers to control Stewart's wilt, which is transmitted by corn flea beetle. Varieties of sweet corn resistant to Stewart's wilt rarely suffer economic damage from flea beetle infestations [415, 657]. For susceptible varieties, growers can predict the likelihood of damage based on scouting and NEWA pest forecasts, and respond with foliar insecticide applications [154]. Row covers can prevent damage, but are only feasible on small farms [1029]. Fields planted midseason generally have lower beetle infestations than early- or late-planted fields [154].

Cultural controls can play an important role in limiting the risk of damage and need for insecticide application for later-season sweet corn pests. Corn leaf aphids, like other aphid species, are preyed upon by a variety of lady beetles, parasitoids, and pathogens [1029]. Aphid damage is most likely on sweet corn planted after mid-June [154]. Susceptibility of sweet corn to picnic (sap) beetles varies by cultivar; varieties with exposed tips are most vulnerable [1029]. The risk of damage may be reduced by keeping fields free of weeds and decaying vegetation [154].

4.3.5 Squash, pumpkin, and other cucurbits

New York produced over $33 million of squash and pumpkin from 9,000 acres in 2018 [945]. This does not account for production of cucumber, watermelon, muskmelons, and other cucurbit crops that are less common in New York.

Neonicotinoids have been registered as a seed treatment for use in cucurbit crops since 2009, but were previously used as in-furrow treatments to protect against early-season pests [1044]. Thiamethoxam (Cruiser, as a component in FarMore FI400) is commonly included in cucurbit seed treatments. Cucumber beetles (*Acalymma vittatum* and *Diabrotica undecimpunctata*) are the major insect pests of cucurbits in the northeast; beetles feed on plants and can transmit bacterial wilt and other diseases. While cucurbits are relatively resilient to leaf damage, severe infestations of seedlings (particularly of cucumber and melon) as well as feeding during bloom can significantly reduce yields [405, 128, 1043, 1041, 1076]. Thiamethoxam concentrations in cucurbits grown from treated seeds are sufficient to protect against insect pests for about three weeks after planting. Due to this limited window or protection, treated seeds are unlikely to protect cucurbits grown as transplants from greenhouses

[1043, 1041]. In addition to FarMore FI400, there are foliar-applied products recommended in the CCE Guidelines for cucumber beetle control. Seedcorn maggot is a sporadic pest of cucurbits and is effectively managed with FarMore FI400; this is the only option for control of seedcorn maggot in field-sown cucurbits [154].

Table 4.10: **Cucurbits: selected neonicotinoid uses, alternatives, and FUEIQ**

	Representative products			***FUEIQ at max rate for representative pests***			
Group	**Active ingredient**	**Product**		Cucumber beetles	Aphids	Squash bug	Squash vine borer
NEO	Acetamiprid	Assail 30SG	Foliar	**3**	**2**	**3**	**3**
NEO	Imidacloprid	Admire Pro	Soil	**10**	**10**		
NEO	Thiamethoxam	Platinum 75SG	Soil	**6**	**6**		
NEO	Thiamethoxam	Actara[1]	Foliar	**3**	**2**		
BT	*Bacillus t.* (Bt)	Agree WG	Foliar				**13**
CRB	Carbaryl	Sevin XLR Plus	Foliar	**20**		**20**	
FLN	Flonicamid	Beleaf 50SG	Foliar		**1**		
PAD	Pymetrozine	Fulfill	Foliar		**2**		
PYR	Esfenvalerate	Asana XL	Foliar	**2**		**2**	**2**
PYR	Lambda-cyhalothin	Warrior II	Foliar	**1**	**1**	**1**	**1**
PYR	Permethrin	Pounce 25 WP	Foliar	**6**	**6**	**6**	**6**
SPY	Spinosad	Entrust SC	Foliar				**2**

Notes: (1) Sale and use prohibited in Nassau and Suffolk counties.
Pest and insecticide combinations highlighted in green are listed in the most recent Cornell pest management guide Cornell Cooperative Extension [154]. Omits combinations not labeled for summer squash, winter squash, *and* pumpkin. FUEIQ is the estimated risk of a product, adjusted to application rate. It consists of three equally weighted components: consumer, farm worker, and ecological. Please see the introduction to EIQ in Chapter 2 for a description of its uses and limitations. FUEIQ values in this table were calculated based on the maximum labelled application rate for a given pest. See Table 2.1 for active ingredient group abbreviations.

Imidacloprid and thiamethoxam soil drenches, chemigation, or foliar sprays may be applied after transplanting cucurbits to protect plants from cucumber beetles and, less commonly, aphids [548, 388, 470, 427, 831]. Scouting and the use of economic thresholds allow growers to effectively target insecticide applications [154]. In 2020, the USEPA recommended a prohibition on use of imidacloprid-, clothianidin-, and thiamethoxam-based products on cucurbits between vining and harvest,[39] to protect pollinators [998]. If adopted, this would limit post-emergence uses (after the growing seedling has broken the surface of the soil and has started photosynthesis) of imidacloprid and thiamethoxam, but not acetamiprid.

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[39] Clothianidin-based products have never been approved for this use in New York State.

Acetamiprid foliar sprays may be used against cucumber beetles, aphids, squash bug (*Anasa tristis*), or squash vine borer (*Melittia cucurbitae*) from the time the plants emerge or are transplanted. Aphids are a secondary pest in cucurbits, most damaging if natural predator populations are suppressed (e.g., following insecticide applications) [1041]. In addition to causing feeding damage, aphids can decrease yields by attracting ants, promoting fungal growth, and vectoring viruses [831, 154]. Squash bugs damage cucurbits directly through feeding on foliage or fruit and indirectly by introducing toxic saliva into foliage [831]. Squash vine borer larvae feed inside the vines of cucurbits with hollow stems, cutting off the exchange of water and nutrients between roots and leaves. It is difficult to control squash vine borers with insecticides once they have entered a vine [154].

Although anthranilic diamide (chlorantraniliprole) and high-dose spinosyn (spinosad) seed treatments have performed well against seedcorn maggot in cucurbit field tests [645, 646, 647], these active ingredients are not currently labeled for this use by the USEPA. Therefore, New York cucurbit growers rely heavily on neonicotinoid-treated seeds to manage early season pests. According to Crop Profiles published by CCE prior to the widespread use of neonicotinoid-treated seeds, less than 10% of New York pumpkin growers and less than 2% of squash growers used available chlorpyrifos (Lorsban) or lindane (Isotox) seed treatments to control early-season seedcorn maggot and cucumber beetles [876, 878]. Growers seeking an alternative to preventive thiamethoxam seed treatments are more likely to turn to soil-applied neonicotinoids at planting or transplant. If those are not available, they may use pyrethroid or organophosphate products applied as soil drenches or foliar sprays. Table 4.10 lists several insecticides listed in the relevant CCE Guidelines for control of major cucurbit insect pests.

Non-chemical pest management can substantially reduce the risk of damage from cucurbit pests as well. For some producers, early season insecticide use for cucumber beetle control can be reduced through the use of perimeter trap crops. Planting a cucurbit variety attractive to cucumber beetles (the trap crop) around the entire perimeter of a field greatly reduces pest pressure on the principal cucurbit crop that it surrounds. Trials in Connecticut, Massachusetts, and New Jersey successfully used Blue Hubbard winter squash trap crops to protect fields of summer and butternut squash. Growers may control cucumber beetles with insecticide applications to the trap crop alone rather than the entire field [371, 72, 417]. Where practical, growers may plant varieties that minimize risk of damage from cucumber beetles, squash bugs, or aphid-borne diseases [831]. Predators of cucumber beetles, aphids, squash bugs, and squash vine borers can significantly reduce pest populations. Row covers and, to a limited extent, crop rotation are effective defenses against cucumber beetles and squash vine borer [914, 154]. Removing crop debris before and/or after the growing season may reduce populations of cucumber beetle, squash bug, and squash vine borer in the following season [831]. Mulch (plastic or organic), baited traps, and trap crops may reduce the risk of cucumber beetle damage [405].

4.4 Ornamentals, turf, and landscape management

Due to the diversity of plants used in commercial landscapes, outdoor nurseries, and managed turf, it can be difficult to generalize about pest control strategies in these sectors.[40] However, neonicotinoid products certainly play a significant role. In 2014, neonicotinoids were the most popular class of insecticide products in U.S. plant nurseries (28.6%), commercial lawn care (43%), and landscape ornamentals (37.4%) [628]. Imidacloprid was, by far, the most-used active ingredient. Several of neonicotinoids' advantages may be particularly important in these markets. A broad-spectrum insecticide may be particularly attractive to pesticide applicators dealing with the pest complexes of many species. Broadly speaking, the market value of ornamental plants falls sharply with even superficial pest damage, encouraging preventive rather than curative (responsive) insecticide use. Neonicotinoids have lower mammalian toxicity than many alternatives, an important characteristic when unprotected staff, customers, or people using a landscape may come into contact with treated plants. Finally, neonicotinoid insecticides are relatively inexpensive compared to alternatives with similar efficacy, versatility, and toxicity.

One useful perspective on the importance of neonicotinoids to the turfgrass and ornamentals industries comes from a 2014 survey of North American turf and ornamental professionals [628]. The survey and subsequent report were sponsored by Bayer CropScience, Syngenta, Valent, and Mitsui to solicit the input of U.S. professionals on the value of neonicotinoid products relative to likely substitutes. Survey respondents placed a high value on neonicotinoid products. Most asserted that there were "no acceptable" or "not enough acceptable" alternatives to neonicotinoids.[41] By industry segment,

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[40] This report does not address neonicotinoid use in greenhouses and other indoor cultivation systems.

[41] Separated by industry segment, the percentage varied from 66.7% (landscape ornamentals) to 83.7% (lawn care).

respondents anticipated that the most difficult pests to control in the absence of neonicotinoids would be grubs (lawncare: 68.4%), flatheaded borers (landscape ornamentals and trees: 37.5% and 36%), and aphids (nurseries: 35.4%). The survey also asked participants about which insecticides they would use most if they did not have access to neonicotinoids. The results suggest that landscape, ornamentals, and tree care professionals would largely turn to substitutes in the pyrethroid or organophosphate classes, the same classes that lost market share after the introduction of neonicotinoids in the 1990s and 2000s (see *Chapter 3*). Anthranilic diamides would likely be the most common substitutes for neonicotinoid products in lawn and turf care.

4.4.1 Outdoor ornamentals

In 2017, New York contained approximately 1,200 Christmas tree farms with nearly 20,000 acres in production [949], generating approximately $8.2 million in annual sales [947]. Another 14,000 acres were devoted to outdoor plant nurseries, a vital part of the state's $122 million plant nursery industry [949].

Christmas trees

Major Christmas tree pests treated with neonicotinoids include adelgids,[42], aphids,[43] armored scale insects,[44] and midges[45] [151]. Neonicotinoids may be applied as a soil treatment (imidacloprid and thiamethoxam products),[46] basal spray (dinotefuran), or foliar spray (acetamiprid, imidacloprid, and thiamethoxam), depending on the target pest. Table 4.11 lists the FUEIQ of several neonicotinoids and alternative insecticides used to control these pests.

Previously, adelgids on Christmas trees were controlled with a variety of organophosphates (e.g., chlorpyrifos, diazinon), carbamates (carbaryl), organochlorines (e.g., endosulfan, methoxychlor), and pyrethroids (e.g., fenvalerate, permethrin) [367, 24, 1014]. At introduction, imidacloprid-based products combined comparable or superior pest control with lower vertebrate toxicity than those older insecticides [24, 1014]. The relevant Cornell Pest Management Guide lists acetamiprid, imidacloprid,

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[42] Notably the Cooley spruce gall adelgid (*Adelges cooleyi*) and balsam woolly adelgid (*Adelges piceae*)

[43] The balsam twig aphid (*Mindarus abietinus*) and others.

[44] Including the elongate hemlock scale (*Fiorinia externa*)and cryptomeria scale (*Aspidiotus cryptomeriae*.)

[45] The Balsam gall midge (*Paradiplosis tumifex*) and Douglas fir needle midge (*Contarinia pseydotsugae*).

[46] Soil *injections* of these products are not allowed on Long Island.

Table 4.11: **Christmas trees: neonicotinoid uses, selected alternatives, and FUEIQ**

	Representative products		***FUEIQ at max rate for representative pests***			
Group	**Active ingredient**	**Product**	Cooley spruce gall adelgid	Balsam twig aphid	Elongate hemlock adelgid	Douglas fir needle midge
NEO	Acetamiprid	TriStar 8.5SL[1]	**3 [F]**	**1 [F]**	**[B,I]**[2]	
NEO	Dinotefuran	Safari 20G			**[B]**[2]	
NEO	Imidacloprid	Admire Pro	**3 [F]**	**3 [F]**		
NEO	Thiamethoxam	Flagship 25WG	**4 [F]**	**9 [F]**		**9 [F]**
CRB	Carbaryl	Sevin SL	**20 [F]**	**20 [F]**	**20 [F]**	
FLN	Flonicamid	Aria 50WDG[1]		**1 [F]**	**1 [F]**	
OP	Acephate	Orthene 97[1]		**12 [F]**	**12 [F]**	**12 [F]**
PAD	Pymetrozine	Endeavor 50WDG		**6 [F]**		
PYR	Bifenthrin	OnyxPro[1]	**5 [F]**	**5 [F]**	**5 [F]**	**5 [F]**
TTA	Spirotetramat	Movento 2SC	**5 [F]**	**5 [F]**	**5 [F]**	

Application methods: **[F]** Foliar **[B]**: Basal spray **[I]**: Trunk injection

Notes: (1) 100 gallons per acre; (2) FUEIQ not calculated for basal sprays and trunk injections.

FUEIQ is the estimated risk of a product, adjusted to application rate. It consists of three equally weighted components: consumer, farm worker, and ecological. Please see the introduction to EIQ in Chapter 2 for a description of its uses and limitations. FUEIQ values in this table were calculated based on the maximum labelled application rate for a given pest. See Table 2.1 for active ingredient group abbreviations.

and thiamethoxam as management options [151]. While less common, imidacloprid-based trunk injections such as Xytect are also registered for Christmas tree pests in New York State. Some Christmas tree growers may reduce adelgid pressure with summer pruning, by supporting natural predators, and by selecting less susceptible species for new plantings, but these are not reliable alternatives to chemical insecticides [615, 723, 151]. Non-neonicotinoid active ingredients labelled for some or all adelgid pests of New York Christmas trees include organophosphates (chlorpyrifos), carbamates (carbaryl), pyrethroids (bifenthrin, esfenvalerate, fluvalinate), tetronic acids (spirotetramat), horticultural oils, and insecticidal soaps (e.g., M-Pede) [151].

Acetamiprid, imidacloprid, and thiamethoxam are registered for control of aphids on Christmas trees, notably balsam twig aphid on true firs. Even severe infestations of balsam twig aphid typically do not kill trees, but can cause cosmetic damage that reduces their value in the last years before harvest [634]. Moderate aphid damage more than two years before harvest is unlikely to affect a fir's final appearance and marketability [287]. Growers may not derive any benefit from insecticide treatment of minor aphid infestations before this point, and unnecessary insecticide applications may increase longer-term pest damage by interfering with natural predation[47] [288, 453, 634]. In the absence of

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[47] As further discussed in Chapter 7, insecticide applications can create an opening for non-insect pests by eliminating insect herbivores that compete with such pests and insect predators that limit their population growth.

neonicotinoids, conventional Christmas tree growers would likely turn to foliar insecticides from a variety of IRAC groups. Table 4.11 lists six examples. Producers would, however, have fewer options for long-lasting soil, basal, and trunk injected treatments.

Armored scale insects, notably the elongate hemlock scale and cryptomeria scale, have become more significant pests of Christmas trees in the Northeast over recent decades [161]. Armored scales feed on the underside of conifer needles, with true firs being particularly susceptible [151]. There is no established economic threshold for scale infestations; even small populations can cause damage [725]. In addition to direct feeding damage, affected trees may be harmed by the toxicity of scale saliva [161]. Foliar insecticide products (available from several IRAC groups: see Table 4.11) are generally most effective during the brief crawler stage,[48] after scales hatch but before they develop a protective cover (the "armor" of the common name). Growers using foliar sprays may need to make several applications to ensure an effective dose throughout the crawler emergence periods (there are two generations per year in New York) [376, 644, 727, 725, 151]. However, neonicotinoids can provide longer-lasting protection than alternative insecticides if applied as a basal spray or trunk injection [161]. This means of application also requires less active ingredient and reduces insecticide exposure for insect predators of scales. Strong predator populations may reduce the risk that scale populations will rebound after treatment [539, 161].

Balsam gall midge and Douglas fir needle midge can cause serious damage to true firs or Douglas firs, respectively. Midge larvae cause swelling and formation of galls while feeding on needles. Those galls shelter the larvae during development [187, 632]. Infested trees may appear discolored or denuded, prematurely dropping infested needles. This reduces the value of Christmas trees due to be harvested and sets back the growth of others [445]. Chemical treatment, when necessary, requires careful timing. Insecticides target adult midges arriving at the target plant to lay eggs, leaving only a brief window for treatment [632, 724]. Thiamethoxam is one of several effective active ingredients against these target pests. The most practical non-neonicotinoid alternatives are the carbamate carbaryl, organophosphates chlorpyrifos and acephate, and the pyrethroid bifenthrin [445, 151].

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[48] Horticultural oil sprays are a partial exception: they may be applied to dormant scales before bud break [725].

Commercial landscapes and outdoor nurseries

Reflecting the challenge of horticultural pest control, Cornell's most recent *Pest Management Guide for Commercial Production and Maintenance of Trees and Shrubs* includes over 150 significant insect and mite pests of 50 kinds of commercially-grown ornamentals. Acetamiprid and imidacloprid are the neonicotinoids most often used in commercial landscapes and outdoor nursery production. In outdoor nurseries, imidacloprid-based treatments are frequently applied to soil (or growing media) to control white grubs (scarab beetle larvae), weevils, mealybugs, and flatheaded borers, among many others. Pests targeted using by acetamiprid and imidacloprid products include aphids, adelgids, adult scarab beetles, leafhoppers, lepidopterans, and scales [609, 151]. It's difficult to summarize neonicotinoid usage in outdoor nurseries because there are such a variety of host plants and pests. This section highlights several important target pests controlled, at least in part, by neonicotinoid-based products. It is by no means a complete list.

Soil-applied imidacloprid provides effective, long-lasting protection for the invasive viburnum leaf beetle [1046, 151]. Both the larval and adult stage of the beetle feed extensively on viburnum trees and shrubs, damaging or killing plants through repeated defoliation. The initial population boom of viburnum leaf beetle in New York State was devastating to susceptible species across the region. While several foliar sprays based on organophosphate, pyrethroid, or spinosyn insecticides are labelled for viburnum, all have shorter residual activity than imidacloprid [506].

Acetamiprid-based trunk injections and basal sprays are important tools for the control of several species of soft and armored scale. While other foliar sprays can target scale insects during their crawler stage [151], acetamiprid is almost unique in that it can reach scale insects after they settle on needles and start to feed [162].

Imidacloprid and thiamethoxam are also valuable as soil-applied insecticides for controlling oriental beetle larvae (one of several species called white grub) [619, 730]. The pest feeds on the roots of many host species, and can also cause damage by tunneling in the root zone. Relatively few insecticides are available for this pest on ornamentals. For nurseries, the only non-neonicotinoid alternatives are chlorpyrifos and bifenthrin (container-grown plants only). For landscape ornamentals, the only labelled products are imidacloprid, trichlorfon, and chlorantraniliprole (outside of Long Island) [151]. In this context, neonicotinoid products are often the best available product for oriental beetle control, providing a useful combination of low toxicity and long residual activity.

For ornamental landscape nurseries, neonicotinoid-based products are the only chemical treatment available for hemlock woolly adelgid. Section 4.5 describes this pest, a significant threat to New York forests, in greater detail.

4.4.2 Commercial turf management

Major insect pests of turfgrass in New York may be divided into six pest complexes: white grubs,[49] weevils,[50] chinch bug,[51] caterpillars,[52] mound-building ants, and leatherjackets[53] [147]. Imidacloprid-based products are labelled for target pests in all six complexes, but are most important for control of white grubs. The white grub complex is likely the most damaging turfgrass pest in New York State [147]. White grub infestations can quickly kill large areas of turf, especially if that infestation coincides with drought or other environmental stresses. The presence of white grubs often attracts digging predators (e.g., raccoons, skunks, opossums, and moles) that cause further damage [113, 837]. In upstate New York, studies on home lawns and golf fairways suggest that insecticide treatments for white grubs are necessary for about 20% of sites in a given year [147]. Turfgrass managers using insecticides for white grub may adopt either a preventive or curative approach. Imidacloprid-based treatments (such as Bayer's Merit products) are mainly preventive, but can be applied effectively as an early curative insecticide.

If applied shortly before egg laying, a single preventive imidacloprid application can control white grubs for an entire season. Effective imidacloprid concentrations in soil, roots, and grass foliage persist for several weeks [609]. Acelepryn and Ference, based on chlorantraniliprole and cyantraniliprole, respectively, are effective non-neonicotinoid alternatives in this role [147], but are 2-3 times more

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[49] White grubs, here, are the soil-dwelling larval form of several scarab beetle species (native and exotic) that feed on grass roots and/or damage roots by tunneling. These include Japanese beetle (*Popillia japonica*), May and June beetles (*Phyllophaga spp.*), oriental beetle (*Anomala orientalis*), and others.

[50] Primarily annual bluegrass weevil (*Listronotus maculicollis*) and bluegrass billbug (*Sphenophorus parvulus*).

[51] Adult and nymph stages of the the hairy chinch bug (*Blissus leucopterus*), a sucking pest.

[52] Black cutworm (*Agrotis ipsilon*), fall armyworm (*Spodoptera frugiperda*), and various sod webworms damage turf through foliar feeding.

[53] The soil-dwelling maggot stage of European crane flies (*Tipula spp.*), invasive pests first detected in New York State in 2004 [662].

Table 4.12: **Turfgrass: neonicotinoid uses, selected alternatives, and FUEIQ**

Representative products			*FUEIQ of representative pests*				
Group	**Active ingredient**	**Product**	White grubs	Annual blue- -grass weevil	Hairy chinch bug	Black cutworm	European crane flies
NEO	Imidacloprid	Merit 0.5G	**15**	**15**	**15**	**15**	**15**
NEO	Imidacloprid	Armortech IMD 75	**15**	**15**	**15**	**15**	**15**
AND	Chlorantraniliprole	Acelepryn G[1]	**4**	**4**	**4**	**4**	**4**
AND	Cyantraniliprole	Ference[2]	**2**	**3**	**3**	**2**	**2**
BT	*Bacillus t.* (Bt)	DiPel Pro DF				**14**	
CRB	Carbaryl	Sevin SL	**171**	**171**	**171**	**86**	**171**
OXD	Indoxacarb	Provaunt WDG		**7**		**2**	**7**
PYR	Bifenthrin	0.15G ProSect		**9**	**18**	**4**	**17**
PYR	Trichlorfon	Dylox 420SL	**141**	**141**	**141**	**141**	
SPY	Spinosad	Conserve SC		**6**		**6**	

Notes: (1) Sale and use prohibited in Nassau, Suffolk, Kings, and Queens counties; (2) In Nassau, Suffolk, Kings, and Queens counties, this product may only be used to control annual bluegrass weevil on golf course turfgrass.

FUEIQ is the estimated risk of a product, adjusted to application rate. It consists of three equally weighted components: consumer, farm worker, and ecological. Please see the introduction to EIQ in Chapter 2 for a description of its uses and limitations. FUEIQ values in this table were calculated based on the maximum labelled application rate for a given pest. See Table 2.1 for active ingredient group abbreviations.

expensive [641]. Comparing prices listed by online vendors,[54] the product required to treat one acre for white grub (at the maximum rate) would cost roughly $365 if using the chlorantraniliprole-based Acelepryn G but just $125 if using the imidacloprid-based Merit 0.5G. Generic imidacloprid-based products are even less expensive. In addition, chlorantraniliprole and cyantraniliprole may not be used on Long Island.[55] Studies of biological white grub control with diseases, insect parasites, or predatory nematodes have produced mixed results. Entomopathogenic nematodes are the most reliable non-chemical treatment for white grub in New York turfgrass, but management with nematodes is also relatively expensive [458, 382, 147].

Turfgrass managers may also choose to identify at-risk areas by monitoring for grubs after egg hatch[56] and using a curative treatment for areas exceeding treatment thresholds [147]. This approach allows for spot treatments where needed, reducing the total amount of active ingredient applied to a site

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[54] Based on the lowest published bulk price of Acelepryn G (chlorantraniliprole) and Merit 0.5G (imidacloprid) sold by Forestry Distributing, Seed World, and DoMyOwn.com in October 2019.

[55] Although chlorantraniliprole and cyantraniliprole have favorable toxicity profiles, they are water soluble and quite mobile in groundwater. NYSDEC prohibits nearly all uses of these active ingredients on Long Island to limit the risk of contaminating the aquifer. However, NYSDEC has issued a Special Local Need registration for use of a chlorantraniliprole-based product, Acelepryn, and a cyantraniliprole-based product, Ference, to control annual bluegrass weevil infestations on Long Island golf courses.

[56] early- to mid-August, depending on the area and weather conditions.

compared to preventive treatments. It also allows natural soil arthropods (suppressed by imidacloprid) to prey on white grub eggs [663]. If an infestation is detected early, curative applications of imidacloprid-based insecticides are effective. The anthranilic diamides chlorantraniliprole and cyantraniliprole, where permitted, are effective non-neonicotinoid alternatives. The organophosphate trichlorfon (under the Dylox brand) and the carbamate carbaryl (Sevin) are fast-acting alternatives that can be used later in white grubs' growth, even after damage is visible. Both, however, have higher toxicity, require a greater application rate, and are less effective than imidacloprid, chlorantraniliprole, or cyantraniliprole [147]. Entomopathogenic nematodes can also be used curatively with some success.

Imidacloprid plays an important role in white grub control throughout the state. On Long Island, there is no practical alternative for preventive treatment since anthranilic diamides are not permitted due to groundwater contamination concerns.[57] There is one other Long Island permitted insecticide that can effectively treat white grubs. Entomopathogenic nematodes can also be used in response to a white grub infestation. Though turfgrass managers have more options in other parts of New York, the existence of an alternative does not mean that imidacloprid is easily replaceable. In the absence of imidacloprid, turfgrass managers would face higher white grub control costs and, with few active ingredients available, would have greater difficulty in managing insecticide resistance.

4.4.3 Private homes and gardens

In a willingness-to-pay experiment with residential pesticide users, Yue and Hurley [1115] concluded that homeowners prioritized efficacy, safety of people and pets, and ease of use when comparing insecticides. The authors, associating neonicotinoids with those attributes, estimated that homeowners would be willing to pay significantly more for a neonicotinoid than for a pyrethroid, carbamate, organophosphate, or organic alternative, but less than for an alternative anthranilic diamide (chlorantraniliprole) or avermectin (emamectin benzoate).

Many imidacloprid- and acetamiprid-based plant protection products are available to consumers in New York State, though regional restrictions limit their availability on Long Island. With limited exceptions, New York State does not allow nitro-substituted neonicotinoids for outdoor uses to be sold, sold into, distributed, or used on Long Island due to concerns about contamination of aquifers [613].

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[57] Imidacloprid and anthranilic diamides have similar solubility profiles in water.

The NYSDEC has enforced this restriction, notably fining Costco $60,000 in 2004 for carrying an imidacloprid-based product in one of its Long Island stores [218].

Of course, regional restrictions have not entirely eliminated use of unregistered products on Long Island. Bad actors can simply bring in banned products purchased in another county. More concerning, unwary customers can easily purchase pesticides online that are not permitted in their area. According to the USEPA, it is generally "the seller's responsibility to ensure that pesticides sold over the internet are... registered both by the USEPA and any state in which they are distributed before offering them for sale" [958]. However, it is difficult for states to enforce restrictions on online sellers, and online retailers do not necessarily verify whether a given insecticide is labelled for use where it is being shipped. In 2018, Amazon paid a $1.2 million penalty following a USEPA investigation of unregistered pesticide sales on its platform. As part of the settlement agreement, Amazon also agreed to institute mandatory training for entities selling pesticides on Amazon.com [991].

This agreement has not, however, eliminated inappropriate sales through Amazon or other online vendors. During the USEPA investigation of Amazon, inspectors in a regional USEPA office tested Amazon's oversight of pesticide sales by ordering pesticides not permitted in the United States through the site in March 2015. The authors of this report attempted a similar order in May 2019, buying two neonicotinoid-based tree and shrub insecticides on Amazon.com for delivery to Suffolk County, on Long Island. Both are popular products, among the best-selling insecticides in their category on Amazon. One, containing imidacloprid, is registered for use elsewhere in New York State, but its label explicitly prohibits sale, distribution, or use on Long Island. The other, containing both imidacloprid and clothianidin, is not registered for use in New York State at all. Both orders were processed by Amazon, and the insecticides were delivered to an Amazon Prime locker in Suffolk County in two business days. While hardly conclusive, this experience suggests that online shoppers may circumvent region-specific pesticide restrictions (even inadvertently) with relative ease.

4.5 Conservation and forestry

Acetamiprid, dinotefuran, and imidacloprid play an important role in controlling three invasive forest pests: Asian longhorned beetle, emerald ash borer, and hemlock woolly adelgid. Soil drenches, basal sprays, trunk injections, and time-release tablets can protect susceptible trees for a season or more without reapplications. Foliar sprays based on acetamiprid, dinotefuran, or imidacloprid offer a shorter window of protection, but can reach pests in the crown quickly and penetrate into leaf or fruit tissue at concentrations sufficient for weeks or months of residual protection.

4.5.1 Asian longhorned beetle

Imidacloprid injections are an effective means of controlling the Asian longhorned beetle (*Anoplophora glabripennis*), an invasive wood-boring pest that infests maples, elms, birches, horse chestnuts, and poplars [1034, 935, 936]. New York jurisdictions have used imidacloprid in this role since 2001 [84, 416]. It has been the principal insecticide used against this pest in North America [345], and imidacloprid-based products are the only insecticides to have Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) 2(ee) recommendations for control of Asian longhorned beetle in New York State [609]. Injections based on emamectin benzoate or azadirachtin also appear to be effective, but are not registered for this use [1034].

Asian longhorned beetle larvae kill trees by tunnelling into and feeding on the living phloem and cambium tissue under the bark. Unless treated, such infestations progressively cut off the vascular system, the mechanism that allows exchange of nutrients between the roots and the crown of the tree. Eventually, larvae girdle the trunk of infested trees, killing them [104]. Since the beetle can infest a wide range of hardwood species, the potential impacts of Asian longhorned beetle on New York is enormous. Susceptible species include many of the most common trees in New York's forests, vital for the state's maple syrup, horticulture, and timber industries. They also make up roughly a third of urban trees [627]. However, successful quarantine and eradication campaigns have contained the pest to central Long Island in New York State, with the potential to eliminate the pest from New York in the near future [950, 155].

4.5.2 Emerald ash borer

Emerald ash borer is a highly invasive insect pest of ash trees that, in the absence of treatment, kills nearly 100% of infested trees [385]. Like the Asian longhorned beetle, emerald ash borer larvae feed under the bark of infested trees and kill by cutting off the vascular system [104].

Emerald ash borer is the most costly forest pest in history. Across the United States, the annual cost of tree treatment, removal, and replacement related to emerald ash borer is likely over $1 billion [460, 27]. In New York, roughly 8% of all trees were ash species before emerald ash borer [286]. Ash is especially common as a New York street tree, as many communities planted ash trees to replace losses to Dutch elm disease [711]. Several insecticides effectively control emerald ash borer infestations of individual trees, but long-term protection requires repeated applications. Abandoning treatment, however, can be even *more* costly. Dead and dying ash trees are expensive for municipalities to remove,[58] but risky and unsightly to leave standing [27, 1012]. Emerald ash borer infestations also cause serious environmental impacts. The loss of ash trees from New York's forests threatens native species that rely on ash trees for food or habitat. Ash trees are frequently a keystone species in riparian forests and along shorelines and riverbanks [301].

Dinotefuran and imidacloprid are front-line insecticides used against emerald ash borer, though they are no longer the most effective products on the market. Dinotefuran (Safari or Transtect) may be applied as a basal spray; imidacloprid products are effective as a soil treatment (Merit, Xytect, and others) or trunk injection (Ima-jet). Both of these neonicotinoids can protect an ash tree from emerald ash borer with annual reapplications [586, 386].

For emerald ash borer control, emamectin benzoate trunk injections (Tree-äge) are the most likely systemic alternative to dinotefuran and imidacloprid. Emamectin benzoate is effective against emerald ash borer for 2-3 years, even longer than dinotefuran or imidacloprid [386, 387, 541]. Systemic azadirachtin-based insecticides (TreeAzin, Azasol, and others) are highly effective against emerald ash borer as well, suppressing reproduction and development for 1-2 years, depending on the severity of infestation [546, 541]. Pyrethroid sprays (Onyx, Tempo) or trunk injections (Pointer) can also protect ash trees, though these products are less persistent [387]. Insecticide treatments are most effective when coupled with regional efforts to slow emerald ash borer infestations and reduce pest populations (e.g., quarantines, trap trees, and introduction of biological control agents) [215, 543].

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[58] The emerald ash borer makes ash trees brittle and unstable, adding to the difficulty and expense of removal.

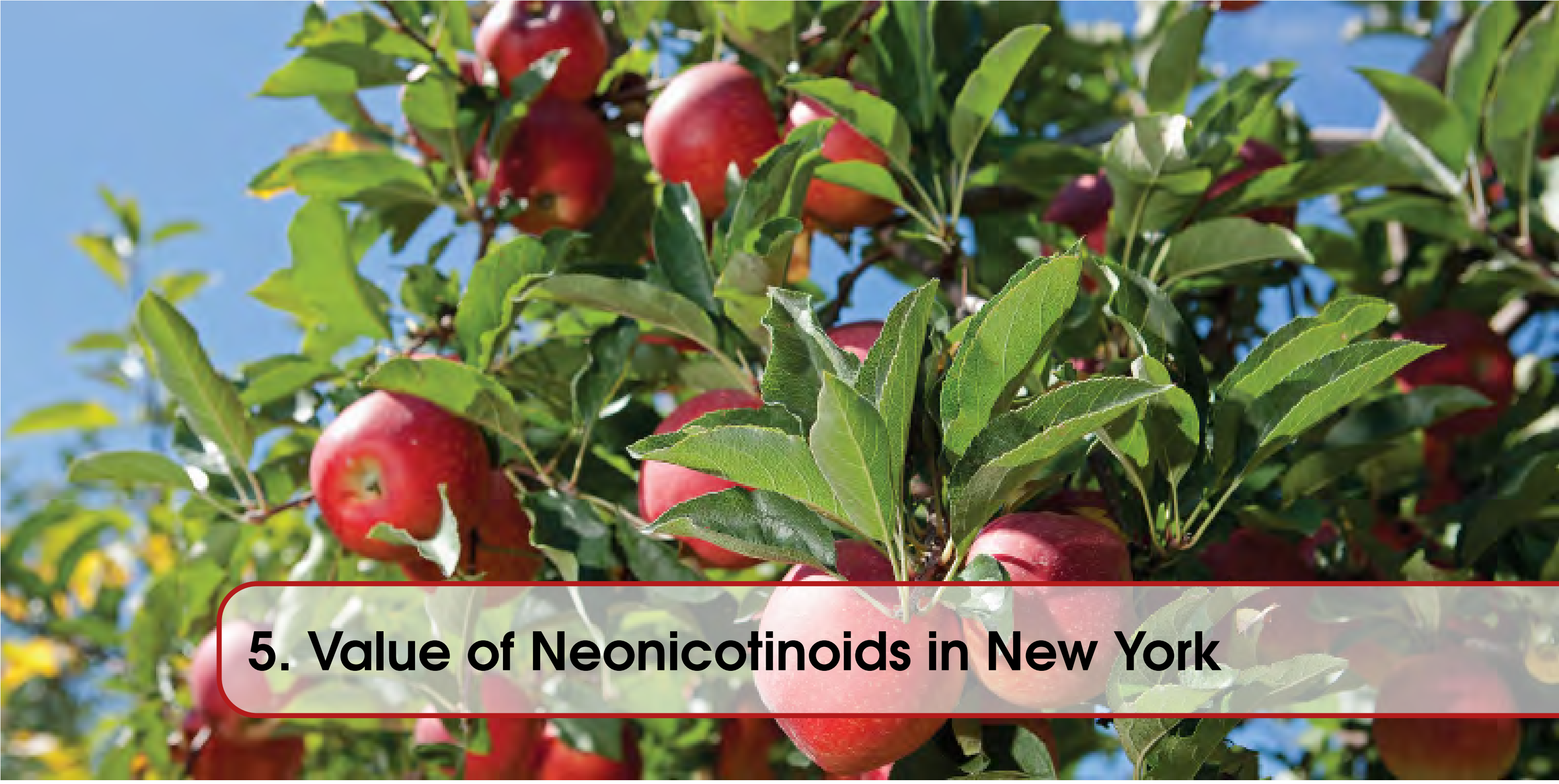
4.5.3 Hemlock woolly adelgid

Eastern hemlock is the third most common tree in the state, and in some watersheds (such as the Lake George watershed) hemlock comprises 60% of the forest. It is considered a foundation species, a species that creates the habitat that many other species depend upon. For example, hemlocks play a unique role in creating good spawning grounds for trout by shading and cooling headwater streams. In the Delaware Water Gap, there are nearly three times as many trout in watersheds with hemlock than in hardwood-dominated watersheds [758]. Hemlock-dominated swamp is a rare habitat in New York that is targeted specifically for conservation by the NYSDEC.

Hemlock woolly adelgid (*Adelges tsugae*) arrived in New York State in the 1980s, and has now been reported throughout Long Island, the lower Hudson Valley, the Catskills, and the Southern Tier, with isolated infestations in urbanized areas of Western New York [612]. Hemlock woolly adelgid feeds on hemlock twigs, gradually cutting off the flow of nutrients to the end of the twigs and preventing new growth. This inability to produce new growth starves and kills trees in infested stands over 6-20 years depending on hemlock woolly adelgid population growth and other stressors on the tree. Hemlock mortality in untreated, infested stands approaches 100% [241, 80].

Neonicotinoid insecticides are a core component of hemlock woolly adelgid management in New York State. A dinotefuran spray to the base of a hemlock tree offers relatively rapid (an effective dose typically reaches the canopy in 2-3 weeks) protection [163, 1047]. It is often used in conjunction with an imidacloprid-based soil treatment, trunk injection, or basal spray. Imidacloprid spreads more slowly, taking up to 3 months to reach useful concentrations throughout the tree, but can be effective for up to seven years [160, 235, 53]. Imidacloprid-based products are the only insecticides labelled for hemlock woolly adelgid control that are available to users other than Certified Pesticide Applicators (e.g., homeowners and community organizations) [1047].

In the immediate future, there are no obvious alternatives to dinotefuran and imidacloprid for the systemic control of hemlock woolly adelgid. Biological control (e.g., with introduced silver flies or *Laricobius* beetles) is promising, but will take many years to implement. It is not a replacement for targeted insecticide treatments [508]. No non-neonicotinoid insecticides are labeled for control of the pest (or have a FIFRA 2(ee) recommendation) in New York State. Further study would be needed to assess the efficacy of other systemic alternatives in the field and their likely environmental impacts.



5. Value of Neonicotinoids in New York

In this chapter, we examine the value of neonicotinoids in terms of users' outcomes of interest. For each common use of neonicotinoids, we estimate how the outcomes would change if users had to switch to a different pest management product or technique. Due to practical considerations of this analysis and available data, our focus is primarily on the relative value of neonicotinoids compared to alternative chemical insecticides (or simply stopping insecticide usage). This analysis does not formally address the non-chemical insecticides and IPM methods that can complement, or even replace, chemical control of certain insect pests of New York crops. However, we highlight several of these potential options in *Chapter 7*.

For agricultural uses, we assume that farmers use insecticides to maximize their net income and minimize financial risk.[1] Whenever possible, we use crop yield in conjunction with crop prices as a proxy for income per hectare. When yield data are not available (e.g., plot yield is rarely measured when foliar neonicotinoid sprays are compared to other insecticide sprays in tree fruits), we focus analyses on damage to crops from insect pests or suppression of pest populations. When crop damage is the response variable, we compare reported insect damage from paired trials of neonicotinoid

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Photo by Peggy Greb, USDA Agricultural Research Service.

[1] Many users also consider health risks when choosing insecticides. We briefly outline human health impacts of neonicotinoids and their alternatives in Section 2.4, alerting the reader to the extensive work done on this topic by the USEPA and NYSDEC.

and alternative insecticide treatments, or neonicotinoid treatment and an untreated control.[2] When pest suppression is the response variable, pest populations are compared between neonicotinoid and alternative insecticide treatments, or a neonicotinoid treatment and no treatment.

It is more difficult to quantify outcomes for non-agricultural users. Whereas a farmer profits directly from increased crop yield and/or decreased pest damage, non-agricultural pesticide users often benefit indirectly. It is difficult to place a definitive value on marginal pest damage to, say, an attractive commercial landscape, a productive personal garden, or healthy trees in a public park. For commercial, residential, and conservation users, therefore, we assume that users want to keep pest damage below a certain threshold and will choose the least costly pest management strategy that will reliably achieve that goal. We thus compare the cost of pest control with neonicotinoid insecticides to the cost of comparable control using other products.

Pesticide users benefit from neonicotinoids in less direct ways as well. Preventive uses of neonicotinoids, particularly seed treatments, are valuable in part as a risk management tool for farmers. Even if neonicotinoid use does not increase the average expected yield relative to no treatment, a farmer may find treatment worthwhile if it reduces the risk of an unlikely, but severe loss. In this context, preventive insecticide use may be considered a form of crop insurance. Although this is an important benefit of preventive neonicotinoid use, we do not quantify it in this report. With existing data on target pests in New York, we cannot confidently estimate the risk of damaging infestations in the absence of widespread neonicotinoid use. New data could allow meaningful quantification of the "insurance value" of preventive neonicotinoid products to farmers; we discuss this possibility further in *Chapter 7*.

Finally, pesticide users benefit from having access to several pest management products for any given application. Those following IPM guidelines try to avoid repeated application of a single chemical or chemicals in the same mode of action group in order to slow the development of insecticide resistance in target pest populations [154]. Insecticide rotation, ideally across generations of the target pest, decreases the likelihood of resistance to any single insecticide or mode of action group in the pest population [314, 868]. Each insecticide in the rotation is then effective for a longer period of time. Restrictions that remove neonicotinoids from rotation would, to some extent, increase the risk of pest

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[2] We consider comparisons with control groups treated with non-insecticidal crop protection products ("fungicide-only" controls) separately.

resistance to other insecticides. Where appropriate, we assume that neonicotinoid products are used in rotation,[3] and that farmers would attempt to maintain diversity in modes of action if they lost access to neonicotinoids. We discuss where restrictions on a given neonicotinoid use are particularly likely to have implications for insecticide resistance. We do not, however, attempt to quantify that risk.

5.1 Methodology

As noted above, the economic analysis for agricultural crops defines efficacy in terms of grower income. Of the three types of study responses used in this report (crop yield, damage to crops from insect pests, and suppression of pest populations), crop yield is most closely related to income. For corn and soybean, where sufficient data exist, we use the difference in average yields reported in paired field trials of neonicotinoid products and alternatives (in conjunction with crop prices) as a proxy for gross income per hectare. The net income analyses also consider the relative cost of purchasing and using neonicotinoid-based and alternative products. If usage of an insecticide increases expected yield, the average net financial return from insecticide application is the value of the average increase in yield minus the average cost of treatment (including costs related to crop scouting and application). This approach means that not all neonicotinoid efficacy studies in corn and soybean (i.e., those reporting damage to crops or suppression of pests, but not yield) contribute to this assessment of net benefits. Many efficacy studies use stand density, germination rates, or other measures related to the early-season growth and development of the target crop as the outcome of interest. These responses can be practical endpoints for research, allowing scientists to quantify the effect of an insecticide treatment within a few days or weeks of application. Full-season tests that focus on crop yield or financial return are more expensive and logistically challenging. Nevertheless, it is important to bear in mind that mid-season measures of crop health or pest abundance are imperfect proxies for farmer financial outcomes.

Studies focusing on short-term crop injury, stand density, and other measures of early season growth and vigor can *over*-state an insecticide's efficacy in terms of grower income. Many crops, including corn and soybean, can exhibit compensatory growth following early-season damage [329, 159, 184, 464]. While early-season damage certainly has an effect on yield, it is not a linear relationship. The ability of

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[3] Neonicotinoid-treated seeds are an exception. Farmers using insecticide-treated seed typically do not rotate neonicotinoids and other modes of action.

crops to recover from early-season pest damage can vary greatly among cultivars, and depends upon on the degree of damage and growing conditions following that damage. If conditions are otherwise favorable, even modest stand reductions may not impact yield at the end of the season. Furthermore, the net benefit of using an insecticide early in the season is lower if the insecticide kills beneficial insects, such as natural predators of later-season pests. This effect can occur with almost any insecticide. In regard to neonicotinoids, several studies have linked neonicotinoid usage to higher populations of slugs or spider mites via release from insect predation, which in turn can increase crop damage and/or decrease yield [892, 212, 731, 765].

Studies focusing only on suppression of pest populations may *under*-state the value of insecticides to growers. Importantly, neonicotinoids do not need to kill pests to be useful to farmers. Many pests survive concentrations of neonicotinoids encountered in the field, but are less damaging due to the sublethal effects of neonicotinoids. For example, two studies comparing the efficacy of thiamethoxam and fipronil seed treatments (neonicotinoid and phenylpyrazole insecticides, respectively) to control wireworms found that the two had similar effects on wheat stand density even though thiamethoxam killed fewer wireworms[4] [1018, 581]. Other studies have confirmed that sub-lethal neonicotinoid exposure limits wireworm feeding and mobility [1020, 120, 244], and may make them more vulnerable to desiccation and predation [1017]. In such cases, studies measuring pest population or pest mortality as the outcome of interest do not fully reflect the value of neonicotinoids for crop protection.

5.1.1 Literature review

A systematic literature review was conducted to collect and summarize all peer-reviewed studies addressing the efficacy of neonicotinoid-based products relative to no treatment or to alternative pest control products and techniques. The initial search, finished on April 15, 2019 via the Thomson Reuters Web of Science, used the search string Topic=(neonicotinoid OR neonicotinoids OR neonics OR acetamiprid OR clothianidin OR dinotefuran OR imidacloprid OR nitenpyram OR nithiazine OR thiacloprid OR thiamethoxam OR “seed treatment” OR “seed treatments” OR “seed dressings”) AND (yield OR yields OR income OR benefit OR benefits OR production OR output OR returns OR value

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[4] In Morales-Rodriguez and Wanner [581], wireworms exposed to thiamethoxam suffered 10-31% mortality, whereas 72-90% of wireworms died in the fipronil treatment groups.

OR economic OR economics OR investment OR profits OR profitability OR efficacy OR effectiveness). After assessing results for relevance, this initial search produced 289 results, excluding duplicates, to which we added 278 references by following citations. An additional 97 references were added by exhaustively reviewing reports of field trials published in New York and its closest neighboring states and provinces. Specifically, field trial reports were gathered from Cornell Cooperative Extension, Penn State Extension, the Rutgers Agricultural Research and Extension Center, University of Connecticut Extension, UMass Extension, University of New Hampshire Cooperative Extension, University of Vermont Extension, and Agriculture and Agri-Food Canada. We assessed selected studies and excluded those that were inappropriate for this analysis. This resulted in a final data set of 550 relevant studies.

5.1.2 Analysis

Each study in the final data set included mean values and information regarding statistical significance for comparisons in yield, pest damage, or pest populations reported from crop trials involving at least one neonicotinoid-based treatment and one non-neonicotinoid treatment and/or untreated control. A large portion of the underlying data lacked information regarding sample sizes or variance, so we were unable to perform a formal meta-analysis. Instead, we used Stata's repeated measures Analysis of Variance (ANOVA) command to test the significance of differences in means.[5] If the distribution of underlying data appeared to be non-normal or sample size was low, we also report the results of a Wilcoxon signed-rank test.[6] For the ANOVA analysis, we weighted data based on the number of locations and years that contributed to a reported value (some studies only reported mean values pooled across multiple locations and/or years).[7] It is important to note that the ANOVA and Wilcoxon signed-rank analyses of study means do not propagate error or weight sample sizes from the underlying data. This could lead to less conservative results than meta-analysis (i.e., results reported as "significant" here may not be significant via meta-analysis). Again, it was not possible to perform a formal meta-analysis

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[5] ANOVA (or F-test) analyses assume that the dependent variable has a normal distribution and that its variance is constant across groups. Compared to other parametric tests, ANOVA is quite robust with respect to violations of these assumptions [63, 64]. Nevertheless, we also report the results of a non-parametric test if an underlying distribution appeared to be non-normal or sample size was low.

[6] The Wilcoxon signed-rank test is a nonparametric paired difference technique, appropriate when the sample size is small and one cannot assume a normal distribution [1049]. It reports the likelihood that two independent groups have the same population distribution. Here, it tests the research hypothesis (H_1) that average yields after using neonicotinoids are *not* equal to average yields in the control against a null hypothesis hypothesis (H_0) that there is no difference in yields.

[7] This controls for pseudoreplication. The available data did not allow weighting based on inverse variance [79].

because a large portion of the underlying data lacked information regarding sample sizes or variance.

The subsequent economic analysis builds on the ANOVA results using a model similar to that outlined in Alford and Krupke [15] and Krupke et al. [463]. We calculate a mean yield effect (YE) and standard error from the mean difference in reported yields within paired neonicotinoid-treated and non-neonicotinoid observations, expressed as a percentage of mean yield in the neonicotinoid-treated group. The YE may be understood as the expected change in yield resulting from shifting to a non-neonicotinoid pest management product or technique. We also estimate a "low" and "high" yield effect estimate (YE_{low} and YE_{high}) based on the 95% confidence interval of YE. The baselines for yield (MY) and commodity prices (P) come from USDA annual survey results in New York from 2016-2018 [949].

The difference in estimated costs between treatments is C. Estimated product costs are based on, in descending order of preference, average costs reported in grower surveys, data from the manufacturer, or publicly-available pesticide price lists. Sources are noted in each section. For foliar alternatives, we assume that scouting a field for insect pests costs \$12.17 per hectare and that a early-season application of a foliar spray costs \$21.16 per hectare. We assume that using a soil-applied insecticide at planting adds \$3.05 per hectare to planting costs. These values are based on mean values from recent state extension surveys of farm custom work rates[8] [148, 677, 1036, 46, 204, 484, 690, 538].

$$NI_{low} = YE_{low} \times MY \times P - C \tag{5.1}$$

$$NI_{high} = YE_{high} \times MY \times P - C \tag{5.2}$$

Most of the analyses below focus on *average* differences in yield or financial returns between

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[8] For each state, we first took the mean of relevant values in a given cost category (e.g., if both are given, taking an average of the estimated cost of insecticide application using both a self-propelled and pull-type sprayer), then calculated an overall mean based on state-level averages.

plots receiving neonicotinoid treatments compared to plots using an alternative treatment. Reported averages reflect all sites and years in the relevant data set. A statistically significant difference may be understood as the expected yield benefit (or penalty) for a typical producer planting neonicotinoid-treated corn instead of using a given non-neonicotinoid alternative.[9] This is a particularly useful metric for neonicotinoid-treated seeds in conventional field corn, which are used by nearly all conventional farmers. However, surveys show that pest pressure varies greatly, and field trials suggest that both pest pressure and yield response associated with these products varies greatly. New York producers facing higher pest risk likely benefit more from neonicotinoid-treated seeds than those facing average pest risk. We partially address this concern with analyses highlighting studies that directly supplemented pest populations (by, for instance, inoculating a site with corn rootworm larvae), managed the test site to increase the likelihood of natural infestation (e.g., applying manure or another bait with the express purpose of attracting seedcorn maggot), or selected test sites to take advantage of existing or likely high pest populations.

Due to the limited number of yield and efficacy studies conducted in New York State itself, we draw upon data from other North American studies for our analysis. Results based on the "Regional" data set reflect field trials that took place in New York, Connecticut, Massachusetts, New Hampshire, New Jersey, Ohio, Ontario,[10] Pennsylvania, Quebec, Rhode Island, or Vermont (see Figure 5.1). "North American" results are based on data from field trials throughout the United States and Canada (including New York and the states and provinces in the Regional data set). Please note, however, that the literature review for this project prioritized collecting data from New York and its neighbors. As described in Section 5.1, we identified sources by searching the Thomson Reuters Web of Science (which emphasizes peer-reviewed publications), by following citations in published works, and by reviewing reports of field trials conducted by *regional* extension and research institutions. This process did not capture many extension field trials conducted outside of the region, except for those reported in peer-reviewed journals.

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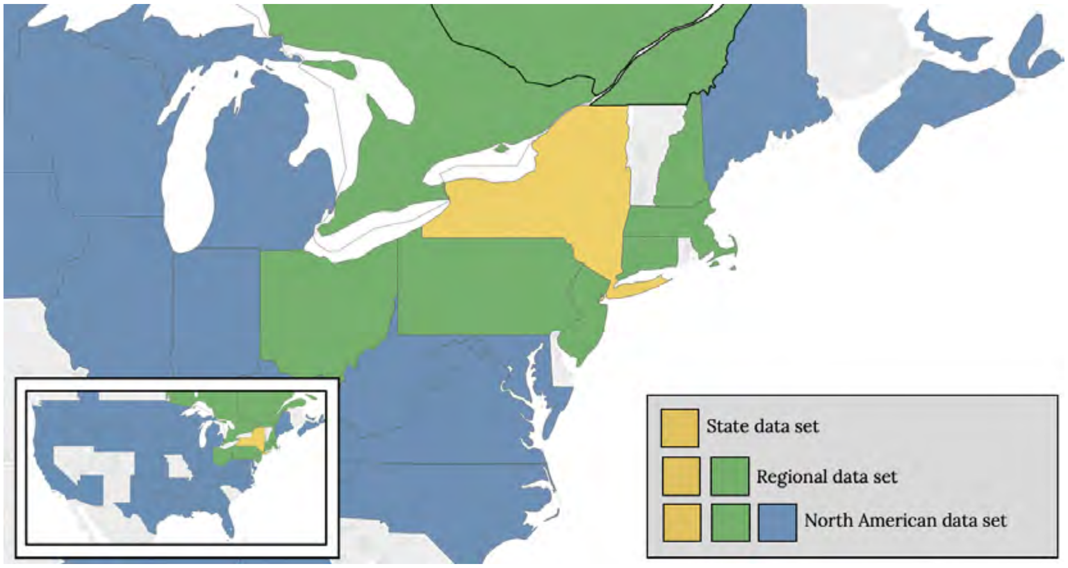
[9] Results highlighted in green suggest higher expected yields or net returns associated with neonicotinoid-treated seeds than the given alternative. Those highlighted in red suggest better performance by the non-neonicotinoid alternative. Results in gray are not statistically significant.

[10] Note that the overwhelming majority of Ontario agricultural production takes place in the southeastern part of the province, close to Lake Erie, Lake Ontario, and the St. Lawrence River. Quebec's agricultural heartland, similarly, is the southernmost part of the province along and south of the St. Lawrence River.

Figure 5.1: **States and provinces included in state-, regional-, and North American-level analysis, all commodities**



Often, data from field studies are not directly comparable. There are many ways to quantify insect pest damage to crops or to measure pest population. When the outputs captured in a data set are highly heterogeneous, it is not always possible to use ANOVA or signed-rank tests to analyze all paired observations. In such cases, we use a binomial sign test to determine if there is a significant difference in the *number* of field trials in which neonicotinoid-treated plots outperformed an alternative or vice-versa. While this test has lower power than the Wilcoxon signed-ranks test, it requires no assumptions about the distribution of data, and allows us to incorporate data from all available trials. The sign test is based on a count of paired observations in which the difference in means between the paired neonicotinoid-treated and comparison group is positive or negative.[11] If two treatments have equivalent performance, the true proportion of positive to negative mean differences is 1:1. The difference in means in a given pair of observations is equally likely to be positive or negative. We test that null hypothesis against two alternative hypotheses: that neonicotinoids performed better than alternatives in a significantly larger number of field trials, and that non-neonicotinoid alternatives

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[11] Simple transformations of our data ensure that "positive" denotes greater efficacy in terms of higher yield, lower crop damage, or lower pest populations.

performed better than neonicotinoids in a significant majority of field trials. Thus,

$$\text{If } D = Y_{neonicotinoid} - Y_{alternative}, \text{ then } H_0 : Prob[D > 0] = \frac{1}{2}$$
$$H_{a1} : Prob[D > 0] > \frac{1}{2}$$
$$H_{a2} : Prob[D < 0] > \frac{1}{2}$$

5.2 Field corn

This report draws on 82 studies of neonicotinoid efficacy in field corn, allowing 1,093 unique pairwise comparisons of mean yields from trials involving a neonicotinoid-based product and either an alternative insecticide treatment or an untreated control. Three of these studies (16 pairwise comparisons) took place in New York State itself [168, 169, 170]. Another 36 (472 pairwise comparisons) were conducted in Ohio, Ontario, or Quebec and contribute to our regional results (see Figure 5.1).

The overwhelming majority of New York corn growers plant seeds treated with clothianidin (Poncho) or imidacloprid (Gaucho). These insecticides provide 2-4 weeks of protection against target pests. Several pests that are reasonably common in New York cornfields can be controlled by neonicotinoid-treated seeds in the weeks after planting: seedcorn maggot, wireworms, white grubs, and corn rootworms. As noted in *Chapter 4*, neonicotinoid-treated seeds are intended to provide early-season protection only. For some target pests, such as seedcorn maggot and wireworm, this window of protection largely eliminates the risk of economic damage. For pests that pose a threat to crops later in the growing season as well, notably corn rootworms, neonicotinoid-treated seeds may be one component of season-long management. Insecticidal seed treatments are preventive products; farmers must decide which seed treatment(s) to order well in advance of planting, before target pest populations are known and with limited information about conditions in the upcoming season.

Neonicotinoids are only one ingredient in the seed treatments discussed here. Seed coatings nearly always contain one or more fungicides and may include nematicides, germination promoters, micronutrients, a second insecticide, or other components. In studies comparing seed treatments with

Table 5.1: **Relative insecticide costs used in field corn financial analysis**

Product purchase price of comparisons used in analysis, relative to neonicotinoid-treated seeds					
	Representative	Unit	*Relative* cost		
Comparison	Product	Cost	Per acre	Per hectare	Source
No treatment			-$20.15	-$49.77	
Non-insecticidal ("fungicide-only") seed treatment			-$ 6.80	-$16.80	North et al. [625]
Seed-applied anthranilic diamides	Lumivia *(0.25 mg ai/seed)*		$ 17.00	$ 42.00	See notes[1]
Soil-applied tefluthrin	Force 3G *5.5 lb/A*[1]	$0.40/oz	$ 28.40	$ 70.14	Knodel et al. [455]
Soil-applied chlorpyrifos	Lorsban 15G *(8.45 lb/A)*	$0.14/oz	$ 12.13	$ 29.95	Knodel et al. [455]
Other costs associated with soil-applied alternatives					
			Per acre	Per hectare	Source
Insecticide application at planting			$ 1.24	$3.05	Farm custom rate lists[2]

Notes: (1) Estimated based on relative cost of chlorantraniliprole and clothianidin active ingredients (in dollars per fluid ounce of active ingredient); (2) Maximum allowable rate in New York State. Force 3G may be applied at up to 10.9 lb/A in other states. (3) The difference in custom rates between planting with and without attachments to apply insecticide, taken from from an average of recent state extension surveys of farm custom work rates [677, 46, 204, 538].

multiple active ingredients to an untreated control, it is usually impossible to attribute differences in performance to any single component of the seed treatment. In such studies, we note that the comparison is to an "untreated control." Other trials compare neonicotinoid-treated seeds to a control group with nearly-identical seed coatings, omitting only the neonicotinoid active ingredient. An observed treatment effect may then be attributed to the neonicotinoid active ingredient. We refer to such trials as having a "fungicide-only control" (though the seed treatment may include non-insecticidal components other than fungicides).

The financial analysis compares estimated net returns of neonicotinoid-treated seeds relative to seed-applied anthranilic diamides, soil-applied tefluthrin, soil-applied chlorpyrifos, non-insecticidal seed treatments, and no treatment. Costs used for this analysis are listed in Table 5.1. We assume that growers cannot reliably predict risk from early-season pests, so preventive soil-applied alternatives would be used annually (like seed treatments). Under these conditions, growers could not reduce costs by forgoing treatment at low-risk sites or in low-risk seasons.

Of the 1.1 million acres of corn harvested in New York State, roughly 60% is grown for grain and 40% for silage (forage) [945]. The distinction is important for this analysis, as conditions impacting grain yield do not necessarily have the same effect on forage yield [488]. In particular, economic injury levels for insect pests tend to be lower in corn grown for forage than in corn grown for grain [487]. The impact of neonicotinoids on corn grain yield is relatively well-studied, but only two studies in our data set (both from New York State) report effects on corn silage yield.

5.2.1 Yield effects

Proportion of studies observing yield increases via neonicotinoid insecticide usage

Overall, the evidence at the state, regional, and North American levels shows that neonicotinoid-treated seeds do not consistently increase yield compared to untreated controls, fungicide-only controls, or other insecticide treatments (Table 5.2, Figure 5.2). For studies conducted in New York, two of twelve comparisons (17%) observed a significant increase in yield when comparing neonicotinoid-treated seeds to untreated or fungicide-only controls. The other ten of twelve comparisons (83%) observed no differences in yield, and none of the four comparisons between neonicotinoid-treated seeds and alternative soil-applied insecticides observed differences in yield.

In the larger, regional data set (New York, Ontario, Quebec, and Ohio), 32 of 336 comparisons (9%) observed a significant increase in yield when comparing neonicotinoid-treated seeds to untreated or fungicide-only controls. In this data set, 321 of 336 comparisons (88%) observed no differences in yield, while 13 of 336 comparisons (4%) observed significant decreases in yield when comparing neonicotinoid-treated seeds to untreated or fungicide-only controls.[12] None of the 124 comparisons (0%) between neonicotinoid-treated seeds and alternative seed treatments or soil-applied insecticides observed increases in yield, and 6 of 124 comparisons (5%) observed decreases in yield.

Results from the North American data set (New York, Ontario, Ohio, Quebec, and 13 additional states; see Table A.1) were similar to the state and regional data sets; 73 of 613 comparisons (12%) observed a significant increase in yield when comparing neonicotinoid-treated seeds to untreated or fungicide-only controls. In this data set, 518 of 613 comparisons (85%) observed no differences in

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[12] Percentages do not sum to 100% due to rounding.

yield, while 20 of 613 comparisons (3%) observed significant decreases in yield when comparing neonicotinoid-treated seeds to untreated or fungicide-only controls. Twenty-six of 430 comparisons (6%) between neonicotinoid-treated seeds and alternative seed treatments or soil-applied insecticides observed increases in yield, 387 of 430 comparisons (90%) observed no difference in yield, and 17 of 430 comparisons (4%) observed decreases in yield.

Table 5.2: **Statistical significance of all field corn yield trials comparing performance of neonicotinoid-treated seeds to specified non-neonicotinoid treatments or untreated controls, summarized at the state, regional, and North American scales**

	New York State			NYS & region			North America		
Comparison	Y+	Y-	N	Y+	Y-	N	Y+	Y-	N
NTS[1] **vs. other seed treatment**				0	0	14	16	0	74
NTS vs. soil-applied insecticide	0	0	4	0	6	104	10	17	313
NTS vs. fungicide-only control	1	0	9	20	3	211	30	5	248
NTS vs. untreated control	1	0	1	12	10	110	43	14	273

Notes: (1) Neonicotinoid-treated seeds.

Number of field trials reporting significantly higher yield (Y+, green), lower yield (Y-, red), or no significant difference in yield (N, gray) in plots using NTS compared to plots using the specified non-neonicotinoid treatment or untreated control. "NYS & region" includes studies from New York, Ohio, Ontario and Quebec. States and provinces included in the "North America" data set are listed in Table A.1. Note that some field trials did not report statistical significance; those trials are not included in this table, but mean yield reported in those trials could still be used for subsequent analyses.

New York State studies

Two studies in New York State have examined the effects of neonicotinoid seed treatments on corn silage yield. Cox et al. [168] compared yield in plots of two corn hybrids planted with clothianidin-treated seeds, at concentrations of 0.25 or 1.25 mg active ingredient per seed, to control plots that used a fungicide-only seed treatment. The fields studied had been in a corn-soybean rotation for over a decade, and the authors did not note unusual pest pressure in either year of the study. The study concluded that "[c]lothianidin did not affect forage quality or calculated milk yield" averaged across hybrids and years.[13] The authors do note some significant differences between treatment and control groups. In 2004, one of the two 1.25 mg clothianidin groups had significantly higher dry matter yield

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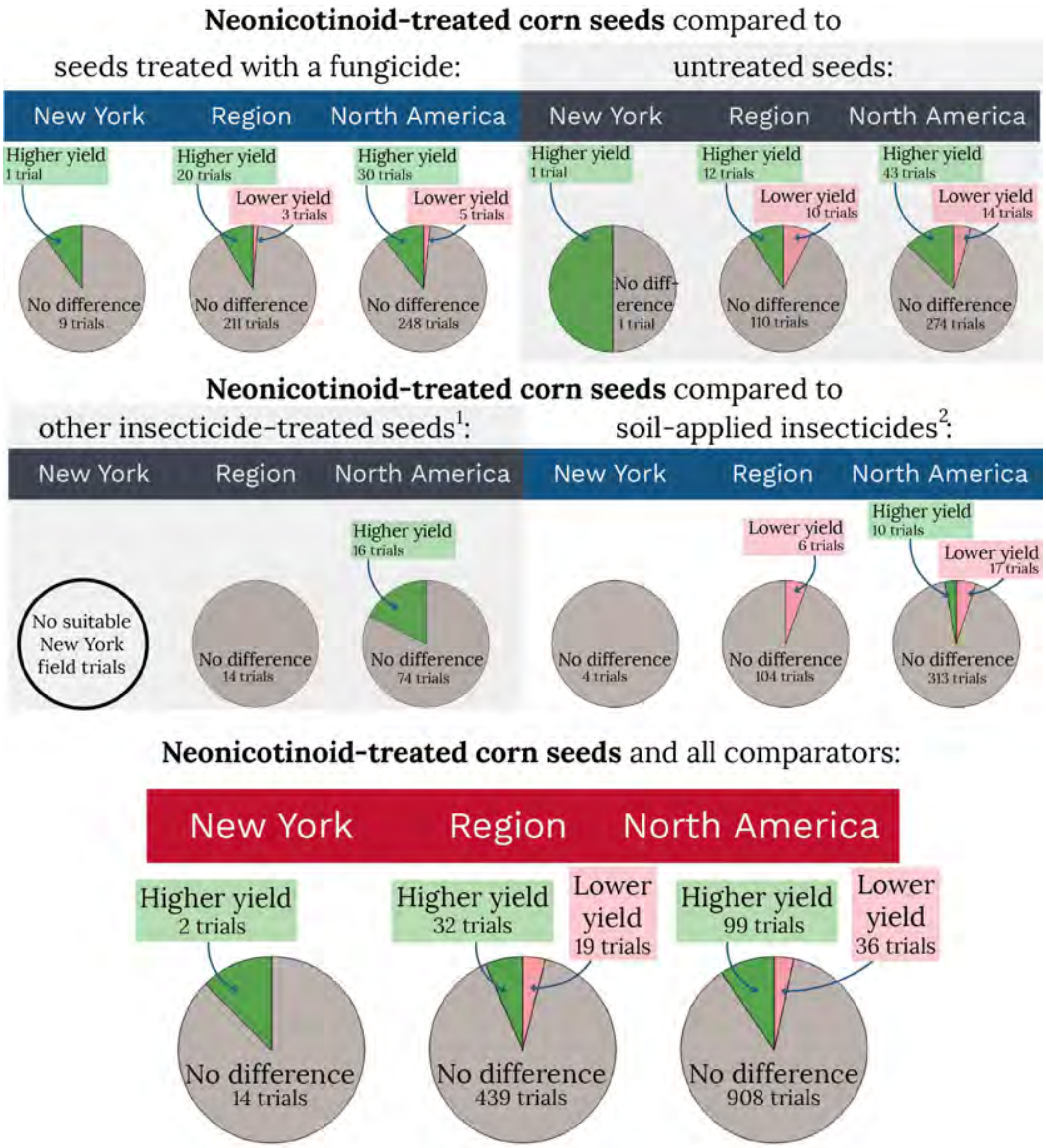
[13] Cox et al. [168] reported an F-value of 0.14 for the combined analyses of variances for dry matter yield and 0.28 for the combined analyses of variances for calculated milk yield.

Figure 5.2: **Number of corn field trials reporting significantly higher (green), significantly lower (red), or no difference (gray) in yields in plots using neonicotinoid-treated seeds compared to plots using a non-neonicotinoid treatment or untreated control**



Notes: Regional results used data from field trials in New York, Ohio, Ontario, and Quebec. North American results used data from New York, Ohio, Ontario, Quebec, and 13 other states (see Table A.1). Note that some field trials did not report statistical significance; those trials are not included in this table, but mean yield reported in those trials could still be used for subsequent analyses. (1) A pyrethroid (tefluthrin) was the only alternative tested in the regional data set; North American field trials included tefluthrin, anthranilic diamides (chlorantraniliprole and cyantraniliprole), and a phenylpyrazole (fipronil). (2) The only alternative tested in New York field trials was a pyrethroid (tefluthrin). Regional field trials included tefluthrin, organophosphates (chlorethoxyfos, terbufos), phenylpyrazole (fipronil), and apyrethroid-organophosphate mix (cyfluthrin/tebupirimphos). North American field trials included all active ingredients in the regional analysis as well as additional pyrethroids (bifenthrin and esfenvalerate), an organophosphate (chlorpyrifos), and a carbamate (carbaryl).

than the control plots.[14] In 2005, the 0.25 mg clothianidin plots had significantly greater average plant density than the control plots.[15]

A similar study by Cox et al. [169] focused on continuous corn, testing clothianidin and thiamethoxam seed treatments (1.25 mg a.i./seed) against a fungicide-only control, plots treated with a soil-applied pyrethroid insecticide (Force 3G, with tefluthrin), and plots treated with a combination of clothianidin (0.25 or 1.25 mg a.i./seed) and tefluthrin. Plots in this study were managed to encourage corn rootworm infestations.[16] Overall, plots in the study experienced moderate corn rootworm pressure and little pressure from other pests. When averaged across both seasons, dry matter yield and calculated milk yield (estimated milk production from dairy cows fed corn silage) were significantly higher in the clothianidin-treated (1.25 mg a.i./seed) and tefluthrin plus clothianidin-treated (1.25 mg a.i./seed) plots compared to control plots. It is important to note that this study used a significance level of $\alpha = 0.1$; the difference in yields may not be significant at the $\alpha = 0.05$ level, which is standard for biological literature and used in the analyses in this report. There was no difference in dry matter yield or calculated milk yield between the thiamethoxam-treated (1.25 mg a.i./seed) plots compared to control plots, tefluthrin-treated plots compared to control plots, or tefluthrin plus clothianidin-treated (0.25 mg a.i./seed) plots compared to control plots. Furthermore, there was no difference in dry matter yield or calculated milk yield between the clothianidin-treated (1.25 mg a.i./seed), tefluthrin plus clothianidin-treated (0.25 mg a.i./seed), or thiamethoxam-treated (1.25 mg a.i./seed) plots compared to tefluthrin-treated plots.

Aggregating data from these studies, which were both conducted in New York and focused on corn grown for silage, we find that mean dry matter yield in the neonicotinoid-treated plots was significantly higher than in those planted with fungicide-only treated seeds (see Table 5.3). The average yield benefit from neonicotinoid seed treatment was 725 kg/ha (± 208). A Wilcoxon matched-pairs signed-ranks test also found a positive, significant relationship between neonicotinoid seed treatment and dry matter

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[14] The treatment group produced 22.6 Mg/ha of dry matter, while yield in the control group was 21.3 Mg/ha. The least significant difference in means at $\alpha = 0.05$ (LSD(0.05)) was 1.3).

[15] 66,673 and 63,025 plants per hectare, respectively (LSD(0.05)=3295). There were no significant differences in dry matter yield or calculated milk yield.

[16] It is often desirable to induce high pest pressure in crop field trials. Among other techniques, researchers may directly supplement pest populations, bait plots to draw in pests, or select sites with a pre-existing infestation or known risk factors. In the following sections, we compare yield responses for neonicotinoid-treated seeds, relative to alternatives, in field trials that were or were not managed for high pest pressure.

yield. At the same time, we note that this significant increase in *average* yield was largely due to the influence of one comparison. Indeed, as shown in Table 5.2 and Figure 5.2, only one of ten comparisons (10%) found a significant increase in yield when comparing neonicotinoid-treated seeds to fungicide-only controls. The other 9 of 10 comparisons (90%) found no differences in yield when comparing neonicotinoid-treated seeds to fungicide-only controls. Due to the small sample size (n = 2), we did not compare differences in yields between neonicotinoid-treated seeds and soil-applied tefluthrin.

Table 5.3: **Silage yield of field corn planted with neonicotinoid-treated seeds compared to alternatives in paired New York field trials**

		ANOVA results			Signed-ranks test		
Comparison	Paired obs.	**Mean diff.**	**F-value**	**P-value**	**% Pos.**	**Z-score**	**P-value**
NTS[1] vs. **fungicide-treated seeds**	10	3.8%	12.16	0.004	88%	2.14	0.032

Notes: (1) Neonicotinoid-treated seeds.

Throughout this report, results highlighted in green suggest significantly higher corn yields with neonicotinoid-treated seeds than with the listed alternative.

A third New York State study, Cox et al. [170], reported grain yield in plots continuously growing corn under corn rootworm pest pressure (plots were managed to encourage corn rootworm infestation). The authors conducted field trials in 2005 and 2006, experiencing high environmental stress in the first season and low environmental stress in the second. In these conditions, the authors reported that grain yield in plots planted with clothianidin-treated seeds (1.25 mg a.i./seed) was higher than in untreated control plots. This difference in yield was significant at the $\alpha = 0.1$ level used in Cox et al. [170].[17] There was no significant difference in yield between control plots and plots with thiamethoxam-treated seeds (1.25 mg a.i./seed). Yields in plots that used soil-applied tefluthrin, either alone or in combination with a clothianidin seed treatment, were not significantly different from yield in control plots or plots that used only a neonicotinoid seed treatment. The authors also noted that root node damage was less severe in neonicotinoid-treated plots than in control plots.[18]

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[17] As noted above, for our analyses in this report, we use the significance level $\alpha = 0.05$, which is standard for biological literature.

[18] On a scale of 0-3, the damage rating in control plots was 1.40 (moderately severe). The damage rating in plots using clothianidin- or thiamethoxam-treated seeds was 0.18 (minor) and 0.39, respectively.

Regional studies

Given the limited number of field trials conducted in New York itself, it is useful to consider crop research from nearby states and provinces. The regional data set drew on field trials from 36 suitable studies that reported corn grain yield conducted in Ontario, Ohio, and Quebec,[19] as well as Cox et al. [170], conducted in New York State. We did not include the New York State studies of silage yield in this analysis, as conditions impacting grain yield do not necessarily have the same effect on forage yield.[20] This data set allowed 478 pairwise yield comparisons of neonicotinoid seed treatments and non-neonicotinoid alternatives or untreated controls. Regional data is not a perfect substitute for state-specific research, and conclusions based on regional data should be interpreted appropriately.

Growing conditions and pest pressures differ across states, and even among New York's corn-growing regions. Some factors that may influence corn production include climate, the proportion of corn production dedicated to silage, and manure use. As shown in Figure 4.1, New York grain corn production is concentrated in Western and Central New York, with significant silage production in the North Country. Growers in New York, Ontario, and Quebec have a shorter growing season than those in Ohio, and therefore have fewer available pest management strategies. Approximately 40% of New York's corn acreage is devoted to silage, serving the state's dairy industry. This is a greater proportion than in Ohio, Ontario, or Quebec, an important difference if silage producers are more vulnerable to early-season stand loss than grain producers.[21] Manure usage in New York State may also affect pest pressures relative to neighboring states, as manure applications shortly before planting can increase the risk of infestation by seedcorn maggot, among other pests. New York uses more than twice as much manure, per acre of cropland, as Ohio. Manure usage in Ontario is roughly equivalent to New York. Manure usage in Quebec is significantly higher.[22]

The pyrethroid tefluthrin is the neonicotinoid alternative best represented in regional studies,

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[19] The authors of this report did not find any results of field trials in Connecticut, Massachusetts, Pennsylvania, New Hampshire, New Jersey, Rhode Island, or Vermont that were suitable for this analysis.

[20] No other studies gathered for this report assessed silage yield.

[21] Between 2016 and 2018, silage (forage) corn made up about 5.5% of Ohio's harvested corn acreage, 12.5% of Ontario's, and 15.2% of Quebec's [945, 640, 418].

[22] The 2017 U.S. Agricultural Census estimated that manure was applied to nearly 1 million acres of New York farmland. In 2017, manure application acreage in New York was 22% of cropland acreage. In Ohio it was 8%. According to Canada's 2016 Census of Agriculture, manure application area in Ontario and Quebec was equivalent to 20% and 46% of land in crops, respectively [949, 872].

Table 5.4: **Relative field corn grain yield in regional studies comparing neonicotinoid-treated seeds and alternatives: results from New York, Ohio, Ontario, and Quebec**

		ANOVA results			Signed-ranks test		
Comparison	Paired obs.	**Mean diff.**[2]	**F-value**	**P-value**	**% Pos.**	**Z-score**	**P-value**
NTS[1] vs. **untreated seeds**	132	5.2%	11.92	0.001	66%	3.175	0.002
NTS vs. **fungicide-treated seeds**	224	4.0%	37.75	< 0.001	67%	4.501	< 0.001
NTS vs. **soil-applied organophosphates**	10	-1.0%	0.09	0.772	45%	-0.307	0.759
NTS vs. **tefluthrin-treated seeds**	14	35.9%	11.4	0.005	93%	2.96	0.003
NTS vs. **soil-applied tefluthrin**	91	-5.7%	6.01	0.016	39%	-1.938	0.053

Notes: Results highlighted in green suggest significantly higher corn yields with neonicotinoid-treated seeds than with the listed alternative. Results highlighted in red suggest significantly lower yield. Results in grey are not statistically significant. (1) Neonicotinoid-treated seeds; (2) Mean difference in yield within paired observations of plots planted with neonicotinoid-treated seeds and plots using the given alternative.

present in 105 paired field trials with neonicotinoid seed treatments. While neonicotinoid-treated seeds outperformed tefluthrin-treated seeds, expected net returns in plots using soil-applied tefluthrin (despite higher application and product costs) were comparable to those using neonicotinoid-treated seeds. Average yields were higher in the tefluthrin-treated plots (see Tables 5.4 and 5.9). There were no significant yield differences between neonicotinoid-treated seeds and soil-applied organophosphates. These results are not surprising; pyrethroids and organophosphates have historically performed well against corn pests that are also controlled with neonicotinoid seed treatments.

Average grain yield was significantly higher in neonicotinoid-treated plots than in paired plots planted with untreated seeds or non-insecticidal seed treatments (Table 5.6).[23] Curiously, the neonicotinoid yield benefit was stronger in pairings with fungicide-only seed treatments than with wholly untreated seeds. This may be a result of poor performance in field trials that attempted to induce high pest pressure (see Table 5.5). As with the New York data above, these significant increases in *average* yield were largely due to the influence of a small proportion of comparisons with large yield differences between treatment groups. As shown in Figure 5.2, only 20 of 234 comparisons (8.5%) observed a significant increase in yield when comparing neonicotinoid-treated seeds to fungicide-only

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[23] "Fungicide-only" treatments include one or more fungicides and may contain other non-insecticidal active ingredients.

controls, while 12 of 132 comparisons (9.1%) observed a significant increase in yield when comparing neonicotinoid-treated seeds to untreated controls.[24]

Table 5.5: **Mean grain yields in regional field corn plots (New York, Ohio, Ontario, and Quebec) treated with neonicotinoids compared alternatives, either managed to induce high pest pressure or not**

Treatment	Managed to induce/increase pest pressure[2]	Paired obs.	ANOVA results			Signed-ranks test		
			Mean difference	**F-value**	**P-value**	**% Pos.**	**Z-score**	**P-value**
NTS[1] vs. **untreated seeds**	**YES**	49	0.6%	0.11	0.739	51%	0.09	0.929
	NO	83	9.1%	16.6	< 0.001	74%	3.82	< 0.001
NTS vs. **fungicide-treated seeds**	**YES**	36	15.3%	35.74	< 0.001	97%	4.88	< 0.001
	NO	188	2.4%	15.63	< 0.001	60%	2.42	0.016
NTS vs. **soil-applied tefluthrin**	**YES**	25	3.4%	4.63	0.038	67%	1.52	0.128
	NO	66	-10.6%	9.61	0.003	30%	-2.78	0.005

Notes: Results highlighted in green suggest significantly *higher* corn yields with neonicotinoid-treated seeds than with the listed alternative. Results highlighted in red suggest significantly *lower* corn yields with neonicotinoid-treated seeds than with the listed alternative. Results in grey are not statistically significant. (1) neonicotinoid-treated seeds; (2) for this analysis, we consider field trials to be "managed for pest pressure" if researchers directly supplemented natural populations, attracted pests with bait or bait crops, intentionally selected a trial site at high risk of infestation, or took other actions with the express purpose of increasing pest pressure on the research plots.

Pest pressure in regional field trials varied, and key target pests for neonicotinoids were not present during every trial. In 117 of the 476 field trials, researchers selected or managed the study site to maximize the likelihood of infestation by target pests.[25] Table 5.5 repeats the analysis above, but separates trials that were and were not managed to induce pest pressure. Attempts to induce pest pressure had little apparent impact on the yield benefits from neonicotinoid seed treatments relative to untreated controls. However, fungicide-only control groups fared relatively poorly under high pest pressure; yield in the neonicotinoid plots was an average of 15% higher, whereas in trials that were not managed for pest pressure, neonicotinoid-treated seeds' yield benefit was just 2%. Finally, plots planted with neonicotinoid-treated seeds yielded significantly more than tefluthrin-based soil insecticides under induced pest pressure, while in plots without induced pest pressure, the reverse was true: yield was

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[24] The number of observations used in ANOVA and signed-ranks analysis differs from that in counts of statistical significance, as some studies did not report both yield and statistical significance.

[25] Studies designed to increase pest pressure were not always successful in doing so, and some of these studies did not monitor pest pressure over the course of the experiment. Similarly, some trials under normal field conditions did not measure pest pressure or reported very high pest pressure. The study reporting the worst losses from pests in the North American data was conducted under normal field conditions. In Mississippi field trials described in Cook and Gore [140], grain yield in untreated control plots was 86-87% lower than in plots planted with neonicotinoid-treated seeds, following infestations by corn rootworm and wireworm.

greater in tefluthrin-treated plots. These results suggest that pyrethroids' shorter window of protection and non-systemic mode of action may not be a handicap compared to neonicotinoids in most situations, but that neonicotinoids may offer better protection under high pest pressure. Again, as noted throughout this section, these significant differences in *average* yield were largely influenced by a small proportion of comparisons (Table 5.2, Figure 5.2).

North American studies

Efficacy studies from other corn-producing regions of North America will not necessarily reflect New York or regional conditions, and wherever possible, analyses in this report are based on data from New York and its nearby region.[26] However, data from other North American studies can help shed light on effects that are ambiguous or unaddressed in state and regional studies. For example, the regional data does not include some newer non-neonicotinoid active ingredients, particularly the anthranilic diamides chlorantraniliprole and cyantraniliprole. Furthermore, it is useful to place the analyses and conclusions of this report in a broader context and in relation to previous studies of the value of neonicotinoid seed treatments to corn growers, notably Mitchell and Nowak [571] and North et al. [625].

The larger data set allows pairwise comparisons of neonicotinoid seed treatments with a greater range of seed- and soil-applied alternatives. Table 5.6 shows ANOVA and Wilcoxon signed-rank results by application method, insecticide class, and (if sufficient data exist) active ingredient of non-neonicotinoid alternatives. The table also allows consideration of active ingredients that do not appear in the regional data set. Anthranilic diamides (chlorantraniliprole or cyantraniliprole seed treatments) are frequently touted as potential neonicotinoid alternatives, as they have a systemic mode of action, act against many of the same key pests, and are generally less toxic to non-target organisms, including pollinators. Unfortunately, we did not identify any suitable field corn trials involving both neonicotinoid-treated and diamide-treated seed in New York or the region. Thus, we draw on trials from elsewhere in North America to gain further insight into the performance comparison between neonicotinoids and anthranilic diamides.

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[26] Due to this focus, the regional data set used here is more comprehensively researched than the North American data set. As described in Section 5.1, we identified sources by searching academic databases (limiting results to North America) and by combing through reports from New York State and regional field trials by agricultural extension services and New York State and regional agencies.

Table 5.6: **Relative field corn yield comparing neonicotinoid-treated seeds vs. alternatives by application method, insecticide class, and active ingredient: based on North American data**

		ANOVA results			Signed-ranks test		
Comparison	Paired obs.	**Mean diff.**[2]	**F-value**	**P-value**	**% Pos.**	**Z-score**	**P-value**
NTS[1] vs. **untreated seeds**	322	5.5%	36.99	< 0.001	69%	5.841	< 0.001
NTS vs. **fungicide-treated seeds**	271	6.5%	29.79	< 0.001	68%	5.224	< 0.001
Alternatives by application method							
NTS vs. **insecticide-treated seeds**	77	9.5%	40.51	< 0.001	83%	5.106	< 0.001
NTS vs. **soil-applied insecticides**	338	-2.2%	12.12	0.001	41%	-2.776	0.006
Alternatives by insecticide class							
NTS vs. **soil-applied pyrethroids**	189	-1.6%	2.87	0.091	46%	-0.361	0.390
NTS vs. **anthranilic diamide-treated seeds**	33	4.6%	13.52	0.001	80%	2.993	0.003
NTS vs. **soil-applied organophosphates**	73	-4.2%	12.61	0.001	29%	-3.10	0.002
Alternatives by active ingredient							
NTS vs. **soil-applied bifenthrin (pyrethroid)**	33	2.0%	2.08	0.159	68%	1.823	0.068
NTS vs. **tefluthrin-treated seeds (pyrethroid)**	20	11.9%	4.41	0.049	70%	1.722	0.085
NTS vs. **soil-applied tefluthrin (pyrethroid)**	140	-4.1%	7.4	0.007	39%	-2.318	0.020
NTS vs. **chlorantraniliprole-treated seeds (anthranilic diamide)**	26	5.4%	14.09	0.001	83%	2.959	0.003
NTS vs. **cyantraniliprole-treated seeds (anthranilic diamide)**	7	1.8%	0.55	0.486	68%	0.845	0.398
NTS vs. **soil-applied chlorpyrifos (organophosphate)**	21	-8.7%	24.9	< 0.001	4%	-3.667	< 0.001
NTS vs. **soil-applied terbufos (organophosphate)**	21	2.9%	1.87	0.186	66%	1.304	0.192

Notes: Results highlighted in green suggest significantly higher corn yields with neonicotinoid-treated seeds than with the listed alternative. Results highlighted in red suggest significantly lower yield. Results in grey are not statistically significant. (1) Neonicotinoid-treated seeds; (2) Mean difference in yield within paired observations of plots planted with neonicotinoid-treated seeds and plots using the given alternative.

Overall, yield in plots using neonicotinoid-treated seeds was slightly but significantly lower (-2%) than in plots using soil-applied insecticides (all alternatives pooled). Plots with soil-applied tefluthrin (pyrethroid) or chlorpyrifos (organophosphate) had significantly higher yield than those with neonicotinoid treated seeds (with average difference in yield of 4% and 9%, respectively), while plots with soil-applied bifenthrin (pyrethroid) or terbufos (organophosphate) had no difference in average yield compared to those planted with neonicotinoid-treated seeds. Neonicotinoid-treated seeds led to significantly higher yield than other insecticide-treated seeds that were tested. Plots with neonicotinoid-treated seeds produced an average of 12% more grain, by weight, than plots using tefluthrin-treated seeds (statistically significant in ANOVA, but not in Wilcoxon signed-rank test at $\alpha = 0.05$). Plots using neonicotinoid-treated seeds also had significantly higher yield (5%) than those using the anthranilic diamide chlorantraniliprole. There was no significant difference in yield of neonicotinoid-treated seeds compared to cyantraniliprole-treated seeds, but the sample size was quite small (n=7). As above, significant differences in *average* yield were largely influenced by a small proportion of comparisons (Table 5.2, Figure 5.2).

Pairwise comparisons of neonicotinoid seed treatments with non-insecticidal controls in North America produced similar results as in the regional data set. North American data suggests an average yield benefit of 6% and 7% for neonicotinoid-treated seeds relative to untreated seeds and fungicide-only controls, respectively (Table 5.6). Prior to this report, the largest review of neonicotinoid seed treatment efficacy in North America, which drew on both the public literature and registrant studies, estimated an average yield benefit of 17% relative to untreated seeds or fungicide-only seed treatments [569]. However, state-specific findings suggested considerable variation, particularly when comparing results from northern and southern corn production regions. Mitchell [569] used studies from states in the eight USDA production regions east of the Rockies.[27] Of these, the reported yield benefit from neonicotinoid seed treatments in the northern states[28] was 12%. In the southern states[29], the average yield was 36% higher in neonicotinoid-treated plots. In state-by-state results, Mitchell and Nowak [571] found no significant difference in corn yield between neonicotinoid-treated and untreated plots in

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[27] Mitchell [569] does not include any U.S. observations in the Pacific or Mountain USDA production regions.

[28] Here, the Northern Plains, Lake States, Corn Belt, and Northeast production regions.

[29] Here, the Southern Plains, Delta, Southeast, and Appalachian production regions.

New York State.[30]

A second major meta-analysis, which focused on four mid-South states, also found statistically significant benefits of neonicotinoid seed treatments [625]. In 91 field trials by cooperators at four universities, the average yield for neonicotinoid-treated corn was 8% higher and expected 4% higher net returns than for fungicide-only controls. In state-by-state analysis, North et al. [625] reported a statistically significant yield benefit in two of four states (13.9% in Louisiana and 4.6% in Mississippi) and a net income benefit in one of four states (9.2% in Louisiana).

Table 5.7: **Grain yield in field corn plots treated with neonicotinoids and alternatives and managed for high pest pressure or not: North American data set**

	Managed to		ANOVA results			Signed-ranks test		
Treatment	induce/increase pest pressure[2]	Paired obs.	**Mean difference**	**F-value**	**P-value**	**% Pos.**	**Z-score**	**P-value**
NTS[1] vs. **untreated seeds**	**YES**	72	8.2%	9.43	0.003	66%	2.30	0.022
	NO	250	4.7%	30.56	< 0.001	69%	5.24	< 0.001
NTS vs. **fungicide-treated seeds**	**YES**	38	15.1%	37.13	< 0.001	96%	4.95	< 0.001
	NO	233	5.4%	17.58	< 0.001	63%	3.37	0.001
NTS vs. **insecticide-treated seeds**[1]	**YES**	27	13.8%	21.01	< 0.001	87%	3.35	0.001
	NO	50	7.4%	20.54	< 0.001	81%	3.87	< 0.001
NTS vs. **soil-applied insecticides**[2]	**YES**	60	4.3%	11.52	0.001	69%	2.59	0.010
	NO	278	-3.4%	22.98	< 0.001	36%	-4.10	< 0.001
NTS vs. **terbufos** (soil-applied)	**YES**	14	6.7%	7.16	0.019	85%	2.33	0.044
	NO	7	-3.9%	3.14	0.127	11%	-1.78	0.006
NTS vs. **chlorpyrifos** (soil-applied)	**YES**	6	-5.9%	7.07	0.045	0%	-2.20	0.028
	NO	15	-9.6%	20.6	0.001	5%	-3.07	0.002
NTS vs. **tefluthrin** (soil-applied)	**YES**	31	6.6%	13.56	0.001	78%	-1.88	0.006
	NO	109	-7.4%	16.86	< 0.001	29%	-3.81	< 0.001

Notes: Results highlighted in green suggest significantly *higher* corn yields with neonicotinoid-treated seeds than with the listed alternative. Results highlighted in red suggest significantly *lower* yield. Results in grey are not statistically significant. (1) neonicotinoid-treated seeds; (2) for this analysis, we consider field trials to be "managed for pest pressure" if researchers directly supplemented natural populations, attracted pests with bait or bait crops, intentionally selected a trial site at high risk of infestation, or took other actions with the express purpose of increasing pest pressure on the research plots.

Pest pressure in North American field trials varied, and key target pests for neonicotinoids were not present during every trial. In 234 of the 1,093 field trials, researchers selected or managed the study site to maximize the likelihood that test plots would experience high pest pressure. Attempts to induce pest pressure had little impact on the yield benefits from neonicotinoid seed treatments relative to untreated controls (see Table 5.7). However, similar to the regional data set, untreated and

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[30] As with this report, Mitchell and Nowak [571] faced data constraints. The three New York corn studies they used are also the basis for our state-specific analysis (though this report distinguishes between silage and grain yield, leading to slightly differing conclusions).

fungicide-only control groups fared relatively poorly in trials managed for high pest pressure. Yield in the neonicotinoid plots was an average of 8% and 15% higher than in untreated and fungicide-only plots, respectively, in trials managed for high pest pressure. In trials that did not manipulate pest pressure, neonicotinoid-treated seeds' yield benefit was 5% relative to both untreated and fungicide-only controls. Furthermore, in trials managed for high pest pressure, neonicotinoid-treated seeds were more effective than soil-applied tefluthrin. In 31 trials at test sites managed to increase pest pressure, yield following neonicotinoid-treated seeds was significantly higher (by an average of 7%) than yield following a tefluthrin application. In 109 trials that did not manipulate pest pressure, the reverse was true: yield in neonicotinoid-treated plots was significantly lower (by 7%, on average) than in tefluthrin-treated plots. The same relationship was visible in comparisons of neonicotinoid-treated seeds and soil-applied terbufos, an organophosphate. Neonicotinoids performed better in trials managed for high pest pressure (7% higher yield), but terbufos-treated plots performed as well or better than neonicotinoid-treated plots in other trials.[31] As noted throughout this section, each of these significant increases or decreases in *average* yield were largely influenced by a small proportion of comparisons; between 83-88% of field trials observed non-significant results within the state, region, or North America (Table 5.2, Figure 5.2).

5.2.2 Cost effectiveness relative to alternatives

In general, use of an agricultural pesticide is cost effective if the expected outcome of higher yields has value that exceeds the purchase and application costs for that product. In this report, we also consider relative cost effectiveness of neonicotinoid products compared to non-neonicotinoid alternatives. The treatment plan that maximizes net income for the farmer is not necessarily the plan that maximizes yield per acre. This section estimates the net income effects of discontinuing use or replacing neonicotinoid seed treatments in field corn using estimated yield effects from preceding efficacy analysis combined with data on typical yields, prices, and treatment costs.

To establish a baseline for per-hectare gross income, we use average yield and prices received by New York farmers in calendar years 2016-18 for corn grain and 2015-17 for corn silage, the most recent years for which USDA data are available [945]. Using average neonicotinoid seed prices provided by

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[31] The difference was not statistically significant in the ANOVA results, but was significant in a signed-rank test.

Bayer CropScience in North et al. [625],[32] we assume that neonicotinoid-treated seeds cost $16.80 more per hectare than a fungicide-only seed treatment and $49.77 more per hectare than untreated seeds. This assumes an average application rate of 0.25 mg a.i./seed, the rate used for control of seedcorn maggot and wireworm.[33] The cost of insecticide application at planting ($3.05 per hectare) is based on recent state extension surveys of farm custom work rates [677, 46, 204, 538], and represents the difference between custom planting prices with and without insecticide attachments. Insecticide product prices are drawn from a 2020 extension service price list Knodel et al. [455].[34] Publicly available data on the price of chlorantraniliprole applied to corn seed is limited, as this product is relatively new to the U.S. market and has a small market share. Therefore, the analysis uses the relative costs of other products containing chlorantraniliprole and clothianidin (the most common neonicotinoid applied to corn seed) to approximate those active ingredients' relative cost in a seed treatment. In foliar- and soil-applied products, chlorantraniliprole costs between 2.2 and 3.9 times (mean: 3.3) as much as clothianidin per fluid ounce of active ingredient. To be conservative, we assume that 0.25 mg of chlorantraniliprole applied to a corn seed will be 3.5 times the price of the same amount of clothianidin.

As discussed in Chapter 4, the most likely alternatives to neonicotinoid seed treatments in corn are soil-applied pyrethroids (tefluthrin), soil-applied organophosphates (chlorpyrifos or terbufos), and seed treatments based on an anthranilic diamide (chlorantraniliprole or cyantraniliprole). Growers could also choose not to use a preventive insecticide at planting. This analysis compares yield and estimated net returns for neonicotinoid-treated seeds relative to non-neonicotinoid seed treatments, soil-applied preventive insecticides, non-insecticidal ("fungicide-only") seed treatments, and untreated seeds in paired observations from studies conducted under varying conditions. As noted in Sections 5.1 and 2.2, this analysis does not include all possible alternatives to neonicotinoid seed treatments, nor does it reflect differences between management techniques used in different studies (including IPM practices). Using state, region, and North American-level data, we find that estimated net income

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[32] These prices are consistent with those cited in other studies, such as Mitchell [567] and Jordan et al. [441].

[33] This is a conservative estimate of application rate. No suitable grower survey data on application rates exist for New York or the region, though a 2007 New York study noted that Pioneer Hi-Bred had significant sales of clothianidin-treated seeds at both the 0.25mg/kernel and 1.25mg/kernel rates [168].

[34] To ensure that listed in Knodel et al. [455] were representative of the broader market, the authors checked those prices against older pesticide price guides from the University of Nebraska-Lincoln and (for non-restricted use pesticides) three online pesticide retailers.

effects of replacing neonicotinoids in corn vary depending on the particular set of replacements.

Table 5.8: **Net returns from neonicotinoid-treated seeds in field corn grown for silage, relative to alternatives, based on New York data**

Comparison	Paired obs.	Marginal costs/ha		Est. yield response	Net income effect (mean and range)	Effect as % of income/ha
		Product[1]	Application[2]			
NTS[3] vs. **fungicide-treated seeds**	10	$ 16.80		**3.8%** (± 0.8%)	**$ 61.42** $ 31.05 - $90.87	**3.0%** 1.5% to 4.4%

Notes: Results highlighted in green suggest significantly higher net returns with neonicotinoid-treated seeds than with the listed alternative. Results highlighted in red suggest significantly lower returns. Results in grey are not statistically significant. (1) Approximate cost of purchasing neonicotinoid-treated seeds relative to the given alternative. We use neonicotinoid-treated seed prices provided by Bayer CropScience in North et al. [625]. Other 2020 product prices from Knodel et al. [455], adjusted for application rate. Prices assume that the grower will use fungicide-treated seeds with a soil-applied insecticide. (2) The difference in custom rates between planting with and without attachments to apply insecticide, taken from from an average of recent state extension surveys of farm custom work rates [677, 46, 204, 538]. (3) Neonicotinoid-treated seeds.

For farmers focusing on silage production (40% of New York corn acres), the New York data set (*n* = 10 comparisons) indicates that neonicotinoid-treated seeds[35] were more cost-effective than using fungicide-only seeds, resulting in a mean net income benefit of $61.42 per hectare (3% increase in income per hectare) relative to using fungicide-only seeds (see Table 5.8). Similar to the yield results in Section 5.2.1, it is important to note that, when significant here and below, differences in *mean* net income were largely influenced by a small proportion of comparisons. This is because the yield data summarized in Section 5.2.1 are used in the calculation of net income effects and a small proportion of those trials observed significant differences in yield (see Table 5.2 and Figure 5.2). In other words, the data indicate that when there are overall economic benefits of using neonicotinoid-treated seeds, a small proportion of farmers will experience significant economic benefits, while the majority of farmers will not. Unfortunately, because variance was rarely noted in the underlying yield studies, it is not possible to estimate the exact proportion of farmers that are likely to experience significant net income benefits of using neonicotinoid-treated seeds, though the number is probably similar to the proportion of trials experiencing significant yield benefits.

For farmers focusing on grain production (60% of New York corn acres), the regional data set must be used for comparisons since few studies concentrating on grain have been conducted in New

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[35] Unless otherwise noted, insecticide-treated seeds referenced in this report were also treated with one or more fungicides. Some seed treatments included other products to protect against non-insect pests or provide other benefits to germinating seeds.

York. Using the regional data set (New York, Ohio, Ontario, and Quebec), we find no significant difference in mean net income between neonicotinoid-treated seeds and untreated seeds or between neonicotinoid-treated seeds and soil-applied tefluthrin (Table 5.9). However, there was a significant difference in mean net income between plots using neonicotinoid-treated seeds and fungicide-only controls (plots using seeds treated with a fungicide but no insecticide): estimated net returns were an an average of $45.13 per hectare (3%) higher in the neonicotinoid plots.

Table 5.9: **Net returns from neonicotinoid-treated seeds in field corn (grain), relative to alternatives, based on New York, Ohio, Ontario, and Quebec data**

Comparison	Paired obs.	Marginal costs/ha		Est. yield response	Net income effect (mean and range)	Effect as % of income/ha
		Product[1]	**Application[2]**			
NTS vs. **untreated seeds**	132	$ 49.77		5.2% (± 1.1%)	**$ 29.68** $ (1.25) - $ 59.39	**1.9%** -0.1% to 3.7%
NTS vs. **fungicide-treated seeds**	224	$ 16.80		4.0% (± 0.5%)	**$ 45.13** $ 31.58 - $58.44	**2.8%** 2.0% to 3.7%
NTS vs. **soil applied tefluthrin[3]**	91	$ (70.14)	$ (3.05)	-5.7% (± 1.7%)	**$ (23.38)** $ (84.01) - $33.20	**-1.5%** -5.3% to 2.1%

Notes: Results highlighted in green suggest significantly higher net returns with neonicotinoid-treated seeds than with the listed alternative. Results in grey are not statistically significant. (1) Approximate cost of purchasing neonicotinoid-treated seeds relative to the given alternative. We use neonicotinoid-treated seed prices provided by Bayer CropScience in North et al. [625]; (2) The difference in custom rates between planting with and without attachments to apply insecticide, taken from from an average of recent state extension surveys of farm custom work rates [677, 46, 204, 538]; (3) 2020 product prices from Knodel et al. [455], adjusted for application rate. Prices assume that the grower will use fungicide-treated seeds with a soil-applied insecticide.

Finally, the North American data set must be used for comparisons with neonicotinoid alternatives that are not represented adequately in the regional data set, specifically seed treatments using anthranilic diamides (chlorantraniliprole and cyantraniliprole) and soil-applied chlorpyrifos. Using the North American data set, we find a mean net income benefit of $123.70 per hectare (8% increase in income per hectare) of using neonicotinoid-treated seeds relative to chlorantraniliprole-treated seeds, a mean net income benefit of $70.99 per hectare (4% increase in income per hectare) of using neonicotinoid-treated seeds relative to cyantraniliprole-treated seeds, no significant difference in mean net income between neonicotinoid-treated seeds and soil-applied tefluthrin (similar to the regional data set), and a mean net income *cost* of $119.63 per hectare (8% decrease in income per hectare) of using neonicotinoid-treated seeds relative to soil-applied chlorpyrifos.

Table 5.10: **Net returns from neonicotinoid-treated seeds in field corn (grain), relative to alternatives, based on North American data**

Comparison	Paired obs.	Marginal costs/ha		Est. yield response	Net income effect (mean and range)	Effect as % of income/ha
		Product[1]	Application[2]			
NTS[3] vs. **chlorantraniliprole-treated seeds**	26	$ (42.00)		**5.4%** (± 1.0%)	**$ 123.70** $ 94.53 to $151.78	**7.7%** 5.9 % to 9.5%
NTS vs. **cyantraniliprole-treated seeds**	7	$ (42.00)		**1.8%** (± 1.8%)	**$ 70.99** $15.94 to $122.43	**4.4%** 1.0% to 7.7%
NTS vs. **soil-applied tefluthrin**	140	$ (70.14)	$ (3.05)	**-4.1%** (± 1.1%)	**$ 4.89** $ (31.83) to $40.06	**0.3%** -2.0% to 2.5%
NTS vs. **soil-applied chlorpyrifos**	21	$ (29.95)	$ (3.05)	**-8.7%** (± 1.2%)	**$ (119.63)** $ (167.32) to ($74.40)	**-7.5%** -10.5% to -4.7%

Notes: Results highlighted in green suggest significantly higher net returns with neonicotinoid-treated seeds than with the listed alternative. Results highlighted in red suggest significantly lower returns. Results in grey are not statistically significant. (1) Approximate cost of purchasing neonicotinoid-treated seeds relative to the given alternative. We use neonicotinoid-treated seed prices provided by Bayer CropScience in North et al. [625]. Other 2020 product prices from Knodel et al. [455], adjusted for application rate. Prices assume that the grower will use fungicide-treated seeds with a soil-applied insecticide. (2) The difference in custom rates between planting with and without attachments to apply insecticide, taken from from an average of recent state extension surveys of farm custom work rates [677, 46, 204, 538]. (3) Neonicotinoid-treated seeds.

5.3 Soybean

This report draws on 176 studies of neonicotinoid efficacy in soybean, allowing 1,602 unique pairwise comparisons of mean yields from trials involving a neonicotinoid and either an alternative insecticide treatment or untreated control. Three of these studies (13 pairwise comparisons) took place in New York State itself [170, 165, 167]. Another 41 (384 pairwise comparisons) were conducted in nearby states or provinces.[36] Neonicotinoid-treated seeds are common in conventional New York soybean. Growers often decide which, if any, seed treatments they will use well before planting; they are preventive products. As in field corn, neonicotinoids are typically one component of a seed coating containing one or more fungicides and, often, other crop protection products.

Most of the analyses in this section compare average soybean yield following the use of neonicotinoid-treated seeds with yield in plots treated with other insecticides or that were not treated at all (the mean yield response). We distinguish between studies that pair neonicotinoid-treated seeds with an "untreated control" and those that pair neonicotinoid-treated seeds with a group that received non-insecticidal treatment(s): a "fungicide-only" control. Results highlighted in green suggest a positive, statistically significant mean yield response from neonicotinoid-treated seed use relative to the the given alternative. Results highlighted in red suggest a negative yield response (yield was significantly higher in the

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[36] Ontario (172 pairs), Pennsylvania (5 pairs), Ohio (206 pairs), or Quebec (1 pair).

comparison or control group). Gray highlighting indicates a result that is not statistically significant (at α=.05).

Table 5.11: **Relative insecticide costs used in soybean financial analysis**

Product purchase price of comparisons used in analysis, relative to neonicotinoid-treated seeds					
Comparison	**Product**	**Cost**	**Per Acre**	**Per hectare**	**Source**
No treatment[1]			-$20.70	-$51.12	Cox and Cherney [167]
Non-insecticidal (“fungicide-only”) seed treatment			-$ 5.10	-$12.59	Cox and Cherney [167]
Soil-applied anthranilic diamides	Prevathon *14 oz/A*	$1.14/oz	$ 10.86	$ 26.83	Knodel et al. [455]
Foliar lambda-cyhalothrin	Warrior II *(1.92 fl oz/A)*	$2.65/oz	-$0.01	-$0.02	Knodel et al. [455]
Foliar chlorpyrifos	Lorsban 4E *(16 oz/A)*	$0.43/oz	$ 1.78	$ 4.40	Knodel et al. [455]
Other costs associated with soil-applied and foliar alternatives					
Scouting for insect pests			$ 4.93	$ 12.17	Average values in state extension farm custom rate lists[4]
Foliar insecticide application			$ 8.57	$ 21.16	
Insecticide application at planting[3]			$ 1.24	$ 3.05	

Notes: (1) *Un*-adjusted for inflation, farm-level data suggests participating farmers paid an average of $18.32 per acre more for seeds treated with a neonicotinoid (and other crop protectants) than untreated seeds; (2) *Un*-adjusted for inflation, farm-level data suggests participating farmers paid an average of $4.51 more for for seeds treated with a neonicotinoid (and other crop protectants) than treated seeds that omitted the insecticide; (3) The difference in custom rates between planting with and without attachments to apply insecticide. As described in Section 4.1, soil-applied formulations of several pyrethroids (bifenthrin, permethrin), organophosphates (phorate), and anthranilic diamides (chlorantraniliprole, cyantraniliprole) are effective against certain early-season soybean pests; (4) Scouting and insecticide application costs taken from from an average of recent state extension surveys of farm custom work rates [148, 677, 1036, 46, 204, 484, 690, 538].

We also estimate net income effects for growers using neonicotinoid-treated seeds in soybean, relative to alternatives. The methodology is identical to that used in the field corn section. Estimated scouting and application costs for soil-applied and foliar insecticides are based on mean values from recent state extension surveys of farm custom work rates [148, 677, 1036, 46, 204, 484, 690, 538]. We draw upon Cox and Cherney [167] for the cost of neonicotinoid-treated seeds relative to fungicide-treated and untreated seeds, based on partial costs and returns analysis of four New York farms.[37]

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[37] We do not vary the seeding rate in this analysis because, as noted above, the estimated yield response is based on paired observations of research plots. Seeding rate does not vary within pairs, so the within-pair difference in yield only reflects yield response *at that seeding rate* rather than at the optimal seeding rate for each treatment. In this context, calculating product costs based on the optimal seeding rate would be misleading.

Table 5.12: **Mean soybean yield responses producing net income parity between neonicotinoid-treated seeds and non-neonicotinoid alternatives, given relative product and application costs**

To achieve the same net income per acre, yield in soybean plots using neonicotinoid-treated seeds would need to be approximately:		
105%	of yield in a plot using	**untreated seeds**;
101%	of yield in a plot using	**fungicide-treated seeds**;
98%	of yield in a plot using	**soil-applied anthranilic diamides**;
97%	of yield in a plot using a	**foliar lambda-cyhalothrin (pyrethroid) product;** or,
96%	of yield in a plot using a	**foliar chlorpyrifos (organophosphate) product.**

Notes: This table is based on the relative purchase price and application costs of different products. It does not reflect their relative efficacy or costs arising from indirect effects of insecticide choice on farm operations or planning.

Field trials in our data sets varied in their pest pressure. Some studies reported high pest pressure (due to field conditions or intervention by researchers); in other cases, few if any target pests were present. Due to the nature of neonicotinoid-treated seeds, this variation is helpful to our analyses. As in field corn, soybean seed treatments are preventive products; farmers must decide which seed treatment(s) to order well in advance of planting with limited information about conditions in the upcoming season. Soybean grower surveys and industry listening sessions suggest that growers often use seed treatments to prevent infestation by a range of pests that could occur in any given year, not to target a specific pest [591, 567, 832]. This does not mean that preventive neonicotinoid use in soybean is unjustified or excessive, but it does suggest that the use of neonicotinoid-treated seeds is not limited to sites facing atypical risk of insect damage. In this context, it is important to consider how neonicotinoid-treated seeds affect yield under all possible pest pressures and environmental conditions, so an evaluation of all available field trials is crucial. This study does report relative soybean yield response under elevated insect stress (see Tables 5.16 and 5.18), but as with field corn, most of our analyses assume that soybean growers using neonicotinoid-treated seeds face pest pressures typical for their region, with all of the variability and unpredictability that is inherent.[38]

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[38] As noted elsewhere in this report, neonicotinoid seed treatments are valuable to users in large part because they decrease risk when growers cannot confidently predict the abundance of early-season pests. We do not attempt to quantify this insurance value. Furthermore, current pest pressures are not necessarily predictive of pressure in the absence of widespread use of neonicotinoid-treated seeds. As discussed in *Chapter 7*, new data on these topics could allow meaningful quantification of these benefits to growers.

5.3.1 Yield effects

Proportion of studies observing yield increases via neonicotinoid insecticide usage

Overall, the evidence at the state, regional, and North American levels shows that neonicotinoid-treated seeds and foliar sprays do not consistently increase soybean yield compared to untreated controls, fungicide-only controls, or other insecticide treatments (Table 5.13, Figures 5.3, 5.4). For studies conducted in New York, 4 of 11 (36%) comparisons observed a significant increase in yield when comparing neonicotinoid-treated seeds to untreated or fungicide-only controls, while 64% of studies found no significant difference in yield. No published studies from New York to date have assessed the efficacy of foliar neonicotinoid insecticides compared to alternatives or untreated controls.

Results from the larger regional data set (New York, Pennsylvania, Ontario, Ohio, and Quebec) were similar but expanded upon the limited New York State data; 47 of 305 regional comparisons (15%) observed a significant increase in yield when comparing neonicotinoid-treated seeds to untreated or fungicide-only controls, while 256 of 305 comparisons (84%) observed no differences in yield. In this data set, 2 of 305 comparisons (1%) observed significant decreases in yield when comparing neonicotinoid-treated seeds to untreated or fungicide-only controls. Two of 32 comparisons (6%) of neonicotinoid-treated seeds to alternative seed treatments observed increases in yield, 4 of 32 comparisons (13%) observed decreases in yield, and 26 of 32 (81%) observed no differences in yield. All 5 comparisons (100%) between foliar neonicotinoids and untreated controls and all 15 comparisons (100%) between foliar neonicotinoids and alternative foliar insecticides failed to document a significant difference in yield.

Results from the North American data set (New York, Pennsylvania, Ontario, Ohio, Quebec, and 13 additional states; see Table A.1) were similar to the state and regional data sets; 83 of 563 comparisons (14%) observed a significant increase in yield when comparing neonicotinoid-treated seeds to untreated or fungicide-only controls, while 485 of 563 comparisons (85%) observed no differences in yield. In this data set, 5 of 563 comparisons (1%) observed significant decreases in yield when comparing neonicotinoid-treated seeds to untreated or fungicide-only controls. Eleven of 85 comparisons (13%) between foliar neonicotinoids to untreated or fungicide-only controls observed increases in yield, while 74 of 85 comparisons (86%) found no significant difference in yield. Finally, of 338 comparisons

Table 5.13: **Statistical significance of all soybean yield trials comparing performance of neonicotinoid-treated seeds or foliar neonicotinoids to specified non-neonicotinoid treatments or untreated controls, summarized at the state, regional, and North American scales**

	New York State			NYS & region			North America		
Comparison	Y+	Y-	N	Y+	Y-	N	Y+	Y-	N
NTS[1] vs. untreated control	3	0	4	36	1	130	63	4	280
NTS vs. fungicide-only control	1	0	3	11	1	126	20	1	205
NTS vs. other seed treatment				2	4	26	2	4	26
NTS vs. foliar insecticides	0	0	2	1	0	4	13	19	246
Foliar neonic. vs. untreated control				0	0	5	6	0	35
Foliar neonic. vs. fung.-only control							4	0	11
Foliar neonic. vs. other foliar				0	0	15	10	48	280

Notes: (1) Neonicotinoid-treated seeds.

Number of field trials reporting significantly higher yield (Y+, green), lower yield (Y-, red), or no significant difference in yield (N, gray) in plots using neonicotinoid treated seed (NTS) compared to plots using the specified non-neonicotinoid treatment or untreated control. "NYS & region" includes studies from New York, Ohio, Ontario, Pennsylvania, and Quebec. States and provinces included in the North American data set are listed in Table A.1. Note that some field trials did not report statistical significance; those trials are not included in this table, but mean yield reported in those trials could still be used for subsequent analyses.

between foliar neonicotinoids and alternative insecticides, 10 comparisons (3%) observed increases in yield, 48 (14%) observed decreases, and 280 (83%) found no significant differences.

New York State studies

Three peer-reviewed studies have reported the effects of neonicotinoid seed treatments on soybean yield in New York State, relative to a foliar insecticide treatment (2 paired observations), fungicide-only seed treatments (4 pairs),[39] or untreated seeds (7 pairs)[40] [171, 166, 167]. Table 5.14 aggregates data from these studies. Taken together, the limited data (n = 7 paired observations) suggest a significant yield benefit associated with neonicotinoid-treated seeds relative to untreated control plots. There was no significant difference in yields between plots with neonicotinoid-treated seeds compared to plots with fungicide-treated seeds.

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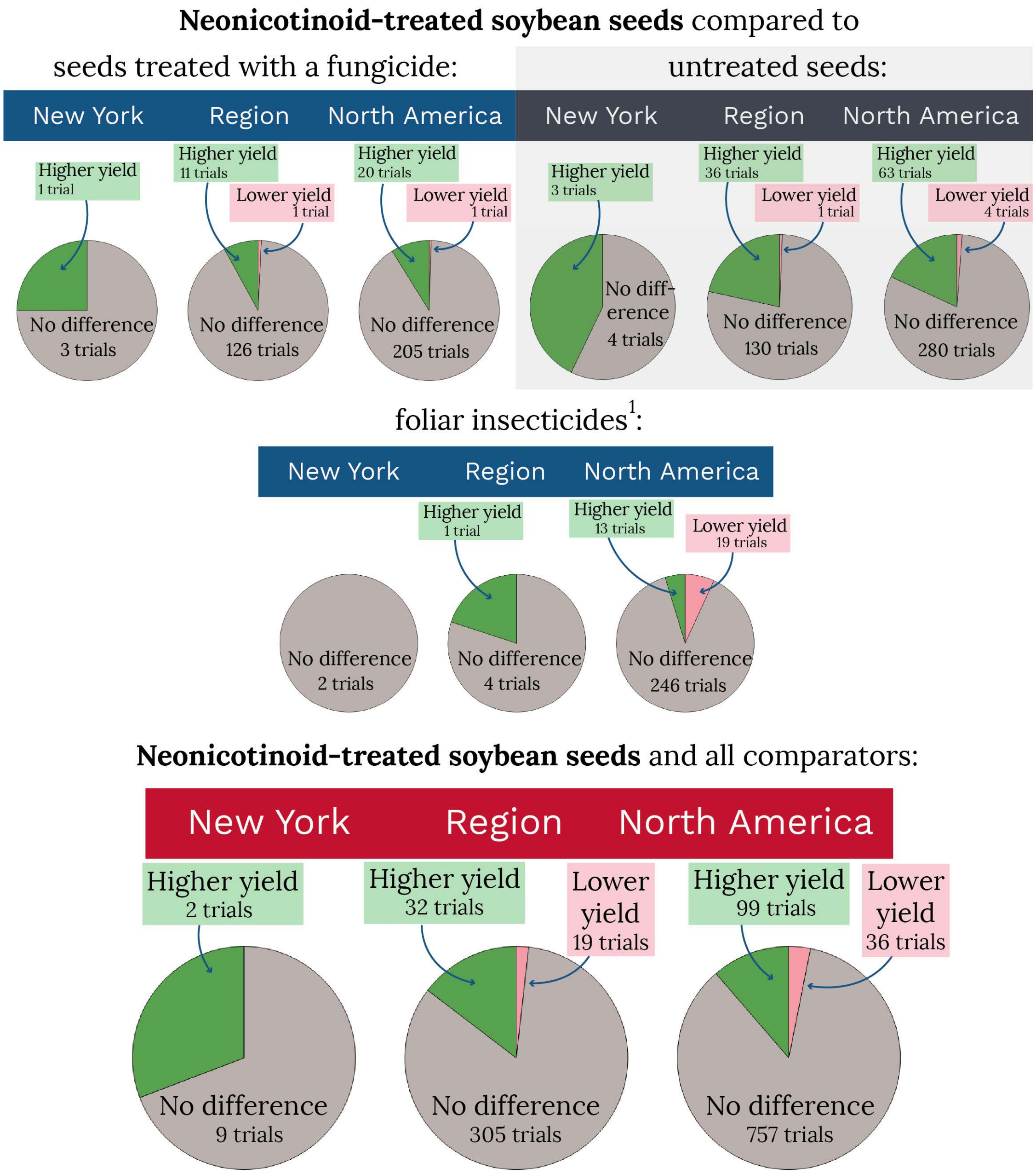
[39] These seed coatings included other non-insecticidal components in addition to fungicides, but we use the term “fungicide-only” for consistency.

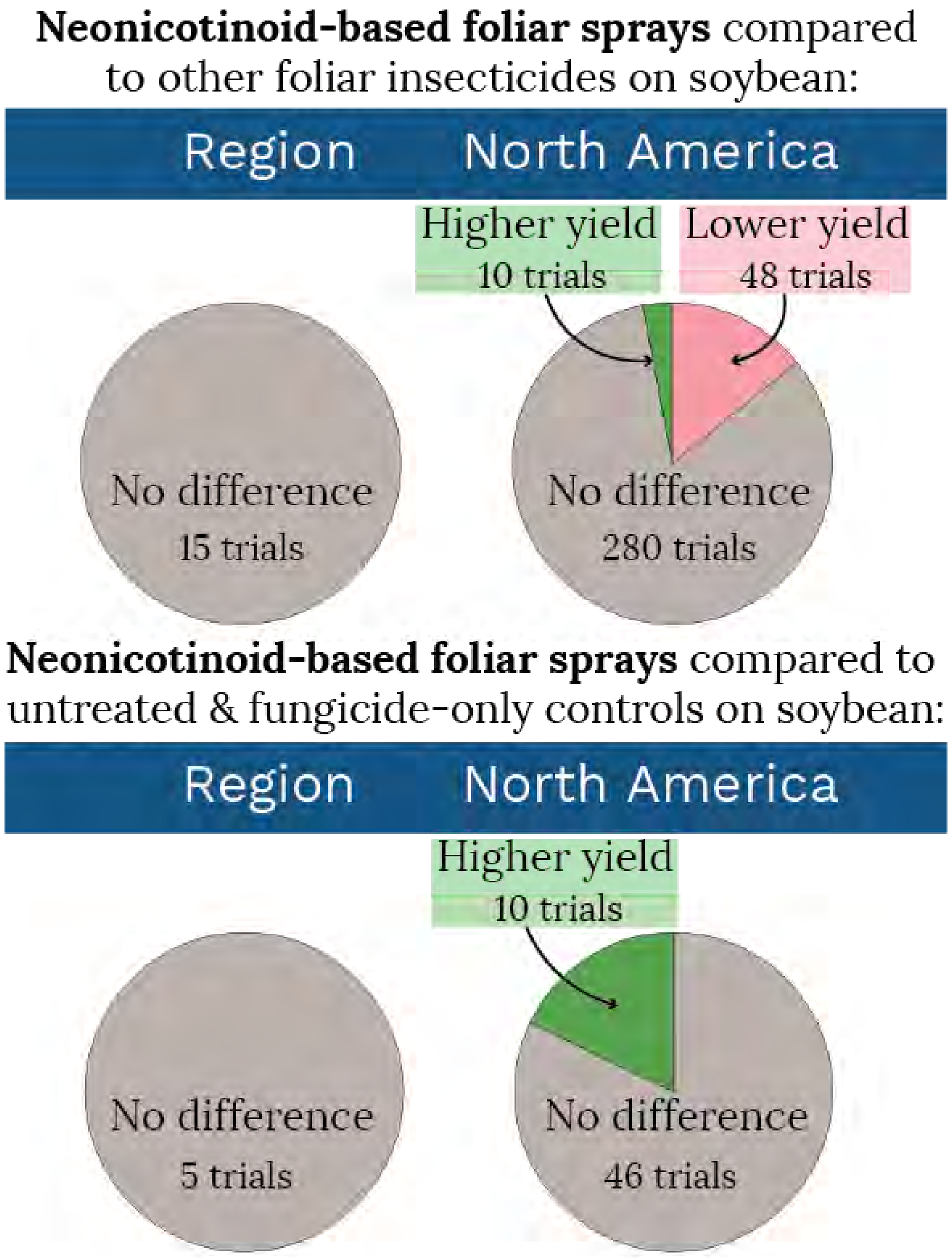
[40] Several of these results reflect average yield over several study sites and two study years. The paired observations, taken together, represent 38 location-year combinations.

Figure 5.3: **Number of soybean field trials reporting significantly higher (green), significantly lower (red), or no difference (gray) in yields in plots using neonicotinoid-treated seeds compared to plots using a non-neonicotinoid treatment or untreated control**



Notes: Regional results used data from field trials in New York, Ohio, Ontario, and Pennsylvania. North American results used data from New York, Ohio, Ontario, Pennsylvania, and 19 other states and provinces (see Table A.1). Note that some field trials did not report statistical significance; those trials are not included in this table, but mean yield reported in those trials could still be used for subsequent analyses. (1) A pyrethroid (lambda-cyhalothrin) was the only foliar alternative used in New York and Regional trials. Trials in the North American data set used foliar sprays based on pyrethroids (beta-cyfluthrin, bifenthrin, cyfluthrin, deltamethrin, esfenvalerate, gamma-cyhalothrin, lambda-cyhalothrin, zeta-cypermethrin), organophosphates (acephate, chloryprifos, dimethoate), carbamates (carbaryl), tetronic acids (spirotetramat), butenolides (flupyradifurone), flonicamid (flonicamid), avermectins (abamectin), pyridine azomethine derivatives (pymetrozine, pyrifluquinazon), sulfoximines (sulfoxaflor), and pyropenes (afidopyropen).

Figure 5.4: **Number of soybean field trials reporting significantly higher (green), significantly lower (red), or no difference (gray) in yields in plots using neonicotinoid-based foliar sprays compared to plots using a non-neonicotinoid spray or untreated control**



Notes: Regional results used data from field trials in Ontario. Note that some field trials did not report statistical significance; those trials are not included in this table, but mean yield reported in those trials could still be used for subsequent analyses. (1) Foliar alternatives used in regional field trials were based on pyrethroids (esfenvalterate and lambda-cyhalothrin) and organophosphates (dimethoate). Alternatives used in North American (Ontario and 5 states) field trials included pyrethroids (beta-cyfluthrin, bifenthrin, cyfluthrin, deltamethrin, esfenvalerate, gamma-cyhalothrin, lambda-cyhalothrin, zeta-cypermethrin), organophosphates (acephate, chloryprifos, dimethoate), carbamates (carbaryl, methomyl), a tetronic acid (spirotetramat), a butenolide (flupyradifurone), flonicamid (flonicamid), an avermectin (abamectin), a pyridine azomethine derivative (pymetrozine, pyrifluquinazon), a sulfoximine (sulfoxaflor), and a pyropene (afidopyropen).

Table 5.14: **Soybean yield in New York field trials comparing neonicotinoid-treated seeds to fungicide-only or untreated controls**

		ANOVA results			Signed-ranks test		
Comparison	Paired obs.	**Mean diff.**[2]	**F-value**	**P-value**	**% Pos.**	**Z-score**	**P-value**
NTS[1] vs. **untreated seeds**	7	2.6%	99.9	< 0.001	93%	2.032	0.042
NTS vs. **fungicide-treated seeds**	4	2.0%	0.68	0.471	60%	0.365	0.715

Notes: Results highlighted in green suggest significantly *higher* soybean yields with neonicotinoid-treated seeds than with the listed alternative. Results in grey are not statistically significant. (1) Neonicotinoid-treated seeds; (2) Mean difference in yield within paired observations of plots planted with neonicotinoid-treated seeds and plots using the given alternative.

Regional studies

Due to the small number of field trials in New York, it is useful to consider these results in conjunction with the results of paired field trials from nearby states: Pennsylvania, Ontario, Ohio, and Quebec.[41] At the regional level, we found yield benefits of neonicotinoid-treated seeds relative to fungicide-only seed treatments and untreated seeds: yields were an average of 7% and 5% higher, respectively (Table 5.15). In 20 pairwise comparisons, the yields from plots planted with neonicotinoid-treated seeds were not significantly different than in those relying on pyrethroid-based foliar sprays. Similar to the field corn analyses, we note this significant increase in *average* yield was driven by a small proportion of comparisons. As shown in Table 5.13, 47 of 305 comparisons (15%) found a significant increase in yield when comparing neonicotinoid-treated seeds to fungicide-only or untreated controls, while the other 258 (85%) comparisons found no differences in yield.[42]

The regional data also allow us to compare trials that managed for or induced high pest pressure and those that did not. Forty of 138 comparisons with a fungicide-only control (29%) and 12 of 173 pairs with an untreated control (7%) took place at sites selected or managed for high pest pressure (see Table 5.16). Notably, neonicotinoid seed treatments performed well in trials managed to induce pest pressure,[43] with yields 35% higher than in untreated controls and 44% higher than in fungicide-only

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[41] We did not identify suitable soybean field trials in Connecticut, Massachusetts, New Hampshire, New Jersey, Rhode Island, or Vermont.

[42] The number of observations used in ANOVA and signed-ranks analysis differs from that in counts of statistical significance, as some studies did not report both yield and statistical significance.

[43] This includes studies in which researchers directly supplemented pest populations, baited plots to attract pests, selected locations with pre-existing infestations or risk factors, or took other actions explicitly intended to increase pressure from target pests.

Table 5.15: **Soybean yield in regional (New York, Ohio, Ontario, Pennsylvania, and Quebec) field trials comparing neonicotinoid-treated seeds to fungicide-only controls, untreated controls, or a foliar pyrethroid**

		ANOVA results			Signed-ranks test		
Comparison	obs.	**diff.**[2]	**F-value**	**P-value**	**% Pos.**	**Z-score**	**P-value**
NTS[1] vs. **untreated seeds**	167	4.5%	78.42	< 0.001	79%	6.62	< 0.001
NTS vs. **fungicide-treated seeds**	138	6.8%	37.34	< 0.001	81%	6.345	< 0.001
NTS vs. **foliar lambda-cyhalothrin**	20	-0.1%	0.01	0.924	38%	-0.97	0.331

Notes: Results highlighted in green suggest significantly *higher* soybean yields with neonicotinoid-treated seeds than with the listed alternative. Results in grey are not statistically significant. (1) Neonicotinoid-treated seeds; (2) Mean difference in yield within paired observations of plots planted with neonicotinoid-treated seeds and plots using the given alternative.

controls. This result certainly suggests that neonicotinoid seed treatments have significant benefits in the presence of target pests. Conversely, trials under field conditions (presumably with more variable and typical pest pressures) observed a smaller yield benefit from neonicotinoid seed treatments: 4% compared to untreated controls and 3% compared to fungicide-only seed treatments.

Table 5.16: **Soybean yield in regional field trials (New York, Ohio, Ontario, Pennsylvania, and Quebec) comparing neonicotinoid-treated seeds to fungicide-only and untreated controls in plots managed to increase pest pressure or not**

			ANOVA results			Signed-ranks test		
Treatment	Managed to induce/increase pest pressure[2]	Paired obs.	**Mean difference**	**F-value**	**P-value**	**% Pos.**	**Z-score**	**P-value**
NTS[1] vs. **untreated seeds**	**YES**	12	34.9%	2.99	0.003	99%	2.84	0.005
	NO	161	3.5%	71.00	< 0.001	76%	5.84	< 0.001
NTS vs. **fungicide-treated seeds**	**YES**	40	43.7%	18.57	0.001	92%	4.58	< 0.001
	NO	98	3.0%	25.41	< 0.001	75%	4.31	< 0.001

Notes: Results highlighted in green (including all results in this table) suggest significantly *higher* soybean yields with neonicotinoid-treated seeds than with the listed alternative. (1) neonicotinoid-treated seeds; (2) for this analysis, we consider field trials to be "managed for pest pressure" if researchers directly supplemented natural populations, attracted pests with bait or bait crops, intentionally selected a trial site at high risk of infestation, or took other actions with the express purpose of increasing pest pressure on the research plots.

North American studies

Regional data include a large number of trials comparing yields in plots using neonicotinoid-treated seeds and plots using no insecticides. However, the regional data set includes only a few pairwise comparisons with other insecticides. To compare neonicotinoids to specific classes of alternatives, we need a larger data set. The North American data set includes pairwise comparisons of neonicotinoid seed treatments and foliar sprays based on products from 10 IRAC insecticide groups (including components of pre-mixed products), and also comparisons of neonicotinoid foliar sprays and alternative foliar sprays.

Table 5.17: **Soybean yield in North American field trials comparing neonicotinoid-treated seeds to untreated controls, fungicide-only controls, and alternative soil-applied or foliar insecticide alternatives**

		ANOVA results			Signed-ranks test		
Comparison	Paired obs.	**Mean diff.**[2]	**F-value**	**P-value**	**% Pos.**	**Z-score**	**P-value**
NTS[1] vs. **untreated seeds**	346	3.3%	205.45	< 0.001	76%	8.298	< 0.001
NTS vs. **fungicide-treated seeds**	228	3.1%	77.43	< 0.001	77%	7.077	< 0.001
NTS vs. **foliar insecticides**	270	0.5%	1.78	0.183	51%	0.396	0.692
Alternatives by insecticide group							
NTS vs. **soil-applied anthranilic diamides**	4	11.4%	20.01	0.021	100%	1.826	0.068
NTS vs. **foliar organophosphates**	49	2.6%	11.39	0.002	73%	2.800	0.005
NTS vs. **foliar pyrethroids**	148	-0.4%	0.96	0.328	42%	-1.740	0.082
Alternatives by active ingredient							
NTS vs. **foliar chlorpyrifos**	27	2.9%	6.36	0.018	72%	2.042	0.041
NTS vs. **foliar lambda-cyhalothrin**	82	-0.2%	0.13	0.716	45%	-0.821	0.412
NTS vs. **foliar zeta-cypermethrin**	19	-3.0%	6.47	0.020	18%	-2.435	0.015
NTS vs. **foliar beta-cyfluthrin**	12	-1.2%	0.91	0.361	31%	-1.177	0.239
NTS vs. **foliar bifenthrin**	10	1.4%	2.09	0.183	71%	1.172	0.241
NTS vs. **foliar pymetrozine & pyrifluquinazon**	12	-1.2%	0.89	0.389	33%	-0.734	0.463
NTS vs. **foliar sulfoxaflor**	12	-1.5%	2.35	0.153	27%	-1.412	0.158

Notes: Results highlighted in green suggest significantly *higher* soybean yields with neonicotinoid-treated seeds than with the listed alternative. Results highlighted in red suggest significantly *lower* soybean yields with neonicotinoid-treated seeds. Results in grey are not statistically significant. (1) Neonicotinoid-treated seeds; (2) Mean difference in yield within paired observations of plots planted with neonicotinoid-treated seeds and plots using the given alternative.

Broadly speaking, soybean plots using neonicotinoid-treated seeds had comparable yield with plots using foliar sprays (see Table 5.17), with the exception of the organophosphate chlorpyrifos and the pyrethroid zeta-cypermethrin. Yield in neonicotinoid-treated seed plots was 3% higher than in plots sprayed with foliar chlorpyrifos, while yield was 3% lower than yield in plots treated with foliar zeta-cypermethrin.

Similar to the regional data, higher yields were observed with neonicotinoid-treated seeds than

Table 5.18: **Soybean yield in North American field trials comparing neonicotinoid-treated seeds and alternatives in plots managed to induce pest pressure or not**

			ANOVA results			Signed-ranks test		
Treatment	Managed to induce/increase pest pressure[2]	Paired obs.	**Mean difference**	**F-value**	**P-value**	**% Pos.**	**Z-score**	**P-value**
NTS vs. **untreated seeds**	**YES**	16	17.2%	17.96	< 0.001	98%	3.18	0.002
	NO	330	3.0%	199.08	< 0.001	74%	7.62	< 0.001
NTS vs. **fungicide-treated seeds**	**YES**	40	43.7%	18.57	< 0.001	92%	4.65	< 0.001
	NO	188	1.9%	74.22	< 0.001	73%	5.41	< 0.001

Notes: Results highlighted in green (including all results in this table) suggest significantly *higher* soybean yields with neonicotinoid-treated seeds than with the listed alternative. (1) neonicotinoid-treated seeds; (2) for this analysis, we consider field trials to be "managed for pest pressure" if researchers directly supplemented natural populations, attracted pests with bait or bait crops, intentionally selected a trial site at high risk of infestation, or took other actions with the express purpose of increasing pest pressure on the research plots.

fungicide-only or untreated seeds: 3% higher than either untreated seeds or fungicide-treated seeds across all studies, and similar to the regional results, greater yield differences in plots with augmented pest pressure compared to plots that were not artificially managed to increase pest pressure (Table 5.18). Again, we note that these significant increases in *average* yield were due to the influence of a small proportion of comparisons. As shown in Table 5.13, 76 of 597 comparisons (13%) observed a significant increase in yield when comparing neonicotinoid-treated seeds to untreated or fungicide-only controls, while 521 of 597 comparisons (87%) observed no differences or significant reductions in yield.

These results are similar to those found in previous studies. An industry-supported review of neonicotinoid seed treatment efficacy in 2014 found an average yield benefit of 3.6% in North America and 3.2% in New York State [569]. A second major meta-analysis, which focused on four mid-South states, also found statistically significant benefits of neonicotinoid seed treatments [624]. Based on 170 field trials in Arkansas, Louisiana, Mississippi, and Tennessee, the authors estimated an average yield benefit of 4.5% and an average increase in net economic returns of 2.8% relative to fungicide-only controls. The yield effect was significant in all four states, and a significant effect on economic returns was observed in two of the four states.

For studies that compared foliar neonicotinoids to non-neonicotinoid alternatives or untreated controls (see Table 5.19), we separated neonicotinoid-based foliar sprays based on the cyanoamidine acetamiprid and those based on nitroguanidine neonicotinoids: clothianidin, imidacloprid, and thi-

Table 5.19: **Soybean yield in North American field trials comparing neonicotinoid-based foliar sprays to untreated controls or alternative foliar sprays**

		ANOVA results			Signed-ranks test		
Comparison	Paired obs.	**Mean diff.**[1]	**F-value**	**P-value**	**% Pos.**	**Z-score**	**P-value**
***Acetamiprid** foliar sprays and alternatives*							
Foliar acetamiprid vs. **untreated controls**	4	18.6%	13.97	0.014	100%	1.826	0.068
Foliar acetamiprid vs. **foliar organophosphates**	4	10.7%	4.71	0.082	100%	1.826	0.068
Foliar acetamiprid vs. **foliar pyrethroids**	10	8.2%	9.72	0.008	93%	2.395	0.017
***Nitroguanidine neonicotinoid** foliar sprays (clothianidin, dinotefuran, imidacloprid, and thiamethoxam) and alternatives*							
Foliar nitroguanidines vs. **untreated controls**	53	0.2%	0.02	0.891	58%	1.018	0.309
Foliar nitroguanidines vs. **all foliar alternatives**	457	-1.3%	18.03	< 0.001	40%	-3.855	< 0.001
Foliar nitroguanidines vs. **foliar pyrethroids**	248	-1.3%	10.78	0.001	38%	-3.211	0.001
Foliar nitroguanidines vs. **foliar organophosphates**	99	-3.6%	21.89	< 0.001	28%	-3.826	< 0.001
Foliar nitroguanidines vs. **IRAC group 9 alternatives**[2]	10	-1.1%	3.04	0.115	18%	-1.784	0.075
***Imidacloprid-based** foliar sprays and alternatives*							
Foliar imidacloprid vs. **untreated controls**	25	0.9%	0.22	0.643	59%	0.794	0.427
Foliar imidacloprid vs. **all foliar alternatives**	222	-0.8%	3.59	0.060	44%	-1.439	0.150
Foliar imidacloprid vs. **foliar pyrethroids**	121	-1.0%	3.08	0.082	42%	-1.562	0.118
Foliar imidacloprid vs. **foliar organophosphates**	50	-2.0%	3.65	0.062	41%	-1.052	0.293

Notes: Results highlighted in green suggest significantly *higher* corn yields with the neonicotinoid-based treatment than with the listed alternative. Results highlighted in red suggest significantly *lower* yield. Results in grey are not statistically significant. (1) Mean difference in yield within pairs of neonicotinoid-treated and comparison plots. (2) Includes foliar sprays based on pyrifluquinazon or pymetrozine (IRAC group 9B) or afidopyropen (IRAC group 9D).

amethoxam. As described in *Chapters 3 & 6*, there are important differences between these groups in terms of use patterns, spectrum of target pests, and toxicity to pollinators. Worldwide, acetamiprid-based products are not subject to many of the regulations restricting uses of nitroguanidine neonicotinoids. Thus, where feasible, it is useful to consider acetamiprid-based products separately. Average yield in plots sprayed with acetamiprid was higher than in untreated control plots, though this is based on very few observations (*n*=4). ANOVA results suggest a significant yield benefit (19%), but the signed-ranks test was not statistically significant. A greater number of trials compared foliar acetamiprid to pyrethroid-based foliar insecticides. Yield was significantly higher in plots sprayed with acetamiprid (8% yield response). Yield in nitroguanidine-treated plots was significantly lower than in paired plots using a foliar pyrethroid (-1% yield response) or organophosphate (-4% yield response). There was no significant difference in average yield between the nitroguanidines and foliar treatments in IRAC group 9 (afidopyropen, pyriproxyfen, and pymetrozine). There was also no difference in yield when comparing nitroguanidine-treated plots to untreated controls. We repeated this analysis with just imidicloprid, the neonicotinoid active ingredient most commonly used in field trials. There was no significant difference in yield between plots treated with foliar imidacloprid products and those using no insecticides or a foliar pyrethroid or organophosphate alternative (Table 5.19).

5.3.2 Cost effectiveness relative to alternatives

This analysis uses the same methodology as in the field corn section, but with the constants adjusted for soybean. Average gross income is based on USDA survey data [945]. Between 2016 and 2018, New York soybean farmers produced an average 46 bu/A of soybean, receiving an average of $9.01 per bushel: $9.23 if adjusted for inflation. Our analysis of net income effects therefore assumes gross income of $421 per acre or $1,040 per hectare of soybean harvested. New York seed and seed treatment prices are drawn from Cox and Cherney [167], adjusted for inflation. Relative to untreated seeds, we assume that a fungicide treatment adds $38.53 to costs per hectare and that adding a neonicotinoid seed treatment component adds an additional $12.59 per hectare. Thus, seeds treated with both neonicotinoids and fungicides cost $51.12 more than untreated seeds per hectare. This analysis also assumes that growers using foliar insecticides in lieu of seed treatments will need to do additional scouting for pests and will, on average, make one additional insecticide application in the four weeks after planting.[44] The cost of scouting ($12.17/ha) and foliar pesticide application ($21.16/ha) is based on the mean cost of hiring a contractor for these tasks, based on mean values from recent state extension surveys of farm custom work rates [148, 677, 1036, 46, 204, 484, 690, 538]. Insecticide product prices are drawn from a 2020 extension service price list [455].[45]

Table 5.20: **Net returns from neonicotinoid-treated seeds in soybean, relative to alternatives, based on regional data (New York, Ohio, Ontario, Pennsylvania, and Quebec)**

Comparison	**Paired obs.**	**Marginal costs/ha** **Product**	 **Application**[1]	**Est. yield response**	**Net income effect (mean and range)**	**Effect as % of income/ha**
NTS[2] vs. **untreated seeds**[3]	173	$ 51.12		**4.5%** (± 0.4%)	**-$ 6.37** -$13.13 to $ 0.30	**-0.6%** -1.3% to 0.0%
NTS vs. **fungicide-treated seeds**[3]	138	$ 12.59		**6.8%** (± 0.8%)	**$ 53.84** $ 39.53 to $ 67.74	**5.2%** 3.8% to 6.5%
NTS vs. **foliar lambda-cyhalothrin**[4]	20	-$ 0.14	-$ 33.33	**-0.1%** (± 0.7%)	**$ 32.43** $ 18.53 to $ 45.97	**3.1%** 1.8% to 4.4%

Notes: Results highlighted in green suggest significantly *higher* soybean returns with neonicotinoid-treated seeds than with the listed alternative. Results highlighted in gray suggest no significant difference in returns. (1) Difference in planting costs per hectare, assuming that growers switching to foliar-based products will incur additional scouting costs and will require, on average, one additional foliar spray application during the 3-4 weeks after planting. Estimated scouting and insecticide application costs are mean values reported by state extension services (see Section 5.1); (2) Neonicotinoid-treated seeds; (3) Cost of neonicotinoid-treated seeds, relative to fungicide-only and untreated seeds, from Cox and Cherney [167] (adjusted for inflation); (4) 2020 product prices from Knodel et al. [455], adjusted for application rate.

While the few studies conducted in New York limit generalizations from those studies, it is worth noting that two studies conducted an informative economic analyses of their own. Cox and Cherney [166, 167] estimated growers' partial costs and returns, comparing use of neonicotinoid-treated seeds to fungicide-only seeds. In their 2014 article, the authors reported that higher yields led to a significant, positive effect on growers' partial returns (relative to untreated or fungicide-only controls) in field trials that took place in Seneca County (8 location-years), but found no significant effect on partial returns in Livingston, Tompkins, or Yates County field trials (24 location-years) [167]. Cox and Cherney [166] also found no significant effect on estimated partial returns based on on-farm trials in Jefferson, Livingston, and Ontario Counties. They did, however, note an interaction between seeding rate and

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[44] This may overstate the relative cost of foliar alternatives, as it assumes that growers could not combine application of a foliar insecticide with other sprays applied to their fields. It also does not capture potential savings from not spraying when scouting suggests low pest pressure.

[45] To ensure that listed in Knodel et al. [455] were representative of the broader market, the authors checked those prices against older pesticide price guides from the University of Nebraska-Lincoln and (for non-restricted use pesticides) three online pesticide retailers.

seed treatment for partial return, with seed treatments providing an advantage at lower seeding rates. This is consistent with extension guidance on seed rates for soybean with and without insecticidal seed treatments.

Table 5.21: **Net returns from neonicotinoid-treated seeds in soybean, relative to alternatives, based on North American data**

Comparison	Paired obs.	Marginal costs/ha		Est. yield response	Net income effect (mean and range)	Effect as % of income/ha
		Product	Application[1]			
NTS[2] vs. **untreated seeds**[3]	346	$51.12		**3.3%** (± 0.2%)	**-$17.41** -$20.57 to -$14.26	**-1.7%** -2.0% to -1.4%
NTS vs. **fungicide-treated seeds**[3]	228	$12.59		**3.1%** (± 0.3%)	**$19.08** $14.22 to $23.89	**1.8%** 1.4% to 2.3%
NTS vs. **soil-applied anthranilic diamides**[4]	4	-$26.83	-$3.05	**11.4%** (± 1.8%)	**$130.29** $99.70 to $159.00	**12.5%** 9.6% to 15.3%
NTS vs. **foliar lambda-cyhalothrin**[4]	82	$0.02	-$33.33	**-0.2%** (± 0.4%)	**$31.06** $22.43 to $39.55	**3.0%** 2.2% to 3.8%
NTS vs. **foliar chlorpyrifos**[4]	27	-$4.40	-$33.33	**2.9%** (± 0.8%)	**$66.70** $50.98 to $81.94	**6.4%** 4.9% to 7.9%

Notes: Results highlighted in green suggest significantly *higher* soybean returns with neonicotinoid-treated seeds than with the listed alternative. (1) Difference in planting costs per hectare, assuming that growers switching to foliar-based products will incur additional scouting costs and will require, on average, one additional foliar spray application during the 3-4 weeks after planting. Estimated scouting and insecticide application costs are mean values reported by state extension services (see Section 5.1); (2) Neonicotinoid-treated seeds; (3) Cost of neonicotinoid-treated seeds, relative to fungicide-only and untreated seeds, from Cox and Cherney [167] (adjusted for inflation); (4) 2020 product prices from Knodel et al. [455], adjusted for application rate.

In the regional data set, estimated net returns were comparable in plots using untreated soybean seeds and in those using neonicotinoid-treated seeds (see Table 5.20). Yield was 4.5% higher in neonicotinoid-treated plots, but the lower price of untreated seeds compensated for lower yield.[46] Conversely, there was a mean net income benefit of $55.84 per hectare (5% increase in income per hectare) relative to using fungicide-only seeds, and mean net income benefit of $32.43 per hectare (3% increase in income per hectare) relative to foliar lambda-cyhalothrin. Forgoing seed treatments and using an additional early-season foliar spray did not reduce yields relative to neonicotinoid seed treatments, but cost more per hectare after considering scouting and application costs.

Using the North American data set and estimating net returns to soybean growers allows for two additional comparisons: the comparison between neonicotinoid-treated seeds and soil-applied anthranilic diamides, and the comparison between neonicotinoid-treated seeds and foliar chlorpyrifos.

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[46] The average effect on net income does not capture the insurance value of neonicotinoid seed treatments.

There was a mean net income benefit of \$130.29 per hectare (13% increase in income per hectare) by using neoinicotinoid-treated seeds relative to soil-applied anthranilic diamides, and a mean net income benefit of \$66.70 per hectare (6% increase in income per hectare) relative to foliar chlorpyrifos (Table 5.21). We note the comparison with anthranilic diamides is based on a low sample size (n = 4) and should be interpreted with caution. As in the regional data set, estimated net returns were significantly higher in neonicotinoid-treated plots than in fungicide-only controls (by a mean of \$19.08/ha: 2% of gross income). However, neonicotinoid-treated seeds produced significantly lower expected net returns than plots using untreated seeds (by a mean of \$17.41/ha: 2% of gross income).

Table 5.22: **Net returns following neonicotinoid foliar sprays in soybean, relative to alternatives, based on North American data**

Comparison	**Paired obs.**	**Product costs/ha**		**Est. yield response**	**Net income effect mean and range**	**Effect as % of income/ha**
		Neonic.[1]	**Alt.**[2]			
***Acetamiprid** foliar sprays and alternatives*						
Foliar acetamiprid vs. **foliar pyrethroids**[3]	16	\$ 26.24	\$12.22	**8.2%** (± 1.9%)	**\$50.49** (\$17.09 to \$81.71)	**4.9%** (1.6% to 7.9%)
***Imidacloprid** foliar sprays and alternatives*						
Foliar imidacloprid vs. **foliar pyrethroids**[3]	164	\$5.33	\$12.22	**-0.7%** (± 0.3%)	**\$6.25** (-\$0.66 to \$13.07)	**0.6%** (-0.1% to 1.3%)
Foliar imidacloprid vs. **foliar lambda-cyhalothrin**	29	\$5.33	\$12.57	**-1.2%** (± 0.6%)	**\$1.96** (-\$10.02 to \$13.68)	**-0.2%** (-1.0% to 1.3%)
Foliar imidacloprid vs. **foliar beta-cyfluthrin**	26	\$5.33	\$17.84	**-0.6%** (± 0.9%)	**\$18.33** (\$0.28 to \$35.77)	**1.8%** (0.0% to 3.4%)
Foliar imidacloprid vs. **foliar chlorpyrifos**	16	\$5.33	\$16.99	**-2.8%** (± 1.4%)	**-\$6.38** (-\$38.47 to \$23.88)	**-0.6%** (-3.7% to 2.3%)

Notes: Results highlighted in green suggest significantly *higher* soybean returns with neonicotinoid-treated seeds than with the listed alternative under both high and low yield response scenarios. Results highlighted in gray suggest no significant difference in net return between listed alternative. (1) Product cost of Assail 30SG (acetamiprid) or Admire Pro (imidacloprid) per hectare, using prices from Knodel et al. [455] and the most common foliar application rates in North American soybean field trials; (2) Product cost of non-neonicotinoid foliar sprays based on lambda-cyhalothrin (Warrior II), beta-cyfluthrin (Baythroid XL), bifenthrin (Brigade 2EC), chlorpyrifos (Lorsban 4E), and esfenvalerate (Asana XL) per hectare, using prices from Knodel et al. [455] and the most common foliar application rates in North American soybean field trials. (3) Non-neonicotinoid product cost calculated based on a weighted average of common pyrethroid (lambda-cyhalothrin, beta-cyfluthrin, bifenthrin, and esfenvalerate) foliar product prices compared to acetamiprid- and imidacloprid-treated plots in field trials.

To compare net returns associated with neonicotinoid- and non-neonicotinoid foliar insecticides (see Table 5.22), we assume that application and scouting costs do not vary between foliar products. Therefore, the net income effect in our analysis is derived from the estimated difference in yield between alternatives and their relative purchase price. We also assume that foliar insecticides are applied twice per season, both times with the same product. This is not representative of how foliar sprays are used in the field, as it ignores variation in pest pressures between sites and seasons, but is a useful framework for comparing cost and efficacy of different active ingredients.

As laid out in Table 5.19, yield in test plots treated with a foliar form of the cyanoamidine neonicotinoid acetamiprid[47] was significantly higher than in soybean plots using foliar pyrethroid and organophosphate alternatives: the mean yield response was 5% relative to foliar pyrethroid alternatives.[48] Even with relatively high product costs, acetamiprid-treated plots had mean estimated net returns $50.49 higher than in paired plots (5% of expected income per hectare). Yield in plots using foliar imidacloprid products was comparable to that in plots using foliar pyrethroids or organophosphates, and there was no significant difference in returns between imidacloprid and pyrethroid or organophosphate comparators except for the pyrethroid beta-cyfluthrin. Although yield was comparable in trials involving both imidacloprid and beta-cyfluthrin, the lower cost of the representative imidacloprid-based product in our analysis (Admire Pro) led to higher expected returns for farmers. We expect a mean benefit of $18.33 per hectare, approximately 2% of expected returns.

Similar to the economic analyses for corn in Section 5.2, it is important to note that, when significant, differences in mean net income were largely influenced by a small proportion of comparisons. This is because the yield data for soybeans (summarized in Section 5.3.1) are used in the calculation of net income effects and a small proportion of those trials observed significant differences in yield (see Table 5.13 and Figures 5.3 and 5.4). In other words, the data indicate that when there are overall economic benefits of using neonicotinoid-treated seeds, a small proportion of farmers will experience significant economic benefits, while the majority of farmers will not. Because variance was rarely noted in the underlying yield studies, it is unfortunately not possible to estimate the exact proportion of farmers that are likely to experience significant net income benefits.

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[47] When data allow, we consider acetamiprid separately from the nitroguanidine neonicotinoids: clothianidin, dinotefuran, imidacloprid, and thiamethoxam. Acetamiprid is substantially less toxic to pollinators than nitroguanidine neonicotinoids, and is exempt from many neonicotinoid-focused regulations (like the European Union's "ban" on neonicotinoids).

[48] The comparison group included the pyrethroids beta-cyfluthrin, deltamethrin, esfenvalerate, and lambda-cyhalothrin.

5.4 Fruit crops

5.4.1 Apples and tree fruits

Conventional tree fruit crops are treated with multiple foliar insecticides over the course of a season. As such, many of the field trials used for this analysis focused on season-long treatment plans incorporating insecticides from several IRAC groups rather than a direct comparison of insecticides with a single active ingredient each. For the below analysis, we compare the results of treatment plans that included a neonicotinoid (separated by active ingredient, where possible) to those that contained only non-neonicotinoid active ingredients.

Effective non-neonicotinoid alternatives are available for the principal pests of tree fruits in New York State (see Table 4.2). Overall, 33 of 182 pairwise comparisons in our data set[49] (18%) found a significant, positive difference in outcomes (yield, insect damage, or pest populations) between tree fruit plots that used foliar neonicotinoids (alone or with other active ingredients) and either alternative insecticides or untreated controls (Table 5.23).[50] This does not, however, mean that there are no costs associated with replacing neonicotinoid foliar sprays with alternatives. Many potential substitutes are more expensive, less persistent, or less versatile. Furthermore, analysis focusing on specific active ingredients suggests that foliar treatment plans including foliar acetamiprid-based products performed better than plans including nitroguanidine neonicotinoids in trials against non-neonicotinoid foliar treatment plans.

As described in Section 5.1, the economic analysis for agricultural crops defines efficacy in terms of grower income. Of the three categories of study responses gathered for this report–crop yield, damage to crops from insect pests, or suppression of pest populations–crop yield is most closely related to income, followed by damage to crops and, finally, pest suppression. With available data, we could not compare yield in neonicotinoid-treated and non-neonicotinoid tree fruit plots. In most of the tree fruit trials we collected (169 of 182), the outcome of interest was damage to the tree or crop. Therefore, the bulk of the analysis in this subsection deals with differences in crop damage between plots treated with

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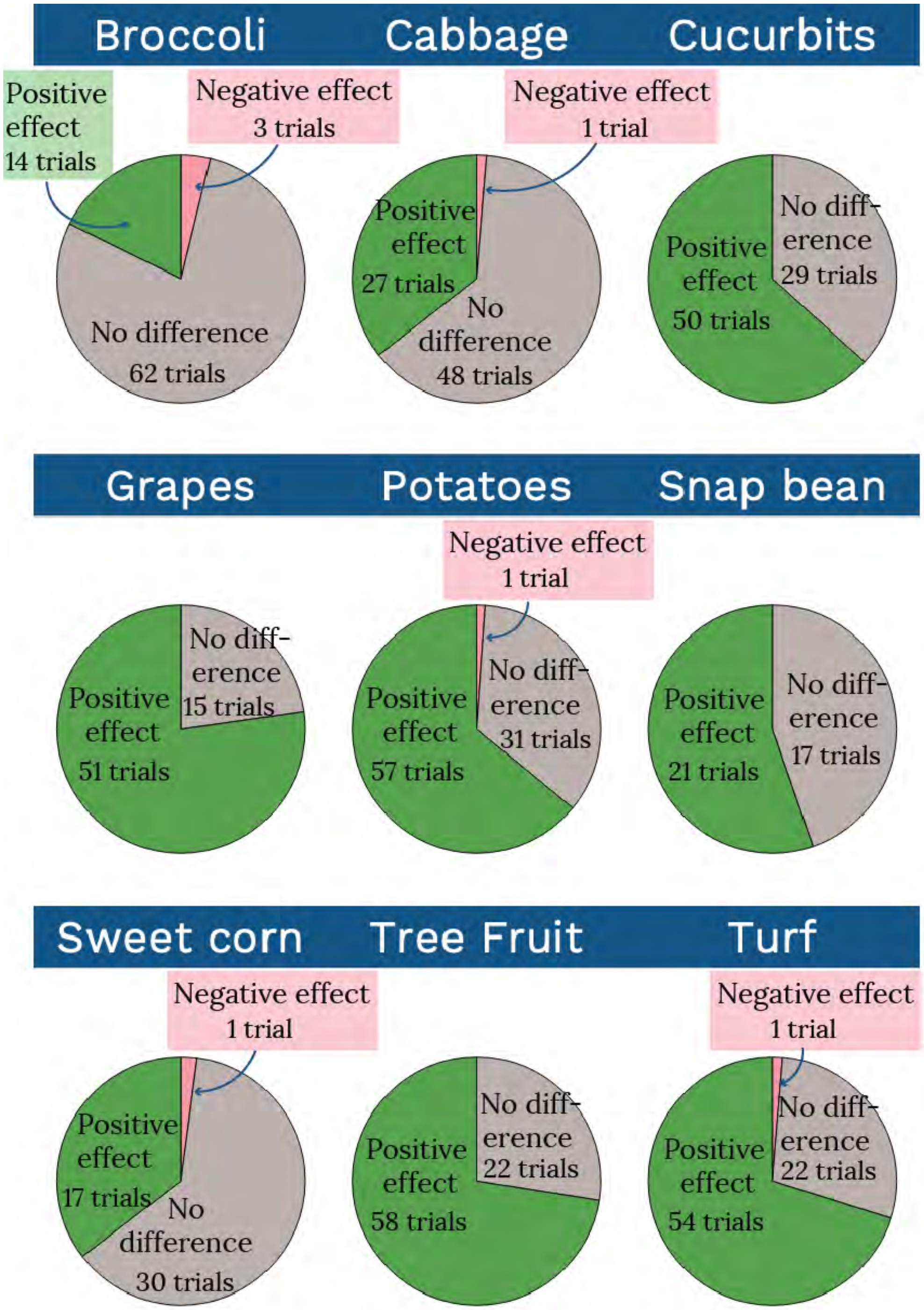
[49] This figure differs slightly from that in Table 5.23 because it includes the results of 17 trials in which some plots were treated with both an acetamiprid- and a nitroguanidine-based foliar spray.

[50] This assumes, of course, that neonicotinoid foliar sprays in tree fruit would be replaced with another chemical insecticide. Outcomes in untreated control plots were significantly worse. Plots treated with a neonicotinoid-based foliar spray performed significantly better than untreated plots in 58 of 80 trials (73%).

Figure 5.5: **Number of North American field trials reporting significantly better performance (green), significantly worse performance (red), or no significant difference (gray) in terms of yield, crop damage, or pest control for neonicotinoid-treated plots compared to no-insecticide controls**[1]



Notes: (1) Includes both untreated controls and controls treated with non-insecticidal crop protectants.

Table 5.23: **Number of tree fruit field trials reporting significantly positive (green), negative (red), or no difference in yield, crop damage, or pest populations in tree fruit plots treated with foliar acetamiprid or nitroguanidine neonicotinoid products, compared to untreated controls of plots treated with only non-neonicotinoid foliar insecticides**

	New York State			NYS & region[1]			North America		
Comparison	Y+	Y-	NS	Y+	Y-	NS	Y+	Y-	NS
Acetamiprid foliar sprays and alternatives									
Foliar acetamiprid vs. untreated controls	1	0	0	20	0	7	22	0	7
Foliar acetamiprid vs. other foliar insecticides	0	2	1	8	2	37	9	2	41
Nitroguanidine neonicotinoid foliar sprays and alternatives									
Foliar nitroguanidines vs. untreated controls	12	0	0	30	0	13	33	0	15
Foliar nitroguanidines vs. other foliar insecticides	0	4	53	15	6	71	15	10	80

Notes: (1) Regional results used data from field trials in New York and Ontario. This analysis compares reported significance of differences in yield, crop damage, or pest populations following treatment using (a) a foliar neonicotinoid (acetamiprid and/or nitroguanidine neonicotinoid(s)) product or (b) a non-neonicotinoid foliar insecticide or no insecticide treatment (untreated control).

a foliar neonicotinoid product or a foliar non-neonicotinoid alternative.

We separate foliar sprays based on the cyanoamidine neonicotinoid acetamiprid and those based on the nitroguanidine neonicotinoids: clothianidin,[51] dinotefuran, imidacloprid, and thiamethoxam. As described in *Chapters 3 & 6*, there are important differences between nitroguanidine neonicotinoids and acetamiprid (the only non-nitroguanidine neonicotinoid in common U.S. use) in terms of use patterns, spectrum of target pests, and toxicity to pollinators. Acetamiprid is less toxic to bees by an order of magnitude and, worldwide, acetamiprid-based products are not subject to many regulations restricting uses of nitroguanidine neonicotinoids. Thus, where feasible, it is useful to consider acetamiprid-based products separately. In trials against non-neonicotinoid foliar sprays, both acetamiprid-based and nitroguanidine neonicotinoid-based products had performance broadly comparable to other foliar insecticides. In New York, there was no significant difference in crop or fruit damage in 16 of 20 trials (80%) involving acetamiprid-treated and non-neonicotinoid groups. For nitroguanidine neonicotinoids, 68 of 74 of New York trials (92%) found no significant difference relative to non-neonicotinoid foliar insecticides. In regional data (including studies from New York and Ontario), 46 of 57 (81%) of acetamiprid and 86 of 109 (79%) nitroguanidine product trials found no significant difference in crop

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[51] Clothianidin-based products are not registered for outdoor foliar uses in New York State. We include clothianidin-based foliar products (e.g., Belay, Clutch) in analyses comparing nitroguanidine neonicotinoids as a group to non-neonicotinoid alternatives, but do not analyze its performance as an individual active ingredient.

Table 5.24: **Performance of tree fruit foliar treatment plans including neonicotinoid-based products, relative to non-neonicotinoid foliar treatment plans: sign test of paired North American trials**

Comparison	Paired obs.	**Percent Positive**	Significantly more successes with: H_{a1}: **neonic.** P-value	H_{a2}: **alternative** P-value
Foliar treatment plans with **acetamiprid** vs. non-neonicotinoid foliar treatment	70	57%	0.071	0.957
Foliar treatment plans with **imidacloprid** vs. non-neonicotinoid foliar treatment	40	41%	0.895	0.174
Foliar treatment plans with **thiamethoxam** vs. non-neonicotinoid foliar treatment	38	34%	0.983	0.037

Notes: The outcomes of interest in these trials were damage by insect pests to trees, leaves, or fruit. Results highlighted in red suggest that the neonicotinoid-treated plot performed worse than its paired alternative in a significantly higher proportion of field trials than vice-versa. Results in grey are not statistically significant. (1) The right two columns reflect significance of the null hypothesis that the true proportion of positive to negative mean differences is 1:1 ($H_0 : Prob[D > 0] = \frac{1}{2}$) against two alternative hypotheses: that the neonicotinoid-treated group performs better than the alternative-treated group in a majority of field trials ($H_{a1} : Prob[D > 0] > \frac{1}{2}$) and that the alternative-treated group performed better in a majority of crop damage trials ($H_{a2} : Prob[D < 0] > \frac{1}{2}$). This test makes no assumptions about the distribution of data.

damage compared to alternatives (Table 5.23).

Since crop damage can take many forms, we could not always directly compare the results of the 47 studies on apple (114 paired observations), peach (61 paired observations) and plum (24 paired observations) used in this analysis. Of 169 paired observations, 115 reported the percentage of trees damaged by insect pests, 50 reported the percentage of fruit damaged or undamaged, and 4 reported a damage score. Table 5.24 uses all observations for a simple sign test of neonicotinoid active ingredients used in fruit tree trials. The "Percent Positive" column reports the number of paired observations in which damage (however defined) was lower in the neonicotinoid-treated group than in the group treated with non-neonicotinoid foliar sprays.[52] The right two columns reflect t-tests with the null hypothesis that the true proportion of positive to negative mean differences is 1:1 and two alternative hypotheses: that the neonicotinoid-treated group performs better than the alternative-treated group in a majority of crop damage trials "H_a: NF>OF," and that the alternative-treated group performed better in a majority of crop damage trials "H_a: OF>NF." For acetamiprid and imidacloprid, there was no significant difference in the number of trials in which neonicotinoids outperformed alternatives

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[52] The only thing measured in this count is whether the difference in means is positive or negative; it does not reflect the magnitude of the difference or its statistical significance. This test makes no assumptions about distribution.

or vice-versa. However, damage in plots using non-neonicotinoid foliar sprays was lower than in thiamethoxam-treated plots in 66% of field trials, suggesting a significant difference (p=0.037).

Table 5.25: **Effect of neonicotinoid foliar sprays on proportion of trees or fruit undamaged by pests, compared to non-neonicotinoid foliar sprays: results from New York and Ontario**

		ANOVA results			Signed-ranks test		
Comparison	Paired obs.	**Mean diff.**[1]	**F-value**	**P-value**	**Percent positive**	**Z-score**	**P-value**
Foliar treatment plans including **acetamiprid**[2], compared to non-neonicotinoid foliar treatment	15	3%	1.50	0.240	36%	-0.996	0.334
Foliar treatment plans including **imidacloprid**[2], compared to non-neonicotinoid foliar treatment	35	13%	11.41	0.002	14%	-3.702	<0.001
Foliar treatment plans including **thiamethoxam**[2], compared to non-neonicotinoid foliar treatment	27	7%	10.96	0.003	20%	-2.739	0.006

Notes: Results highlighted in red suggest that a significantly higher proportion of the neonicotinoid-treated plot, as a percent of trees, leaves, or produce affected, was damaged by insect pests in plots treated with a foliar neonicotinoid (alone or as part of a season-long foliar insecticide rotation), than in plots using only non-neonicotinoid foliar insecticides. Results in grey are not statistically significant. (1) Here, the mean difference in the percentage of trees, leaves, or produce *not* damaged by insects in neonicotinoid-treated and non-neonicotinoid plots. (2) Excludes pairwise comparisons in which the neonicotinoid-treated plot used both acetamiprid and a nitroguanidine neonicotinoid.

Our data allowed more in-depth analysis of regional paired observations in which the output was a percentage of trees or produce damaged by insect pests. Aggregating data in this way has its limitations; the type of damage measured and target pest of interest varied between studies. Nevertheless, the results in Table 5.25 provide some insight into the performance of acetamiprid-, imidacloprid-, and thiamethoxam-based foliar sprays relative to non-neonicotinoid alternatives against a range of pests present in New York and Ontario. The data suggest no significant difference in performance between foliar products based on acetamiprid and non-neonicotinoid alternatives. The percentage of trees or fruit undamaged by pests was significantly lower in imidacloprid-treated and thiamethoxam-treated plots than in comparison groups.

5.4.2 Grapes

There are alternatives to neonicotinoid foliar sprays for most target pests in grape. Treatment plans that included one or more neonicotinoid products[53] provided significantly better pest control than non-neonicotinoid alternatives (in terms of crop damage or pest count) in 17 of 206 paired North American field trials in our data set (8%), and significantly worse in 38 of 206 trials (18%) (Table 5.26). Crop damage (in terms of the percent of grape leaves, clusters, or bunches damaged) was significantly higher in neonicotinoid-treated plots than in paired plots using only non-neonicotinoid insecticides (see Table 5.27). However, this result is most relevant for products based on nitroguanidine neonicotinoids (clothianidin, dinotefuran, imidacloprid, and thiamethoxam). There was no significant difference in crop damage between plots treated with the neonicotinoid acetamiprid and non-neonicotinoid alternatives.

Table 5.26: **Number of grape field trials reporting significantly positive (green), negative (red), or no difference in yield, crop damage, or pest populations in plots treated with foliar acetamiprid or nitroguanidine neonicotinoid products, compared to untreated controls of plots treated with only non-neonicotinoid foliar insecticides**

	NYS & region[1]			North America		
Comparison	Y+	Y-	NS	Y+	Y-	NS
Acetamiprid foliar sprays and alternatives						
Foliar acetamiprid vs. untreated controls	9	0	3	24	0	11
Foliar acetamiprid vs. other foliar insecticides	2	6	31	5	8	45
Nitroguanidine neonicotinoid treatments and alternatives						
Nitroguanidine neonicotinoids vs. untreated controls[2]	23	0	3	27	0	4
Nitroguanidine neonicotinoids vs. alternative insecticides[3]	1	13	15	12	30	106

Notes: This analysis compares reported significance of differences in yield, crop damage, or pest populations following an insecticide treatment plan that included a neonicotinoid component or an alternative treatment plan that (a) used only non-neonicotinoid insecticides or (b) used no insecticides. (1) Regional results used data from field trials in New York, Ohio, and Ontario. (2) Includes products based on clothianidin, dinotefuran, imidacloprid, and thiamethoxam. (3) Includes products based on clothianidin, dinotefuran, imidacloprid, and thiamethoxam.

The data set allowed analysis of acetamiprid-based or nitroguanidine neonicotinoid performance relative to alternatives for four specific pests (see Table 5.28). As noted in Section 4.2, grape berry moth is the most damaging arthropod pest of New York grapes, but neonicotinoids are not the principal mode of action used for its control. Non-neonicotinoid insecticides performed better than paired

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[53] As with tree fruits, many field trials on grape compared the efficacy of season-long insecticide treatment plans that each included several different products, rather than comparing single products.

neonicotinoids in a significant majority of field trials. However, nitroguanidine neonicotinoid-based foliar products performed as well as alternatives in field trials that focused on crop damage from leafhoppers or Japanese beetle on grape. There was also no significant difference in the number of studies finding lower crop damage from leaf-form grape phylloxera following acetamiprid or alternative insecticide treatment (Table 5.27).

Table 5.27: **Effect of neonicotinoid foliar sprays on proportion of grape leaves, clusters, or bunches damaged by pests, compared to non-neonicotinoid foliar sprays: North American field trials**

		ANOVA results			Signed-ranks test		
Comparison	Paired obs.	**Mean diff.**[1]	**F-value**	**P-value**	**Percent Positive**	**Z-score**	**P-value**
Foliar treatment plans including **any neonicotinoid**, compared to non-neonicotinoid foliar treatment	81	71%	3.315	0.001	3.3%	3.71	0.058
Foliar treatment plans including a **nitroguanidine**[2], compared to non-neonicotinoid foliar treatment	65	74%	3.327	0.001	3.9%	3.46	0.067
Foliar treatment plans including **acetamiprid**, compared to non-neonicotinoid foliar treatment	16	56%	0.572	0.567	0.8%	0.32	0.579

Notes: Results highlighted in red suggest significantly greater crop damage in neonicotinoid-treated plots, as a percent of grape leaves, clusters, or branches affected, than in plots using only non-neonicotinoid foliar insecticides. Results in grey are not statistically significant. (1) Here, the mean difference in the percentage of leaves, bunches, or clusters damaged by insects in neonicotinoid-treated and non-neonicotinoid plots. (2) Neonicotinoid active ingredients in the nitroguanidine group are clothianidin, dinotefuran, imidacloprid, and thiamethoxam.

It is important to note that none of the trials in our data set focused on *root*-form phylloxera (see Section 4.2). Neonicotinoid-based products are the most cost-effective insecticides for control of root-form phylloxera. While phylloxera is largely controlled by hybridization and grafting, vineyards still need to use un-grafted, non-resistant vines for some purposes. Root-form phylloxera can also reduce productivity for resistant cultivars. In these circumstances, soil-applied neonicotinoids can substantially increase yields. Only one non-neonicotinoid active ingredient is widely available for this use: spirotetramat [511, 1113]. While effective, spirotetramat (marketed as Movento) is several times the price of neonicotinoid-based alternatives.

In comparisons with other insecticide groups on grape, we found no significant difference between acetamiprid and organophosphate foliar sprays or between nitroguanidine neonicotinoids and spinosyn

Table 5.28: **Performance of grape foliar treatment plans including neonicotinoid-based products, relative to non-neonicotinoid foliar treatment plans: binomial sign tests of paired North American crop damage trials**

Comparisons by alternative insecticide group **Comparison group**[1]	**Neonicotinoid**	Paired obs.	**Percent Positive**	Significantly more successes with: H_{a1}: **neonic.** P-value[2]	H_{a2}: **alternative** P-value[2]
Organophosphates (1B)	Acetamiprid	7	29%	0.891	0.344
	Nitroguanidines[3]	20	5%	> 0.999	< 0.001
Pyrethroids (3A)	Acetamiprid	22	14%	> 0.999	0.001
	Nitroguanidines	21	10%	> 0.999	< 0.001
Spinosyns (5)	Nitroguanidines	12	42%	0.726	0.500

Comparisons by target pest: **Target pest**	**Neonicotinoid**	Paired obs.	**Percent Positive**	Significantly more successes with: H_{a1}: **neonic.** P-value[2]	H_{a2}: **alternative** P-value[2]
Grape berry moth	Acetamiprid	23	4%	> 0.999	< 0.001
	Nitroguanidines	83	16%	> 0.999	< 0.001
Leafhoppers	Nitroguanidines	55	53%	0.097	0.994
Japanese beetle	Nitroguanidines	9	33%	0.910	0.254
Leaf-form grape phylloxera	Acetamiprid	10	30%	0.945	0.172

Results highlighted in red suggest that a significantly higher proportion of the neonicotinoid-treated plot, as a percent of plants, leaves, or produce affected, was damaged by insect pests in plots treated with a foliar neonicotinoid (alone or as part of a season-long foliar insecticide rotation), than in plots using only non-neonicotinoid foliar insecticides. Results in grey are not statistically significant.

Notes: (1) IRAC group numbers in parentheses (see Table 2.1) (2) The right two columns reflect significance of the null hypothesis that the true proportion of positive to negative mean differences is 1:1 ($H_0 : Prob[D > 0] = \frac{1}{2}$) against two alternative hypotheses: that the neonicotinoid-treated group performs better than the alternative-treated group in a majority of field trials ($H_{a1} : Prob[D > 0] > \frac{1}{2}$) and that the alternative-treated group performed better in a majority of crop damage trials ($H_{a2} : Prob[D < 0] > \frac{1}{2}$). This test makes no assumptions about the distribution of data. (3) Neonicotinoid active ingredients in the nitroguanidine group are clothianidin, dinotefuran, imidacloprid, and thiamethoxam.

(spinosad or spinetoram) or methoxyfenozide products (Table 5.27). Crop damage in pyrethroid-treated plots was lower than in plots treated with acetamiprid or a foliar nitroguanidine neonicotinoid in a significant majority of trials. Two other comparisons were significant: organophosphate-based and methoxyfenizide-based treatments led to lower crop damage than plots using nitroguanidine and acetamiprid neonicotinoids,respectively. However, this result may be skewed by the large number of field trials in our data set that were principally concerned with grape berry moth.

5.4.3 Berries

As in grape, substitutes are available for foliar neonicotinoids against most major target pests of berry crops. This analysis draws on 14 studies and 88 pairwise comparisons, and the data set included 43 strawberry, 38 blueberry, and 7 blackberry field trials (Table 5.29). Overall, there was no significant difference in performance between neonicotinoid insecticides and other insecticides on berry crops in our data set (Table 5.30). However, this may simply reflect the relatively limited data available (37 paired observations for acetamiprid foliar products vs. non-neonicotinoid insecticides, 18 paired observations between nitroguanidine foliar products vs. non-neonicotinoid insecticides).

Table 5.29: **Number of blackberry, blueberry, and strawberry field trials reporting significantly positive (green), negative (red), or no difference in yield, crop damage, or pest populations in plots treated with foliar acetamiprid or nitroguanidine neonicotinoid products, compared to untreated controls of plots treated with only non-neonicotinoid foliar insecticides**

	NYS & region[1]			North America		
Comparison	Y+	Y-	NS	Y+	Y-	NS
Acetamiprid foliar sprays and alternatives						
Foliar acetamiprid vs. untreated controls	1	0	1	4	0	7
Foliar acetamiprid vs. other foliar insecticides	0	0	7	2	3	30
Nitroguanidine neonicotinoid treatments and alternatives						
Nitroguanidine neonicotinoids vs. untreated controls[2]	5	0	1	5	0	3
Nitroguanidine neonicotinoids vs. alternative insecticides[3]				0	0	12

Notes: This analysis compares reported significance of differences in yield, crop damage, or pest populations following an insecticide treatment plan that included a neonicotinoid component and an alternative (untreated control or treatment plan with only non-neonicotinoid insecticides). (1) Regional results used data from field trials in New Jersey and Ontario. (2) Includes products based on imidacloprid and thiamethoxam.

In strawberries, neonicotinoids are important for controlling root weevils and strawberry sap beetles.

The most likely non-neonicotinoid substitutes are based on the pyrethroid bifenthrin (e.g., Brigade WSB, Bifenture 10DF, or Fanfare). For root weevil, relying on bifenthrin could impose costs related to worker safety and labor (e.g., re-application and scouting). For strawberry sap beetle, a grower replacing the acetamiprid-based Assail SG with a bifenthrin product could face additional spending related to ensuring worker safety, and might have higher pest control costs later in the season due to bifenthrin's higher toxicity to beneficial insect predators [153].

Table 5.30: **Performance of blackberry, blueberry, and strawberry foliar treatment plans including neonicotinoid-based products, relative to non-neonicotinoid foliar treatment plans: binomial sign tests of paired North American crop damage and pest control trials**

			Significantly more successes with:	
Comparison	Paired observations	**Percent Positive**	H_{a1}**: neonic.** P-value	H_{a2}**: alternative** P-value
Acetamiprid foliar products vs. non-neonicotinoid insecticides	37	46%	0.691	0.434
Nitroguanidine neonicotinoids vs. non-neonicotinoid insecticides	18	56%	0.227	0.895

Notes: Results highlighted in red suggest that a significantly higher proportion of the neonicotinoid-treated plot, as a percent of plants, leaves, or produce affected, was damaged by insect pests in plots treated with a foliar neonicotinoid (alone or as part of a season-long foliar insecticide rotation), than in plots using only non-neonicotinoid foliar insecticides. Results in grey are not statistically significant. (1) The right two columns reflect significance of the null hypothesis that the true proportion of positive to negative mean differences is 1:1 ($H_0 : Prob[D > 0] = \frac{1}{2}$) against two alternative hypotheses: that the neonicotinoid-treated group performs better than the alternative-treated group in a majority of field trials ($H_{a1} : Prob[D > 0] > \frac{1}{2}$) and that the alternative-treated group performed better in a majority of crop damage trials ($H_{a2} : Prob[D < 0] > \frac{1}{2}$). This test makes no assumptions about the distribution of data. (2) Neonicotinoid active ingredients in the nitroguanidine group are clothianidin, dinotefuran, imidacloprid, and thiamethoxam.

5.5 Vegetable crops

5.5.1 Cabbage and crucifers

Cabbage is New York's most valuable vegetable crop. As discussed in Section 4.3, neonicotinoid-based insecticides are commonly used to control several pests of cabbage and other crucifers. In particular, New York's cabbage farmers rely heavily on acetamiprid and imidacloprid for control of Swede midge.

This analysis draws on 315 pairwise comparisons of outcomes in cabbage plots following applica-

Table 5.31: **Number of cabbage field trials reporting significantly positive (green), negative (red), or no difference in yield, crop damage, or pest populations in plots treated with foliar acetamiprid or nitroguanidine neonicotinoid products, compared to untreated controls of plots treated with only non-neonicotinoid foliar insecticides**

	New York State			NYS & region[1]			North America		
Comparison	Y+	Y-	NS	Y+	Y-	NS	Y+	Y-	NS
Acetamiprid foliar sprays and alternatives									
Foliar acetamiprid vs. untreated controls	3	0	1	11	0	11	11	0	11
Foliar acetamiprid vs. other foliar insecticides	4	0	9	5	0	85	5	0	85
Nitroguanidine neonicotinoid treatments and alternatives									
Nitroguanidine neonicotinoids vs. untreated controls[2]	2	0	0	12	0	24	17	1	37
Nitroguanidine neonicotinoids vs. alternative insecticides[3]	4	0	2	6	0	100	10	12	128

Notes: This analysis compares reported significance of differences in yield, crop damage, or pest populations following an insecticide treatment plan that included a neonicotinoid component and an alternative (untreated control or treatment plan with only non-neonicotinoid insecticides). (1) Regional results used data from field trials in New York, Massachusetts, and Ontario. (2) Includes neonicotinoid products based on clothianidin, dinotefuran, imidacloprid, and thiamethoxam. (3) Includes neonicotinoid products based on clothianidin, dinotefuran, and imidacloprid.

tions of a neonicotinoid product and non-neonicotinoid alternative. In trials comparing neonicotinoids to untreated controls, 27 of 76 (36%) observed better outcomes in the treated plot (in terms in yield, crop damage, or pest population); only 1 of 76 trials (1%) reported significantly better outcomes in the control plot (Table 5.31, Figure 5.5). In 239 trials comparing neonicotinoid-treated cabbage to cabbage treated with a chemical alternative, the neonicotinoid-treated plot had a significantly better outcome than the alternative in 15 (6%) and a significantly worse outcome in 12 (5%). There was no significant difference between treatments in 212 of 239 trials (89%).

Field trials in Hallett et al. [351] allow 48 pairwise comparisons of foliar neonicotinoids to foliar alternatives, 16 comparisons of soil-applied neonicotinoids to foliar alternatives, and 8 trials with a neonicotinoid and an untreated control. Plots treated with neonicotinoids consistently out-produced untreated plots, but there was no significant difference between neonicotinoid-treated plots and those treated with other foliar insecticides. There was no difference between yields following neonicotinoid sprays and those associated with the pyrethroid lambda-cyhalothrin or the benzoylureas novaluron.

Table 5.32: **Performance of neonicotinoid-based insecticides on cabbage, relative to non-neonicotinoid insecticides: binomial sign tests of paired North American yield, crop damage, and pest control trials**

			Significantly more successes with[1]:	
Comparison	Paired obs.	Percent Positive	H_{a1}: **neonic.** P-value	H_{a2}: **alternative** P-value
Crop yield trials comparing neonicotinoid to non-neonicotinoid insecticides	82	44%	0.888	0.160
Crop damage trials comparing neonicotinoid to non-neonicotinoid insecticides	140	82%	< 0.001	> 0.999
Pest control trials comparing neonicotinoid to non-neonicotinoid insecticides	18	39%	0.881	0.240
Comparisons of neonicotinoid and non-neonicotinoid insecticides by alternative insecticide group				
Acetamiprid vs. **pyrethroid** alternatives (IRAC group 3A)	20	85%	0.001	> 0.999
Nitroguanidine[2] neonicotinoids vs. **pyrethroid** alternatives (IRAC group 3A)	34	53%	0.364	0.757
Acetamiprid vs. **spinosyn** alternatives (IRAC group 5)	39	72%	0.003	0.999
Nitroguanidine neonicotinoids vs. **spinosyn** alternatives (IRAC group 5)	46	63%	0.052	0.973
Nitroguanidine neonicotinoids vs. **pyridine azomethine derivatives** (IRAC group 9B)	12	83%	0.019	0.997
Acetamiprid vs. **benzoylureas** alternatives (IRAC group 15)	20	80%	0.006	0.999
Nitroguanidine neonicotinoids vs. **benzoylureas** alternatives (IRAC group 15)	28	71%	0.018	0.994
Nitroguanidine neonicotinoids vs. **anthranilic diamide** alternatives (IRAC group 28)	28	32%	0.982	0.044
Comparisons of neonicotinoid and non-neonicotinoid insecticides against flea beetle and Swede midge				
Acetamiprid vs. non-neonicotinoid alternatives against **flea beetle**	16	44%	0.773	0.402
Nitroguanidine neonicotinoids vs. non-neonicotinoid alternatives against **flea beetle**	36	39%	0.934	0.122
Acetamiprid vs. non-neonicotinoid alternatives against **Swede midge**	100	69%	< 0.001	> 0.999
Nitroguanidine neonicotinoids vs. non-neonicotinoid alternatives against **Swede midge**	76	79%	< 0.001	> 0.999

Notes: Results highlighted in **green** suggest that a significantly *lower* proportion of plants, leaves, or produce was damaged by insect pests in plots treated with a neonicotinoid product (alone or as part of a season-long insecticide rotation), than in plots using only non-neonicotinoid insecticides. Results highlighted in **red** suggest significantly *higher* damage in neonicotinoid-treated plots. Results in **grey** are not statistically significant.

(1) The right two columns reflect significance of the null hypothesis that the true proportion of positive to negative mean differences is 1:1 ($H_0 : Prob[D > 0] = \frac{1}{2}$) against two alternative hypotheses: that the neonicotinoid-treated group performs better than the alternative-treated group in a majority of field trials ($H_{a1} : Prob[D > 0] > \frac{1}{2}$) and that the alternative-treated group performed better in a majority of crop damage trials ($H_{a2} : Prob[D < 0] > \frac{1}{2}$). This test makes no assumptions about the distribution of data. (2) Neonicotinoid active ingredients in the nitroguanidine group are clothianidin, dinotefuran, imidacloprid, and thiamethoxam.

However, sprays based on the spinosyn spinosad were associated with significantly higher pest numbers.

Neonicotinoids demonstrated greater efficacy against specific target pests. In 6 studies focused on common cabbage pests, neonicotinoid products significantly outperformed potential substitutes. Neonicotinoid products are particularly important for control of Swede midge in New York State. In trials of insecticide efficacy on crucifers, use of a neonicotinoid product led to a greater reduction in Swede midge population in 258 of 372 pairwise comparisons (69%) (Table 5.32).

5.5.2 Potatoes

Most potato yield studies in our data set included applications of several foliar insecticides over the course of a season (as is typical in commercial production), with or without a seed piece or soil treatment at planting. Our yield analysis compares strategies that contained a neonicotinoid component (seed piece treatment, soil treatment, or foliar spray) to those that did not. Due to differences in how prior studies reported potato yield, we could not directly compare potato yield per hectare as in in the field corn and soybean sections above. Instead, this analysis considers yield associated with a given treatment as a percentage of the highest yield reported in a given study.[54] For example, if considering a two-plot field trial in which plot A produced 50 units of potatoes and plot B produced 40 units, we would consider plot B to have produced 80% of the maximum yield observed in that field trial.

Table 5.33: **Number of potato field trials reporting significantly positive (green), negative (red), or no difference in yield, crop damage, or pest populations in plots treated with foliar acetamiprid or nitroguanidine neonicotinoid products, compared to untreated controls of plots treated with only non-neonicotinoid foliar insecticides**

	NYS & region[1]			North America		
Comparison	Y+	Y-	NS	Y+	Y-	NS
Nitroguanidine neonicotinoids vs. untreated controls[2]	19	0	1	57	1	36
Nitroguanidine neonicotinoids vs. alternative insecticides[3]	4	3	21	98	28	210

Notes: This analysis compares reported significance of differences in yield, crop damage, or pest populations following an insecticide treatment plan that included a neonicotinoid component and an alternative (untreated control or treatment plan with only non-neonicotinoid insecticides). (1) Regional results used data from field trials in Ontario and Quebec. (2) Includes neonicotinoid products based on clothianidin, imidacloprid, and thiamethoxam. (3) Includes neonicotinoid products based on clothianidin, imidacloprid, and thiamethoxam.

Plots planted with neonicotinoid-treated seed pieces or a soil-applied neonicotinoid insecticide

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[54] As in previous sections, we use ANOVA and Wilcoxon signed-rank tests to assess the significance and magnitude of differences in yield. If the output is pest population or pest damage, we use only the Wilcoxon signed-rank test.

produced significantly more potatoes than plots not treated with an insecticide, and yield was less variable. Treated plots produced, on average, 89% of the maximum yield reported in a given study. Plots not treated with an insecticide produced an average of just 73% of the maximum (p=0.002). However, there was no significant difference in yield between seed piece treatments and soil treatments based on neonicotinoids and those based on another insecticide (p=0.813). There was also no difference in yield between insecticide rotations using neonicotinoid-based soil/seed treatments and rotations using only non-neonicotinoid foliar sprays (p=0.126; Table 5.34).

Table 5.34: **Effect of neonicotinoid-based products on potato yield (as a percent of maximum yield) in North American field trials**

		ANOVA results			Signed-ranks test		
Comparison	Paired obs.	**Mean diff.**[1]	**F-value**	**P-value**	**Percent Positive**	**Z-score**	**P-value**
Yield in plots using neonicotinoid-treated seed pieces or soil-applied neonicotinoids compared to:							
Untreated and fungicide-only control plots	38	21%	10.94	0.002	75%	2.66	0.008
Alternative seed piece treatments or soil-applied insecticides	26	1%	0.06	0.813	45%	-0.47	0.639
Plots using only non-neonicotinoid foliar insecticides	120	-3%	2.38	0.126	43%	-1.38	0.182
Yield in plots treated with neonicotinoid-foliar sprays compared to:							
Untreated control plots	6	46%	8.38	0.034	100%	2.20	0.028
Plots using only non-neonicotinoid foliar insecticides	12	6%	7.68	0.018	87%	2.28	0.023

Notes: Results highlighted in green suggest higher yield (as a percentage of maximum reported yield) in neonicotinoid-treated plots than in non-neonicotinoid plots. Results in grey are not statistically significant. (1) Expressed as a percentage of maximum reported yield.

We compared performance of pest management strategies that included or excluded neonicotinoids against two common potato pests: Colorado potato beetle and aphids (see Table 5.35). Aphid populations were significantly lower in strategies including neonicotinoids than in those with no neonicotinoid products ($p < 0.001$). There was no difference in Colorado potato beetle control between plans that included neonicotinoids and those that did not against Colorado potato beetle (p=0.411). However, single-season results would not capture benefits to growers associated with Colorado potato beetle insecticide resistance management. As noted in *Chapter 4*, diverse insecticide rotations are particularly important where Colorado potato beetle is a significant pest.

Table 5.35: **Performance of potato pest management plans including neonicotinoids, relative to those using only non-neonicotinoid insecticides: binomial sign tests of paired North American yield, crop damage, and pest control trials**

			Significantly more successes with:	
	Paired	**Percent**	H_{a1}: **neonic.**	H_{a2}: **alternative**
Comparisons by ***target pest***	obs.	**Positive**	P-value^2	P-value^2
Colorado Potato Beetle	80	51%	0.411	0.674
Aphids	63	92%	< 0.001	> 0.999

			Significantly more successes with:	
	Paired	**Percent**	H_{a1}: **neonic.**	H_{a2}: **alternative**
Comparisons by ***alternative insecticide***^{1}	obs.	**Positive**	P-value^2	P-value^2
Organophosphates (1B)	18	44%	0.760	0.407
Spinosyns (5)	27	56%	0.351	0.779
Anthranilic diamides (28)	183	76%	< 0.001	> 0.999

Results highlighted in green suggest that outcomes (in terms of crop yield, crop damage, or pest control) were better in plots treated with a neonicotinoid product (alone or as part of a season-long insecticide rotation) than in plots using only non-neonicotinoid insecticides in a significant majority of field trials. Results in grey are not statistically significant.

Notes: (1) IRAC group numbers in parentheses (see Table 2.1) (2) The right two columns reflect significance of the null hypothesis that the true proportion of positive to negative mean differences is 1:1 ($H_0 : Prob[D > 0] = \frac{1}{2}$) against two alternative hypotheses: that the neonicotinoid-treated group performs better than the alternative-treated group in a majority of field trials ($H_{a1} : Prob[D > 0] > \frac{1}{2}$) and that the alternative-treated group performed better in a majority of trials ($H_{a2} : Prob[D < 0] > \frac{1}{2}$). This test makes no assumptions about the distribution of data.

Table 5.35 also compares outcomes (in terms of crop yield, crop damage, or pest control) associated with pest management plans including neonicotinoids compared to outcomes with pest management plans including alternative insecticides. There was no significant difference in the number of field trials that observed better or worse outcomes in neonicotinoid-treated plots compared to organophosphate-treated (p=0.760) or spinosyn-treated (p=0.867) plots. However, insect management plans that included neonicotinoids produced better outcomes than insect management plans that included anthranilic diamides (but no neonicotinoids) in a significant majority of potato field trials ($p < 0.001$).

5.5.3 Snap bean

Existing efficacy studies seem to suggest consistent yield and financial benefits from routine, preventive seed treatment in snap bean. As shown in Table 5.37, snap bean plots planted with neonicotinoid-treated snap bean seeds had better outcomes (in terms of yield, crop damage, or pest population) in a significant

Table 5.36: **Number of snap bean field trials reporting significantly positive (green), negative (red), or no difference in yield, crop damage, or pest populations in plots treated with foliar acetamiprid or nitroguanidine neonicotinoid products, compared to untreated controls of plots treated with only non-neonicotinoid insecticides**

	New York State			North America		
Comparison	Y+	Y-	NS	Y+	Y-	NS
Acetamiprid foliar sprays and alternatives						
Foliar acetamiprid vs. untreated controls				3	0	2
Foliar acetamiprid vs. other foliar insecticides				5	0	44
Nitroguanidine neonicotinoid treatments and alternatives						
Nitroguanidine neonicotinoids vs. untreated controls[1]	9	0	0	18	0	15
Nitroguanidine neonicotinoids vs. alternative insecticides[2]	20	0	33	32	1	54

Notes: This analysis compares reported significance of differences in yield, crop damage, or pest populations following an insecticide treatment plan that included a neonicotinoid component or an alternative treatment plan that (a) used only non-neonicotinoid insecticides or (b) used no insecticides. (1) Includes products based on imidacloprid and thiamethoxam. (2) Includes products based on imidacloprid and thiamethoxam.

number of field trials compared to plots using an alternative insecticidal seed treatment[55] ($p=0.002$), soil-applied insecticide[56] ($p < 0.001$), or untreated controls ($p < 0.001$).

Outcomes for plots using neonicotinoid-based foliar sprays had were similar to those in plots using other foliar insecticides. There were no significant differences in the number of field trials finding better or worse outcomes between snap bean plots using neonicotinoid-based foliar sprays and those using other foliar sprays (Table 5.37).

5.5.4 Sweet corn

With the exception of flea beetles (which vector Stewart's wilt), the major early-season insect pests of sweet corn are the same as those for field corn. However, neonicotinoid-treated seeds may be more valuable in sweet corn, both because sweet corn is usually planted later than field corn (so the 2-4 week window of protection from treated seeds is more likely to protect against mid-season pests) and because the economic threshold for insect damage is lower for sweet corn than for field corn. Growers also have fewer alternatives to neonicotinoid-treated seeds than in field corn: chlorantraniliprole-based seed

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[55] This data set included seeds treated with the anthranilic diamides chlorantraniliprole (10) and cyantraniliprole (6), the organophosphate chlorpyrifos (10), the phenylpyrazole fipronil (6), and the triazine insect growth regulator cyromazine (6).

[56] Based on comparisons to chlorantraniliprole-based seed treatments.

Table 5.37: **Performance of neonicotinoid-based insecticides on snap bean, relative to non-neonicotinoid insecticides: binomial sign tests of paired North American yield, crop damage, and pest control trials**

Comparison	Paired obs.	**Percent Positive**	Significantly more successes with: H_{a1}: **neonic.** P-value^2	H_{a2}: **alternative** P-value^2
Neonicotinoid-treated seeds vs. untreated controls	19	95%	< 0.001	> 0.999
Neonicotinoid-treated seeds vs. alternative insecticide-treated seeds	41	73%	0.002	0.999
Neonicotinoid-treated seeds vs. soil-applied alternative insecticides	8	100%	< 0.001	> 0.999
Foliar acetamiprid vs. non-neonicotinoid foliar insecticides	44	41%	0.785	0.318
Foliar nitroguanidine neonicotinoids vs. non-neonicotinoid foliar insecticides	10	40%	0.746	0.500

Results highlighted in green suggest that outcomes (in terms of crop yield, crop damage, or pest control) were better in plots treated with a neonicotinoid product than in comparison plots using non-neonicotinoid products in a significant majority of field trials. Results in grey are not statistically significant.

Notes: (1) The right two columns reflect significance of the null hypothesis that the true proportion of positive to negative mean differences is 1:1 ($H_0 : Prob[D > 0] = \frac{1}{2}$) against two alternative hypotheses: that the neonicotinoid-treated group performs better than the alternative-treated group in a majority of field trials ($H_{a1} : Prob[D > 0] > \frac{1}{2}$) and that the alternative-treated group performed better in a majority of trials ($H_{a2} : Prob[D < 0] > \frac{1}{2}$). This test makes no assumptions about the distribution of data.

treatments are not currently labeled for sweet corn use in the United States.

This analysis draws on eight studies of neonicotinoid efficacy in sweet corn, allowing 19 pairwise yield comparisons and 51 pairwise crop damage comparisons. Mean yield in plots planted with neonicotinoid-treated seeds was 15% (2183 kg unhusked ears per hectare ± 274) higher than in untreated or fungicide-only control plots ($p < 0.001$) (see Table 5.39). In studies that focused on sweet corn stands (a measure of crop damage), plots planted with neonicotinoid-treated seeds had higher stand counts than untreated controls ($p < 0.001$), but not fungicide-only controls ($p=0.397$).

5.5.5 Squash, pumpkin, and other cucurbits

Plots using nitroguanidine neonicotinoid treatments had significantly better grower outcomes (in terms of crop yield, crop damage, or pest populations) than untreated controls in 8 of 18 regional field trials and 38 of 60 North American field trials gathered for this study (see Table 5.40). In studies comparing neonicotinoid products to other insecticides, results were mixed.

Table 5.38: **Number of sweet corn field trials reporting significantly positive (green), negative (red), or no difference in yield, crop damage, or pest populations in plots treated with neonicotinoid products, compared to untreated controls of plots treated with only non-neonicotinoid insecticides**

	NYS & region[1]			North America		
Comparison	Y+	Y-	NS	Y+	Y-	NS
Nitroguanidine neonicotinoids vs. untreated controls	4	0	2	19	1	30
Nitroguanidine neonicotinoids vs. alternative insecticides				5	5	1

Notes: This analysis compares reported significance of differences in yield, crop damage, or pest populations following an insecticide treatment plan that included a neonicotinoid component or an alternative treatment plan that (a) used only non-neonicotinoid insecticides or (b) used no insecticides. (1) Regional results used data from field trials in New York and Ontario. (2) Includes products based on clothianidin, imidacloprid, and thiamethoxam. (3) Includes products based on clothianidin and imidacloprid.

Table 5.39: **Effect of neonicotinoid-treated seeds on sweet corn yield and stand, relative to control plots: North American field trials**

		ANOVA results			Signed-ranks test		
Comparison	Paired obs.	**Mean diff.**[1]	**F-value**	**P-value**	**Percent Positive**	**Z-score**	**P-value**
Yield (kg of unhusked ears/ha): NTS[1] vs. untreated controls	18	15%	31.8	< 0.001	95%	3.376	0.001
Sweet corn stand (percentage): NTS vs. untreated controls	21	54%	73.74	< 0.001	100%	4.017	< 0.001
Sweet corn stand (percentage): NTS vs. fungicide-only controls	21	3%	0.75	0.3971	70%	1.601	0.110

Notes: Results highlighted in green suggest significantly higher yield or significantly higher stand count in plots planted with neonicotinoid-treated seeds, compared to the given control group. Results in grey are not statistically significant. (1) Neonicotinoid-treated seeds.

Regional pairwise yield comparisons are drawn from field trials of Pennsylvania pumpkin, Pennsylvania muskmelon, and Ohio pumpkin. In 14 of 21 pairs (67%), yield was lower in untreated and fungicide-only controls than in plots receiving a neonicotinoid-based treatment.[57] This result falls short of statistical significance in the regional data set (p=0.095). In the broader North American data set, neonicotinoid-treated plots out-produced control plots in 34 of 42 paired results (81%, p < 0.001) and yield was also greater compared to alternative chemical insecticides in 45 of 77 pairs (58%, p=0.040).

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[57] In 2 pairs, treated cucurbits were grown from a neonicotinoid-treated seed; in the remainder, plants were treated with a neonicotinoid at transplanting from greenhouse to field.

Table 5.40: **Number of cucurbit field trials reporting significantly positive (green), negative (red), or no difference in yield, crop damage, or pest populations in plots treated with foliar acetamiprid or nitroguanidine neonicotinoid products, compared to untreated controls of plots treated with only non-neonicotinoid insecticides**

	NYS & region[1]			North America		
Comparison	Y+	Y-	NS	Y+	Y-	NS
Acetamiprid foliar sprays and alternatives						
Foliar acetamiprid vs. untreated controls	0	0	3	0	0	4
Foliar acetamiprid vs. other foliar insecticides				3	3	8
Nitroguanidine neonicotinoid treatments and alternatives[2]						
Nitroguanidine neonicotinoids vs. untreated controls	8	0	10	38	0	22
Nitroguanidine neonicotinoids vs. alternative insecticides				21	11	71

Notes: (1) Regional results used data from field trials in Ohio and Pennsylvania. This analysis compares reported significance of differences in yield, crop damage, or pest populations following treatment using (a) a foliar neonicotinoid (acetamiprid or nitroguanidine neonicotinoid(s)) product or (b) a non-neonicotinoid foliar insecticide or no insecticide treatment (untreated control).

5.6 Ornamentals, turf, and landscape management

In a 2014 survey of professionals in several segments of the turf and ornamental industries, between 43% (landscape ornamentals) and 68% (lawncare professionals) of respondents expected their company's income to decline if it could no longer use neonicotinoids [628]. Most expected that switching to non-neonicotinoid products would entail higher labor costs and more applications of insecticides.

In pest control efficacy studies on turf, neonicotinoid-based products were highly effective compared to untreated control plots. Neonicotinoid-treated plots had significantly less turf damage or lower pest populations than untreated controls in 54 of 78 North American field trials (69%) (see Table **??**). In comparisons to other insecticides, neonicotinoid-treated turf plots had less pest damage or lower pest populations in 49 of 250 field trials (20%); non-neonicotinoid alternatives performed significantly better in just 11 of 250 trials (4%).

As shown in Table 5.42, imidacloprid-based products are especially effective against white grubs, the most important insect pest of turf in New York State. Test plots treated with an imidacloprid-based product had less turf damage from or lower populations of white grubs in a significant majority of regional field trials ($p < 0.001$). We extend this analysis using the full North American data set, which has sufficient data for efficacy comparisons of neonicotinoids with four groups of alternatives:

Table 5.41: **Number of turfgrass field trials reporting significantly positive (green), negative (red), or no difference in yield, crop damage, or pest populations in plots treated with foliar acetamiprid or nitroguanidine neonicotinoid products, compared to untreated controls of plots treated with only non-neonicotinoid foliar insecticides**

	New York State			NYS & region[1]			North America		
Comparison	Y+	Y-	NS	Y+	Y-	NS	Y+	Y-	NS
Nitroguanidine neonicotinoid products vs. **untreated controls**[2]	6	0	3	44	1	11	54	1	22
Nitroguanidine neonicotinoid products vs. **alternative insecticides**[3]	5	0	40	43	6	146	49	11	190

Notes: This analysis compares reported significance of differences in yield, crop damage, or pest populations following an insecticide treatment plan that included a neonicotinoid component or an alternative treatment plan that (a) used only non-neonicotinoid insecticides or (b) used no insecticides. (1) Regional results used data from field trials in New York, Massachusetts, New Hampshire, Ohio, and Pennsylvania. (2) Includes products based on clothianidin, dinotefuran, imidacloprid, and thiamethoxam. (3) Includes products based on clothianidin, dinotefuran, imidacloprid, and thiamethoxam.

anthranilic diamides (chlorantraniliprole), pyrethroids (bifenthrin, cyfluthrin, deltamethrin, and lambda-cyhalothrin), biological insecticides (several formulations) incorporating a strain of the bacterium *Bacillus thuringiensis*, and biological insecticides (several formulations) incorporating the fungus *Beauveria bassiana*. The neonicotinoid-treated plots had less turf damage from or lower populations of white grubs in a significant majority of comparisons with pyrethroids and the biological insecticides. However, the anthranilic diamide chlorantraniliprole provided better white grub control than neonicotinoid products in a significant majority of trials. Anthranilic diamides are, like neonicotinoids, systemic insecticides labeled for preventive treatment of common turf pests. Outside of Long Island,[58] anthranilic diamides are the only preventive alternative to neonicotinoids for controlling white grub on turf.

Switching from neonicotinoid soil treatments to anthranilic diamides would, however, add substantial costs for turfgrass managers. It would cost roughly $365/acre to purchase enough Acelepryn G (which uses the anthranilic diamide chlorantraniliprole) to treat turf at the maximum labeled rate for white grub.[59] It would cost just $125 to use the imidacloprid-based Merit 0.5G. Generic imidacloprid-based products are still less expensive. A switch from neonicotinoids to anthranilic diamides would likely not result in significant changes to labor, equipment, or other application and scouting costs

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[58] Anthranilic diamides may not be used on Long Island.

[59] This represents only the product purchase price, based on average prices from online retailers.

associated with pest management on turf.

Table 5.42: **Performance of imidacloprid products against turfgrass pests, relative to non-neonicotinoid insecticides: binomial sign tests of paired turf damage and pest control trials**

				Significantly lower pest counts with[1]:	
Imidacloprid products compared to:	Target pest	Paired obs.	Percent Positive[2]	H_{a1}: **neonic.** P-value	H_{a2}: **alternative** P-value
Regional data*: Comparisons of turf damage from or populations of target pests following treatment with imidacloprid or a non-neonicotinoid alternative*					
Alternative insecticides	White grubs	101	66%	< 0.001	> 0.999
Alternative insecticides	Billbugs	43	23%	> 0.999	0.001
Alternative insecticides	Leatherjackets	9	67%	0.145	0.965
North American data*: Comparisons of turf damage from or populations of white grubs following treatment with imidacloprid or a non-neonicotinoid alternative, by mode of action*					
Anthranilic diamides	White grubs	66	23%	0.998	0.005
Pyrethroids	White grubs	35	74%	0.002	> 0.999
Bt var. japonensis	White grubs	5	100%	0.031	> 0.999
Beauveria bassiana	White grubs	8	100%	0.004	> 0.999

Notes: Results highlighted in **green** suggest that turfgrass plots treated with a neonicotinoid insecticide had significantly less insect damage or lower pest populations compared to plots treated with a chemical alternative. Results highlighted in **red** suggest significantly greater insect damage or higher pest populations in neonicotinoid-treated plots. Results in **grey** are not statistically significant.

(1) The right two columns reflect significance of the null hypothesis that the true proportion of positive to negative mean differences is 1:1 ($H_0 : Prob[D > 0] = \frac{1}{2}$) against two alternative hypotheses: that the neonicotinoid-treated group performs better than the alternative-treated group in a majority of field trials ($H_{a1} : Prob[D > 0] > \frac{1}{2}$) and that the alternative-treated group performed better in a majority of crop damage trials ($H_{a2} : Prob[D < 0] > \frac{1}{2}$). This test makes no assumptions about the distribution of data. (2) Percent of field trials that reported less pest damage or lower pest populations in neonicotinoid-treated plots than in plots treated with an alternative insecticide.

Switching from neonicotinoids to "next-best" insecticides would entail additional pest management costs for some landscape ornamentals and nursery plants. Target pests of particular concern include white grub, viburnum leaf beetle, and armored scale insects. For white grub, the marginal costs of control in landscapes would be similar to those in turf: outside of Long Island, chlorantraniliprole is the active ingredient most likely to substitute for imidacloprid (with the attendant costs described above). On Long Island, professionals would likely rely on curative applications of a pyrethroid or organophosphate. While these substitutes are not expensive, switching to curative treatments would require more extensive (and therefore expensive) scouting. In nurseries, chlorantraniliprole is not available for container-grown plants; growers would likely turn to pyrethroids and organophosphates (e.g., bifenthrin and chlorpyrifos) for white grub control. Replacing imidacloprid with these products as a drench at planting or a curative treatment for grubs in late summer would be no more expensive in terms of product cost; product costs are comparable at common application rates. However, additional costs could by associated with replacing imidacloprid with these alternatives if growers must scout for pests more often or if their new insecticide choice requires more worker protections.

Nurseries managing for viburnum leaf beetle could turn to organophosphate, pyrethroid, and (for larvae) spinosyn alternatives. However, these alternatives come with increased expenses due to additional labor costs. While a single application of imidacloprid can control adults for a full season, the same is not true for these alternatives; frequently monitoring and, if needed, repeated insecticide applications would increase labor costs.

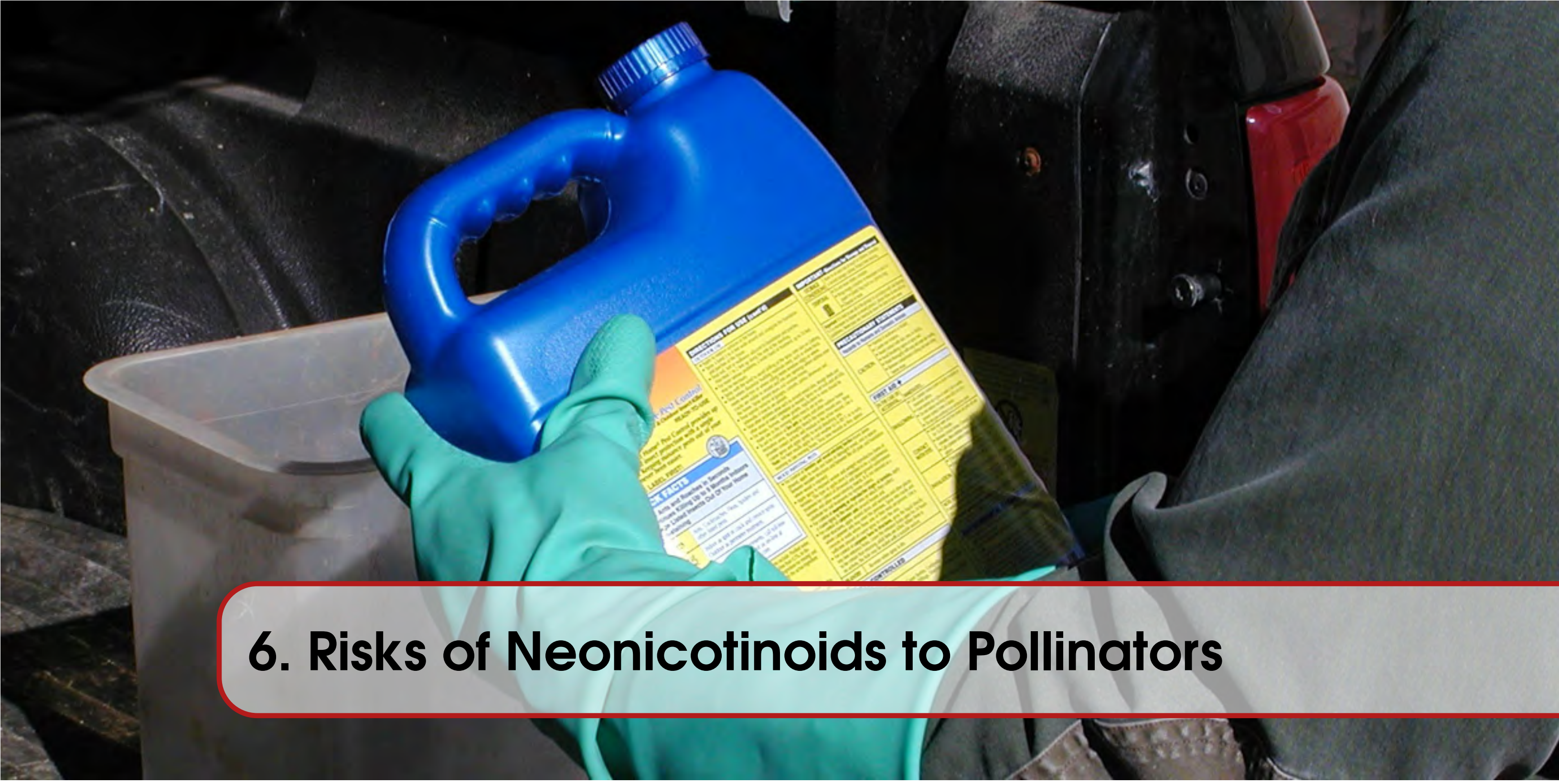
Management of armored scale insects (e.g., elongate hemlock scale and cryptomeria scale) could be significantly more difficult and costly without neonicotinoids. As noted in the previous chapter, neonicotinoids' persistence and systemic mode of action give users longer protection and more flexibility in application timing than any current alternatives. Growers using foliar sprays may need to make several well-timed applications to ensure an effective dose reaches scale crawlers while they are still vulnerable to insecticides.

5.7 Conservation and forestry

There are currently no alternatives to neonicotinoid-based products for large-scale chemical control of hemlock woolly adelgid. If uncontrolled, hemlock woolly adelgid spreads easily and kills almost 100% of trees infested. As such, the value of this neonicotinoid application, at present, is nearly equivalent to the value of retaining hemlocks in New York forests. The Eastern hemlock is the third most common tree in the state (up to 60% of trees in some watersheds), and is a foundation forest species. It provides irreplaceable habitat for native species, including several dozen native bird species [915]. Eastern hemlock even plays an important role in supporting freshwater fish populations. Trout are often associated with hemlock, to the extent that an older name for brook trout was "hemlock trout." In the Delaware Water Gap, there are three times as many trout in watersheds with hemlock than in hardwood dominated watersheds [758]. A major decline in the hemlock population (let alone its complete loss) would be costly to the state. Economic impacts in affected communities could include property value decline [406], costs related to removal and replacement of dead trees [27], and loss of tourism and recreational resources [714]. However, these pale in importance next to the enormous potential ecological and aesthetic impacts on the state.

Imidacloprid is also the mainstay of quarantine and eradication efforts for Asian longhorned beetle. As noted in Section 4.5, this pest has the potential to cause major impacts to New York forests. Maples, elms, birches, horse chestnuts and poplars are all susceptible. State control efforts have been successful to date; within New York, Asian longhorned beetle is currently contained to central Long Island. With no substitute available, eliminating this use of imidacloprid could greatly increase the pest's economic and ecological costs in New York.

Emerald ash borer is the most expensive forest pest in history. Across the United States, the annual cost of tree treatment, removal, and replacement related to emerald ash borer is likely over $1 billion [460, 27]. However, more alternatives to neonicotinoids are available for this pest than for hemlock woolly adelgid and Asian longhorned beetle. Several products based on emamectin benzoate, azadirachtin, and pyrethroids are effective. Treatment with emamectin benzoate, in particular, provides longer-lasting protection than neonicotinoids at a comparable cost [460, 386, 387].



6. Risks of Neonicotinoids to Pollinators

In this chapter, we summarize the environmental risks of neonicotinoid usage, focusing specifically on non-target risk to pollinators. We do not cover risk to other non-target organisms such as invertebrates, amphibians, and fish in aquatic ecosystems, and non-pollinator arthropods and birds in terrestrial ecosystems. We also do not cover linkages between aquatic and terrestrial ecosystems, since those topics are not within the scope of this risk assessment. In addition, we do not address risk to human health in this section. Instead, risk to human health is briefly described in Section 2.4 and the reader is encouraged to explore the substantial research summarized on this topic by the USEPA and NYSDEC [971, 974, 978, 983, 989]. The USEPA and NYSDEC each consider risks to non-target organisms, including pollinators, when determining whether and how neonicotinoid pesticides may be used. A comprehensive list of risk assessments that have been completed by the USEPA since 2016 regarding neonicotinoid insecticides is shown in Table 6.1.

As explained in *Chapter 2*, risk from a pesticide is a product of hazard (i.e., its toxicity) and exposure. Thus, risk is the likelihood that exposure in real-world settings will cause harm to an organism. In this chapter, we focus mainly on assessing risk from neonicotinoid insecticides to the western honey bee, *Apis mellifera*. There are two reasons for this focus. First, *A. mellifera* is used as a model organism for toxicological studies by the USEPA, regulatory agencies outside of the U.S., and many academic laboratories. Thus, a relatively large amount of data exists regarding pesticide hazards

Table 6.1: **USEPA registration review for neonicotinoid insecticides: preliminary risk assessments and proposed interim decisions**

	Acetamiprid	Clothianidin	Dinotefuran	Imidacloprid	Thiamethoxam
Human health risks	Dec-17 [971]	Sep-17 [974]	Sep-17 [978]	Jun-17 [983]	Dec-17 [989]
Dietary exposure and risk	Dec-17 [969]	Aug-17 [973]	Jun-17 [980]	Jun-17 [982]	Aug-17 [988]
Occupational and residential exposure	Dec-17 [972]	Sep-17 [975]	Sep-17 [979]	Jun-17 [984]	
Pollinator risk	Dec-17 [970]	Jan-17 [985]	Jan-17 [976]	Jan-16 [965]	Jan-17 [985]
Risks to terrestrial ecosystems	Dec-17 [970]		Nov-17 [977]	Nov-17 [990]	Nov-17 [987]
Risks to aquatic ecosystems	Dec-17 [970]		Nov-17 [977]	Dec-16 [967]	Nov-17 [987]
Proposed interim decisions	**Jan-20 [995]**	**Jan-20 [996]**	**Jan-20 [997]**	**Jan-20 [998]**	**Jan-20 [996]**

Notes: The USEPA has published the above reports in the course of its ongoing review of neonicotinoid pesticide registrations. These are not the only published documents from that review, nor do they represent all data and priorities considered. The proposed interim decisions summarize the USEPA's findings from the registration review process and the agency's recommendations. We highlight proposed changes that, if accepted, are likely to impact major uses of neonicotinoids in New York State in Section 3.4.

to *A. mellifera*, and a moderate amount of data exists regarding exposure. Second, very little data exists regarding the hazard of pesticides to most other invertebrate pollinators, and even less data exists regarding exposure of pesticides to non-*Apis* pollinators. It is therefore difficult to assess risk from neonicotinoid insecticides and their likely alternatives for most pollinators other than *A. mellifera* given currently available data. This lack of data is of course a major shortcoming of this risk assessment and all similar risk assessments that have been conducted to date on this topic.

We begin this section by describing the diversity and status of New York's pollinators, then estimating the direct value of pollinators to New York's agricultural economy (Section 6.1). We do not attempt to estimate the indirect value of New York's pollinators in terms of contributions to tourism, recreation, or other indirect measures; value is only estimated in terms of pollination services to crops and products sold by New York's beekeepers. Next, in Section 6.2 we describe previous federal and state-level risk assessments for neonicotinoid insecticides that have been published to date. In Section 6.3, we discuss the environmental fate of neonicotinoids that can lead to non-target exposures to pollinators, and in Section 6.4 we show data on changes in loading of neonicotinoids and other insecticides to the environment over the past 20 years.

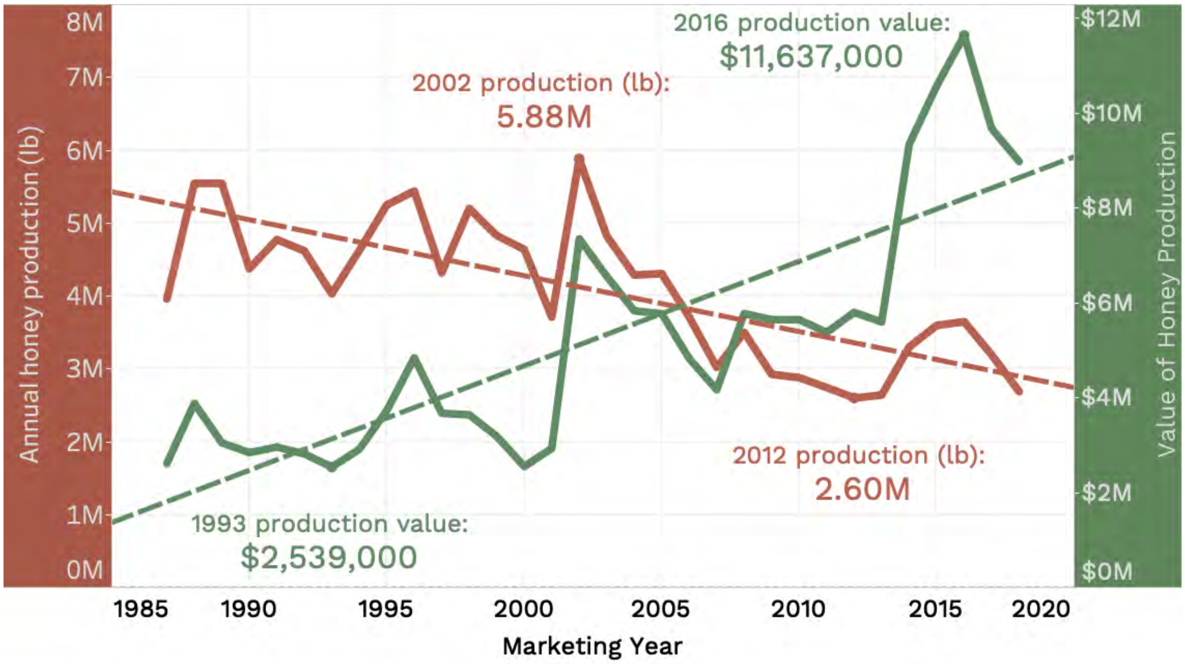
Finally, in Sections 6.5-6.7, which are the main quantitative focuses of this risk assessment, we present original data on pesticide risk to bees in New York, summarize results from a systematic literature review and quantitative risk assessment for bees from neonicotinoid insecticides in the same application contexts highlighted throughout this report (field crops; fruit crops; vegetable crops; ornamentals, turf, & landscape management; and conservation & forestry), then compare risk from common neonicotinoid-based insecticide products to alternatives used in New York. The goal of presenting risk in this way is to provide side-by-side comparisons of the economic benefits (*Chapter 5*) and risk to pollinators (*Chapter 6*) from neonicotinoids and their alternatives in each application context. As in *Chapter 5*, we do not formally address the numerous non-chemical insecticides and IPM methods that can complement, or even replace, chemical control of certain insect pests of New York crops. However, we highlight several of these options in *Chapter 7* and discuss their likely impact on pollinator risk.

6.1 Introduction to New York's pollinators

New York is home to approximately 3,000 beekeepers who manage approximately 80,000 colonies of the western honey bee, *Apis mellifera* [397]. These beekeepers produce numerous products, including honey, wax, nucleus colonies, queens, and other apiary products. Honey is the most valuable product, though production by New York beekeepers has declined over the past several decades (see Figure 6.1) [944]. Between 1987 and 2005, mean annual honey production in New York was 4.7 million pounds. Between 2006 and 2017, mean annual honey production was 3.1 million pounds, with the lowest-producing year in the state's recorded history in 2012 (2.6 million pounds). At the same time, production value has increased due to beekeepers receiving a higher price for their honey (Figure 6.1) [944].

While several factors are likely contributing to reduced honey production in New York, unsustainable losses of managed honey bee colonies are undoubtedly playing a role. Since annual loss data have been systematically recorded (starting in 2010), New York has lost between 40.4% and 68.1% of its managed honey bee colonies each year (mean = 48.9% colonies lost per year) [82]. These loss rates are well above what beekeepers consider acceptable via survey data collected by the Bee Informed Partnership.

Figure 6.1: **New York State annual honey production, 1987-2018**



Data from the USDA Bee and Honey Inquiry Survey [944].

New York is also home to three additional managed bee species. The common eastern bumble bee (*Bombus impatiens*) is used for greenhouse and outdoor pollination of tomatoes and other crops. The mason bee (*Osmia cornifrons*) is used for pollination of early-season crops, especially tree fruits such as apple and cherry. And the alfalfa leafcutter bee (*Megachile rotundata*) is used for mid- to late-season pollination of crops.

6.1.1 Wild bees and other insect pollinators

We estimate from the literature that New York is home to 417 species of bees, 413 of which are wild and unmanaged [321, 535, 281, 820, 819, 25, 767]. Note this is likely an incomplete list of New York bees because no systematic survey has ever been conducted on the wild bees of New York State. This gap in knowledge is currently being remedied via the New York Natural Heritage Program's Empire State Native Pollinator Survey[1], which was undertaken in response to the New York State Pollinator Protection Plan.

Forty-two of the 425 genera of bees in the world occur in New York [562]. Our most common (and speciose) genera are *Andrena*, *Lasioglossum*, *Nomada*, *Sphecodes*, *Megachile*, *Colletes*, *Osmia*, *Hylaeus*, *Melissodes*, *Bombus*, and *Coelioxys*. The majority (54%) of bees in New York are digger bees (ground-nesting, solitary bees), such as *Andrena*, *Lasioglossum*, *Colletes*, and *Melissodes*). Several bee species also make nests in preexisting cavities, such as twigs, hollow stems, beetle burrows, or in sites above ground. This includes the mason bees, the wool carder bees and various resin bees. Mason bees in New York include genera such as *Osmia*, *Hoplitis*, *Prochelostoma*, and *Heriades*. Other cavity- and stem-nesting bees include the leaf-cutter bees in the genus *Megachile*, carder bees in the genus *Anthidium*, *Pseudoanthidium*, and *Paranthidium*, and the yellow-faced bees in the genus *Hylaeus*. Another important group of bees are the carpenter bees, including the small (*Ceratina*) and large (*Xylocopa*) carpenter bees. The carpenter bee *Xylocopa virginica* is common in New York and contributes to crop pollination, but is also an occasional pest, especially of older wooden structures. Finally, cleptoparasitic bees (i.e., bees that lay their eggs in the nests of other bees and trick them such that the other bees feed and rear their offspring) comprise 23% of the bee species in New York. The two largest genera of cleptoparasitic bees are *Sphecodes* and *Nomada*.

The majority of bees in New York are solitary or parasitic, however it is also home to important eusocial bees (i.e., bees with an advanced level of social organization including a reproductive division of labor, overlapping generations, and cooperative care of young). New York's social bees include both ancestral eusocial taxa, in which queens and workers are distinguishable from each other based only on size or behavior, and derived eusocial taxa in which queens and workers are morphologically

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[1] see `http://www.nynhp.org/pollinators`.

distinct (such as *A. mellifera*, the western honey bee). Ancestral eusocial taxa include the 18 species of *Bombus* (bumblebees; Apidae), as well as *Augochlorella*, *Halictus*, and some species of *Lasioglossum* (Halictidae). We estimate that approximately 19 percent of the bee species in New York State are eusocial.

In addition to bees, New York is home to many other pollinators, including hummingbirds, flies, moths, beetles, butterflies, and several other insects. While the relative contribution of each taxa to pollination in New York has not been assessed previously, global data suggest bees, flies, and moths are the most important pollinators, with beetles, butterflies, hummingbirds, and other insects being less prominent pollinators [721].

Of New York's 417 species of bees, 53 species (13%) are known to be experiencing range contractions or population declines [1025, 98, 132, 43, 1055]. This is likely an underestimate of the true conservation status of the state's wild bees, as most species have poor historical records regarding population sizes and range boundaries. Less is known about the conservation status of most other pollinator taxa in New York, with the exception of the monarch butterfly (*Danaus plexippus*). Monarchs have been experiencing well-documented population declines over the past several years [8].

6.1.2 Insect pollinators and New York agriculture

The direct value of pollinators to New York agriculture is two-fold. First, beekeepers in New York produce approximately $10 million of honey annually [944]. In addition, beekeepers produce several million dollars[2] of other apiary products such as wax, nucleus colonies, and queen bees, in addition to value-added goods.

Second, many of New York's most high-value fruits and vegetables are dependent on pollinators for successful production. Major pollination-dependent crops in New York include apple (worth $\tilde{\$}$320 million/year), soybeans ($125 million/year), squash and pumpkins ($38 million/year), cucumbers ($12 million/year), strawberries ($9.5 million/year), peaches ($6.6 million/year), raspberries and blackberries ($5 million/year), pears ($4.4 million/year), and blueberries ($3.6 million/year). As shown in Table 6.2, the total value of all New York pollination-dependent crops is approximately $624 million/year [945]. Based on the reliance of each crop on pollinators for successfully producing fruit (e.g., apples are

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[2] NYSDAM does not estimate production of apiary products other than honey.

Table 6.2: **Estimated direct value of pollination services to New York agriculture**

	Crop	**Value of NYS production**[1]	**Estimate 1, using Morse and Calderone [585]**		**Estimate 2, using Klein et al. [450]**	
			EPD (%)[2]	**Value**[3]	**EPD (%)**[2,4]	**Value**[3]
1	Apples	$ 321,839,333	100%	$ 321,839,333	65%	$ 209,195,567
2	Soybeans	$ 125,701,333	10%	$ 12,570,133	25%	$ 31,425,333
3	Squash	$ 27,615,667	90%	$ 24,854,100	95%	$ 26,234,883
4	Cucumbers	$ 12,184,000	90%	$ 10,965,600	65%	$ 7,919,600
5	Pumpkins	$ 10,625,667	90%	$ 9,563,100	95%	$ 10,094,383
6	Strawberries	$ 9,496,000	20%	$ 1,899,200	25%	$ 2,374,000
7	Peaches	$ 6,698,333	60%	$ 4,019,000	65%	$ 4,353,917
8	Raspberries and blackberries	$ 4,981,000	90%	$ 4,482,900	65%	$ 3,237,650
9	Pears	$ 4,427,000	70%	$ 3,098,900	65%	$ 2,877,550
10	Blueberries	$ 3,667,000	100%	$ 3,667,000	65%	$ 2,383,550
Eight other crops		$ 92,345,489		$ 42,170,956		$ 8,068,972
	Total	**$ 624,111,823**		**$ 439,130,223**		**$ 308,165,406**

Notes: (1) Mean annual value of production, 2016-2018 [945]; (2) Estimated pollinator dependence (EPD) represents expected production reduction in the absence of animal pollination, based on studies by Morse and Calderone [585] and Klein et al. [450]; (3) The estimated direct value of pollination, here, is the value of NYS production multiplied by the EPD of a given crop; (4) Mean values from Klein et al. [450].

highly reliant on pollinators, whereas many cultivars of soybeans are not highly reliant on pollinators), we estimate that direct pollination services to New York's crops are worth between $308 million and $439 million annually (see Table 6.2). It is important to note that this figure does not include indirect benefits pollinators provide to agriculture by maintaining plant populations important for livestock forage, soil erosion, water quality, and other ecosystem services. For comparison with the values shown in Table 6.2, Gallai et al. [305] estimated the value of pollination services to the global economy at approximately $170 billion/year, and Calderone [93] estimated that pollination services contribute over $15 billion annually to the U.S. economy.

6.2 Regulatory reviews of neonicotinoid risks

Each of the major neonicotinoids used in New York State have undergone comprehensive risk assessments at the federal and state level. As required for registering any pesticide product, the USEPA conducted an extensive review to assess potential risks associated with each neonicotinoid active ingredient before registering any product containing them. The USEPA is also currently undertaking a regularly scheduled review of neonicotinoid active ingredients, and has released updated assessments of ecological and human health risks. The NYSDEC conducted its own reviews before granting state registrations for neonicotinoid-based products, and also published an additional analysis in support of the Long Island Pesticide Pollution Prevention Strategy. This section describes the review processes used by the USEPA, NYSDEC, and major output documents published to date.

6.2.1 U.S. Environmental Protection Agency risk assessment

The principal federal laws governing pesticides are the FIFRA[3] and the Federal Food, Drug and Cosmetic Act (FFDCA)[4]. With few exceptions, each use of a pesticide must be registered by the USEPA. The USEPA, in turn, is responsible for evaluating the benefits and risks of each registered pesticide product to people and the environment. It may impose a wide variety of conditions and restrictions on the use of pesticide products [956, 266, 311]. If the use of a product will lead to residues in food or animal feed, the USEPA must also establish pesticide tolerances: maximum residues allowed on crops at harvest to ensure a reasonable certainty of no harm from dietary exposure[5] [1112].

The USEPA conducts a comprehensive risk assessment prior to registration of pesticides with a new active ingredient, and the company applying for registration is responsible for providing sufficient scientific data for the USEPA to evaluate likely risks [961]. Data requirements laid out in USEPA regulations[6] list well over 100 tests (each with agency-approved protocols) that may be required for registration, depending on the nature of the product and expected use patterns. A company seeking to register, for instance, a conventional pesticide with a new active ingredient would have to generate and provide extensive data on product chemistry, product performance, acute and chronic toxicology, ecological effects (including to honey bees), possible human exposure, environmental fate, and characteristics of pesticide residues. However, FIFRA grants the USEPA a great deal of flexibility in setting the data needs for a given application. The agency may choose to waive certain data requirements if existing data are either sufficient or if the requested pesticide use pattern indicates

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[3] 7 U.S.C. ch. 6 § 136 et seq.

[4] 21 U.S.C. §301 et seq.

[5] For a more comprehensive summary of U.S. pesticide laws, see Yen and Esworthy [1112].

[6] 40 CFR 158

that particular data would be unnecessary (e.g., effects on honey bees if the use pattern is indoors only). It can also impose additional data requirements if the studies described in its regulation are insufficient to evaluate risks. In addition to registrant-provided studies, the USEPA also considers research from the open literature and solicits input from other agencies and the public.

The agency takes earlier risk assessments into account when considering new pesticide products or new proposed uses of currently registered products [961]. In general, the USEPA does not ask registrants to duplicate research conducted for earlier reviews; registrants need only submit new data insofar as a proposed formulation or use is substantially different than approved uses of already-registered products. For example, the USEPA might require a company planning to use an already-registered product on a new crop to submit data on new risks (if any) associated with that specific use.

As required by the Food Quality Protection Act, all active ingredients must undergo registration review every 15 years[7]; the review can take years to complete. During a registration review, the agency assesses whether a given pesticide still meets FIFRA requirements in light of new research, changes in risk assessment standards, changes in use patterns and/or volume, and/or regulatory and policy actions [959]. As in the initial registration process, the agency has broad discretion to expand the scope of its review. It may require registrants to submit new data if previous studies are insufficient given changes in the years since initial registration. As appropriate, it may disallow specific uses of the product, impose new restrictions, require mitigation by users, or even cancel a pesticide's registration altogether [1112].

The USEPA issued its first registrations of imidacloprid-based products in 1994, publishing pesticide tolerances the same year [955]. The other major neonicotinoids followed between 1999 and 2004 (see Table 3.1). The USEPA is in the last stages of a routine registration review for all five common neonicotinoids, having issued proposed interim decisions in January, 2020.

Specifically related to pollinators (and more specifically using the honey bee, *A. mellifera*, as a model organism), the USEPA has conducted risk assessments for all five neonicotinoids used in New York: acetamiprid [970], clothianidin [985], dinotefuran [976], imidacloprid [965], and thiamethoxam [985]. We draw on data from these USEPA risk assessments in this chapter. In addition, we draw on

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[7] The USEPA began its registration review of neonicotinoids between 7 and 14 years after the active ingredients' initial registrations. This timing allows for concurrent review of the neonicotinoids and supports regulatory consistency within IRAC group 4A [994].

the peer-reviewed literature that may or may not have been considered by the USEPA in their risk assessments.

6.2.2 New York State Department of Environmental Conservation reviews

Although the USEPA oversees pesticide regulation at the federal level, FIFRA delegates authority for implementation and enforcement to responsible state agencies[8] [849]. States retain a great deal of regulatory authority, provided that state regulations do not permit pesticide uses or sales prohibited under federal regulations. State regulations may be more restrictive than federal law. States may issue Special Local Needs registrations[9] allowing uses not covered by a pesticide product's current label. States can also approve limited variations from pesticide labels under another FIFRA provision (2(ee) recommendations). This allows states flexibility in responding to local developments (e.g., the arrival of an invasive pest) [608].

Article 33 of New York's Environmental Conservation Law assigns responsibility for regulation of pesticides to the NYSDEC. Prior to registering products with a new active ingredient, the NYSDEC conducts a risk assessment. Applicants must submit all documents relevant to USEPA review and registration. The NYSDEC may require applicants to provide additional reports or data [608]. Based on its review, the NYSDEC may identify concerns which can be mitigated by state- or county-specific restrictions or additional label statements [607]. States cannot require label changes; however, registrants can change their federally approved pesticide label in order to mitigate state-specific concerns.

Over 570 neonicotinoid-based products are registered with the NYSDEC[10]. However, as noted in Section 4.3, the agency has imposed state-specific restrictions on the use of dinotefuran, imidacloprid, and thiamethoxam (see Table 3.2). The NYSDEC has not registered any clothianidin-based insecticides for outdoor agricultural use. Its decision cites potential risks to groundwater, as well as to fish and wildlife, that were not adequately addressed by registrant-submitted data [603]. The NYSDEC denied applications to register dinotefuran-based insecticides for outdoor agricultural use on a similar basis: "potential for unacceptable risks to non-target organisms and groundwater resources" [604].

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[8] FIFRA allows the USEPA to retain these powers if a given state fails to meet standards laid out in 7 U.S. Code §136.

[9] Also called 24(c) registrations, after the FIFRA section allowing them.

[10] Of these, 170 are registered for flea and tick control on domestic animals.

Imidacloprid users on Long Island are subject to additional restrictions to protect Long Island's shallow, vulnerable aquifer. As a condition for registering imidacloprid-based products in 1995, the NYSDEC required Bayer CropScience to establish groundwater monitoring sites in Long Island. In response to imidacloprid detections from groundwater monitoring wells,[11] NYSDEC sought additional data from the registrant and studied options to reduce imidacloprid infiltration of the aquifer [600]. It ultimately imposed further restrictions on many uses of imidacloprid on Long Island [607, 606, 609].

6.3 Environmental fate of neonicotinoid insecticides

To evaluate risk to pollinators, it is first important to understand how pollinators may be exposed to insecticides. Pesticide use always entails some potential for exposures to non-target organisms, and neonicotinoids are no exception. Non-target exposures may occur if pollinators are present at a site during application, via transport of the insecticide away from the application site to a location where pollinators are present, or via persistence at the application site such that pollinators are exposed after the application occurs. The USEPA mandates that pollinator protection language is present on all product labels for pesticides applied in New York and where the USEPA has determined that risk to pollinators may occur (see Tables 6.4 through 6.8 for several examples). If the labels are followed by applicators (which is mandated by law), risk to pollinators is likely to be minimized. However, it is still possible for exposure to occur. This is the reason for the analyses put forward in this chapter.

6.3.1 Seed treatment dust and spray drift

Drift of dust from treated seeds and aerosols from foliar sprays can transport insecticides away from an application site to a location where pollinators are present, such as wildflowers and soils in field margins, or hives on nearby properties. In New York, allowing pesticides to drift from an application site is illegal. But drift is also difficult to eliminate in 100% of circumstances given constantly-changing environmental conditions and variable possession of the newest drift-reducing technologies for treated seeds and foliar sprays.

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[11] The majority of imidacloprid detections in groundwater monitoring wells were below the NYS drinking water standard of 50 parts per billion (ppb). There were no exceedances of the NYS drinking water standard for imidacloprid in any of the samples taken from public water supply wells [609].

Seed coatings account for the majority of neonicotinoid insecticides used in New York (see *Chapters 3 & 4*), and abrasion of seed coatings during transport, loading, and planting can create insecticide-contaminated dust. This dust can drift from the application site and result in pollinator exposures (see Section 6.6). The amount of dust produced depends on how the seeds are coated, how they're cleaned, the lubricating agent used during planting, the type of planter used, and environmental conditions during planting [12] [630].

The adhesives and methods used during seed coating have a major impact on abrasion and, thus, dust drift. Seed coating technology has improved dramatically since the introduction of neonicotinoids [818, 294], though there is no publicly-available data on the adoption of low-dust coating technologies in New York or elsewhere in the U.S. The choice of seed lubricant also affects seed abrasion and dust. Talc and graphite are commonly added to planter boxes to lubricate seeds during planting, but these lubricants can become contaminated with active ingredients and thereby contribute to dust drift. Advanced seed lubricants, such as Bayer's Fluency Agent Advanced for corn and soybeans, have been shown to reduce dust due to abrasion of seed coatings by more than 88% over talc [51]. However, advanced seed lubricants are significantly more expensive than talc or graphite, and as a consequence are used less commonly. Unfortunately, there are no publicly-available data on the proportion of New York or U.S. growers using advanced seed lubricants as opposed to talc and graphite. Finally, planter technology can also have a major effect on dust drift, combining with environmental conditions like humidity and wind to determine the likelihood of the dust moving throughout the environment [620]. In general, mechanical-type planters produce less dust during planting than vacuum-type machines [630]. In one study, over 90% of neonicotinoid dust surrounding corn fields after planting could be traced back to the exhaust from vacuum-type planters, and another study reported that 12.6% of the active ingredient clothianidin on coated seeds was recovered from the exhaust of a commercial pneumatic planter after seeding fields [1107, 805]. Overall, production of dust drift can be mitigated by using appropriate seed coating formulations and lubricants, redirecting or filtering exhaust of planters, and avoiding planting during dry and windy conditions [294].

Foliar sprays can result in drift of aerosolized insecticides away from an application site to a location

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[12] A standard test (the Heubach test) measures the amount of dust produced per set number or weight of seeds by simulating potential mechanical stress [630].

where pollinators are abundant. Formulation, type of sprayer, wind speed and direction, and other environmental conditions can affect the movement and persistence of sprays through the environment. While it is always possible for sprays to move off-target, smaller droplets are more likely to drift because they stay in the air longer [279]. The height at which droplets are released also influences the time they spend in the air and, therefore, the likelihood that they will move from the application site [279]. It is possible to mitigate spray drift by planting windbreak crops, maintaining spray-free buffer zones, spraying only when the weather is appropriate, and using appropriate nozzle types, shields, spray pressure, dosages, and tractor speeds [279, 396]. Foliar spray exposures to pollinators can also be mitigated by applying the spray when plants are not flowering, or at dawn or dusk when bees are not foraging. Labels on pesticide products intended for foliar use include detailed, legally enforceable application instructions to minimize spray drift.

6.3.2 Persistence/movement in soils and uptake by non-target plants

One advantage of insecticidal seed treatments is they require less active ingredient than an equivalent soil drench or in-furrow granule [21]; the active ingredient is thus more precisely targeted for uptake by the germinating plant. However, the target plant only absorbs between 1.6% and 20% of the active ingredient in an insecticidal seed coating, depending on the crop and environmental conditions [888]. The remainder of the insecticide can persist in soils at the application site, or move from the application site via leaching or transport in surface water or ground water. Similar persistence and movement can occur for active ingredients in foliar sprays that contact soils. This persistence and movement in soils can result in direct soil exposures to pollinators (the majority of New York's 417 species of bees are ground-nesting), and it can also lead to nectar/pollen exposures in field margins via contaminated wildflowers that systemically take up neonicotinoids from the soil (see Section 6.6).

Goulson [325] found that the half-lives of neonicotinoids in soil ranged from fewer than 90 days (dinotefuran) to several years (over 8 years for imidacloprid and 19 years for clothianidin). Persistence in soil depends on pH, temperature, moisture content, organic matter, root systems, and soil structure and soil texture [828, 414, 593, 722]. Similarly, persistence of neonicotinoids in water depends on UV radiation and pH. When in surface water (and therefore exposed to sunlight) the half-lives of imidacloprid, clothianidin, and thiamethoxam are short (<3.5 days) and the half-lives of thiacloprid and acetamiprid are slightly longer (8-68 days) [519]. A study by Lu et al. [519] found that the photolysis of thiamethoxam was negligible at depths greater than 8 cm, indicating longer half-lives in deeper groundwater compared to surface water. Importantly, metabolism of neonicotinoids in soil and water does not render them harmless. For example, some metabolites of imidacloprid are more toxic than the parent compound [414]. Thiamethoxam breaks down, in part, into clothianidin [713], which is similarly toxic to bees.

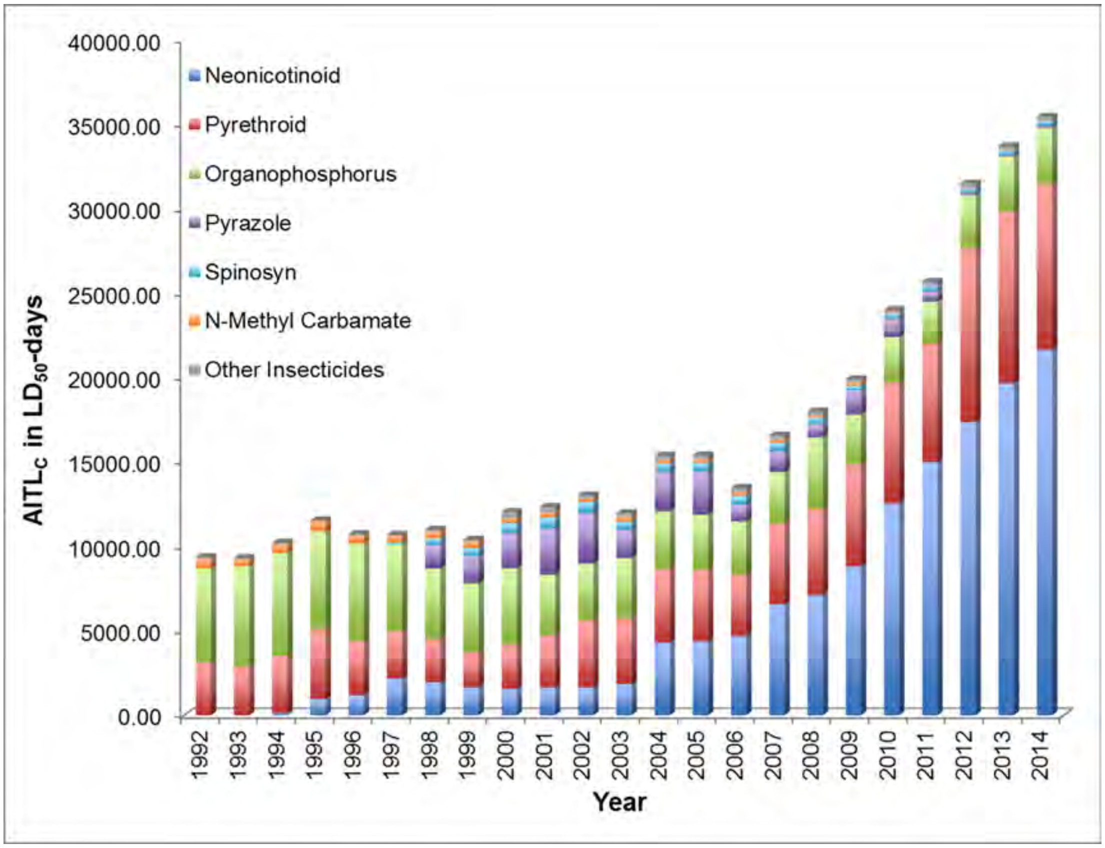
Because movement of neonicotinoids in soil and water is influenced by so many variables, it is difficult to predict the extent to which neonicotinoids will move through the environment in every environmental context. However, neonicotinoids are generally highly mobile compared to most other insecticides due to their high water solubility and other chemical characteristics. Because of this fact (and their systemic activity in plants), numerous studies have found neonicotinoids in pollen and/or nectar of wildflowers in field margins (see Section 6.6). This is true despite evidence suggesting that up to 90% of neonicotinoids in soil are not bioavailable to plants [1106].

6.4 Changes in loading of pesticides to the environment

Several recent efforts in the United States and elsewhere have attempted to quantify changes in pesticide loading to the environment over the past several decades (e.g., DiBartolomeis et al. [201], Douglas et al. [214]). For example, an analysis conducted by DiBartolomeis et al. [201] estimated Acute Insecticide Toxic Load (AITL) from all pesticides used in the United States between 1992 and 2014. The AITL metric is particularly pertinent to the current pollinator analysis since it takes into account two factors: 1) all foliar, soil, and seed-treatment pesticide uses, and 2) toxicity of each pesticide as measured via honey bee LD_{50} values (i.e., the lethal dose for 50% of organisms tested). While considering quantity of each pesticide and its LD_{50} value gives some insight into pesticide hazard, the AITL metric does not estimate exposure and therefore it is not an estimate of risk. Instead, the metric is useful for measuring changes in pesticide loading to the environment, expressed in biological terms (i.e., LD_{50} equivalents) instead of less biologically relevant terms such as pounds of active ingredient.

Results of the DiBartolomeis et al. [201] analysis are striking. Between 1992 to 2014, there was

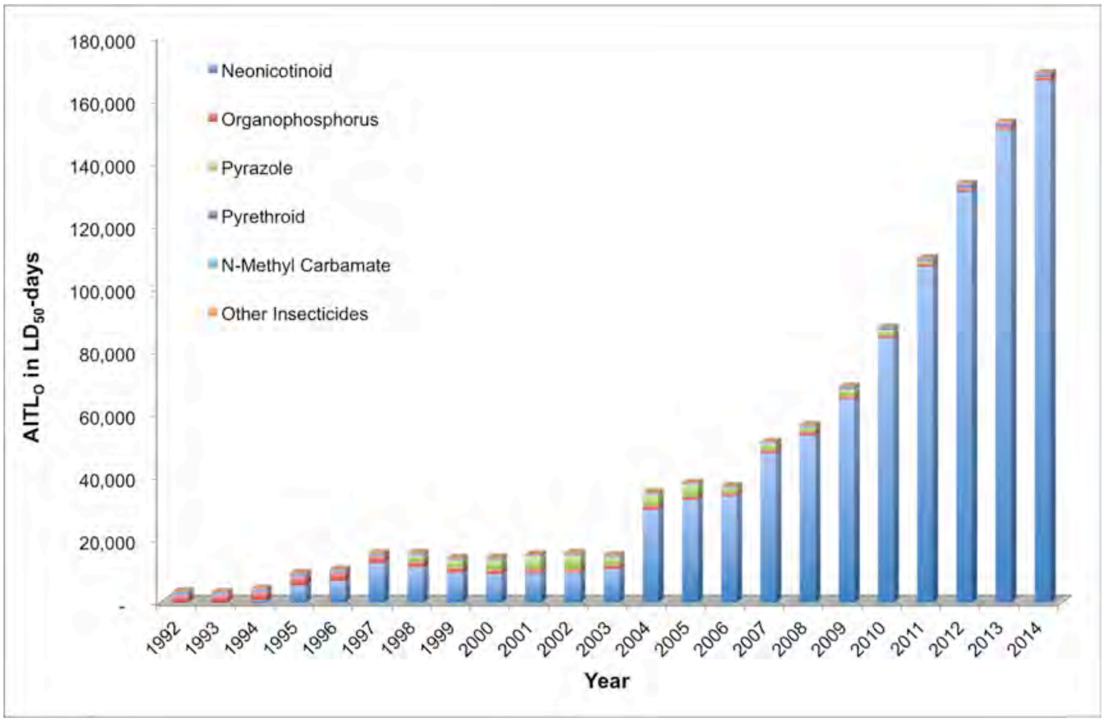
Figure 6.2: **Contact acute insecticide toxicity loading (AITL$_C$) in the United States by chemical class, 1992–2014**



The AITL metric is an estimate of pesticide loading to the environment that has the potential to influence non-target organisms, specifically honey bees. Blue portion of bars represents portion of AITL$_C$ attributed to neonicotinoid insecticides (61% in 2014, the most recent year). Figure from DiBartolomeis et al. [201]

a 4-fold and 48-fold increase in AITL for contact and oral toxicity to honey bees, respectively, from pesticides applied in the United States (Figures 6.2 and 6.3; DiBartolomeis et al. [201]). Widespread adoption of neonicotinoid insecticides during this period was primarily responsible for the increase, with neonicotinoids representing between 61 percent (contact) and nearly 99 percent (oral) of total United States AITL in 2014 (blue portion of Figures 6.2 and 6.3). The crops most responsible for the increase in AITL during this period were corn and soybeans, which is not surprising given the widespread adoption of neonicotinoid seed treatments on these crops over the past approximately 15 years as shown in *Chapter 4*.

Figure 6.3: **Oral acute insecticide toxicity loading ($AITL_O$) in the United States by chemical class, 1992–2014**



The AITL metric is an estimate of pesticide loading to the environment that has the potential to influence non-target organisms, specifically honey bees. Blue portion of bars represents portion of $AITL_O$ attributed to neonicotinoid insecticides (nearly 99% in 2014, the most recent year). The reason neonicotinoids represent a greater proportion of $AITL_O$ than $AITL_C$ is because some of them (particularly clothianidin, imidacloprid and thiamethoxam) are much more toxic to honey bees via oral exposure compared to topical exposure. Figure from DiBartolomeis et al. [201].

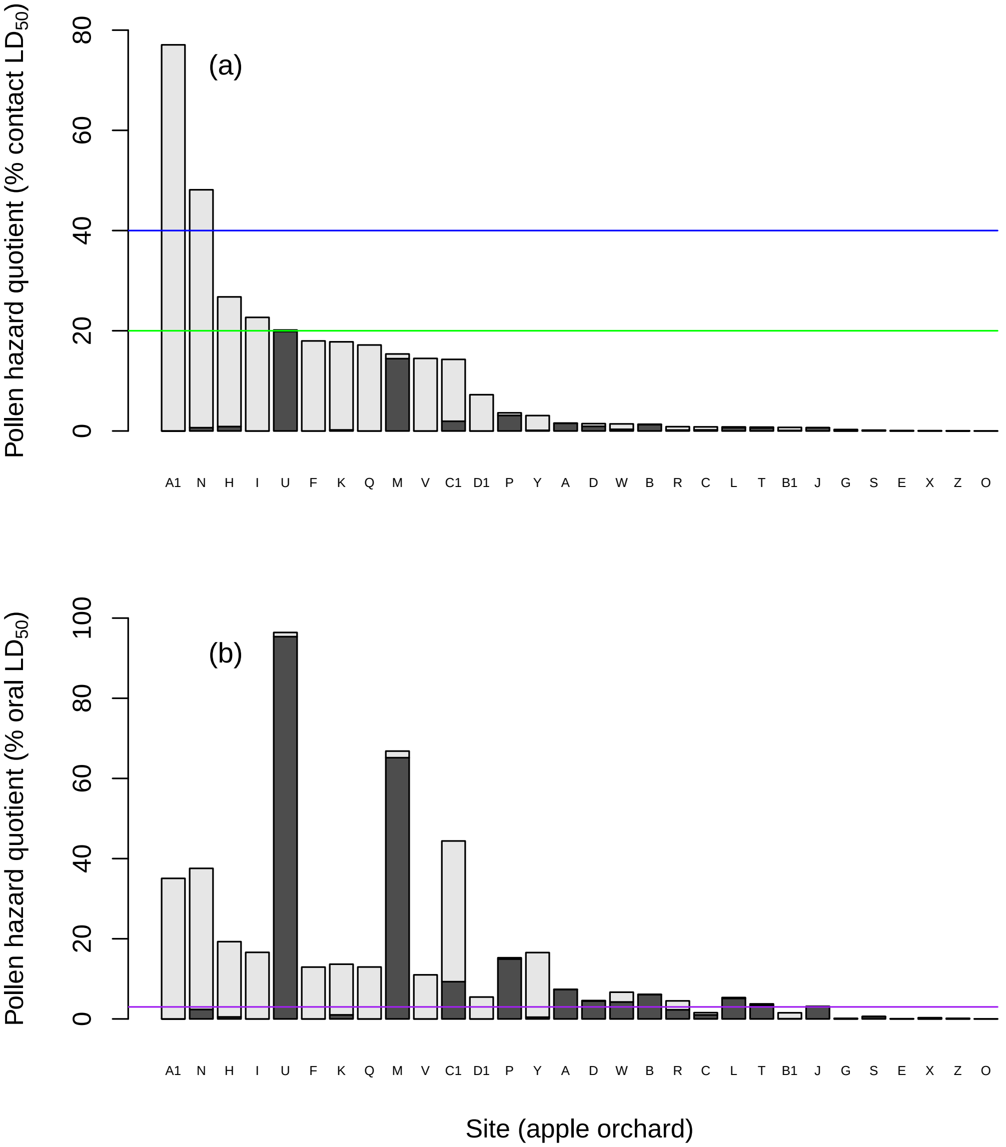
6.5 Risk to pollinators: Hazard Quotient results

As outlined in *Chapter 2* and throughout this chapter, the environmental risk of a pesticide depends on hazard and exposure. A hazard is any potentially harmful effect that a pesticide can have on a person, organism, or ecological system of interest. Exposure is the quantity of pesticide that the person, organism, or ecological system contacts or ingests. Thus, if honey bees are never exposed to any of the pesticides that are released into the environment and contribute to AITL (Figures 6.2 and 6.3), the conclusion would be there is no risk to honey bees. In other words, data regarding exposure are required if the goal is to assess risk from pesticides.

In this section, we summarize risk using the Hazard Quotient (HQ) approach. This metric assesses exposure by quantifying pesticide residues in a given matrix that bees contact or ingest (e.g., pollen or wax), then weights exposure by the toxicity of each pesticide residue by dividing by its LD_{50} value (for a more detailed description, see Section 2.3). Several regulatory agencies (including the USEPA) and peer-reviewed studies use HQ to estimate pesticide risk to pollinators. Perhaps the most comprehensive analysis was that of Sanchez-Bayo and Goka [773], who conducted a worldwide analysis of eighteen studies that assessed more than 100 different in-hive pesticide residues from over 1,000 samples of pollen, wax and honey. The authors made a slight modification to HQ that also considers duration of exposure, but the fundamental metric is the same. Specifically, they defined risk as the probability of reaching LD_{50} in a given amount of time based on exposure levels. If exposure leads to LD_{50} from a pesticide within 2 days, risk is more than 5% (considered high risk). If exposure leads to LD_{50} between 2-7 days, risk is between 1-5% (considered moderate risk). Anything below 1% is considered low risk. From this analysis, five pesticides emerged as exhibiting high risk: thiamethoxam (risk ranging from 3.7–29.6%), phosmet (14.6–23.9%), chlorpyrifos (8.3–12.9%), imidacloprid (10.3–49%), and clothianidin (1.0–13.3%). Three of the five high risk pesticides are neonicotinoids (thiamethoxam, imidacloprid, and clothianidin). These compounds posed high risk to bees based of their prevalence and concentrations in pollen, wax, and honey, and their high toxicity to both honey bees and bumble bees. Thus, from their analysis, Sanchez-Bayo and Goka [773] show that pesticide risk to honey bees and bumble bees can be high in many parts of the world, and three neonicotinoid insecticides contribute substantially to risk.

Within New York, the HQ approach has also been used to determine risk posed to bees from pesticides. A study from McArt et al. [537] found generally high risk from pesticides in pollen collected and used by honey bees during bloom in 30 New York apple orchards. In this study, bee-collected pollen from two orchards was above the USEPA level of concern for acute contact exposure, pollen from five orchards was above the European Food Safety Authority (EFSA) level of concern for acute contact exposure, and pollen from 22 of the 30 orchards was above the EFSA level of concern for 10-day chronic oral exposure (Figure 6.4). Because the hives were in each orchard for 10-13 days (typical for beekeepers conducting apple pollination), the 10-day chronic oral exposure level of concern

Figure 6.4: **Hazard quotient for pesticide residues in honey bee-collected pollen (bee bread) from hives placed at 30 New York state apple orchards during bloom**



Contact (a) and oral (b) pollen hazard quotients (expressed as percent of honey bee LD_{50}) in recently accumulated bee bread collected from hives at 30 New York apple orchard sites during bloom in 2015. Figure adapted from McArt et al. [537] such that **dark gray portion of bars represents proportion of hazard quotient attributed to neonicotinoid insecticides (acetamiprid, clothianidin, imidacloprid, thiacloprid and thiamethoxam)**. Light gray portion of bars represents proportion of hazard quotient attributed to all other pesticides. Solid blue line corresponds to the current United States Environmental Protection Agency level of concern for acute contact exposure (risk quotient = 0.4) [964]. Solid green line corresponds to the European Food Safety Authority (EFSA) level of concern for acute contact exposure (exposure/toxicity = 0.2) [268]. Solid purple line corresponds to EFSA level of concern for 10-day chronic oral exposure (exposure/toxicity = 0.03) [268].

is relevant.

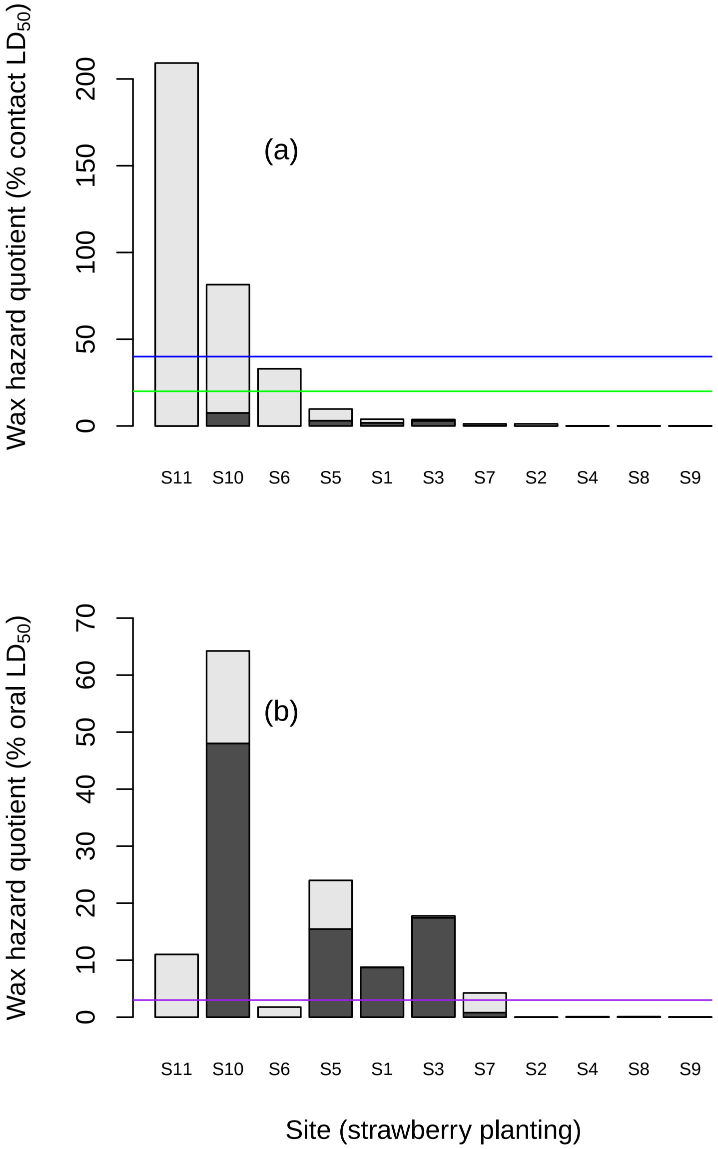
In Figure 6.4, the contribution of neonicotinoid insecticides to contact and oral HQ at each orchard is shown using dark gray shading. Overall, neonicotinoids contributed 15.1% of total risk from contact exposure and 50.4% of total risk from oral exposure across the 30 orchards. Thus, pesticide risk to honey bees during apple pollination in New York can be high, neonicotinoids contribute approximately half of that risk when considering oral exposure, and other pesticides are also important contributors to risk, especially via contact exposure. In a follow-up study to the above, wildflowers in field margins up to 30 m from orchards were tested for pesticide residues [536]. This study found neonicotinoid residues in wildflowers from 13 of 25 orchards. However, neonicotinoids contributed minimally to risk: chlorpyrifos (organophosphate) residues contributed to 74% of risk in this study.

An additional study in New York conducted by Hale [350] assessed risk from pesticides in wax from experimental bumble bee hives that were placed at 11 New York strawberry plantings during bloom. In this study, wax from two plantings was above the USEPA level of concern for acute contact exposure, wax from three plantings was above the EFSA level of concern for acute contact exposure, and wax from 6 of the 11 plantings was above the EFSA level of concern for 10-day chronic oral exposure (Figure 6.5). Similar to Figure 6.4, in Figure 6.5 the contribution of neonicotinoid insecticides to contact and oral HQ at each planting is indicated using dark gray shading. Overall, neonicotinoids contributed 4.5% of risk from contact exposure and 68.5% of risk from oral exposure across the 11 plantings. From this analysis, it is clear that pesticide risk to bumble bees during strawberry pollination in New York can be high, neonicotinoids contribute a large portion of risk when considering oral but not contact exposure, and other pesticides are also important contributors to risk, especially via contact exposure.

6.6 Risk to pollinators: LOEC results

Another common approach for assessing risk from pesticides is to compare exposure levels to the LOEC (lowest observable effect concentration) for an organism of interest. This approach is used by regulatory agencies (including the USEPA) and the peer-reviewed literature, and is advantageous since it relies on more information than acute short-term hazard studies (i.e., laboratory LD_{50} studies) to inform

Figure 6.5: **Hazard quotient for pesticide residues in beeswax from bumble bee hives placed at 11 New York state strawberry plantings during bloom**



Contact (a) and oral (b) wax hazard quotients (expressed as percent of LD_{50}) in bumble bee (*Bombus impatiens*) wax taken from hives placed at 11 New York strawberry plantings during bloom. Figure adapted from Hale et al. (in preparation) such that **dark gray portion of bars represents proportion of hazard quotient attributed to neonicotinoid insecticides (acetamiprid, clothianidin, imidacloprid, thiacloprid and thiamethoxam)**. Light gray portion of bars represents proportion of hazard quotient attributed to all other pesticides. Solid blue line corresponds to the current United States Environmental Protection Agency level of concern for acute contact exposure (risk quotient = 0.4) [964]. Solid green line corresponds to the European Food Safety Authority (EFSA) level of concern for acute contact exposure (exposure/toxicity = 0.2) [268]. Solid purple line corresponds to EFSA level of concern for 10-day chronic oral exposure (exposure/toxicity = 0.03) [268].

when a pesticide is likely to be harmful to an organism. Furthermore, the LOEC can be determined for multiple response categories that may be of interest for an organism (e.g., physiology, behavior, reproduction) and exposure data can then be compared with the LOEC for each category. In this way, using a LOEC approach to measure risk ensures that sublethal effects of pesticides are considered. The LOEC approach is especially pertinent to this pollinator risk assessment since sublethal effects from multiple stressors are widely accepted as the cause of current pollinator declines [197, 83, 326].

6.6.1 Literature review and analysis methods

In this section, we perform a systematic literature review regarding exposure to and hazard from neonicotinoid insecticides to bees, then use the data to perform a novel LOEC-based risk analysis in each application context previously considered in this report (i.e., field crops; fruit crops; vegetable crops; ornamentals, turf, & landscape management; and conservation & forestry). The search was carried out using the Thomson Reuters Web of Science. We employed the following search string: Topic = (neonicotinoid OR neonicotinoids OR acetamiprid OR clothianidin OR dinotefuran OR imidacloprid OR thiacloprid OR thiamethoxam) AND (bee OR pollinator OR honey bee OR honeybee OR apis OR bumble bee OR bumblebee OR bombus OR solitary bee OR andrena OR ceratina OR colletes OR osmia OR hylaeus OR lasioglossum OR megachile OR nomada OR peponapis OR xylocopa). This search yielded 1,172 results (February 5, 2020).

The first round of selections was based on relevant titles, which narrowed the source list to 664 studies. Each abstract was then reviewed and categorized into 4 sub-collections: "*Apis mellifera* - exposure", "non-*Apis mellifera* - exposure", "*Apis mellifera* - hazard", and "non-*Apis mellifera* - hazard." In addition, the references cited by and citing each relevant paper were examined for additional publications potentially missed by our search strategy. Relevant studies were imported into a spreadsheet, where details of each study were recorded. During data entry, the list was continually narrowed to only appropriate studies for analysis. The final number of studies analyzed was: 104 for "*Apis mellifera* - exposure", 27 for "non-*Apis mellifera* - exposure", 210 for "*Apis mellifera* - hazard", and 75 for "non-*Apis mellifera* – hazard". The exposure studies were further refined for the goals of the analysis: associations between neonicotinoid exposure and specific usages in field crops, fruit crops, vegetable crops, ornamentals, turf & landscape management, and conservation & forestry. This refinement resulted in 44 exposure studies.

When summarizing the hazard studies, our focus was on sublethal effects with the goal of finding the LOEC for the western honey bee for each neonicotinoid. As mentioned earlier, few data exist regarding hazard (i.e., toxicity) of pesticides to most other pollinators. Indeed, nearly all of the 75 "non-*Apis mellifera* – hazard" studies that we identified focused on two species of bumble bees: *Bombus terrestris*, which does not occur in North America, and *B. impatiens*, which occurs in North America and in New York. However, since only 16 hazard studies focused on *B. impatiens*, we chose to focus on *A. mellifera* for analyses in this section since this species had 210 hazard studies from which to estimate the LOEC. Sublethal effects were grouped into effects on physiology (e.g., metabolism, respiration), behavior (e.g., navigation, learning), or reproduction (e.g., egg laying, mating success). It is important to note that numerous recent studies have found non-*Apis* pollinators to be more sensitive to the same concentration of a pesticide compared to *A. mellifera.* Thus, the risk analyses in this section are likely to provide conservative results (i.e., underestimates of risk) when considering the full diversity of New York's bees and other invertebrate pollinators, though further research is clearly needed to validate this assumption.

When summarizing the exposure studies, all relevant exposure matrices were considered: bee-collected pollen (bee bread and trapped pollen), nectar, honey, wax, dead bees, soil contacted by bees, planting dust contacting bees, or plant guttation fluids contacted by bees. Since the species used for comparison with hazard data was the honey bee (*A. mellifera*), all of these exposures are relevant and frequently encountered by *A. mellifera* with the possible exception of soil. Honey bees do not interact extensively with soil, however it is important to note that the majority of New York's wild bees are ground-nesting bees. Indeed, New York is home to at least 227 species of ground-nesting bees, which accounts for 54% of bee species in the state. These bees dig through soil to build their nests, then rear their young in that soil; thus, contaminated soil is important to consider as a route of exposure for a large portion of pollinator diversity in New York.

To assess risk using the LOEC-based approach, mean exposure levels in a particular study and setting (e.g., mean clothianidin levels in pollen collected from a particular study in corn fields) were compared quantitatively to the LOEC for each effects category (physiology, behavior, reproduction). We included *all* exposure data from each study. In other words, we included data where no neonicotinoids were detected and data where neonicotinoids were detected. This approach results in the most realistic picture of risk from neonicotinoids in each setting, since it includes instances where neonicotinoids were screened for but not found in addition to screenings that did find neonicotinoids. This approach is analogous to our treatment of yield data in *Chapter 5*; specifically, *all* yield data (including trials where no differences in yield were observed) were evaluated. Sufficient data existed to quantify risk to bees in four major application contexts relevant to New York: field crops, fruit crops, vegetable crops, and ornamentals, turf, & landscape management (see Section 6.6.4 and Figures 6.6 and 6.7).

6.6.2 Hazard of neonicotinoids to bees

As of February 5, 2019, a total of 285 studies have investigated lethal and sublethal effects of neonicotinoids on wild and managed bees, with 210 studies assessing effects on *A. mellifera*. Below, these studies are summarized in four categories: lethal effects (i.e., studies with an endpoint of mortality), sublethal effects on physiology, sublethal effects on behavior, and sublethal effects on reproduction. A full list of the studies evaluated for this analysis is presented in Appendix B (Table B.1).

Lethal effects

Our search found 112 peer-reviewed studies that have investigated the impact of neonicotinoid insecticides on mortality of honey bees. These studies range from short-term (24-hr to 96-hr) laboratory LD_{50} studies on individual bees, to multi-year whole-colony dosing manipulations where colony death was measured. Because *A. mellifera* is a model species for toxicological studies, LD_{50} information is generally more available for this species compared to other species of bees. Table 6.3 summarizes honey bee LD_{50} values for each neonicotinoid as accepted by the USEPA [970, 985, 976, 965, 985]. As can be seen in the table, the nitroguanidine neonicotinoids (clothianidin, dinotefuran, imidacloprid, and thiamethoxam) are more acutely toxic than the cyanoamidine neonicotinoid (acetamiprid) in short-term (48-hr and 96-hr) LD_{50} trials and 10-day no observed adverse effects concentration (NOAEC) trials where the endpoint is mortality.

Table 6.3: **Acute and chronic toxicity of neonicotinoids to the western honey bee (*Apis mellifera*) as summarized by the USEPA**

	Acute Contact Toxicity **96-hr LD50**	*Acute Oral Toxicity* **48-hr LD50**	*Chronic Oral Toxicity* **10-day NOAEC mortality endpoint**
Acetamiprid	<12.5 µg/bee	>10.21 µg/bee	2.42 µg/bee/day
Clothianidin	0.0275 µg/bee	0.0037 µg/bee	0.000 36 µg/bee/day
Dinotefuran	0.024 µg/bee	0.0076 µg/bee	0.0035 µg/bee/day
Imidacloprid	0.043 µg/bee	0.0039 µg/bee	0.000 16 µg/bee/day
Thiamethoxam	0.0235 µg/bee	0.0032 µg/bee	0.000 31 µg/bee/day

Note that since clothianidin and thiamethoxam are so similar, identical data are used to assess the toxicity of both pesticides. Amount of thiamethoxam is converted to “clothianidin equivalents” by multiplying by the molecular weight ratio of clothianidin to thiamethoxam, which is 0.856.

Sublethal effects: Physiology

Physiological effects of neonicotinoids on *A. mellifera* are defined as impacts on cellular, organ, and/or organismal function. These effects include impacts on gene expression, enzyme activity, protein synthesis, cellular or organismal respiration, and cellular or organismal metabolism. Among the 89 studies that have observed effects of neonicotinoids on physiology, the LOECs are 0.5 ng/g (ppb) for imidacloprid [853], 0.01 ng/g (ppb) for thiamethoxam [900], and 0.1 ng/g (ppb) for clothianidin [2].

Worker honey bees removed from a colony and allowed access to 0.5 ng/g (ppb) imidacloprid for 24 hours via a sucrose feeder experienced reduced hypopharyngeal gland diameters, elevated heat shock proteins, and extended expression of cell death [853]. Larvae exposed to 0.01 ng/g (ppb) thiamethoxam on the 4th day of development showed increased acetylcholinesterase (AChE) activity in all subsequent developmental stages and increased glutathione-S-transferase (GST) and carboxylesterase para (CaEp) activities at the pupal stage [900]. Finally, adult male bees (drones) allowed access to a sucrose feeder dosed with 0.1 ng/g (ppb) clothianidin for 3 hrs/day over 20 days experienced significant increases in superoxide dismutase, glutathione peroxidase, catalase, and malondialdehyde levels, and a significant decrease in protein content of semen [2].

Sublethal effects: Behavior

Studies investigating the impact of neonicotinoids on behavior have assessed responses such as motor function, learning, memory, navigation, homing ability, foraging, and grooming. Among the 72 studies that have tested behavioral responses, the LOECs are 2.55 ng/g (ppb) for imidacloprid [1100], 2.91 ng/g (ppb) for thiamethoxam [1074], and 0.9 ng/g (ppb) for clothianidin [583].

Adult worker honey bees exposed orally to 2.55 ng/g (ppb) imidacloprid were less likely to learn to associate floral scent with a reward. The response persisted for 24 hrs, indicating impaired short-term olfactory memory in foraging-age bees [1100]. Similarly, adult worker bees that were allowed access to sucrose dosed with either 2.55 ng/g (ppb) imidacloprid or 2.91 ng/g (ppb) thiamethoxam for 24 hrs were more likely to lose postural control, fall over, and fail to right themselves [1074]. Finally, adult workers allowed access to sucrose dosed with 0.9 ng/g (ppb) clothianidin for 7 days were less likely to self-groom for the *Varroa* mite and correspondingly showed increased levels of Deformed Wing Virus (DWV) [583]. This study in particular highlights the importance of sublethal effects of neonicotinoids and how they interact with other stressors to impact pollinator health. Specifically, the *Varroa* mite is the most important world-wide pest of honey bees, is the major vector of DWV, and *Varroa* and DWV levels are often the best predictors of honey bee colony losses in New York and elsewhere [397, 596, 1053].

Sublethal effects: Reproduction

Studies investigating the impact of neonicotinoids on reproduction have assessed responses such as queen longevity, egg laying, brood production, and mating frequency and success. Among the 47 studies that have observed effects on reproduction, the LOECs are 6.4 ng/g (ppb) for imidacloprid [1105] and 5.12 ng/g (ppb) for both thiamethoxam and clothianidin [1054]. In the study by Williams et al. [1054], the researchers created a treatment comprised of 4.16 and 0.96 ng/g (ppb) for thiamethoxam and clothianidin, respectively. Because thiamethoxam and clothianidin are so similar and have nearly identical acute and chronic toxicological effects on *A. mellifera* (see Table 6.3), here we use the combined value of 5.12 ng/g (ppb) as the LOEC for each of these neonicotinoids.

Over three weeks in controlled field trials, access to 6.4 ng/g (ppb) imidacloprid in sucrose feeders significantly reduced honey bee queen fecundity, leading to by 50% fewer eggs in treated hives [1105]. When colonies were provided with supplemental pollen patties dosed with 5.12 ng/g (ppb) thiamethoxam and clothianidin during the queen-rearing period, new queens that were exposed to neonicotinoids during development were 34% less likely to survive four weeks after emergence and, of the queens that did survive, 38% less likely to lay eggs compared to queens reared in control colonies [1054]. Furthermore, of the queens that did lay eggs, those exposed to neonicotinoids had fewer viable spermatazoa stored in their spermathecae [1054].

6.6.3 Exposure of bees to neonicotinoids

A total of 118 studies have found neonicotinoids in bee-collected pollen (bee bread and trapped pollen), nectar, honey, wax, dead bees, soil contacted by bees, planting dust contacting bees, or plant guttation fluids contacted by bees. In this section, we quantify all exposures that can be related to specific usages in field crops, fruit crops, vegetable crops, turf, ornamentals & landscape management, and conservation & forestry. This refinement resulted in 42 relevant exposure studies. Again, for purposes of the risk assessment (see Figures 6.6 and 6.7), we focus on mean exposures including all exposure data (i.e., all instances where neonicotinoids were and were not detected). In this way, we summarize the most realistic picture of risk to bees from exposures that are and are not occurring in various contexts. Section 6.6.3 summarizes exposure data and section 6.6.4 summarizes risk from these exposures given the hazards described in Section 6.6.2.

Exposure in Field Crops: Corn

Pesticide exposure to bees can occur via multiple routes in and near seed-treated corn fields, including direct contact from planting dust, ingestion of contaminated surface water or plant guttation fluids, contact or ingestion of contaminated corn pollen, contact or ingestion of contaminated pollen or nectar from wildflowers in field margins, and contact with contaminated soils (especially for ground-nesting bees) within fields and in field margins.

Direct contact from planting dust leads to exposures with the highest concentration of neonicotinoids. However, it is also the easiest route of exposure to mitigate. Dust drift can be minimized by choosing high-quality seed lubricants, redirecting or filtering exhaust from planters, and avoiding planting during dry and windy conditions (see Section 6.3). In bees that had died after exposure to planting dust 24 hours after sowing, a study by Marzaro et al. [529] found clothianidin residues at a mean of 514 ng/bee (5,140 ppb assuming an average bee mass of 0.1 g) in low humidity conditions and 279 ng/bee (2,790 ppb) in high humidity conditions. In another study, Tapparo et al. [897] found clothianidin concentrations in foraging bees at a mean of 570 ng/bee (5,700 ppb) after planting of Poncho-treated seeds, thiamethoxam concentrations at 189 ng/bee (1,890 ppb) after planting of Cruiser-treated seeds, and imidacloprid concentrations of 325 ng/bee (3,250 ppb) after planting Gaucho-treated seeds. Similarly, Girolami et al. [323] found clothianidin concentrations in dead bees in front of hive entrances or a nearby food source at a mean of 417.5 ng/bee (4,175 ppb) up to three hours after planting Poncho-treated seeds and imidacloprid concentrations at at mean of 1,164 ng/bee (11,640 ppb) up to four hours after planting Gaucho-treated seeds. This study also tested residue levels in bees that died near hives one day after planting, finding clothianidin concentrations at a mean of 118 ng/bee (1,180 ppb) and imidacloprid concentrations at at mean of 29 ng/bee (290 ppb).

Wildflowers in corn field margins can also become contaminated with dust from neonicotinoid-treated seeds. Greatti et al. [332] found that planting of Gaucho-treated seeds resulted in mean imidacloprid concentrations of 32 ppb in wildflowers immediately following planting. These results were similar to a follow-up study by Greatti et al. [333] where the authors found that dandelions in corn field margins had mean imidacloprid concentrations of 57 ppb several hours after planting Gaucho-treated seeds.

While planting of treated seeds can lead to acute bee exposures from direct dust contact and/or drift onto nearby wildflowers, it is important to note that exposures still occur for months or even years after after planting treated seeds due to the environmental persistence and systemic activity of neonicotinoids. For example, in a well-designed study, Krupke et al. [461] found multiple routes of exposure before, during, and after corn planting in Indiana. The authors looked for thiamethoxam and clothianidin residues in wildflowers (dandelions) adjacent to fields during planting, then in corn pollen during July/August bloom, foraging bees, honey bee-collected pollen, bee bread, and nectar during bloom. They found neonicotinoid residues in the majority of samples, with mean clothianidin concentrations of 3.9 ppb in corn pollen, 13.8 ppb in honey bee-collected pollen, 6.8 ppb in bee bread, 0 ppb in nectar, 6.6 ppb in foraging bees, and 3.8 ppb in wildflowers adjacent to fields. Thiamethoxam concentrations were lower, but still present, with mean concentrations of 1.7 ppb in corn pollen, 3.7 ppb in honey bee-collected pollen, 1.1 ppb in bee bread, 0 ppb in nectar, 0 ppb in foraging bees, and 1.2 ppb in wildflowers adjacent to fields. These concentrations were similar to those found by Xu et al.

[1106], who found mean clothianidin concentrations of 1.8 ppb in pollen of Poncho-treated corn plants.

Bonmatin et al. [69] assessed concentrations of imidacloprid in corn panicles and corn pollen during bloom from fields planted with Gaucho-treated seeds in France. In addition, they assessed concentrations in honey bee-collected pollen from 15 hives near the edge of corn fields during bloom. Corn pollen made up approximately 30% of the total pollen collected by bees in the bee-collected pollen samples. Of 48 panicle samples, 48 were positive for imidacloprid at a mean concentration of 6.6 ppb. Of 47 pollen samples, 41 were positive at a mean concentration of 2.5 ppb. Of 11 honey bee-collected pollen samples, 6 were positive at a mean concentration of 1.1 ppb. Similarly, Cutler et al. [179] sampled corn pollen from four different seed-treated fields in Ontario, finding clothianidin residues in 4 of 8 samples tested (mean concentration = 0.4 ppb) and thiamethoxam residues in none of the 8 samples tested. The authors also looked at pollen collected by bumble bee (*B. impatiens*) colonies at each field, finding a maximum of 1.8% corn pollen collected by the bees.

The prevalence of neonicotinoids in bee-collected nectar near corn fields was lower in a study conducted in Belgium by Nguyen et al. [616]. In their study, the authors found only 4 positive detections of imidacloprid of 48 samples tested (mean = 0.3 ppb), which may not be surprising since corn does not produce nectar. Conversely, in Poland, Pohorecka et al. [710] found very high concentrations of clothianidin in honey bee-collected pollen, with 100% of samples (20 of 20) containing clothianidin at a mean concentration of 27 ppb. The authors did not find clothianidin in nectar-foraging bees, which again may not be surprising since corn does not produce nectar. In a two-year study that investigated wildflower strips adjacent to four fields planted with Poncho-treated seeds in South Dakota, Mogren and Lundgren [572] found clothianidin residues in wildflower nectar at a mean of 0.94 ppb. This study also placed experimental honey bee colonies next to the Poncho seed-treated fields, finding that honey in the colonies contained mean clothianidin residues at 6.61 ppb and bee bread contained mean clothianidin residues at 41.6 ppb. These concentrations are slightly higher than those observed by Tsvetkov et al. [934], who found mean clothianidin concentrations at 0.55 ppb, 4.52 ppb, and 4.03 ppb in fresh honey bee bread, and dead bees at the hive entrance, respectively, in honey bee colonies placed near seed-treated corn fields in Ontario, Canada. The same study also found mean thiamethoxam concentrations at 2.65 ppb and 3.37 ppb in fresh honey and bee bread, respectively.

Girolami et al. [322] was the first study to show that guttation droplets from young corn plants could lead to bee exposures. They found that up to 3-week old seedlings produced guttation droplets at mean concentrations of 47.0 mg/L (47,000 ppb) imidacloprid, 23.3 mg/L (23,300 ppb) clothianidin, and 11.9 mg/L (11,900 ppb) thiamethoxam from Gaucho, Poncho, and Cruiser-treated seeds, respectively. A follow-up study by Marzaro et al. [529] also found that dew and guttation droplets on field margin weeds contained lower but still significant concentrations of clothianidin at a mean of 22.25 ppb 1 hour after planting Poncho-treated seeds, with concentrations decreasing to 9.5 ppb 24 hours after planting.

In addition to bees consuming pollen, nectar, and plant guttation fluids, it is also common for bees to collect water from puddles in and near agricultural fields. Samson-Robert et al. [770] tested surface water from 25 corn fields after planting, finding clothianidin residues in 23 of 25 samples (mean = 4.6 ppb) and thiamethoxam residues in 18 of 25 samples (mean = 7.7 ppb). Similarly, Schaafsma et al. [778] found mean clothianidin residues of 2.28 ppb and mean thiamethoxam residues of 1.12 ppb in corn field puddle water in Ontario, Canada. An additional study by Schaafsma et al. [806] assessed ditch water surrounding Poncho-treated fields in Ontario, finding mean clothianidin concentrations at 1.11 ppb.

Exposure to pollinators can also occur via soils, especially for ground-nesting bees who live in field crops soils and margins surrounding the fields. A 2-year study of 25 commercial corn fields in Ontario, Canada sampled soils one week prior to spring planting from fields with a history of using Poncho and Cruiser-treated seeds. This study found widespread contamination of soils: mean concentrations in surface soil dust were 28.29 ppb clothianidin and 31.58 ppb thiamethoxam, while mean concentrations in parent soil (top 6 cm of soil) were 3.45 ppb clothianidin and 0.91 ppb thiamethoxam [507]. These concentrations are similar to those found by Jones et al. [440], where mean concentrations in parent soils were 4.89 ppb clothianidin and 0.41 ppb thiamethoxam, and a study of 50 Midwest corn fields by Xu et al. [1106], where mean soil clothianidin levels were 7.0 ppb. A study by Stewart et al. [874] also found similar results, where concentrations of clothianidin in parent soils of Poncho-treated fields were at a mean of 10.8 ppb and concentrations of imidacloprid in parent soils of Gaucho-treated fields were at a mean of 7.95 ppb. Finally, a study by Main et al. [524] assessed soil residues of 11 Poncho-treated corn fields, finding mean soil clothianidin residues at 8.04 ppb within fields and 1.21 ppb in field margins in June following planting.

Not all studies that test for neonicotinoids in materials used by bees in corn fields find residues. No neonicotinoids were found in honey-bee collected pollen samples from 3 hives placed near a corn field in bloom in Pennsylvania by Frazier et al. [297]. Similarly, no neonicotinoids were detected in pollen samples at concentrations above the detection limit of 0.3 ppb from hives surrounding neonic-treated corn fields in Quebec [67]. In this study, 2-6% corn pollen was collected by the bees placed next to corn fields during bloom. In New York, one detection of imidacloprid and three detections of acetamiprid were found in honey-bee collected pollen samples from 49 hives located in different parts of the state during corn bloom [942]. The imidacloprid detection was 1.46 ppb and acetamiprid detections ranged from 1.43-8.22 ppb. Similar to the study in Quebec, the amount of corn pollen in samples was very low (<4.1% in all pollen samples, and absent from most samples).

Exposure in Field Crops: Soybeans and Wheat

Less is known about neonicotinoid exposures to bees in and around soybean fields compared to corn fields, though the few studies that have been conducted suggest similar patterns. In a study by Stewart et al. [874], approximately 23% of wildflowers collected around recently planted soybean fields in Arkansas, Mississippi, and Tennessee tested positive for neonicotinoids. Clothianidin residues were found in 5 of 78 flowers (mean = 1.4 ppb), imidacloprid residues were found in 5 of 78 flowers (mean = 1.1 ppb), and thiamethoxam residues were found in 11 of 78 flowers (mean = 7.2 ppb). This study did not find neonicotinoids in any of the four composite soybean flower samples that were collected from plants grown from treated seeds. However, the authors did find substantial neonicotinoid levels in field soils prior to planting. Mean soil clothianidin concentrations were 4.2 ppb in fields planted with Poncho-treated seeds the year prior, mean soil imidacloprid concentrations were 17.5 ppb in fields planted with Gaucho-treated seeds the year prior, and mean soil thiamethoxam concentrations were 23.5 ppb in fields planted with Cruiser-treated seeds the year prior [874]. A study by Main et al. [524] assessed soil residues of four Gaucho-treated soybean fields, finding mean soil imidacloprid residues at 4.72 ppb within fields and 0.33 ppb in field margins in June following planting. Finally, a study by Alburaki et al. [12] assessed soybean flowers from four fields planted with Gaucho-treated seeds in Tennessee, finding imidacloprid concentrations at a mean of 1.93 ppb.

In the only study to our knowledge that has assessed routes of exposure in or near seed-treated wheat fields, Botías et al. [71] tested pollen and nectar from wildflowers surrounding winter wheat fields that had been planted with treated seeds in the United Kingdom. The authors found thiamethoxam in 2 of 55 pollen samples (mean = 0.14 ppb), imidacloprid in 4 of 55 samples (mean = 0.16 ppb) and thiacloprid in 4 of 55 samples (mean = 0.04 ppb). Nectar was also sampled from the plants and none of the eight samples contained neonicotinoids.

Exposure in Fruit Crops

Pesticide exposure to bees can occur via multiple routes in and near fruit plantings, including direct contact from sprays, contact or ingestion of contaminated crop pollen or nectar, and contact or ingestion of contaminated pollen or nectar from wildflowers in field margins.

A study by Colwell et al. [139] found that pollen collected from honey bees foraging in apple orchards, blueberry plantings and cranberry bogs in Nova Scotia, New Brunswick, and Prince Edward Island in Canada contained acetamiprid residues in 16 of 50 samples (mean = 3.1 ppb), imidacloprid residues in 25 of 50 samples (mean = 3.0 ppb), thiacloprid in 1 of 50 samples (mean = 0.03 ppb), and thiamethoxam residues in 2 of 50 samples (mean = 0.39 ppb). Similarly, Pettis et al. [674] found acetamiprid in residues in 3 of 4 honey bee pollen trap samples taken from hives in apple orchards (mean = 190.6 ppb), imidacloprid residues in 3 of 5 samples (mean = 10.8 ppb), and thiacloprid in 2 of 5 samples (mean = 4.0 ppb). These types of exposures in apple have also been found in Pennsylvania, where Frazier et al. [297] sampled trapped pollen from honey bee hives and collected pollen and nectar from plants. This study found mean acetamiprid, imidacloprid, and thiamethoxam residues at concentrations of 60.6 ppb, 15.9 ppb, and 0 ppb, respectively, in trapped pollen. The study did not find imidacloprid or thiamethoxam in the apple nectar or pollen samples, but acetamiprid was found at very high levels (mean = 12,390 ppb and 3,820 ppb in nectar and pollen, respectively). This study also assessed neonicotinoid residues in trapped pollen from hives pollinating blueberry in New Jersey, finding no residues of acetamiprid, imidacloprid, or thiamethoxam. An additional study by Favaro et al. [277] assessed residues in trapped pollen from honey bees foraging in apple orchards during and immediately after bloom. This study found imidacloprid residues in 8 of 56 pollen samples and the mean of all 56 pollen samples was 8.23 ppb imidacloprid.

Perhaps most relevant to New York's risk assessment, exposure to neonicotinoids during apple bloom has been found in New York (McArt et al. [537] and see Figure 6.2). In this study, freshly collected bee bread was sampled during bloom among 30 apple orchards and residues of acetamiprid were found in 11 of 30 samples (mean = 58.8 ppb), thiamethoxam residues were found in 5 of 30 samples (mean = 3.6 ppb), thiacloprid was found in 3 of 30 samples (mean = 1.0 ppb), and no residues of imidacloprid or clothianidin were detected. Hale [350] also assessed exposure in wax obtained from experimental bumble bee hives placed at 11 New York strawberry plantings during bloom. In this study, residues of acetamiprid were found in 2 of 42 samples (mean = 0.30 ppb), clothianidin residues were found in 11 of 42 samples (mean = 1.41 ppb), imidacloprid was found in 14 of 42 samples (mean = 2.16 ppb), thiamethoxam was found in 23 of 42 samples (mean = 4.60 ppb), and no residues of thiacloprid were detected.

Further afield, one recent study assessed exposure of bumble bees to imidacloprid in Fraser Valley blueberry plantings in British Columbia. In their study, Bishop et al. [61] found mean imidacloprid concentrations of 4.96 ppb in bumble bee-collected pollen in conventionally managed orchards, 18.40 ppb in organically managed orchards, and no detections in bees. The authors also assessed imidacloprid levels in blueberry flowers, finding mean concentrations of 0.86 ppb in conventionally managed orchards, while imidacloprid was absent from flowers in organically managed orchards.

Exposure in Vegetable Crops

Exposure to neonicotinoids is known to occur via multiple routes in vegetable plantings, including contact or ingestion of contaminated crop pollen or nectar, and contact with soil. Stoner and Eitzer [880] found that imidacloprid and thiamethoxam were present in pollen and nectar of squash (*Cucurbita pepo* cultivars "Multipik," "Sunray" and "Bush Delicata") when applied to soil by two methods: (1) sprayed into soil before seeding, or (2) applied through drip irrigation in a single treatment after transplant. Such treatments are common in squash plantings in New York. Residues of imidacloprid were found in all pollen and nectar samples tested (mean = 14 ppb and 10 ppb, respectively). Residues of thiamethoxam were also found in all pollen and nectar samples tested (mean = 12 ppb and 11 ppb, respectively).

The results from Stoner and Eitzer [880] are similar to a study conducted by Dively and Kamel [206] on pumpkin (*Cucurbita pepo L.* var. 'Howden') treated with several different neonicotinoids and application methods: (1) bedding-tray drench of imidacloprid applied at a reduced rate of 0.005 g per plant (or 30 g ai/ha); (2) transplant water treatment of imidacloprid applied during planting (low label rate of 281 g ai/ha); (3) transplant water treatment of imidacloprid applied during planting (high label rate of 422 g ai/ha); (4) split treatments of imidacloprid applied as half rate in transplant water (211 g ai/ha) and the remaining half rate applied 3 weeks later by drip irrigation; (5) split treatments of dinotefuran applied as a half rate (151 g ai/ha) in transplant water and the remaining half rate applied 3 weeks later by drip irrigation; (6) two foliar treatments of dinotefuran, each 151 g ai/ha at 4 and 6 weeks after transplanting; (7) split treatments of thiamethoxam applied as a half rate (96 g ai/ha) in transplant water and the remaining half rate applied 3 weeks later by drip irrigation; and (8) two foliar treatments of thiamethoxam, each 96 g ai/ha at 4 and 6 weeks after transplanting. This study found mean concentrations of imidacloprid in pollen ranging from 4.9 ppb (bedding drench) to 80.2 ppb (transplant-drip). Mean concentrations in nectar varied between 0.4 ppb (bedding drench) to 11.2 ppb (transplant-drip). Mean thiamethoxam concentrations in pollen were 68.0 ppb (transplant-drip) and 95.2 ppb (two foliar applications), while mean thiamethoxam concentrations in nectar were 9.5 ppb (transplant-drip) and 8.2 ppb (two foliar applications). Similarly, mean dinotefuran concentrations in pollen were 57.5 ppb (transplant-drip) and 88.3 ppb (two foliar applications), while mean dinotefuran concentrations in nectar were 9.2 ppb (transplant-drip) and 7.5 ppb (two foliar applications). These high levels of neonicotinoids were not found in pumpkin anthers sampled during bloom in a field in Pennsylvania [297], where the authors did not detect acetamiprid, imidacloprid, or thiamethoxam.

Another source of exposure in Cucurbita plantings is contaminated soil, which is particularly important for the hoary squash bee (*Peponapis pruinosa*), a ground-nesting bee and the primary pollinator of cucurbits. In a recent study, Chan et al. [112] assessed concentrations of clothianidin, thiamethoxam, imidacloprid and chlorantraniliprole in soil from Cucurbita plantings. Mean clothianidin concentrations were 1.95 ppb, mean imidacloprid concentrations were 2.99 ppb, and mean chlorantraniliprole concentrations were 36.82 ppb. Under acute and chronic exposure scenarios, mean risk to hoary squash bees exceeded the acceptable level for clothianidin and imidacloprid using a solitary bee LC_{50} in this study. Conversely, risk for chlorantraniliprole was below the acceptable threshold for all endpoints.

In 2020, the USEPA recommended a prohibition on use of imidacloprid-, clothianidin-, and thiamethoxam-based products on cucurbits between vining and harvest to protect pollinators. Of all imidacloprid applications studied by the agency, the "strongest evidence of potential pollinator risk" arose from soil applications to cucurbits [998].

Finally, seed treatments used on sunflower resulted in residues in the beebread of honey bee hives near four sunflower plantings in Spain [389]. This study found clothianidin in 5 of 24 beebread samples taken in and around the sunflower bloom period (mean = 0.3 ppb) and thiamethoxam in 13 of 24 samples (mean = 0.1 ppb). These results are similar to those of Schmuck et al. [813], who found mean imidacloprid residues of 3.9 ppb and 1.9 ppb in pollen and nectar, respectively, in plants grown with treated seeds.

Exposure in Ornamentals, Turf, and Landscape Management

Larson et al. [485] treated weedy turf lawns with clothianidin or chlorantraniliprole, an anthranilic diamide, using label guidelines, then introduced bumble bee hives into large enclosures placed over the treated areas. Nectar was collected from the flowers and was found to contain an average of 171 ppb clothianidin (range 89–319 ppb; n = 5). No nectar samples were collected from the chlorantraniliprole-treated areas since the bees had collected all the nectar. The authors found that the bumble bee hives in chlorantraniliprole-treated enclosures gained equivalent weight to control hives over 42 days, while colonies in clothianidin-treated enclosures gained 50% less weight compared to controls and did not produce any queens. The same authors conducted a later study with spray application of imidacloprid and clothianidin [486], finding that mean residues of imidacloprid and clothianidin in weedy clover areas of the turf ranged between 3281-7817 ppb and 1883-4475 ppb, respectively, immediately post-application. Importantly, the concentrations of imidacloprid and clothianidin in nectar dropped to 8.4-26.0 ppb and 6.2-18.0 ppb, respectively, after the first mowing, indicating a simple but highly effective method to reduce exposures to bees when applying insecticides to turfgrass areas: make sure weedy flowers are mowed. However, mowing does not eliminate exposure; the study by Larson et al. [486] also assessed concentrations of imidacloprid in bentgrass guttation droplets, finding averages of 88 ± 35 ppb and 23 ± 3 ppb at 1 week and 3 weeks after treatment, respectively.

Concern about neonicotinoid residues in flowering ornamental plants have led to some work on this topic. An initial study by Lentola et al. [501] found widespread contamination of pollen and nectar in nursery-grown plants. In this study, 70% of plants tested contained neonicotinoids in pollen or nectar, with some detections in pollen up to 29 ppb imidacloprid, 13 ppb clothianidin, and 119 ppb thiamethoxam. Overall, mean pollen concentrations of imidacloprid were 6.9 ppb, mean pollen concentrations of clothianidin were 11.0 ppb, and mean pollen concentrations of thiamethoxam were 11.0 ppb. These levels were slightly higher than concentrations found by Stoner et al. [881] in honey bee-collected pollen when small hives were placed in three large nurseries. In this study, the authors found generally low levels of neonicotinoids in the bee-collected pollen with the exception of a few time-points in one nursery, which the authors were able to trace to one particularly contaminated ornamental species. Overall, mean pollen concentrations of clothianidin at the three nurseries were 17.3 ppb, 0 ppb, and 4.4 ppb, mean pollen concentrations of imidacloprid at the three nurseries were 2.5 ppb, 3.9 ppb, and 2.9 ppb, and mean pollen concentrations of thiamethoxam at the three nurseries were 53.9 ppb, 0 ppb, and 3.9 ppb.

Finally, Mach et al. [521] sought to understand how soil drenches of imidacloprid and dinotefuran to two woody ornamental plants, a broadleaf evergreen tree (*Ilex* × *attenuata*) and a deciduous shrub (*Clethra alnifolia*), influenced concentrations in nectar during bloom of these ornamental plants. Overall, residues in nectar ranged from 166 to 515 ppb for imidacloprid and from 70 to 1,235 ppb for dinotefuran. The authors applied treatments in the spring, summer, or fall, finding that summer application mitigated concentrations of imidacloprid (8–31 ppb), but not dinotefuran (235–1,191 ppb) in nectar. Mean imidacloprid concentrations in *Ilex* nectar were 166 ppb and 276 ppb if soil drenches were applied in the spring or fall, respectively, but only 8 ppb if the drench was applied in the summer. Similarly, imidacloprid concentrations in *Clethra* nectar were 381 ppb and 515 ppb if soil drenches were applied in the spring or fall, respectively, but only 31 ppb if the drench was applied in the summer.

Exposure in Conservation and Forestry

As wind-pollinated trees, hemlocks (*Tsuga* spp.) do not produce nectar and their pollen is not thought to be attractive to bees. However, bees are known to forage on the resins and sap of evergreen trees. Propolis, for example, is a resin-based antimicrobial material used by honey bees to cover the inside of their colonies. A study by Cowles et al. [160] found imidacloprid in hemlock sap at concentrations up to 37.0 ppb several months following soil and trunk injections to control hemlock woolly adelgid (*Adelges* *tsugae*). A later study found imidacloprid residues in hemlock branchlets up to 7 years post-treatment; mean concentrations were 25.8 and 9.7 ppb at 6 years (n = 69) and 7 years (n = 34) post-treatment, respectively [53]. Little is known about how often bees collect hemlock sap.

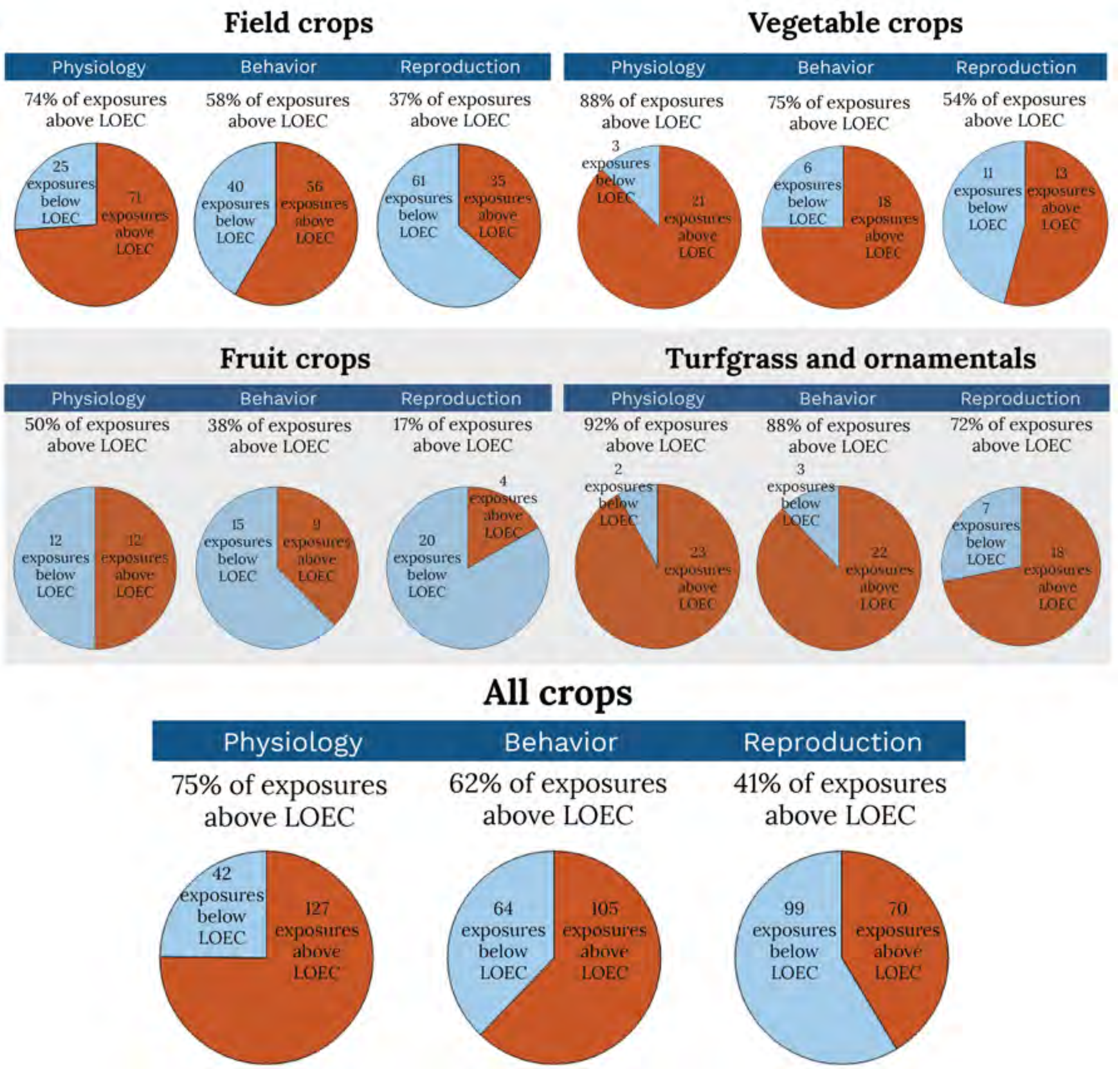
Similar to hemlock, ash trees (*Fraxinus spp.*) are wind pollinated. While several studies have found that bees will visit ash flowers and collect pollen, little is also known about how neonicotinoid soil drenches or trunk injections to control emerald ash borer (*Agrilus planipennis*) result in residues in ash pollen. Mota-Sanchez et al. [586] found that imidacloprid residues were present in trunks, twigs, leaves and roots 2 years after trunk injections, and 71% and 24% of emerald ash borer beetles feeding on these tissues died in the 1st and 2nd year after injection, respectively. However, while this study identified xylem as the main route of systemic transport within ash trees, it is not known how much residues accumulate in pollen and therefore results in exposures to bees.

6.6.4 Risk to bees from neonicotinoids

To assess risk to honey bees from neonicotinoid insecticides, we compare all exposure data described in Section 6.6.3 to the LOEC for each sublethal effects category described in Section 6.6.2 (physiology, behavior, and reproduction). All exposure values above the LOEC are defined as risk, while all values below the LOEC are defined as no risk. The results from this quantitative risk analysis are shown in Figures 6.6 and 6.7 and summarized below. For these analyses, it is important to note that co-exposures have not been considered (e.g., a pollen sample containing both clothianidin and imidacloprid) since individual sample information is rarely available in published studies. Since co-exposures can only increase risk from a given sample, our risk analysis is therefore a conservative estimate of the real risk posed to bees from neonicotinoid insecticides in each application context (i.e., an underestimate of the real risk).

In Figure 6.6., the proportion of known neonicotinoid exposures from the peer-reviewed literature that are above or below the LOEC for each effects category are shown for field crops (corn, soybean, wheat), fruit crops (apple, strawberry, blueberry), vegetable crops (squash, pumpkin, sunflower), and ornamentals, turf & landscape management. We do not quantitatively assess risk from exposures in conservation & forestry due to limited data and low likelihood of exposure to bees in this application

Figure 6.6: **Observed neonicotinoid exposures to bees in field crops, vegetable crops, fruit crops, and turfgrass & ornamentals settings compared to the lowest observed effects concentrations (LOECs) for honey bee physiology, behavior, and reproduction.**



Notes: Risk using the LOEC-based approach uses mean exposure levels in a particular study and setting (e.g., mean clothianidin levels in pollen collected from a particular study in corn fields) and compares each value quantitatively to the LOEC for each effects category (physiology, behavior, reproduction). Here we include all exposure data (i.e., data where no neonicotinoids were detected and data where neonicotinoids were detected) in analyses, thus providing the most realistic picture of risk from neonicotinoids in each setting.

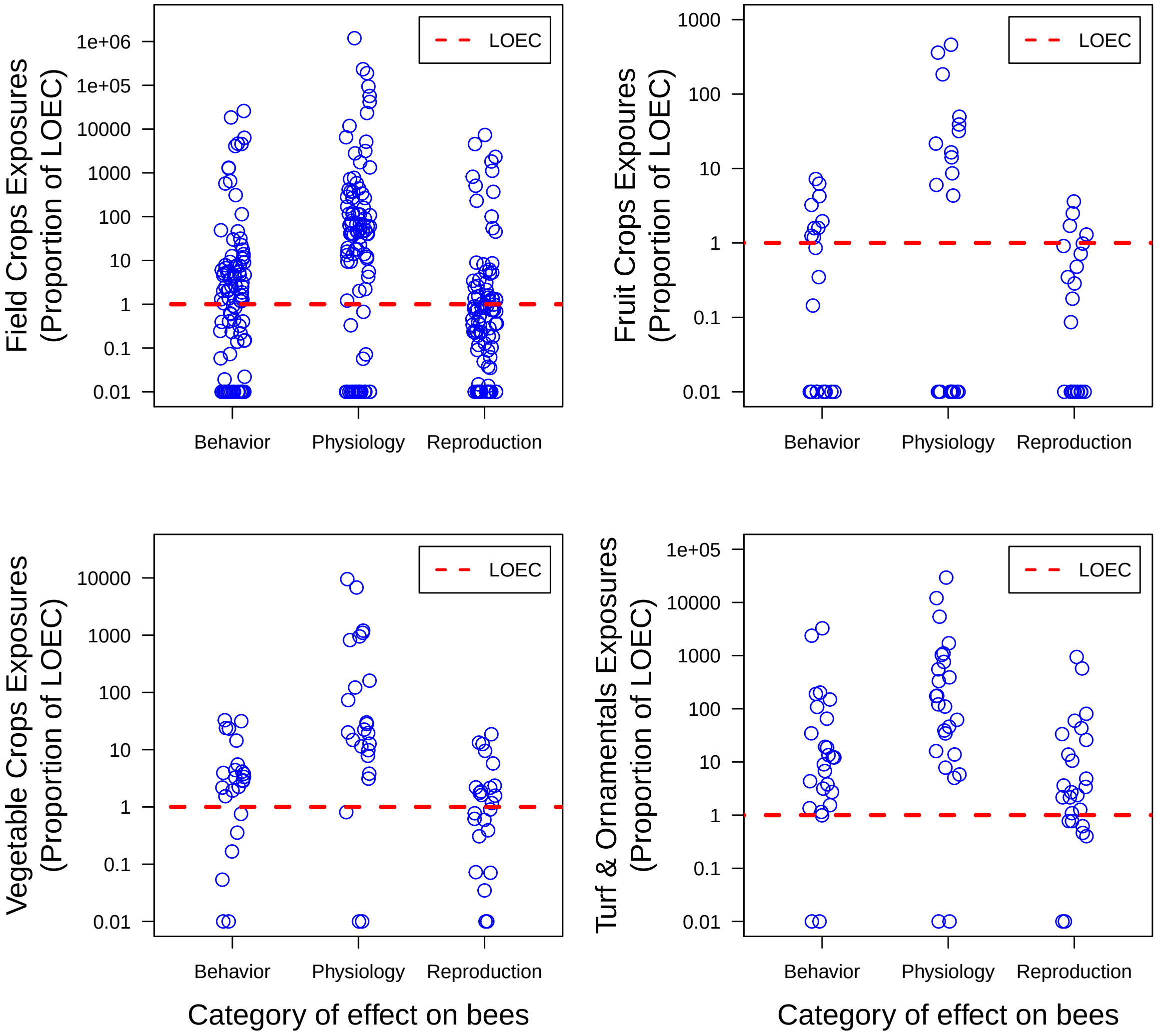
context. Across all application contexts, 75% of mean exposure values (127 of 169 values) were above the LOEC for physiology, 62% were above the LOEC for behavior, and 41% were above the LOEC for reproduction (Figure 6.6). Thus, the data from peer-reviewed literature indicates honey bee physiology is likely to be impacted from neonicotinoid insecticide exposures in 75% of cases, honey bee behavior is likely to be impacted in 62% of cases, and honey bee reproduction is likely to be impacted in 41% of cases.

In Figure 6.7, all individual exposure values are plotted as a proportion of the LOEC, facilitating a more quantitative visualization of magnitude above or below the LOEC for each application context and category of effect on bees. In this figure, the red dashed line indicates the LOEC and the y-axis is plotted on a log scale to visualize the high values more clearly (i.e., some exposures were more than 100,000 times higher than the LOEC). Note that because the log of zero is undefined, all zero values (i.e., when no neonicotinoids were found) were set to 0.1 in this figure. This visualization is especially useful in showing the breadth of knowledge that exists regarding exposures in each application context since each blue circle represents a mean exposure value from a peer-reviewed study. For example, a relatively large amount of knowledge exists regarding exposure and risk in Field Crops (96 blue data points), while a relatively small amount of knowledge exists regarding exposure and risk in Fruit Crops (24 blue data points).

Risk in Field Crops

Overall, 74% of mean exposure values (71 of 96 values) in field crops settings were above the LOEC for physiology, 58% were above the LOEC for behavior, and 37% were above the LOEC for reproduction (Figure 6.6). These results indicate that usage of neonicotinoid seed treatments in corn, soybean or wheat fields are likely to impact honey bee physiology in nearly three quarters of cases, behavior in over half of cases, and reproduction in over a third of cases. We also note the magnitude of risk in field crops settings; exposure values are often found at over 100 times the LOEC (Figure 6.7). Several of these high values are direct exposures from planting dust or drift onto nearby weedy flowers. However, it is important to note that mitigating planting dust will not eliminate exposures that lead to risk. For example, only 34% of exposures above the LOEC for honey bee reproduction came from planting dust; the remaining 66% of exposures were from seedling guttation fluids several weeks after planting,

Figure 6.7: **Quantitative neonicotinoid exposures to bees in field crops, fruit crops, vegetable crops, and turf & ornamentals settings compared to lowest observed effect concentrations (LOECs) for adverse impacts on honey bee behavior, physiology, and reproduction.**



Mean exposures to the neonicotinoids clothianidin, thiamethoxam or imidacloprid experienced by bees in or near each application context expressed as proportion of LOEC (log scale) for each of three response categories (behavior, physiology, and reproduction). Dashed line (at y = 1) indicates the LOEC for each response. Thus, all data points above the dashed line are above the LOEC and indicate risk, while all data below the dashed line are below the LOEC and indicate no risk. Mean values for each individual study and setting are represented by open blue circles; each mean value includes all neonicotinoid exposure data (including zero values) from each study. Note that because the log of zero is undefined, all zero values (i.e., when no neonicotinoids were found) were set to 0.1 in this figure. Data points are jittered in each effects category to improve visualization.

pollen collected by bees later in the summer, corn pollen itself, and contaminated field soils and field margin soils that were tested months or even years after seed treatments were used. Thus, season-long and multi-year exposures that impact bee biology commonly occur when neonicotinoid-treated seeds are used in field crops settings.

For field crops especially, we note the breadth of knowledge that exists regarding exposures (i.e., 96 exposure values shown via blue data points in Figure 6.7). This indicates a broad understanding of exposure to bees in or near fields that use neonicotinoid seed treatments, especially corn fields. Less is known about exposures in and near soybean and wheat fields due to the few studies that have been conducted on those crops. However the multiple studies that have been conducted in soybean suggest similar exposure patterns compared to corn fields. In *Chapter 7*, we outline further research that could be conducted in and near seed-treated soybean and wheat fields to improve the breadth of knowledge regarding risk to bees. In addition, we highlight new technologies and farming practices that are likely to reduce risk.

Risk in Fruit Crops

Overall, 50% of mean exposure values (12 of 24 values) in fruit crops settings were above the LOEC for physiology, 38% were above the LOEC for behavior, and 17% were above the LOEC for reproduction (Figure 6.6). These results indicate that usage of neonicotinoid foliar sprays in apple, strawberry, or blueberry plantings are likely to impact honey bee physiology in half of cases, behavior in over a third of cases, and reproduction in less than one fifth of cases. The magnitude of risk in fruit crops settings was generally much lower than in field crops settings (see Figure 6.7). For fruit crops, we note that data are fairly limited (i.e., 24 exposure values shown via blue data points in Figure 6.7) and therefore the breadth of knowledge that exists regarding exposures is fairly limited. However, complementing this LOEC analysis are our own data from New York apple and strawberry plantings (see Section 6.5), showing that risk from neonicotinoid exposures can be high during the bloom period for these crops, particularly for imidacloprid and thiamethoxam exposures. More research on exposure in a wider variety of fruit crops (e.g., peaches, raspberries, blackberries, pears) is needed to better understand the consistency of risk in New York and elsewhere. In addition, more research on risk mitigation strategies is necessary, which is outlined in *Chapter 7*.

Risk in Vegetable Crops

Overall, 88% of mean exposure values (21 of 24 values) in vegetable crops settings were above the LOEC for physiology, 75% were above the LOEC for behavior, and 54% were above the LOEC for reproduction (Figure 6.6). These results indicate that usage of neonicotinoid seed treatments and soil drenches in squash, pumpkin, and sunflower plantings are likely to impact honey bee physiology in nearly nine of ten cases, behavior in three quarters of cases, and reproduction in over half of cases. The magnitude of risk in vegetable crops settings was intermediate to field crops and fruit crops settings (see Figure 6.7). For vegetable crops, we note that data are also fairly limited (i.e., 24 exposure values shown via blue data points in Figure 6.7) and most of these data come from squash and pumpkins. Therefore the breadth of knowledge that exists regarding exposures is fairly limited. However, these limited data have already led the USEPA to recommend a prohibition on use of imidacloprid-, clothianidin-, and thiamethoxam-based products on cucurbits between vining and harvest to protect pollinators [998]. Because the majority of data presented above come from applications before or during planting (i.e., treatments applied to the soil before planting and at the time of transplanting), the data indicate exposures to pollinators will also occur when neonicotinoids are used before vining.

Beyond cucurbits, little is known regarding how usage of neonicotinoids leads to exposures in other flowering vegetable crops such as beans and peas, non-flowering crops such as carrots (where wildflowers in field margins have the potential to become contaminated), or crops that don't produce above-ground vegetables but do commonly produce flowers when plants are grown to maturity in the field (e.g., potatoes). The surprising absence of peer-reviewed literature on this topic is striking; clearly, more research on exposure in a wider variety of vegetable crops is needed to better understand the consistency or heterogeneity of risk in New York and elsewhere. Furthermore, as is true in all agricultural application contexts summarized in this report, more research on risk mitigation strategies is necessary, which we discuss in *Chapter 7*.

Risk in Ornamentals, Turf and Landscape Management

Overall, 92% of mean exposure values in ornamentals and turf settings were above the LOEC for physiology, 88% were above the LOEC for behavior, and 72% were above the LOEC for reproduction (Figure 6.6). These results indicate that usage of neonicotinoid foliar sprays and soil drenches in ornamental nurseries and turfgrass settings are likely to impact honey bee physiology in over nine of ten cases, behavior in nearly nine of ten cases, and reproduction in nearly three quarters of cases. The magnitude of risk in ornamentals and turf settings was generally high when neonicotinoids were detected (see Figure 6.7). However, we note that data are also fairly limited for ornamentals and turf settings (i.e., 25 exposure values shown via blue data points in Figure 6.7) and split approximately evenly between ornamentals exposures and turf exposures. Therefore, the breadth of knowledge that exists regarding exposures and risk in each of these settings is fairly limited.

For turf, an easy and effective risk mitigation strategy is to ensure weedy flowers are mowed prior to application of neonicotinoids. However, it is important to note that mowing does not eliminate risk; neonicotinoid concentrations in bentgrass guttation droplets were still at levels that led to risk 3 weeks after treatment in one study. Instead, a more promising risk mitigation strategy is to use anthranilic diamides in place of neonicotinoids. In one well-designed study, the use of chlorantraniliprole had no impact on bumble bee reproduction while imidacloprid usage reduced queen production in side-by-side field studies comparing these two insecticides in a turfgrass setting. Overall, more research on risk mitigation strategies would be beneficial, especially in ornamentals settings.

Risk in Conservation and Forestry

Overall, we find little evidence that usage of neonicotinoids to control forest pests is likely to result in risk to bees. That said, further research into usage of hemlock sap (or other tree saps) by bees and typical sap residue levels after treatment of trees is warranted. Similarly, usage of ash pollen by bees and typical pollen residue levels after treatment of trees are current gaps in knowledge.

6.7 Relative risk of neonicotinoid insecticides compared to alternatives

While quantitatively assessing risk to pollinators from neonicotinoid insecticides compared to alternative chemical insecticides is outside the scope of this risk assessment, important insights on this topic can be obtained from label statements that are required by the USEPA on different pesticide products. These label statements are a result of extensive review by the USEPA regarding a product's likelihood to pose risk to bees. They include language regarding the toxicity of a product to the western honey bee (highly toxic, moderately toxic, or no statement), and often include additional language meant to reduce risk to bees during use of the product. For example, statements may prohibit application of the product during crop bloom, when weedy flowers are present, or when bees are foraging in the treated area. In addition, some statements provide more specific details regarding a product, such as whether a product can be applied in the evening when bees are not foraging on flowers, the number of days before bloom when a product can be used, or whether the product is toxic to adult honey bees, larvae, or both.

In Tables 6.4-6.8, we summarize label statements for common neonicotinoid products and their chemical alternatives. Each table includes information on the product (e.g., Warrior II), active ingredient (e.g., lambda-cyhalothrin), its chemical class (e.g., pyrethroid), whether the active ingredient is systemic in plants or not (particularly important for the likelihood of nectar and pollen exposures), the USEPA-determined bee toxicity statement, and all additional bee language that occurs on the label. In the treated seed table (Table 6.4), labeling language is shown for both the seed treatment product (i.e., the product used to treat the seeds) as well as the labeling language required on bags of the treated seeds (i.e., seed tags). Table 6.5 summarizes information for soil-applied insecticides labeled for control of early-season field crops pests. Table 6.6 summarizes information for insecticides labeled for control of common fruit crops pests. Table 6.7 summarizes information for soil-applied insecticides labeled for control of common cucurbit pests. Finally, Table 6.8 summarizes information for insecticides used for control of common turf pests.

Table 6.4: **Bee toxicity statements and seed labeling requirements taken from insecticidal seed treatment product labels**

Group	Active ingredient	Product	Principal use in NYS	Related products used in:	Systemic	Bee toxicity	Additional bee labeling on product	Pollinator seed labeling requirements
NEO	Clothianidin	Poncho 600	Field corn	Sweet corn	Systemic	Highly toxic	None	This compound is highly toxic to bees exposed directly (contact). Ensure that planting equipment is functioning properly in accordance with manufacturing recommendations to minimize seed coat abrasion during planting to reduce dust, which can drift to blooming crops or weeds
NEO	Thiamethoxam	CruiserMaxx	Soybean	Field corn, potato, snap bean, sweet corn, cucurbits	Systemic	Highly toxic[1]	None	Pollinator Precautions: Thiameth-oxam is highly toxic to bees, and effects are possible as a result of exposure to translocated residues in blooming crops.
NEO	Imidacloprid	Gaucho 600	Soybean	Field corn, sweet corn	Systemic	Highly toxic	Ensure that planting equipment is functioning properly in accordance with manufacturing specifications to minimize seed coat abrasion during planting to reduce dust which can drift to blooming crops or weeds.	None
AND	Chlorantraniliprole	Lumivia	Field corn		Systemic	No statement[2]	None	None
AND	Cyantraniliprole	Fortenza Red	Field corn, soybean		Systemic	Highly toxic	This product is highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds.	This product is highly toxic to bees exposed to direct treatment or residues on blooming crop or weeds. Ensure that the planting equipment is functioning properly in accordance with manufacturer specifications.
AND	Cyantraniliprole	Lumiderm	Soybean		Systemic	Highly toxic[1]	None	This product is highly toxic to bees. Ensure that the planting equipment is functioning properly in accordance with manufacturer specifications to minimize seed coat abrasion during planting to reduce dust which can drift to blooming crops and weeds.
PYR	Tefluthrin	Force ST	Field corn	Sweet corn	Non-systemic	No statement[2]	None	None

Notes: See Table 2.1 for active ingredient group abbreviations. (1) This product contained a bee toxicity statement in the seed labeling requirements section, but not in the environmental risk section of the label. (2) There are three reasons why a label may not have a toxicity statement: (a) the product is practically nontoxic to bees; (b) the product is toxic to bees, but there is no potential for exposure to bees; or, (c) the product is nontoxic to bees and there is no potential for exposure to bees.

Table 6.5: **Bee toxicity statements for soil-applied, non-neonicotinoid insecticides used for control of early-season field crop pests, taken from product labels**

Group	Active ingredient	Product	Systemic	Bee toxicity	Additional bee labeling on product
AND	Cyantraniliprole	Verimark	Systemic	Highly toxic	This product is highly toxic to bees exposed to direct treatment on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds if bees are foraging the treatment area.
OP	Phorate	Thimet 15G	Systemic	No statement[1]	None
OP	Terbufos	Counter 20G	Systemic	No statement[1]	None
OP	Chlorpyrifos	Lorsban 15G	Non-Systemic	Highly toxic	This product is highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds if bees are visiting the treatment area.
PYR	Bifenthrin	Capture LFR	Non-Systemic	Highly toxic	This product is highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds while bees are foraging the treatment area.
PYR	Tefluthrin	Force 3G	Non-Systemic	No statement[1]	None

Notes: See Table 2.1 for active ingredient group abbreviations. (1) There are three reasons why a label may not have a toxicity statement: (a) the product is practically nontoxic to bees; (b) the product is toxic to bees, but there is no potential for exposure to bees; or, (c) the product is nontoxic to bees and there is no potential for exposure to bees.

Table 6.6: **Bee toxicity statements for neonicotinoid insecticides and alternatives used for control of common tree fruit and berry pests, taken from product labels**

Group	Active ingredient	Product		Bee toxicity	Additional bee labeling on product
NEO	Acetamiprid	Assail 30SG	Systemic	Toxic	This product is toxic to bees exposed to direct treatment. Do not apply this product while bees are foraging in the treatment area.
NEO	Imidacloprid	Admire Pro Systemic Protectant	Systemic	Highly toxic	This product is highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds if bees are foraging the treatment area. Do not apply pre-bloom or during bloom or when bees are foraging. (**This label includes a Pollinator Protection Box**)[1]
NEO	Thiamethoxam	Actara	Systemic	Highly toxic	This pesticide is highly toxic to bees exposed to direct treatment on blooming crops/plants or weeds. Do not apply this product or allow it to drift to blooming crops/plants or weeds while bees are foraging in/or adjacent to the treatment area. Do not apply Actara or allow it to drift to blooming crops/plants or weeds if bees are foraging in/or adjacent to the treatment area. This is especially critical if there are adjacent orchards that are blooming. After an Actara application, wait at least 5 days before placing beehives in the treated field. If bees are foraging in the ground cover and it contains any blooming plants or weeds, always remove flowers before making an application. This may be accomplished by mowing, disking, mulching, flailing, or applying a labeled herbicide. Consult with your local cooperative extension service or state agency responsible for regulating pesticide use for additional pollinator safety practices. Crop-specific bee labelling: Apples: do not apply Actara after pre-bloom (early pink growth stage) or before post bloom (petal fall growth stage). Pears: do not apply Actara after pre-bloom (green cluster stage) or before post bloom (petal fall growth stage). Stone fruit: do not apply Actara between the pre-bloom (swollen bud) and post bloom (petal fall) growth stages. (**This label includes a Pollinator Protection Box**)[1]
AND	Chlorantraniliprole	Altacor	Systemic	No statement[2]	None
AND	Cyantraniliprole	Exirel	Systemic	Highly toxic	This product is highly toxic to bees exposed to direct treatment on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds if bees are foraging the treatment areas.
AVR	Abamectin	Agri-Mek 8SC	Systemic	Highly toxic	This product is highly toxic to bees exposed to direct treatment on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds while bees are foraging in/or adjacent to the treatment area.
BNZ	Novaluron	Rimon 0.83EC	Non-Systemic	Not toxic to adults	In order to minimize the possibility of developmental effects on pollinator larvae, including honey bee brood, do not use RIMON 0.83EC Insecticide on blooming crops. Orchard Spraying Pollinator Advisory: Because of its mode of action as an insect growth regulator, and since it is not systemic, RIMON 0.83EC Insecticide has no direct effect on fully developed adult stages, such as bees and other beneficial pollinators. However, in order to minimize the possibility of transient effects on honeybee brood development, do not use RIMON 0.83EC Insecticide on blooming crops when bees are actively foraging.
CRB	Carbaryl	Sevin XLR Plus	Systemic	Highly toxic	This product is highly toxic to honeybees and other bees exposed to direct treatment or residues on crops or weeds in bloom. This product may show residual toxicity to honeybees, especially in humid climates and under slow drying conditions. Notifying beekeepers within 1 mile of treatment area at lest 48 hours before product is applied will allow them to take additional steps to protect their bees. Limiting application to times when bees are least active, e,g., within 2 hours of sunrise or sunset, will minimize risk to bees. For crops in bloom (except soybean and corn): Do not apply this product to target crops or weeds in bloom.

Continued on following page

Bee toxicity statements on neonicotinoid insecticides and alternatives used to control common tree fruit and berry pests, continued

Group	Active ingredient	Product		Bee toxicity	Additional bee labeling on product
CRB	Methomyl	Lannate LV 2.4L	Systemic	Highly toxic	This product is highly toxic to bees exposed to direct treatment on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds while bees are actively foraging in the treatment area.
FLN	Flonicamid	Beleaf 50SG	Systemic	No statement[2]	None
OP	Acephate	Orthene 97	Systemic	Highly toxic	This product and its degradate are highly toxic to bees exposed to direct treatment on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds while bees are foraging the treatment area
OP	Phosmet	Imidan 70W	Non-Systemic	Highly toxic	This product is highly toxic to bees exposed to direct treatment on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops while bees are actively visiting the treatment areas.
OP	Malathion	Malathion 5EC	Non-Systemic	Highly toxic	This pesticide is highly toxic to bees exposed to direct treatment on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds while bees are actively visiting the treatment area.
OXD	Indoxacarb	Avaunt 30WDG	Non-Systemic	Highly toxic	This product is highly toxic to bees exposed to direct treatment on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds while bees are foraging in the treatment area.
PYR	Bifenthrin	Brigade WSB	Non-Systemic	Highly toxic	This product is highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds while bees are actively visiting the treatment area.
PYR	Esfenvalerate	Asana XL	Non-Systemic	Highly toxic	This product is highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops if bees are visiting the treatment area. For Caneberries: NOTE: Asana XL can act as a bee repellent, do not apply within 7 days of pollination. Apply as a pre-bloom or post-bloom spray only. Remove bees prior to application. For maximum safety to bees, apply Asana XL in the evening after sunset.
PYR	Fenpropathrin	Danitol 2.4 EC	Non-Systemic	Highly toxic	This product is highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds while bees are visiting the treatment areas.
PYR	Lambda-cyhalothrin	Warrior II	Non-Systemic	Highly toxic	This product is highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds if bees are visiting the treatment area.
SPN	Spinetoram	Delegate WG	Systemic	Toxic	This product is toxic to bees exposed to treatment during the 3 hours following treatment. Do not apply this pesticide to blooming, pollenshedding or nectar-producing parts of plants if bees may forage on the plants during this time period.
SPN	Spinosad	Entrust SC	Systemic	Toxic	This product is toxic to bees exposed to treatment for 3 hours following treatment. Do not apply this pesticide to blooming, pollen-shedding or nectar-producing parts of plants if bees may forage on the plants during this time period.
TTR	Spirotetramat	Movento 240SC	Systemic	Not toxic to adults	This product is potentially toxic to honey bee larvae through residues in pollen and nectar, but not to adult honey bees. Exposure of adult bees to direct treatment or residues on blooming crops can lead to effects on honey bee larvae. See the "Directions for Use" section of this label for specific crop application instructions that minimize risk to honey bee larvae. Pome fruits/Stone fruits: Do not apply until after petal fall.
UN	Azadirachtin	Aza-Direct	Systemic	No statement[2]	None

Notes: See Table 2.1 for active ingredient group abbreviations. (1) This product is a nitroguanidine neonicotinoid product labeled for outdoor foliage use, and is therefore is required by the EPA to have a "Pollinator Protection Box" on the label in addition to the labelling here (see Section 3.1). (2) There are three reasons why a label may not have a toxicity statement: (a) the product is practically nontoxic to bees; (b) the product is toxic to bees, but there is no potential for exposure to bees; or, (c) the product is nontoxic to bees and there is no potential for exposure to bees.

Table 6.7: **Bee toxicity statements for soil-applied insecticides used for control of common cucurbit pests, taken from product labels**

Group	Active ingredient	Product	Systemic	Bee toxicity	Additional bee labeling on product
NEO	Acetamiprid	Assail 30SG	Systemic	Toxic	This product is toxic to bees exposed to direct treatment. Do not apply this product while bees are foraging in the treatment area.
NEO	Imidacloprid	Admire Pro Systemic Protectant	Systemic	Highly toxic	This product is highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds if bees are foraging the treatment area. Do not apply pre-bloom or during bloom or when bees are foraging. (**This label includes a Pollinator Protection Box**)[1]
NEO	Thiamethoxam	Actara	Systemic	Highly toxic	This pesticide is highly toxic to bees exposed to direct treatment on blooming crops/plants or weeds. Do not apply this product or allow it to drift to blooming crops/plants or weeds while bees are foraging in/or adjacent to the treatment area. Pollinator Precautions¥ Actara is highly toxic to bees exposed to direct treatment on blooming crops/plants or weeds. (**This label includes a Pollinator Protection Box**)[1]
CRB	Carbaryl	Sevin XLR Plus	Systemic	Highly toxic	This product is highly toxic to honeybees and other bees exposed to direct treatment or residues on crops or weeds in bloom. This product may show residual toxicity to honeybees, especially in humid climates and under slow drying conditions. Notifying beekeepers within 1 mile of treatment area at lest 48 hours before product is applied will allow them to take additional steps to protect their bees. Limiting application to times when bees are least active, e,g., within 2 hours of sunrise or sunset, will minimize risk to bees. For crops in bloom (except soybean and corn): Do not apply this product to target crops or weeds in bloom .
PYR	Esfenvalerate	Asana XL	Non-Systemic	Highly toxic	This product is highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops if bees are visiting the treatment area. For Caneberries: NOTE: Asana XL can act as a bee repellent, do not apply within 7 days of pollination. Apply as a pre-bloom or post-bloom spray only. Remove bees prior to application. For maximum safety to bees, apply Asana XL in the evening after sunset.
PYR	Lambda-cyhalothrin	Warrior II	Non-Systemic	Highly toxic	This product is highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds if bees are visiting the treatment area.
PYR	Permethrin	Pounce 25WP	Non-Systemic	Highly toxic	This pesticide is highly toxic to bees exposed to direct treatment on blooming crops/plants or weeds. Do not apply this product or allow it to drift to blooming crops/plants or weeds while bees are foraging in/or adjacent to the treatment area.
SPN	Spinosad	Entrust SC	Systemic	Toxic	This product is toxic to bees exposed to direct treatment on blooming crops or weeds. Do not apply this pesticide or allow it to drift to blooming crops or weeds while bees are foraging the treatment area.
PAD	Pymetrozine	Fulfill	Non-Systemic	Low toxicity	Fulfill Insecticide is suitable for Integrated Pest Management (IPM) programs as it has a low toxicity to beneficial insects (including honeybees and bumblebees) and mites. It can be used in IPM programs using beneficial insects and during periods of pollination. However, do not apply Fulfill Insecticide directly to bees that are actively foraging in the field.
BT	Bt	Agree WG	Non-Systemic	No statement[2]	None
FLN	Flonicamid	Beleaf 50SG	Systemic	No statement[2]	None

Notes: See Table 2.1 for active ingredient group abbreviations. (1) This product is a nitroguanidine neonicotinoid product labeled for outdoor foliage use, and is therefore is required by the EPA to have a "Pollinator Protection Box" on the label in addition to the labelling here (see Section 3.1). (2) There are three reasons why a label may not have a toxicity statement: (a) the product is practically nontoxic to bees; (b) the product is toxic to bees, but there is no potential for exposure to bees; or, (c) the product is nontoxic to bees and there is no potential for exposure to bees.

Table 6.8: **Bee toxicity statements from turfgrass insecticide product labels**

Group	Active ingredient	Product	Systemic	Bee toxicity	Additional bee labeling on product
NEO	Imidacloprid	Armortech IMD75	Systemic	Highly Toxic	This product is highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds. DO NOT apply this product or allow it to drift to blooming crops or weeds if bees are foraging the treatment area. This product is toxic to wildlife and highly toxic to aquatic invertebrates. DO NOT allow this product to contact plants in bloom if bees are foraging the treatment area. (**This label includes a Pollinator Protection Box**)[1]
AND	Cyantraniliprole	Ference	Systemic	Highly Toxic	This product is highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds. Do not apply this product or allow it to drift to blooming plants or weeds if bees are foraging the treatment area.
BT	Bt	DiPel Pro DF	Non-Systemic	No statement[2]	None
CRB	Carbaryl	Sevin SL	Systemic	Highly Toxic	Bee caution: may kill honeybees and other bees in substantial numbers. This product is highly toxic to bees exposed to direct treatment or residues on crops or weeds in bloom. For crops in bloom, do not apply this product to target crops or weeds in bloom. Notifying beekeepers within 1 mile of treatment area at least 48 hours before product is applied will allow them to take additional steps to protect their bees. Limiting application to times when bees are least active, e.g., within 2 hours of sunrise or sunset, will minimize risk to bees.
OP	Trichlorfon	Dylox 420SL	Non-Systemic	No mention	None
OXD	Indoxacarb	Provaunt WDG	Non-Systemic	Highly Toxic	This product is highly toxic to bees exposed to direct treatment or to residues on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds while bees are foraging in or adjacent to the treatment area.
SPN	Spinosad	Conserve SC	Systemic	Toxic	This product is toxic to bees exposed to treatment during the 3 hours following treatment. Do not apply this pesticide to blooming, pollen shedding or nectar-producing parts of plants if bees may forage on the plants during this time period.

Notes: See Table 2.1 for active ingredient group abbreviations. (1) This product is a nitroguanidine neonicotinoid product labeled for outdoor foliage use, and is therefore is required by the EPA to have a "Pollinator Protection Box" on the label in addition to the labelling here (see Section 3.1). (2) There are three reasons why a label may not have a toxicity statement: (a) the product is practically nontoxic to bees; (b) the product is toxic to bees, but there is no potential for exposure to bees; or, (c) the product is nontoxic to bees and there is no potential for exposure to bees.

7. Conclusions, Data Gaps, and Further Research

Perhaps the most important conclusion of this report is that economic benefits and risk to pollinators from usage of neonicotinoid insecticides varies by application context. Below, we summarize the economic benefits of using neonicotinoid insecticides, risk to pollinators, and data gaps that exist for each application context. In addition, we highlight promising non-synthetic chemical pest control tools (e.g., biocontrols, bio-pesticides, RNA-based technologies) and new technologies (e.g., scouting for pests using drones with multispectral imagery, and other digital/precision agriculture solutions) that show particular promise as Integrated Pest Management (IPM) approaches in each application context. Further development and incorporation of these tools and technologies will allow New York State to reduce chemical insecticide usage and increase its environmental sustainability without compromising pest control and food security.

7.1 Field crops: Benefits, risks, and data gaps

Neonicotinoid seed treatments in corn and soybean have inconsistent benefits in terms of yield and financial returns for growers. In contrast with studies comparing neonicotinoid foliar sprays to untreated controls in fruit and vegetable crops, which showed clear benefits of neonicotinoid use (see Figure 5.5),

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Photo by Ron Nichols, USDA Natural Resources Conservation Service.

paired trials comparing neonicotinoid-treated corn and soybean seeds to no-insecticide controls rarely found a significant effect on yield (see Figures 5.2 and 5.3). In paired trials of neonicotinoid-treated corn seeds from New York and surrounding states, just 12 of 132 trials (9%) found a significant yield benefit relative to untreated seeds and 20 of 234 trials (9%) found a yield benefit relative to seeds treated with a fungicide but no insecticide. None of the 124 regional field trials comparing yield from neonicotinoid-treated corn seeds to that from using other seed- and soil-applied insecticides produced a significant, positive result. In regional soybean studies, 36 of 167 (22%) trials found significantly higher yield with neonicotinoid-treated soybeans than with untreated controls and 11 of 138 trials (8%) found a yield benefit compared to fungicide-only seeds (see Figure 5.3). This suggests that yield benefits from neonicotinoid-treated seeds are limited to a relatively small proportion of fields.

Neonicotinoid-treated seeds performed best, relative to alternatives, in trials managed to induce high pest pressure. In such trials, plots planted with treated seeds had higher yield and estimated net financial returns compared to plots using untreated seeds, fungicide-only seed treatments, or even (in most comparisons) other chemical insecticides (see Tables 5.5, 5.7, 5.16, and 5.18). In studies that did not manipulate pest pressure (i.e., comparing relative yields under prevailing field conditions), the yield and economic benefits of neonicotinoid-treated seeds were greatly reduced or eliminated.

In regional corn field trials that induced high pest pressure, plots using corn seeds treated with fungicides and a neonicotinoid insecticide produced 15.3% more grain than fungicide-only control plots; in trials that did not manipulate pest pressure, yield in the neonicotinoid-treated plots was just 2.4% higher than in the fungicide-only control plots, approximately the same as the difference in price between neonicotinoid-treated and fungicide-only corn seeds. Regional field trials that compared neonicotinoid-treated seeds to an alternative soil-applied insecticide (the pyrethroid tefluthrin) produced 3.4% higher yields in neonicotinoid-treated plots when managed for high pest pressure, but 10.6% higher yields in *non*-neonicotinoid plots when pest pressure was not manipulated. These relationships were also apparent when drawing on a larger North American data set. Given that neonicotinoid-treated seeds are almost ubiquitous in U.S. conventional corn (including New York State), the data indicate that yield benefits to farmers are uncommon and quite small, but substantial in some circumstances, especially when there is high pest pressure. The data also indicate that high pest pressures are currently rare in New York and its surrounding states and provinces.

In soybean, there was an even more dramatic difference in relative yields observed in trials that were managed for high pest pressure and those that did not manipulate pest pressure. In regional field trials where high pest pressure was induced, yield in plots using neonicotinoid-treated seeds was 34.9% and 43.7% higher than in untreated and fungicide-only control plots, respectively (Table 5.16). In all other trials, the yield benefit was 3.5% relative to untreated seeds and 3.0% compared to fungicide-only controls. The North American results (Table 5.18) were similar. When considered in combination with the small proportion of trials that observed increases in yield, these results suggest uncommon or minor yield benefits for most soybean farmers who use neonicotinoid-treated seeds, but significant benefits for growers experiencing elevated pest pressure.

In comparisons of expected net returns in neonicotinoid-treated and control plots (using the results of both trials that were managed for high pest pressure and those that were not), neonicotinoid-treated seeds produced higher expected net returns than fungicide-only seed treatments (3% higher in regional field corn analysis and 5% higher in regional soybean analysis). However, there was no consistent difference between expected net returns with neonicotinoid-treated seeds and untreated seeds; the higher yields associated with the former were cancelled out by the lower cost of the latter (see Tables 5.9, 5.10, 5.20, and 5.21). This is an important result, as it suggests that the cost to farmers of using neonicotinoid treatments on corn and soybean seeds, on average, is equivalent to the benefits. In other words, there is no overall net income benefit to using neonicotinoid treatments on corn and soybean seeds instead of untreated seeds.

Evidence was also mixed in comparisons of net returns between neonicotinoid-treated seeds and other chemical insecticide treatments. In corn, there was no difference in expected returns for neonicotinoid-treated seeds compared to soil-applied tefluthrin (see Tables 5.9 and 5.10). However, neonicotinoid-treated seeds did perform better than seeds treated with two newer anthranilic diamide insecticides, producing 7.7% and 4.4% more corn grain than seeds treated with chlorantraniliprole and cyantraniliprole, respectively, in North American trials. In contrast, a soil-applied organophosphate, chlorpyrifos, produced significantly higher net returns (by 7.5%) than paired North American plots using neonicotinoid-treated seeds. For soybean, there was insufficient data to estimate relative net returns for the most likely seed- and soil-applied chemical alternatives to neonicotinoid-treated seeds for early-season soil pests. This report did, however, assess neonicotinoid-treated seed performance relative to alternative foliar-applied insecticides in soybean. Foliar insecticides are an alternative to treated seeds for soybean aphid. Nationally, soybean aphid is the pest most frequently targeted by soybean growers using neonicotinoid-treated seeds, despite limited evidence of efficacy. In regional data, paired field trials with a foliar pyrethroid spray (lambda-cyhalothrin) produced nearly-identical average yields, but net income with neonicotinoid-treated seeds was an average of 3.1% higher due to higher application costs associated with foliar sprays (see Table 5.20. North American soybean results were similar (Table 5.21).

Treated seeds are not the only use of neonicotinoids in soybean; growers may use foliar sprays based on several neonicotinoid active ingredients. In North American field trials, yield in plots using foliar sprays containing on the neonicotinoid acetamiprid were 8.2% higher than in plots treated with pyrethroid alternatives and 18.6% higher than in untreated control plots. Other neonicotinoid active ingredients (i.e., nitroguanidine neonicotinoids) did not perform as well. Yield was significantly lower in nitroguanidine neonicotinoid-treated plots compared to pyrethroid- or organophosphate-treated plots, and there was no difference in yield between untreated controls and paired plots using nitroguanidine neonicotinoid foliar sprays. This is an important result in the context of pollinator risk, as acute toxicity of acetamiprid to bees is at least three orders of magnitude lower than that of the nitroguanidine neonicotinoids clothianidin, imidacloprid, and thiamethoxam. Indeed, acetamiprid is considered a reduced-risk insecticide.

Risk to bees from exposures associated with neonicotinoid-treated seeds in field crops settings can be substantial. The data show that exposures in and near seed-treated corn, soybean, and wheat fields are likely to impact honey bee reproduction in over a third (37%) of cases, and honey bee physiology and behavior are likely to be impacted in approximately three quarters and one half of cases (74% and 58%, respectively; Figure 6.7). Furthermore, the magnitude of risk to bees in field crops settings is substantial. Exposures were often observed at over 100 times the concentration known to impact honey bee reproduction (Figure 6.7). While several of these high values were direct exposures from planting dust or drift onto nearby weedy flowers, it is important to note that mitigating planting dust will not eliminate risk in field crops settings. Indeed, only 34% of exposures predicted to impact honey bee reproduction came from planting dust; the remaining 66% of exposures came from contaminated flowers, bees, water, or soil that were tested months or even years after seed treatments were used. Widespread soil contamination is particularly worrisome since 54% of New York's 417 species of bees nest in the ground. Overall, with 96 exposure values in field crops settings and 210 studies that have investigated sublethal effects of neonicotinoids on bees, there is a broad understanding upon which to base conclusions about risk. The evidence indicates season-long and multi-year exposures that impact bee biology commonly occur when neonicotinoid-treated seeds are used in field crops settings.

Inconsistent benefits of neonicotinoid treatments used on corn and soybean seeds do not mean that seed treatments have no benefits to individual farmers. A severe infestation of seedcorn maggot or, to a lesser extent, other early-season pests can cause significant damage. Farms at high risk from those pests are likely to benefit from using preventive seed treatments or soil-applied insecticides at planting. Even farmers at relatively low risk of infestation may value the certainty provided by preventive seed treatments; without preventive insecticides, farmers can reduce but not eliminate the risk of significant damage from seedcorn maggot and other insect pests. As noted above, some currently available alternative insecticides are likely to offer comparable performance against the major pests targeted by neonicotinoid seed treatments, though soil-applied or foliar insecticides are typically more expensive to apply once labor costs are considered. Pyrethroids are not systemic insecticides and therefore applications to seeds or soil are unlikely to pose risk to pollinators. Anthranilic diamides may be a viable systemic alternative to neonicotinoids in some applications, and are substantially less toxic to bees. However, yield and estimated net returns following anthranilic diamide-treated seeds compared unfavorably to neonicotinoids in limited number of studies gathered for this report. This was primarily due to the current high cost of anthranilic diamide seed treatments; if there is greater demand for these seed treatments in the future, cost may decrease.

Some uncertainties and data gaps exist. For example, given the prevalence of neonicotinoid-treated seeds in corn and soybean, current pest pressures may not reflect risks to farms that use other pest management strategies in the future. Similarly, products and practices tested in other states may perform differently under New York conditions (if, for instance, those tests took place in a region with lower organic inputs from manure and cover crops). In soybean, a significant data gap exists due to the lack of pairwise comparison studies between neonicotinoid- and cyantraniliprole-treated seeds. Though this analysis for soybean did not find mean economic benefits of neonicotinoid seed treatments compared to treatment-free seeds, cyantraniliprole-treated seeds are among the most likely substitutes to neonicotinoids, as they act against a similar spectrum of pests and would not require major changes to management techniques. Finally, at the state level, a survey of current seed treatment usage would be highly valuable for tracking the economic and environmental impacts of neonicotinoid use. The most recent publicly-available data on neonicotinoid-treated seed use in New York are from 2014. Since treated seeds almost certainly represent most neonicotinoid usage in the state, this is a significant data gap. Similarly, data on the adoption of low-dust technologies by seed treating facilities and growers is necessary to accurately assess the environmental risks from neonicotinoid-contaminated dust released during planting. Dust drift can be nearly eliminated by using high-quality seed coating adhesives, lubricating agents, planters, and planting techniques that minimize abrasion of seeds and release of contaminated dust. Better data on the adoption of these technologies would allow targeted intervention, if necessary, to reduce risks associated with dust drift.

Further research is needed to fully assess pesticide risk to pollinators in field crops. Specifically, interactions between neonicotinoids and fungicides are known to impact hazard to pollinators, and neonicotinoids are rarely used alone in seed treatments. Instead, several different fungicides are commonly utilized in combination with neonicotinoids, and exposures to pollinators are typically comprised of fungicides and insecticides when both are screened for in field crops settings. While synergisms are known to occur, limited understanding exists regarding the likelihood of synergisms between several specific fungicide-insecticide combinations. Because the available evidence suggests some fungicide-insecticide combinations cause synergies and some don't, the possibility exists to minimize risk to pollinators by, when necessary for pest control purposes, using specific fungicide-insecticide combinations that will not result in synergies but still provide adequate pest and pathogen control.

Further research on new scouting techniques and alternatives to chemical insecticides for pest control would be helpful in field crops settings. For example, new research shows that drones using multispectral imagery can be an easy, cheap, and highly effective means of identifying soybean aphid infestations. Use and refinement of these new scouting methods could reduce unnecessary sprays for soybean aphid while taking advantage of the new Cornell Initiative for Digital Agriculture (CIDA). In addition, the timing of high organic content fertilizer applications in the spring and planting of seeds are both strong determinants of risk from damage from seedcorn maggot, for which emergence is predicted by degree days and temperature. Other states, such as Wisconsin, have developed models to predict the timing of elevated risk from seedcorn maggot. Such capacity potentially exists in New York via the NEWA program, which is run through the New York State IPM program, yet is not currently utilized for seedcorn maggot.

In addition to understanding risk and benefits of seed treatments more comprehensively, further study could support policies that reduce financial risk to farmers who choose to forgo insecticidal seed treatments. For many farmers, preventive neonicotinoid seed treatments are analogous to insurance. Damaging infestations of target pests are unlikely in any given year, but are also unpredictable and potentially costly. In this situation, farmers expecting normal pest pressures might forgo seed treatments in exchange for more generous insurance covering potential damage from early-season pests. Inexpensive insurance would also allow farmers not using treated seeds to continue using cover crops and reduced tillage with confidence. Both practices have substantial environmental and financial benefits, but can increase the risk of infestation by early-season pests. If statewide environmental costs of routine use of neonicotinoid seed treatments are perceived to outweigh net financial benefits, well-designed insurance incentives could reduce neonicotinoid use without imposing new costs or uncertainties on farmers. Additional research and consultation would be needed to design incentives that meet farmers' needs while efficiently reducing neonicotinoid usage.

7.2 Fruit crops: Benefits, risks, and data gaps

Neonicotinoid foliar sprays and/or soil treatments are commonly used in New York grape, berry, and tree fruit production. In contrast to the inconsistent benefits observed in field crops, neonicotinoids provide much more consistent benefits in fruit crops: yield, crop damage, or pest control improved in 109 of 146 (75%) cases when neonicotinoid foliar sprays were compared to no-treatment controls for grapes and tree fruits (Figure 5.5). In grape cultivation, neonicotinoid-based products are the most cost-effective available treatment for root-form phylloxera. Berry growers would have similar difficulty controlling certain root weevils and sap beetles without neonicotinoid-based products. For all three target pests, growers would be entirely dependent on a single class of insecticides (tetronic acids for root-form phylloxera, pyrethroids for root weevils and sap beetles) in the absence of neonicotinoids. This would increase the risk of insecticide resistance in target pests. There are non-neonicotinoid products from multiple insecticide families available for other major pests of fruit, though removing neonicotinoids from insecticide rotations would, to varying degrees, increase the cost and complexity of pest management.

At the same time, we note that the cyanoamidine neonicotinoid, acetamiprid, provides good control of many fruit pests and also poses substantially less risk to pollinators compared to the nitroguanidine neonicotinoids used in fruits (imidacloprid and thiamethoxam). The value of acetamiprid as an alternative to foliar imidacloprid and thiamethoxam products is illustrated in Tables 5.25 and 5.27. Those tables compare the effect of neonicotinoid foliar sprays on crop damage in tree fruits and grapes, respectively, relative to non-neonicotinoid foliar sprays in paired field trials. Acetamiprid, the less toxic option for honey bees, performed as well as non-neonicotinoid sprays: there was no significant difference in damage to trees or fruit. Imidacloprid- and thiamethoxam-treated plots, in contrast, had significantly more damage than plots treated with a non-neonicotinoid insecticide.

Risk to bees from exposures associated with neonicotinoid usage in fruit crops does occur, but both the likelihood and magnitude of risk are lower than in other settings. The evidence shows that exposures are likely to impact honey bee reproduction in less than one fifth (17%) of cases, and honey bee physiology and behavior are likely to be impacted in 50% and 38% of cases, respectively. With 24 exposure values from the peer-reviewed literature, the data upon which to base conclusions about risk are rather limited. However, complementing this data set, our own data from New York apple and strawberry plantings show that risk from imidacloprid and thiamethoxam exposures can be high during the bloom period for these crops (Figures 6.4 & 6.5). In these studies, exposures to acetamiprid were typically far greater than exposures to imidacloprid and thiamethoxam, but because acetamiprid is much less toxic to bees, risk was always lower.

Some important data gaps exist for fruit crops. Specifically, most pollinator exposure data for fruits comes from apple, meaning there is limited understanding of risk to pollinators in other fruit crops. Thus, more research on exposure in a wider variety of fruit crops is needed to better understand consistency or heterogeneity of risk. In addition, it is well-known that fungicide exposures are ubiquitous during pollination of fruit crops since growers regularly spray fungicides during bloom. Recent studies show that fungicides typically represent greater than 90% of pesticide residues by weight in bee-collected pollen during pollination of fruit crops. Because of these exposures and limited understanding regarding the likelihood of synergisms between several fungicide-insecticide combinations, more research on this topic is warranted. In particular for fruit crops, little is known about risk posed from fungicides that may synergize with acetamiprid, which poses little risk to pollinators on its own but is often found in combination with fungicides when residues are assessed. Furthermore, while much research has been conducted on the toxicity of fungicides to honey bee adults, little research has focused on larvae. This is potentially an important gap in knowledge since several recent studies have found that fungicides such as captan and chlorothalonil can be highly toxic to larvae but nontoxic to adults. Indeed, one recent study has found that field-relevant doses of captan can be as toxic to honey bee larvae as field-relevant doses of thiamethoxam.

In addition, research on risk mitigation strategies would be highly useful. For example, recent work in New York apple orchards has shown that pesticide residues are commonly found on wildflowers in and around orchards. While mowing these wildflowers during bloom is likely to reduce risk to pollinators, this topic is actually poorly understood. Since frequent mowing places additional burden on growers, well-designed studies to address this question would be useful. Finally, new research shows that several natural products can be added to fungicide and insecticide sprays that will deter pollinators. This provides a potentially simple but elegant method to reduce pesticide exposure to bees during pollination: use deterrents in pesticide sprays. However, because pollination by bees is often required to produce fruits, the use of deterrents must not interfere completely with pollination. Further research on this topic could lead to novel methods that reduce pesticide risk to pollinators while still facilitating adequate crop pollination.

7.3 Vegetable crops: Benefits, risks, and data gaps

The data also suggest significant benefits from neonicotinoid applications in New York's major vegetable crops (Figure 5.5 and Tables 5.31 through 5.37). Neonicotinoids are the best available product for control of Swede midge, a major pest of cabbage and other brassicas (Table 5.32). Growers would likely struggle to control this pest in the absence of imidacloprid and acetamiprid. In snap bean, neonicotinoid-treated seeds are important for the control of seedcorn maggot and aphids. Neonicotinoid seed treatments are associated with consistently higher yields in snap bean than with alternative seed treatments, soil-applied insecticides, or untreated controls (Table 5.36). In sweet corn, too, there is evidence for better outcomes (in terms of yield, crop damage, or pest control) in plots using neonicotinoid-treated seeds compared to untreated controls (though few paired trials compare neonicotinoid-treated seeds to chemical alternatives in this crop) (Table 5.38). Neonicotinoids also performed well in trials against untreated controls and alternative insecticides in cucurbit crops (Table 5.40). Finally, neonicotinoids play an important role in insecticide rotations for Colorado potato beetle; removing this mode of action from rotations could decrease the effectiveness of other insecticides as well.

Overall, the evidence shows that exposures in vegetables are likely to impact honey bee reproduction in over half (54%) of cases, and honey bee physiology and behavior are likely to be impacted in 88% and 75% of cases, respectively. The magnitude of risk in vegetable crops settings was higher than in fruit crops, but lower than in field crops settings (Figure 6.7). However, similar to fruit crops, only 24 exposure values exist from the peer-reviewed literature, and most of these data come from squash and pumpkins. This means that knowledge in the peer-reviewed literature of risk from neonicotinoid insecticides to bees is fairly limited for vegetable crops, with the exception of cucurbits. Consistent with this knowledge of risk in cucurbits, the USEPA recently recommend a prohibition on use of imidacloprid-, clothianidin-, and thiamethoxam-based products between vining and harvest to protect pollinators [998]. Importantly, our analysis found that neonicotinoid applications before or during planting can also result in exposures to bees that are likely to impact reproduction (Figures 6.6 & 6.7).

Few non-neonicotinoid active ingredients are available as vegetable seed treatments, though products from several IRAC insecticide groups are effective as a soil treatment at planting. Substitutes for neonicotinoid foliar sprays are available for most major vegetable target pests, with the notable exception of Swede midge. At present, only one non-neonicotinoid active ingredient is a viable (albeit more expensive) alternative to imidacloprid and acetamiprid for this pest. In this and several other applications, acetamiprid products may offer comparable performance to imidacloprid products with significantly lower risk to pollinators. Anthranilic diamides would also be predicted to lower risk to pollinators. Overall, there are significant gaps in data comparing efficacy and yield of neonicotinoids and alternative insecticides (particularly those with newer modes of action) in New York and neighboring states. This may limit the practical options available to growers seeking alternatives to nitroguanidine neonicotinoids.

In addition, further research on alternatives to chemical insecticides for pest control would be helpful in vegetable production. For example, new research shows that UV light can be an effective, implementable, and safe method of controlling important pathogens of vegetable crops. In addition, usage of several new biopesticides show promise, but further work is needed to bring these new tools out of the research environment and into production. On a broader scale, longer-term agroecosystem research to make insecticide-reducing IPM tools (e.g., a risk assessment model for seedcorn maggot) useful for commercial producers would be helpful. Finally, aside from cucurbits, relatively little is known regarding how usage of neonicotinoids leads to pollinator exposures in most vegetable crops. This absence of peer-reviewed literature is a major gap in knowledge. Thus, further studies assessing neonicotinoid (and other pesticide) risk to pollinators in a broader array of vegetables is warranted.

7.4 Ornamentals, turf & landscape management: Benefits, risks, and data gaps

Neonicotinoid-based products are the best available pest control products for control of several important pests of ornamentals. Soil-applied imidacloprid provides effective, long-lasting protection for the invasive viburnum leaf beetle. Acetamiprid-based trunk injections and basal sprays are important tools for the control of several species of soft and armored scale. In these and several other applications, switching to non-neonicotinoid products would be difficult. For ornamental hemlocks, neonicotinoid-based products are irreplaceable for woolly adelgid control. However, these critical applications make up a small proportion of neonicotinoid applications in ornamentals. In some applications (e.g., adelgids, soft scales, leafhoppers), acetamiprid products are an effective substitute to imidacloprid or thiamethoxam foliar sprays or soil treatments. Shifting from nitroguanidine neonicotinoids to acetamiprid where feasible could permit pesticide users to retain the benefits of neonicotinoids' mode of action with less risk to pollinators and beneficial insects.

The evidence shows that exposures in ornamentals and turf are likely to impact honey bee reproduction in over half (72%) of cases, and honey bee physiology and behavior are likely to be impacted in 92% and 88% of cases, respectively. The magnitude of risk in ornamentals and turf settings was also high (Figure 6.7). Soil drenches of imidacloprid to woody ornamentals and sprays of imidacloprid and clothianidin to weedy turf resulted in exposures that were either shown experimentally to impact bumble bee reproduction or would always be predicted to impact honey bee reproduction. That said, only 25 exposure values exist from the peer-reviewed literature, so caution should be exercised in making generalizations. More data are needed to robustly assess risk for these applications.

Promising results already exist for neonicotinoid replacements that minimize risk to pollinators in turf settings while providing acceptable pest control. Turfgrass managers rely heavily on neonicotinoids for preventive control of white grub, a common and costly pest. Products based on chlorantraniliprole (an anthranilic diamide) are effective alternatives. Relative to neonicotinoid-based treatments, white grub control with chlorantraniliprole poses much lower risk to pollinators. Indeed, in one recent study, the use of chlorantraniliprole had no impact on bumble bee reproduction while imidacloprid usage reduced queen production in side-by-side field studies comparing these two insecticides in a turfgrass setting. However, chlorantraniliprole products are currently substantially more expensive in New York. Furthermore, we note that chlorantraniliprole products are currently not available on Long Island, where a large portion of the state's turf exists. Aside from chlorantraniliprole, there are no effective alternatives to imidacloprid for preventive white grub control on turfgrass, though pyrethroids are commonly used for curative treatments.

Some risk mitigation techniques exist for turf and ornamentals, though more work is needed to understand how to maximize efficacy of these practices. On turfgrass treated with imidacloprid, mowing immediately before application substantially reduces exposure to pollinators from residues in weedy flowers. In addition, the timing of neonicotinoid application to ornamentals (e.g., fall, spring or summer) is known to dramatically impact residue concentrations in pollen and nectar when some ornamentals bloom. However, limited knowledge exists on this topic and therefore general recommendations are difficult. Further research on how the timing of applications in different ornamental plants impacts residue levels in pollen and nectar would be beneficial.

7.5 Conservation and forestry: Benefits, risks, and data gaps

Imidacloprid and dinotefuran play an important role in controlling three invasive forest pests: hemlock woolly adelgid, Asian longhorned beetle, and emerald ash borer. There is no immediate alternative to imidacloprid and dinotefuran for chemical control of hemlock woolly adelgid. Restrictions on neonicotinoids that affect this application would have dire consequences for New York's Eastern hemlocks, an important foundation species and the third most common tree in the state. If left uncontrolled, hemlock woolly adelgid spreads easily and kills almost 100% of hemlocks infested. Similarly, imidacloprid is the mainstay of quarantine and eradication efforts for Asian longhorned beetle. While currently contained to central Long Island, this pest has the potential to cause major impacts to New York forests and street trees if allowed to escape containment. There is no short-term alternative to imidacloprid in this role. Neonicotinoids also play a role in controlling emerald ash borer: the most expensive forest pest in history. However, several cost-effective alternatives are now available for this pest.

We find little evidence that neonicotinoid usage to control hemlock woolly adelgid, Asian longhorned beetle, or emerald ash borer is likely to result in risk to pollinators. Further research into usage of hemlock sap by bees and typical sap residue levels after treatment of trees would help fill these knowledge gaps. In addition, further research in the usage of ash pollen by bees and typical pollen residue levels after treatment of trees would be helpful. Based on existing research, however, we do not expect substantial risk to pollinators from these potential routes of exposure.

Acronyms

AITL Acute Insecticide Toxic Load. 198–200
ANOVA Analysis of Variance. 123, 124, 126, 136, 137, 139, 141, 152, 157, 174

Bt *Bacillus thuringiensis*. 65, 77, 78, 86, 89, 98, 101

CCE Cornell Cooperative Extension. 30, 31, 74, 76, 84, 85, 89, 94, 98, 100, 101, 104, 105

EFSA European Food Safety Authority. 56
EIQ Environmental Impact Quotient. 34–36, 38

FFDCA Federal Food, Drug and Cosmetic Act. 192
FIFRA Federal Insecticide, Fungicide, and Rodenticide Act. 115, 117, 192–194
FUEIQ Field Use Environmental Impact Quotient. 36, 39

HQ Hazard Quotient. 34, 35, 39, 40

IPM Integrated Pest Management. 84, 91, 99, 119, 120, 142, 187, 240, 244
IRAC Insecticide Resistance Action Committee. 84, 91, 92, 94, 98, 99, 101, 109, 193, 243

LOEC Lowest Observed Effect Concentration. 8, 34, 35, 40, 203, 205–209, 211, 213, 215, 217, 219–225

nAChR nicotinic acetylcholine receptor. 41, 54

NASS National Agricultural Statistics Service. 30, 31

NEWA Network for Environment and Weather Applications. 101, 103, 240

NYSDEC New York State Department of Environmental Conservation. 28, 30, 34, 52, 53, 55, 60–62, 80, 84, 112, 114, 117, 185, 192, 194, 195

ppb parts per billion. 195, 208, 209, 211–220

PPE Personal Protective Equipment. 42, 45–47, 51, 63

PSUR Pesticide Sales Use and Reporting. 30

USDA U.S. Department of Agriculture. 30, 31, 43, 81, 124, 139, 141, 157

USEPA United States Environmental Protection Agency. 12, 28, 34, 35, 38–42, 45–47, 49–53, 55, 56, 58–65, 80, 84, 104, 105, 114, 185, 191–195, 201, 203, 217, 225–227

USGS U.S. Geological Survey. 29, 30, 64

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A. Studies contributing to benefits analysis

The tables in the following pages list the sources underlying analysis in Chapter 5: Value of Neonicotinoids in New York. The methods used to gather studies and extract data during the literature review are described in Section 5.1.

Table A.1: **Sources for field corn yield and efficacy analysis**

Location	Year	Study
		New York State studies
NY	2004	Cox, Cherney, and Shields [168]
NY	2005	Cox, Shields, Cherney, and Cherney [169]
NY	2005-06	Cox, Shields, and Cherney [170]
		Regional data
OH	2002	Ruhl [766]
OH	2004	Bartels [41]
OH	2006	Eisley and Hammond [236]
OH	2006	Paul, Johnston, and Mills [660]
OH	2006	Paul, Johnston, and Mills [661]
OH	2007	Eisley and Hammond [237]
OH	2009	Paul and Wallhead [658]
OH	2009	Paul and Wallhead [659]
OH	2012	LaBarge [481]
OH	2012	Willyerd, Williams, and Paul [1075]
ON	2002	Hooker and Schaafsma [407]
ON	2002	Schaafsma, Paul, Phibbs, and Vujevic [780]
ON	2002	Schaafsma, Paul, Phibbs, and Vujevic [782]
ON	2002	Schaafsma, Paul, Phibbs, and Vujevic [783]
ON	2002	Schaafsma, Paul, Phibbs, and Vujevic [781]
ON	2002	Schaafsma, Paul, Phibbs, and Vujevic [789]
ON	2002	Schaafsma, Paul, Phibbs, and Vujevic [791]
ON	2002	Schaafsma, Paul, Phibbs, and Vujevic [784]
ON	2002	Schaafsma, Paul, Phibbs, and Vujevic [785]
ON	2003	Schaafsma, Paul, Phibbs, and Vujevic [792]
ON	2003	Schaafsma, Paul, Phibbs, and Vujevic [793]
ON	2003	Schaafsma, Paul, Phibbs, and Vujevic [786]
ON	2003	Schaafsma, Paul, Phibbs, and Vujevic [787]
ON	2003	Schaafsma, Paul, Phibbs, and Vujevic [788]
ON	2004	Schaafsma, Paul, Phibbs, and Vujevic [797]
ON	2004	Schaafsma, Paul, Phibbs, and Vujevic [798]
ON	2004	Schaafsma, Paul, Phibbs, and Vujevic [794]
ON	2005	Kullik, Schaafsma, Hooker, and Vujevic [478]
ON	2007	Smith and Phibbs [856]
ON	2008	Smith, Phibbs, and Schaafsma [858]
ON	2008	Smith, Phibbs, and Schaafsma [857]
ON	2008	Wilde, Roozeboom, Ahmad, Claassen, Gordon, Heer, Maddux, Martin, Evans, and Kofoid [1051]
ON	2010	Smith, Phibbs, and Schaafsma [861]
ON	2011	Kullik, Sears, and Schaafsma [479]
ON	2011	Smith, Phibbs, and Schaafsma [862]
QC	2020	Labrie, Gagnon, Vanasse, Latraverse, and Tremblay [482]

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Sources for field corn yield and efficacy analysis, continued

Location	Year	Study
		North American data
AL	2009	Lawrence, Moore, Lawrence, and Akridge [494]
AL	2013	Hagan and Campbell [346]
AL	2013	Hagan and Campbell [347]
CA	2014	Leinfelder-Miles [499]
CA	2014	Leinfelder-Miles [500]
KS	2000-01	Wilde, Roozeboom, Claassen, Janssen, and Witt [1050]
KS	2003	Jardine, Gordon, Janssen, and Long [423]
KS	2004	Jardine, Gordon, and Long [424]
KS	2013	Jardine [421]
IA	1999	Oleson, Nowatzki, Wilson, and Tollefson [636]
IA	2001	Shriver and Munkvold [847]
IA	2003-04	Rice and Oleson [740]
IA	2007	Rodriguez-Brljevich and Robertson [746]
IA	2007	Rodriguez-Brljevich and Robertson [747]
IA	2007	Rodriguez-Brljevich, Shriver, and Robertson [749]
IA	2007	Rodriguez-Brljevich, Shriver, and Robertson [748]
IA	2012	Hodgson and McCarville [400]
IL	2004	Estes, Steffey, and Gray [248]
IL	2004	Estes, Steffey, and Gray [247]
IL	2004	Estes, Schroeder, Steffey, and Gray [245]
IL	2004	Estes, Steffey, and Gray [250]
IL	2005	Estes, Schroeder, Steffey, and Gray [254]
IL	2005	Estes, Schroeder, Steffey, and Gray [255]
IL	2006	Estes, Schroeder, Steffey, and Gray [256]
IL	2006	Estes, Schroeder, Steffey, and Gray [257]
IL	2014	Estes, Gray, and Tinsley [265]
IL/NE	2003-14	Tinsley, Mitchell, Wright, Meinke, Estes, and Gray [917]
IN	2004	Shaner, Buechley, and Long [830]
IN	2012	Krupke, Holland, Long, and Eitzer [463]
LA	1997	Riley, Castro, Calix, and Rabb [743]
MD	2016	Dubey, Lewis, Dively, and Hamby [216]
MD	2018-19	Cramer, Afful, Dively, and Hamby [173]
MI	2015	Battel, Kaatz, Nagelkirk, Vincent, and Alexander [47]

Continued on next page.

Sources for field corn yield and efficacy analysis, continued

Location	Year	Study
		North American data, continued
MS	2007	Lawrence and Caceres [492]
MS	2015	Bateman, Catchot, Bao, Adams, Adams, Crow, Darnell, Dill, Graham, North, et al. [45]
MS	2016	Cook and Gore [140]
NC	2016	Reisig, Herbert, and Malone [732]
NE	2017	DeVries and Wright [198]
NE	2018	Mollet, Hirzel, Oliveira-Hofman, and Peterson [577]
SD	2016	McManus and Fuller [552]
SD	2016	McManus and Fuller [553]
SD	2017	McManus and Fuller [554]
VA	2000	Stromberg and Flinchum [884]
VA	2006-08	Jordan, Youngman, Laub, Tiwari, Kuhar, Balderson, Moore, and Saphir [441]
VA	2009	Phipps and Hu [675]

Table A.2: **Sources for soybean yield and efficacy analysis**

Location	Year	Study
		New York State studies
NY	2005-06	Cox, Shields, and Cherney [171]
NY	2009-10	Cox and Cherney [166]
NY	2012-13	Cox and Cherney [167]
		Regional data
OH	2001	Hammond [356]
OH	2002	Hammond [357]
OH	2003	Hammond [358]
OH	2004	Hammond [359]
OH	2004	Mills, Berry, and Dorrance [565]
OH	2005	Berry, Mills, and Dorrance [54]
OH	2005	Kleinschmidt and Prill [451]
OH	2005	LaBarge [480]
OH	2006	Kleinschmidt and Prill [452]
OH	2007	Hammond [360]
OH	2008	Hammond [361]
OH	2013	Bethel, Kroon Van Diest, McCormick, and Lindsey [55]
OH	2014	Bethel, Kroon Van Diest, McCormick, and Lindsey [56]
OH	2015	Bethel, Kroon Van Diest, McCormick, Hankinson, and Lindsey [57]
OH	2016	Bethel, McCormick, Hankinson, and Lindsey [58]
OH	2015	Dorrance, Winger, and Martin [210]
OH	2017	Clevenger [127]
OH	2017	Looker, McCormick, Hankinson, and Lindsey [515]
OH	2018	Looker and Lindsey [514]
ON	2004	Schaafsma, Paul, Phibbs, and Vujevic [795]
ON	2004	Schaafsma, Paul, Phibbs, and Vujevic [799]
ON	2005	Schaafsma, Paul, Phibbs, and Vujevic [796]
ON	2005	Schaafsma, Paul, Phibbs, Vujevic, and Welsman [800]
ON	2005	Welsman, Hooker, Schaafsma, Bohner, Paul, and Phibbs [1042]
ON	2006	Schaafsma, Paul, Phibbs, and Smith [804]
ON	2006	Schaafsma, Paul, Phibbs, and Smith [801]
ON	2006	Schaafsma, Paul, Phibbs, and Smith [802]
ON	2006	Schaafsma, Paul, Phibbs, and Smith [803]
ON	2007	Smith and Phibbs [855]
ON	2008	Smith, Phibbs, and Schaafsma [859]
ON	2008	Smith, Phibbs, and Schaafsma [860]
ON	2015-16	Gaspar, Mueller, Wise, Chilvers, Tenuta, and Conley [308]
PA	2012	Douglas, Rohr, and Tooker [213]
PA	2015	Voight, Bray, Collins, and Roth [1022]
PA	2016	Voight, Bray, Collins, and Roth [1023]
QC	2020	Labrie, Gagnon, Vanasse, Latraverse, and Tremblay [482]

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Sources for soybean yield and efficacy analysis, continued

Location	Year	Study
		North American data
AL	2009	Ballard and Lawrence [38]
AL	2009	Lawrence and Moore [493]
DE	2015	Kness, Ramage, and Kleczewski [454]
DE	2015	Kleczewski, Cissel, and Whalen [449]
IA	2005	Ohnesorg, Johnson, and O'neal [635]
IA	2008	Johnson, O'Neal, Bradshaw, and Rice [436]
IA	2009	Hodgson and VanNostrand [401]
IA	2012	Hodgson and McCarville [400]
IA	2016	Fawcett, Schneider, Miller, and Nicolaus [278]
IA	2016	Gaspar, Mueller, Wise, Chilvers, Tenuta, and Conley [308]
IA	2016	Hodgson and VanNostrand [402]
IA	2017	Hodgson and VanNostrand [403]
IA	2018	Hodgson and VanNostrand [404]
IL	2004	Estes, Steffey, and Gray [246]
IL	2004	Estes, Steffey, and Gray [249]
IL	2005	Estes, Schroeder, Steffey, and Gray [251]
IL	2005	Estes, Schroeder, Steffey, and Gray [252]
IL	2005	Estes, Schroeder, Steffey, and Gray [253]
IL	2006	Estes, Schroeder, Steffey, and Gray [258]
IL	2007	Estes, Gray, Steffey, Heeran, and Tinsley [259]
IL	2007-08	Tinsley, Steffey, Estes, Heeren, Gray, and Diers [916]
IL	2008	Estes, Gray, Steffey, Heeran, and Tinsley [260]
IL	2011	Estes, Gray, and Tinsley [261]
IL	2012	Estes, Tinsley, and Gray [262]
IL	2012	Estes, Tinsley, and Gray [264]
IL	2012	Estes, Tinsley, and Gray [263]
IL	2011-12	Vossenkemper, Nafziger, Wessel, Maughan, Rupert, and Schmidt [1024]
IN	2011-12	Vossenkemper, Nafziger, Wessel, Maughan, Rupert, and Schmidt [1024]
IN	2016	Gaspar, Mueller, Wise, Chilvers, Tenuta, and Conley [308]
KS	2005	Jardine, Gordon, Maddux, and Long [425]
KS	2006	Whitworth [1048]
KS	2009	Jardine and Maddux [422]
KS	2014	Jardine [421]
KY	2015	Penn and Dale [664]
LA	2009	Davis, Kamminga, and Richter [183]
MD	2015-16	Dubey, Lewis, Dively, and Hamby [216]

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Sources for soybean yield and efficacy analysis, continued

Location	Year	Study
		North American data, continued
MI	2005	Jewett and DiFonzo [429]
MI	2006	Jewett and DiFonzo [430]
MI	2006	Jewett and DiFonzo [431]
MI	2014	Rossman, Byrne, and Chilvers [761]
MI	2014	Battel, Kaatz, Nagelkirk, Vincent, and Alexander [47]
MI	2015	Battel, Kaatz, Nagelkirk, Vincent, and Alexander [47]
MI	2016	Battel, Kaatz, Nagelkirk, Vincent, and Alexander [48]
MI	2015-16	Gaspar, Mueller, Wise, Chilvers, Tenuta, and Conley [308]
MI	2017	Staton [873]
MN	2003-05	McCornack and Ragsdale [540]
MN	2018	da Silva Queiroz, Carlesso Aita, and Koch [180]
MS	2015	Cook, Gore, and Ford [141]
NC	2010	Reisig, Herbert, and Malone [732]
ND	2005	Bradley and Chesrown [76]
ND	2008	Markell, Meyer, Jordahl, and Mathew [526]
NE	2004	Echtenkamp and Hunt [219]
NE	2005	Echtenkamp and Hunt [220]
NE	2005	Echtenkamp and Hunt [221]
NE	2005	Giesler and Ziems [318]
NE	2005-06	Magalhaes, Hunt, and Siegfried [523]
NE	2006	Echtenkamp and Hunt [222]
NE	2006	Echtenkamp and Hunt [223]
NE	2005	Giesler and Ziems [319]
NE	2006	Giesler and Ziems [320]
NE	2007	Giesler and Gustafson [316]
NE	2008	Giesler and Gustafson [317]
PE	2013	Martin, Fleming, and Matters [528]
SD	2013-14	Regan, Ordosch, Glover, Tilmon, and Szczepaniec [731]
SD	2017-18	Dierks [203]
SD	2009-10	Seagraves and Lundgren [822]
TX	2003	Way, Nunez, McCauley, and Minton [1037]
VA	2008-10	Reisig, Herbert, and Malone [732]
WI	2008-10	Esker and Conley [243]
WI	2011-12	Gaspar, Marburger, Mourtzinis, and Conley [306]
WI	2012-13	Gaspar, Mitchell, and Conley [307]
WI	2015-16	Gaspar, Mueller, Wise, Chilvers, Tenuta, and Conley [308]

Table A.3: **Sources for tree fruit yield and efficacy analysis**

Location	**Year**	**Crop**	**Target Pest**	**Study**
			New York State studies	
NY	2000	Apple	Various	Reissig, Combs, and Smith [733]
NY	2002	Apple	Various	Reissig [734]
NY	2002	Apple	Apple maggot	Reissig [734]
NY	2004	Apple	Various	Reissig and Combs [735]
NY	2005	Apple	Various	Reissig and Combs [736]
NY	2010	Apple	Various	Reissig and Combs [737]
NY	2013	Apple	Various	Reissig and Combs [738]
NY	2014	Apple	Various	Agnello and Combs [7]
			Regional data	
ON	2001	Apple	Apple maggot	Franklin, Hardman, and Smith [296]
ON	2001	Apple	Spotted tentiform leafminer & mullein leaf bug	Pogoda and Pree [692]
ON	2003	Peach	Oriental fruit moth	Pogoda and Pree [691]
ON	2004	Apple	Codling moth	Van Driel, Pree, Pogoda, Hermansen, Dick, and Wismer [1003]
ON	2004	Apple	Oblique banded leafroller	Van Driel, Pree, Pogoda, Hermansen, Dick, and Wismer [1003]
ON	2004	Apple	Plum curculio	Van Driel, Pree, Pogoda, Hermansen, Dick, and Wismer [1003]
ON	2004	Peach	Oriental fruit moth	Pogoda and Pree [696]
ON	2004	Peach	Oriental fruit moth	Pogoda and Pree [700]
ON	2004	Peach	Oriental fruit moth	Pogoda and Pree [693]
ON	2004	Peach	Oriental fruit moth	Pogoda and Pree [694]
ON	2004	Peach	Oriental fruit moth	Pogoda and Pree [695]
ON	2004	Peach	Oriental fruit moth	Pogoda and Pree [699]
ON	2004	Plum	Plum curculio	Pogoda and Pree [698]
ON	2004	Plum	Plum curculio	Pogoda, Wismer, and Pree [704]
ON	2005	Plum	Oriental fruit moth	Pogoda, Wismer, and Pree [705]

Continued on next page.

Sources for tree fruit yield and efficacy analysis, continued

Location	Year	Crop	Target Pest	Study
			Regional data, continued	
ON	2006	Apple	European apple sawfly	Pogoda, Van Driel, Wismer, Hermansen, and Appleby [707]
ON	2006	Apple	Plum curculio	Pogoda, Van Driel, Wismer, Hermansen, and Appleby [707]
ON	2006		Plum curculio	Pogoda and Wismer [701]
ON	2006	Apple	Rosy apple aphid	Van Driel, Hermansen, Dick, Wismer, and Pogoda [1004]
ON	2006	Apple	Codling moth	Van Driel, Hermansen, Dick, Wismer, and Pogoda [1005]
ON	2007	Peach	Green peach aphid	Pogoda, Wismer, De Foa, Errampalli, Hermansen, Hammill, and Van Driel [709]
ON	2007	Sweet cherry	Black cherry aphid	Pogoda, Wismer, De Foa, Errampalli, Hermansen, Hammill, and Van Driel [708]
			North American data	
MI	2014	Apple	Codling moth & potato leafhopper	Wise, VanWoerkom, and Gut [1088]
MI	2017	Apple	Woolly apple aphid	Wise, VanWoerkom, Wheeler, and Gut [1089]
MI	2017	Pear	Pear psylla	Wise, VanWoerkom, Wheeler, and Gut [1090]
NC	2015	Apple	Plum curculio	Walgenbach and Schoof [1027]
WA	2014	Apple	Apple mealybug	Bixby-Brosi and Beers [62]

Table A.4: **Sources for grapes and berries yield and efficacy analysis**

Location	**Year**	**Crop**	**Target Pest**	**Study**
			New York and Regional data	
NY	2006	Grape	Grape mealybug	Wallingford et al. [1030]
NJ		Blueberry	Spotted-wing drosophila	[164]
NJ	2018	Blueberry	Aphids	Rodriguez-Saona, Holdcraft, and Kyryczenko-Roth [753]
OH	1995	Grape	Grape berry moth	Williams, Ellis, Fickle, and Ellis [1063]
OH	1995	Grape	Grape erineum mite	Williams and Fickle [1057]
OH	1996	Grape	Grape leafhopper	Williams and Fickle [1056]
OH	1996	Grape	Japanese beetle	Williams, Ellis, Fickle, and Ellis [1062]
OH	1998	Grape	Grape berry moth	Williams, Ellis, and Fickle [1064]
OH	1999	Grape	Grape berry moth	Williams, Ellis, and Fickle [1065]
OH	2000	Grape	Grape leafhopper	Williams and Fickle [1058]
OH	2002	Grape	Grape berry moth	Williams, Fickle, and Ellis [1066]
OH	2004	Grape	Grape phylloxera (foliar)	Williams and Fickle [1059]
OH	2003	Grape	Grape berry moth	Williams, Fickle, and Ellis [1067]
OH	2003	Grape	Grape phylloxera (foliar)	Williams and Fickle [1060]
OH	2004	Grape	Grape berry moth	Williams, Fickle, and Ellis [1068]
OH	2004	Grape	Grape phylloxera (foliar)	Williams and Fickle [1061]
OH	2005	Grape	Grape berry moth	Williams, Fickle, and Ellis [1069]
OH	2006	Grape	Grape berry moth	Williams, Fickle, and Ellis [1070]
ON	2003	Blueberry	White grub	Tolman, Sawinski, Dickinson, and Mayo [921]
ON	2004	Grape	Plum curculio	Pogoda and Pree [697]
ON	2005	Grape	Grape phylloxera	Pogoda, Wismer, and Pree [706]
ON	2005	Grape	Japanese beetle	Pogoda, Wismer, and Pree [703]
ON	2005	Grape	Asian lady beetle	Pogoda, Wismer, and Pree [702]

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Sources for grapes and berries yield and efficacy analysis, continued

Location	Year	Crop	Target Pest	Study
			North American data	
CA	2015	Grape	Vine mealybug	Van Steenwyk, Poliakon, Verdegaal, Wong, and Hernandez [1008]
CA	2016	Grape	Grape leafhopper	Van Steenwyk, Wong, and Cabuslay [1009]
CA	2016	Strawberry	Tarnished plant bug	Joseph and Bolda [442]
FL	2007	Strawberry	Sap beetle	Price and Nagle [718]
ME	2007	Blueberry	Strawberry rootworm	Collins and Drummond [135]
ME	2012	Blueberry	Thrips	Collins and Drummond [134]
ME	2014	Blueberry	Blueberry tip midge	Collins and Drummond [136]
ME	2017	Blueberry	Blueberry gall midge	Collins and Drummond [137]
MI	1995	Grape	Grape leafhopper	Johnson, Kriegel, and Wise [435]
MI	1997	Grape	Grape leafhopper & grape berry moth	Wise and Gut [1078]
MI	1998	Grape	Grape leafhopper & grape berry moth	Wise and Gut [1079]
MI	1999	Grape	Grape leafhopper & grape berry moth	Wise and Isaacs [1080]
MI	2000	Grape	Grape leafhopper	Wise and Isaacs [1081]
MI	2004	Grape	Grape berry moth	Wise, Schoenborn, and Isaacs [1082]
MI	2005	Grape	Grape berry moth	Wise, Schoenborn, and Isaacs [1083]
MI	2005	Strawberry	Strawberry aphid, meadow spittlebug, & tarnished plant bug	Mason and Isaacs [531]
MI	2007	Grape	Grape berry moth	Wise, Vander Poppen, and Isaacs [1084]
MI	2010	Grape	Grape berry moth	Wise, Poppen, and Isaacs [1085]
MI	2017	Blueberry	Spotted-wing drosophila	Wise, VanWoerkom, Wheeler, and Isaacs [1092]
NC	2009	Blackberry	Thrips	Burrack and Chapman [85]

Table A.5: **Sources for brassica yield and efficacy analysis**

Location	Year	Crop	Target Pest	Study
		New York State studies		
NY	2003	Cabbage	Thrips	Shelton, Plate, and Chen [834]
NY	2018	Cabbage & pak choy	Flea beetle	Zaman, Gilrein, and Jackson [1116]
		Regional data		
MA	2014	Cabbage	Flea beetle & cabbage root maggot	Scheufele, McKeag, Campbell-Nelson, and Hazzard [807]
ON	2003	Cabbage	Swede midge	Pitblado, Callow, and Fraser [682]
ON	2003	Cabbage	Swede midge	Pitblado, Callow, and Fraser [683]
ON	2003	Broccoli	Swede midge	Hallett, Heal, and Levac [351]
ON	2003	Broccoli	Swede midge	Pitblado, Callow, and Fraser [684]
ON	2003	Broccoli	Swede midge	Pitblado, Callow, and Fraser [685]
ON	2004	Broccoli	Swede midge	Pitblado, Callow, and Fraser [686]
ON	2004	Broccoli	Swede midge	Pitblado, Callow, and Fraser [687]
ON	2004	Broccoli	Swede midge	Pitblado, Callow, and Fraser [688]
ON	2004	Broccoli	Swede midge	Pitblado, Callow, and Fraser [689]
ON	2006	Broccoli & cabbage	Swede midge	Hallett, Allen, Fraser, May, Heal, and Pitblado [352]
ON	2006	Radish	Cabbage root maggot	Tolman, Minto, Steffler, and Murray [922]
ON	2008	Radish	Cabbage root maggot	Tolman, Steffler, Alhemzawi, and McPherson [923]
NC	2016	Cabbage	Various	Walgenbach and Schoof [1028]
OK	2002	Collard greens	Green peach aphid	Edelson and Damicone [229]
VA	2015	Cabbage	Flea beetle	Mason and Kuhar [530]
VA	2015	Broccoli	Green peach aphid	Kuhar and Doughty [465]

Table A.6: **Sources for potato yield and efficacy analysis**

Location	**Year**	**Study**
		New York State studies
NY	2016	Kuhar and Doughty [468]
NY	2017	Kuhar and Doughty [469]
		Regional data
ON	2003	Cutler, Scott-Dupree, and Roesler [178]
ON	2003	Tolman, Mayo, Dickinson, Murray, and Sawinski [920]
ON	2009	Tolman and Vernon [919]
QC	2001	Bélanger and Pagé [91]
QC	2004	Bélanger and Pagé [92]
		North American data
ME	2010	Johnson [438]
ME	2014	Johnson [439]
ME	2014	Buzza and Alyokhin [87]
ME	2016	Zhang, Jiang, Ge, Marangoni, Dankwa, Song, Giggie, and Hao [1119]
ME	2017	Buzza and Alyokhin [88]
ME	2018	Buzza and Alyokhin [89]
ME	2018	Ge, Li, Ekbataniamiri, Giggie, and Hao [313]
NS	2005	Lees, MacKenzie, Vernon, and Peill [497]
PE	2003	Noronha and Smith [622]
PE	2013	Noronha, Carragher, and Vernon [623]
OR	2018	Rondon and Thompson [756]
VA	2007	Rideout, Waldenmaier, Wimer, and Custis Jr. [741]
VA	2011	Kuhar, Doughty, Wimer, and Jenrette [475]
WI	2012	Groves, Chapman, Frost, Huseth, and Groves [341]
WI	2018	Bradford, Chapman, Crubaugh, and Groves [74]
WI	2018	Bradford, Chapman, Crubaugh, and Groves [75]
WY	2012	Strump and Franc [885]
WY	2008	Franc and Stump [295]

Table A.7: **Sources for snap bean yield and efficacy analysis**

Location	Year	Study
		New York State data
NY	2001	Kuhar, Speese, Stivers, Taylor, and Hoffman [471]
NY	2009	Schmidt-Jeffris and Nault [811]
NY, IL, MN	2001-02	Nault, Taylor, Urwiler, Rabaey, and Hutchison [598]
		North American data
TN	2005	Canaday [99]
TN	2006	Canaday [100]
TN	2006	Canaday [101]
TN	2013	Canaday [102]
TN	2013	Canaday [103]
VA	2015	Kuhar and Doughty [466]
VA	2015	Nottingham, Kuhar, Kring, Herbert, Arancibia, and Schultz [626]
VA	2018	Kuhar and Doughty [468]
VA	2018	Kuhar and Doughty [469]

Table A.8: **Sources for sweet corn yield and efficacy analysis**

Location	Year	Study
		New York and Regional data
NY	2001	Kuhar, Stivers-Young, Hoffmann, and Taylor [472]
ON	2003	Schaafsma, Paul, Phibbs, and Vujevic [790]
ON	2003	Scott-Dupree, Bailey, and Abbott [821]
		North American data
FL	2004	Nuessly and Hentz [629]
ID	2000	Mohan and Bijman [574]
ID	2001	Mohan and Bijman [575]
VA	2012	Kuhar, Doughty, and Jenrette [476]
WA	2010	Wohleb [1097]

Table A.9: **Sources for cucurbit yield and efficacy analysis**

Location	Year	Crop	Target pest	Study
		Regional data		
OH	2009	Pumpkin		Welty, Jasinski, and Precheur [1044]
PA	1996	Muskmelon		Leib, Jarrett, Orzolek, and Mumma [498]
PA	2004	Pumpkin	Cucumber beetle	Johnson et al. [434]
		North American data		
AR	2002	Zucchini	Cucumber beetle	McLeod, Eaton, and Martin [550]
AR	2003	Zucchini	Cucumber beetle	McLeod, Rashid, Eaton, and Martin [551]
AR	2004	Watermelon	Cucumber beetle	McLeod [547]
AZ	1994	Muskmelon	Whitefly	Palumbo and Sanchez [648]
AZ	2010	Cantaloupe	Seedcorn maggot	Palumbo [646]
FL	2003	Summer squash	Leafminer & whitefly	Seal [823]
FL	2006	Zucchini	Aphid & whitefly	Nyoike and Liburd [631]
GA	2013	Pumpkin	Squash bug	Riley [742]
MO	2001	Winter squash	Squash bug	McLeod and Diaz [549]
NC	2009	Zucchini	Squash bug & cucumber beetle	Abney and Davila [3]
NC	2010	Zucchini	Squash bug & cucumber beetle	Abney and Davila [4]
OK	2000	Watermelon	Squash bug	Edelson, Roberts, and Duthie [232]
OK	2001	Watermelon	Squash bug	Edelson and Otieno [230]
OK	2002	Summer squash	Squash bug	Edelson, Duthie, and Roberts [231]
OK	2002	Summer squash	Squash bug	Mackey and Edelson [522]
OK	2003	Summer squash	Squash bug	Eiben, Mackey, Roberts, and Edelson [233]
VA	2004	Pumpkin		Kuhar, Speese, Cordero, and Barlow [473]
VA	2005	Pumpkin	Aphid & cucumber beetle & thrips	Kuhar, Hitchner, and Chapman [474]
VA	2015	Summer squash	Aphid & squash bug	Kuhar and Doughty [467]

Table A.10: **Sources for turfgrass efficacy analysis**

Location	Year	Target Pest	Study
New York State studies			
NY	2005	Leatherjacket	Peck and Morales [662]
NY	2008	White grubs	Olmstead and Peck [638]
NY	2008	White grubs	Olmstead and Peck [639]
Regional data			
MA	2008	White grubs	Vittum, Brocklesby, and Luce [1021]
NH	1997	White grubs	Swier, Rollins, Lamarche, and Hodgson [890]
OH	1997	White grubs	Power, Shetlar, Niemczyk, and Grewal [716]
OH	1998	White grubs	Power, Grewal, and Shetlar [717]
OH	1999	White grubs	Shetlar, Pinkston, and Niemczyk [838]
OH	2000-02	Ants	Shetlar [835]
OH	2008	Ants	Shetlar and Andon [836]
PA	1995	Black cutworm	Heller and Walker [378]
PA	1996	White grubs	Heller and Walker [373]
PA	2005	White grubs	Heller and Kline [377]
PA	2007	White grubs	Heller, Kline, and Houseman [379]
PA	2007	White grubs	Heller, Kline, and Houseman [380]
PA	2007	Billbugs	Heller, Kline, and Houseman [374]
PA	2008	White grubs	Heller, Kline, and Houseman [375]
PA	2008	Billbugs	Heller, Kline, and Houseman [381]
North American data			
MI	1997	White grubs	Smitley and Davis [864]
OK	2004	White grubs	Royer and Walker [764]
OK	2009	White grubs	Rebek [729]
OK	2013	Black cutworm	Seibert and Rebek [825]
VA	2013	White grubs	Gyawaly, Youngman, Laub, and Kuhar [344]
WI	2009-11	Black cutworm	Williamson, Liesch, and Obear [1071]

B. Studies contributing to risk analysis

The tables in the following pages list the sources underlying analysis in Chapter 6: Risks of Neonicotinoids to Pollinators. The methods used to gather studies and extract data during the literature review are described in Section 6.6.1.

Table B.1: **Studies contributing to pollinator risk assessment**

Author	**Title**	**Year**	**Neonicotinoid(s)**
Abbo, Kawasaki, Hamilton, Cook, DeGrandi-Hoffman, Li, Liu, and Chen [1]	Effects of imidacloprid and *Varroa destructor* on survival and health of European honey bees, *Apis mellifera*	2017	IMI
Abdelkader, Kairo, Bonnet, Barbouche, Belzunces, and Brunet [2]	Effects of clothianidin on antioxidant enzyme activities and malondialdehyde level in honey bee drone semen	2019	CLO
Alaux, Brunet, Dussaubat, Mondet, Tchamitchan, Cousin, Brillard, Baldy, Belzunces, and Le Conte [11]	Interactions between *Nosema* microspores and a neonicotinoid weaken honeybees (*Apis mellifera*)	2010	IMI
Alburaki, Steckel, Chen, McDermott, Weiss, Skinner, Kelly, Lorenz, Tarpy, Meikle, et al. [12]	Landscape and pesticide effects on honey bees: forager survival and expression of acetylcholinesterase and brain oxidative genes	2017	IMI
Alburaki, Steckel, Williams, Skinner, Tarpy, Meikle, Adamczyk, and Stewart [13]	Agricultural landscape and pesticide effects on honey bee (Hymenoptera: Apidae) biological traits	2017	IMI
Aliouane, El Hassani, Gary, Armengaud, Lambin, and Gauthier [17]	Subchronic exposure of honey bees to sublethal doses of pesticides: Effects on behavior	2009	ACE, TMX
Alkassab and Kirchner [18]	Impacts of chronic sublethal exposure to clothianidin on winter honeybees	2016	CLO
Alkassab and Kirchner [19]	Assessment of acute sublethal effects of clothianidin on motor function of honeybee workers using video-tracking analysis	2018	CLO
Andrione, Vallortigara, Antolini, and Haase [23]	Neonicotinoid-induced impairment of odour coding in the honeybee	2016	IMI
Badawy, Nasr, and Rabea [30]	Toxicity and biochemical changes in the honey bee *Apis mellifera* exposed to four insecticides under laboratory conditions	2015	ACE, DIN
Bailey, Scott-Dupree, Harris, Tolman, and Harris [32]	Contact and oral toxicity to honey bees (*Apis mellifera*) of agents registered for use for sweet corn insect control in Ontario, Canada	2005	CLO, IMI
Baines, Wilton, Pawluk, de Gorter, and Chomistek [34]	Neonicotinoids act like endocrine disrupting chemicals in newly-emerged bees and winter bees	2017	ACE, CLO, IMI, TMX
Balfour, Toufailia, Scandian, Blanchard, Jesse, Carreck, and Ratnieks [36]	Landscape scale study of the net effect of proximity to a neonicotinoid-treated crop on bee colony health	2017	TMX

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Studies contributing to pollinator risk assessment, continued

Author	**Title**	**Year**	**Neonicotinoid(s)**
Balieira, Mazzo, Bizerra, Guimarães, Nicodemo, and Mingatto [37]	imidacloprid-induced oxidative stress in honey bees and the antioxidant action of caffeine	2018	IMI
Balsamo, Domingues, Silva-Zacarin, Gregorc, Irazusta, Salla, Costa, and Abdalla [39]	Impact of sublethal doses of thiamethoxam and *Nosema ceranae* inoculation on the hepato-nephrocitic system in young Africanized *Apis mellifera*	2019	TMX
Bartling, Vilcinskas, and Lee [42]	Sub-lethal doses of clothianidin inhibit the conditioning and biosensory abilities of the Western honeybee *Apis mellifera*	2019	CLO
Biddinger, Robertson, Mullin, and Frazier [59]	Comparative toxicities and synergism of apple orchard pesticides to *Apis mellifera (L.)* and *Osmia cornifrons (Radoszkowski)*	2013	ACE, IMI
Blanken, van Langevelde, and van Dooremalen [65]	Interaction between *Varroa destructor* and imidacloprid reduces flight capacity of honeybees	2015	IMI
Boily, Sarrasin, DeBlois, Aras, and Chagnon [67]	Acetylcholinesterase in honey bees (*Apis mellifera*) exposed to neonicotinoids, atrazine and glyphosate: laboratory and field experiments	2013	CLO, IMI
Bortolotti, Montanari, Marcelino, and Medrzycki [70]	Effects of sub-lethal imidacloprid doses on the homing rate and foraging activity of honey bees	2003	IMI
Bovi, Zaluski, and Orsi [73]	Toxicity and motor changes in Africanized honey bees (*Apis mellifera L.*) exposed to fipronil and imidacloprid	2018	IMI
Brandt, Gorenflo, Siede, Meixner, and Büchler [77]	The neonicotinoids thiacloprid, imidacloprid, and clothianidin affect the immunocompetence of honey bees (*Apis mellifera L.*)	2016	CLO
Brandt, Grikscheit, Siede, Grosse, Meixner, and Büchler [78]	Immunosuppression in honeybee queens by the neonicotinoids thiacloprid and clothianidin	2017	CLO
Catae, Roat, De Oliveira, Ferreira Nocelli, and Malaspina [106]	Cytotoxic effects of thiamethoxam in the midgut and malpighian tubules of Africanized *Apis mellifera* (Hymenoptera: Apidae)	2014	TMX

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Studies contributing to pollinator risk assessment, continued

Author	Title	Year	Neonicotinoid(s)
Catae, Roat, Pratavieira, da Silva Menegasso, Palma, and Malaspina [107]	Exposure to a sublethal concentration of imidacloprid and the side effects on target and nontarget organs of *Apis Mellifera* (Hymenoptera, Apidae)	2018	IMI
Catae, da Silva Menegasso, Pratavieira, Palma, Malaspina, and Roat [108]	MALDI-imaging analyses of honeybee brains exposed to a neonicotinoid insecticide	2019	IMI
Chaimanee, Evans, Chen, Jackson, and Pettis [110]	Sperm viability and gene expression in honey bee queens (*Apis mellifera*) following exposure to the neonicotinoid insecticide imidacloprid and the organophosphate acaricide coumaphos	2016	IMI
Chambers, Chatimichael, and Tzouvelekas [111]	Sub-lethal concentrations of neonicotinoid insecticides at the field level affect negatively honey yield: Evidence from a 6-year survey of Greek apiaries	2019	IMI, TMX
Charreton, Decourtye, Henry, Rodet, Sandoz, Charnet, and Collet [114]	A locomotor deficit induced by sublethal doses of pyrethroid and neonicotinoid insecticides in the honeybee *Apis mellifera*	2015	TMX
Chen, Gill, Pelz-Stelinski, and Stelinski [119]	Risk assessment of various insecticides used for management of Asian citrus psyllid, *Diaphorina citri* in Florida citrus, against honey bee, *Apis mellifera*	2017	IMI
Chen, Yan, Zhang, Yuan, and Liu [116]	Joint toxicity of acetamiprid and co-applied pesticide adjuvants on honeybees under semi-field and laboratory conditions	2019	ACE
Christen, Mittner, and Fent [121]	Molecular effects of neonicotinoids in honey bees (*Apis mellifera*)	2016	ACE, CLO, IMI, TMX
Christen, Bachofer, and Fent [122]	Binary mixtures of neonicotinoids show different transcriptional changes than single neonicotinoids in honeybees (*Apis mellifera*)	2017	ACE, CLO, IMI, TMX
Christen, Schirrmann, Frey, and Fent [123]	Global transcriptomic effects of environmentally relevant concentrations of the neonicotinoids clothianidin, imidacloprid, and thiamethoxam in the brain of honey bees (*Apis mellifera*)	2018	CLO, IMI, TMX
Ciereszko, Wilde, Dietrich, Siuda, Bąk, Judycka, and Karol [125]	Sperm parameters of honeybee drones exposed to imidacloprid	2017	IMI
Colin, Meikle, Paten, and Barron [130]	Long-term dynamics of honey bee colonies following exposure to chemical stress	2019	IMI

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Studies contributing to pollinator risk assessment, continued

Author	Title	Year	Neonicotinoid(s)
Colin, Meikle, Wu, and Barron [131]	Traces of a neonicotinoid induce precocious foraging and reduce foraging performance in honey bees	2019	IMI
Collison, Hird, Tyler, and Cresswell [138]	Effects of neonicotinoid exposure on molecular and physiological indicators of honey bee immunocompetence	2017	IMI
Cook [142]	Compound and dose-dependent effects of two neonicotinoid pesticides on honey bee (*Apis mellifera*) metabolic physiology	2019	CLO, TMX
Costa, Araujo, Maia, Silva, Bezerra, and Silva [156]	Toxicity of insecticides used in the Brazilian melon crop to the honey bee *Apis mellifera* under laboratory conditions	2014	ACE, TMX
Coulon, Schurr, Martel, Cougoule, Begaud, Mangoni, Dalmon, Alaux, Le Conte, Thiery, Ribiere-Chabert, and Dubois [157]	Metabolisation of thiamethoxam (a neonicotinoid pesticide) and interaction with the chronic bee paralysis virus in honeybees	2018	TMX
Coulon, Schurr, Martel, Cougoule, Begaud, Mangoni, Di Prisco, Dalmon, Alaux, Ribiere-Chabert, Le Conte, Thiery, and Dubois [158]	Influence of chronic exposure to thiamethoxam and chronic bee paralysis virus on winter honey bees	2019	TMX
Cresswell, Page, Uygun, Holmbergh, Li, Wheeler, Laycock, Pook, de Ibarra, Smirnoff, and Tyler [174]	Differential sensitivity of honey bees and bumble bees to a dietary insecticide (imidacloprid)	2012	IMI
Cresswell, Robert, Florance, and Smirnoff [175]	Clearance of ingested neonicotinoid pesticide (imidacloprid) in honey bees (*Apis mellifera*) and bumblebees (*Bombus terrestris*)	2014	IMI
Christopher Cutler and Scott-Dupree [124]	A large-scale field study examining effects of exposure to clothianidin seed-treated canola on honey bee colony health, development, and overwintering success	2007	CLO
Cutler and Scott-Dupree [177]	Exposure to clothianidin seed-treated canola has no long-term impact on honey bees	2014	CLO

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Studies contributing to pollinator risk assessment, continued

Author	Title	Year	Neonicotinoid(s)
Dai, Jack, Mortensen, and Ellis [181]	Acute toxicity of five pesticides to *Apis mellifera* larvae reared in vitro	2017	IMI
Dai, Jack, Mortensen, Bustamante, Bloomquist, and Ellis [182]	Chronic toxicity of clothianidin, imidacloprid, chlorpyrifos, and dimethoate to *Apis mellifera L.* larvae reared in vitro	2019	CLO, IMI
de Sena Fernandes, Fernandes, Picanco, Queiroz, da Silva, and Goicochea Huertas [185]	Physiological selectivity of insecticides to *Apis mellifera* (Hymenoptera: Apidae) and *Protonectarina sylveirae* (Hymenoptera: Vespidae) in citrus	2008	TMX
De Smet, Hatjina, Ioannidis, Hamamtzoglou, Schoonvaere, Francis, Meeus, Smagghe, and de Graaf [186]	Stress indicator gene expression profiles, colony dynamics and tissue development of honey bees exposed to sub-lethal doses of imidacloprid in laboratory and field experiments	2017	IMI
Decio, Ustaoglu, Roat, Malaspina, Devaud, Stoger, and Soller [188]	Acute thiamethoxam toxicity in honeybees is not enhanced by common fungicide and herbicide and lacks stress-induced changes in mRNA splicing	2019	TMX
Decourtye, Le Metayer, Pottiau, Tisseur, Odoux, and Pham-Delegue [189]	Impairment of olfactory learning performances in the honey bee after long term ingestion of imidacloprid	2001	IMI
Decourtye, Lacassie, and Pham-Delègue [190]	Learning performances of honeybees (*Apis mellifera L.*) are differentially affected by imidacloprid according to the season	2003	IMI
Decourtye, Armengaud, Renou, Devillers, Cluzeau, Gauthier, and Pham-Delègue [191]	Imidacloprid impairs memory and brain metabolism in the honeybee (*Apis mellifera L.*)	2004	IMI
Decourtye, Devillers, Cluzeau, Charreton, and Pham-Delègue [192]	Effects of imidacloprid and deltamethrin on associative learning in honeybees under semi-field and laboratory conditions	2004	IMI
Déglise, Grünewald, and Gauthier [193]	The insecticide imidacloprid is a partial agonist of the nicotinic receptor of honeybee Kenyon cells	2004	IMI
Demares, Crous, Pirk, Nicolson, and Human [194]	Sucrose sensitivity of honey bees is differently affected by dietary protein and a neonicotinoid pesticide	2016	TMX
Démares, Pirk, Nicolson, and Human [195]	Neonicotinoids decrease sucrose responsiveness of honey bees at first contact	2018	CLO, IMI, TMX
Derecka, Blythe, Malla, Genereux, Guffanti, Pavan, Moles, Snart, Ryder, Ortori, et al. [196]	Transient exposure to low levels of insecticide affects metabolic networks of honeybee larvae	2013	IMI

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Studies contributing to pollinator risk assessment, continued

Author	Title	Year	Neonicotinoid(s)
Di Prisco, Cavaliere, Annoscia, Varricchio, Caprio, Nazzi, Gargiulo, and Pennacchio [199]	Neonicotinoid clothianidin adversely affects insect immunity and promotes replication of a viral pathogen in honey bees	2013	CLO
Diaz, del Val, Ayala, and Larsen [200]	Alterations in honey bee gut microorganisms caused by *Nosema spp.* and pest control methods	2019	IMI
Dickey [202]	What's killing the buzz? The effects of neonicotinoids on *Apis mellifera* mitochondrial metabolism	2018	IMI
Dively, Embrey, Kamel, and Hawthorne [207]	Assessment of chronic sublethal effects of imidacloprid on honey bee colony health	2015	IMI
Domatskaya, Domatskiy, Levchenko, and Silivanova [208]	Acute contact toxicity of insecticidal baits on honeybees *Apis mellifera*: a laboratory study	2018	ACE
Domingues, Abdalla, Balsamo, Pereira, Hausen, Costa, and Silva-Zacarin [209]	Thiamethoxam and picoxystrobin reduce the survival and overload the hepato-nephrocitic system of the Africanized honeybee	2017	TMX
van Dooremalen, Cornelissen, Poleij-Hok-Ahin, and Blacquiere [1002]	Single and interactive effects of *Varroa destructor*, *Nosema spp.*, and imidacloprid on honey bee colonies (*Apis mellifera*)	2018	IMI
Dussaubat, Maisonnasse, Crauser, Tchamitchian, Bonnet, Cousin, Kretzschmar, Brunet, and Le Conte [217]	Combined neonicotinoid pesticide and parasite stress alter honeybee queens' physiology and survival	2016	IMI
Eiri and Nieh [234]	A nicotinic acetylcholine receptor agonist affects honey bee sucrose responsiveness and decreases waggle dancing	2012	IMI
El Hassani, Dacher, Gary, Lambin, Gauthier, and Armengaud [238]	Effects of sublethal doses of acetamiprid and thiamethoxam on the behavior of the honeybee (*Apis mellifera*)	2008	ACE, TMX
Farooqi, Arshad, et al. [275]	Toxicity of three commonly used nicotinoids and spinosad to *Apis mellifera L.* (Hymenoptera: Apidae) using surface residual bioassays	2016	ACE, IMI, TMX
Faucon, Aurières, Drajnudel, Mathieu, Ribière, Martel, Zeggane, Chauzat, and Aubert [276]	Experimental study on the toxicity of imidacloprid given in syrup to honey bee (*Apis mellifera*) colonies	2005	IMI
Fischer, Mueller, Spatz, Greggers, Gruenewald, and Menzel [283]	Neonicotinoids interfere with specific components of navigation in honeybees	2014	CLO, IMI
Forfert, Troxler, Retschnig, Gauthier, Straub, Moritz, Neumann, and Williams [293]	Neonicotinoid pesticides can reduce honeybee colony genetic diversity	2017	CLO, TMX

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Studies contributing to pollinator risk assessment, continued

Author	Title	Year	Neonicotinoid(s)
Friedli, Williams, Bruckner, Neumann, and Straub [298]	The weakest link: haploid honey bees are more susceptible to neonicotinoid insecticides	2020	CLO, TMX
Friol, Catae, Tavares, Malaspina, and Roat [299]	Can the exposure of *Apis mellifera* (Hymenoptera, Apiadae) larvae to a field concentration of thiamethoxam affect newly emerged bees?	2017	TMX
Gajger, Sakac, and Gregorc [304]	Impact of thiamethoxam on honey bee queen (*Apis mellifera Carnica*) reproductive morphology and physiology	2017	TMX
Gauthier, Aras, Paquin, and Boily [312]	Chronic exposure to imidacloprid or thiamethoxam neonicotinoid causes oxidative damages and alters carotenoid-retinoid levels in caged honey Bees (*Apis mellifera*)	2018	IMI, TMX
Georgiadis, Pistorius, Heimbach, Staehler, and Schwabe [315]	Dust drift during sowing of maize: effects on honey bees	2012	CLO
Girolami, Marzaro, Vivan, Mazzon, Greatti, Giorio, Marton, and Tapparo [323]	Fatal powdering of bees in flight with particulates of neonicotinoids seed coating and humidity implication	2012	IMI
Grassl, Holt, Cremen, Peso, Hahne, and Baer [328]	Synergistic effects of pathogen and pesticide exposure on honey bee (*Apis mellifera*) survival and immunity	2018	TMX
Gregorc and Ellis [336]	Cell death localization in situ in laboratory reared honey bee (*Apis mellifera L.*) larvae treated with pesticides	2011	IMI
Gregorc, Evans, Scharf, and Ellis [337]	Gene expression in honey bee (*Apis mellifera*) larvae exposed to pesticides and *Varroa* mites (*Varroa destructor*)	2012	IMI
Gregorc, Silva-Zacarin, Carvalho, Kramberger, Teixeira, and Malaspina [338]	Effects of *Nosema ceranae* and thiamethoxam in *Apis mellifera*: A comparative study in Africanized and Carniolan honey bees	2016	TMX
Gregore, Alburaki, Rinderer, Sampson, Knight, Karim, and Adamczyk [339]	Effects of coumaphos and imidacloprid on honey bee (Hymenoptera: Apidae) lifespan and antioxidant gene regulations in laboratory experiments	2018	IMI
Grillone, Laurino, Manino, and Porporato [340]	Toxicity of thiamethoxam on in vitro reared honey bee brood	2017	TMX

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Studies contributing to pollinator risk assessment, continued

Author	Title	Year	Neonicotinoid(s)
Guez, Suchail, Gauthier, Maleszka, and Belzunces [342]	Contrasting effects of imidacloprid on habituation in 7-and 8-day-old honeybees (*Apis mellifera*)	2001	IMI
Guez, Belzunces, and Maleszka [343]	Effects of imidacloprid metabolites on habituation in honeybees suggest the existence of two subtypes of nicotinic receptors differentially expressed during adult development	2003	IMI metabolites
Hashimoto, Ruvolo-Takasusuki, and de Toledo [366]	Evaluation of the use of the inhibition esterases activity on *Apis mellifera* as bioindicators of insecticide thiamethoxam pesticide residues	2003	TMX
Hatjina, Papaefthimiou, Charistos, Dogaroglu, Bouga, Emmanouil, and Arnold [368]	Sublethal doses of imidacloprid decreased size of hypopharyngeal glands and respiratory rhythm of honeybees in vivo	2013	IMI
Heard, Baas, Dorne, Lahive, Robinson, Rortais, Spurgeon, Svendsen, and Hesketh [372]	Comparative toxicity of pesticides and environmental contaminants in bees: Are honey bees a useful proxy for wild bee species?	2019	CLO
Henry, Beguin, Requier, Rollin, Odoux, Aupinel, Aptel, Tchamitchian, and Decourtye [383]	A common pesticide decreases foraging success and survival in honey bees	2012	TMX
Henry, Cerrutti, Aupinel, Decourtye, Gayrard, Odoux, Pissard, Rüger, and Bretagnolle [384]	Reconciling laboratory and field assessments of neonicotinoid toxicity to honeybees	2015	IMI, TMX
Hernando, Gámiz, Gil-Lebrero, Rodríguez, García-Valcárcel, Cutillas, Fernández-Alba, and Flores [389]	Viability of honeybee colonies exposed to sunflowers grown from seeds treated with the neonicotinoids thiamethoxam and clothianidin	2018	CLO, TMX
Heylen, Gobin, Arckens, Huybrechts, and Billen [392]	The effects of four crop protection products on the morphology and ultrastructure of the hypopharyngeal gland of the European honeybee, *Apis mellifera*	2011	IMI
Iwasa, Motoyama, Ambrose, and Roe [419]	Mechanism for the differential toxicity of neonicotinoid insecticides in the honey bee, *Apis mellifera*	2004	ACE, CLO, DIN, IMI, TMX

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Studies contributing to pollinator risk assessment, continued

Author	Title	Year	Neonicotinoid(s)
Jacob, Malaquias, Zanardi, Silva, Jacob, and Yamamoto [420]	Oral acute toxicity and impact of neonicotinoids on *Apis mellifera L.* and *Scaptotrigona postica Latreille* (Hymenoptera: Apidae)	2019	ACE, IMI
Jiang, Wang, He, Liu, Li, Yu, and Cao [432]	The effect of neonicotinoid insecticide and fungicide on sugar responsiveness and orientation behavior of honey bee (*Apis mellifera*) in semi-field conditions	2018	TMX
Karahan, Çakmak, Hranitz, and Karaca [443]	Sublethal imidacloprid effects on honey bee flower choices when foraging	2015	IMI
Kessler, Tiedeken, Simcock, Derveau, Mitchell, Softley, Radcliffe, Stout, and Wright [446]	Bees prefer foods containing neonicotinoid pesticides	2015	CLO, IMI, TMX
Koo, Son, Kim, and Lee [457]	Differential responses of *Apis mellifera* heat shock protein genes to heat shock, flower-thinning formulations, and imidacloprid	2015	IMI
Lambin, Armengaud, Raymond, and Gauthier [483]	Imidacloprid-induced facilitation of the proboscis extension reflex habituation in the honeybee	2001	IMI
Laurino, Manino, Patetta, Ansaldi, and Porporato [489]	Acute oral toxicity of neonicotinoids on different honey bee strains	2010	CLO, IMI, TMX
Laurino, Porporato, Patetta, and Manino [490]	Toxicity of neonicotinoid insecticides to honey bees: laboratory tests	2011	ACE, CLO, TMX
Laurino, Manino, Patetta, and Porporato [491]	Toxicity of neonicotinoid insecticides on different honey bee genotypes	2013	CLO, IMI, TMX
Levinson, Blatzheim, Bower, Polk, Lu, Karahn, Gune, Cakmak, Wells, and Hranitz [502]	The neonicotinoid pesticide imidacloprid affects motor responses in honey bees	2014	CLO
Li, Tan, Song, Wu, Tang, Hua, Zheng, and Hu [503]	Sublethal doses of neonicotinoid imidacloprid can interact with honey bee chemosensory protein 1 (CSP1) and inhibit its function	2017	IMI
Li, Li, He, Zhao, Chaimanee, Huang, Nie, Zhao, and Su [504]	Differential physiological effects of neonicotinoid insecticides on honey bees: A comparison between *Apis mellifera* and *Apis cerana*	2017	CLO, IMI
Li, Yu, Chen, Heerman, He, Huang, Nie, and Su [505]	Brain transcriptome of honey bees (*Apis mellifera*) exhibiting impaired olfactory learning induced by a sublethal dose of imidacloprid	2019	IMI
Liu, Liu, He, Zhang, Li, and Tan [509]	Enantioselective olfactory effects of the neonicotinoid dinotefuran on honey bees (*Apis mellifera L.*)	2019	DIN

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Studies contributing to pollinator risk assessment, continued

Author	Title	Year	Neonicotinoid(s)
Liu, Liu, Zhang, Gu, Li, He, and Tan [510]	Application of the combination index (CI)-isobologram equation to research the toxicological interactions of clothianidin, thiamethoxam, and dinotefuran in honeybee, *Apis mellifera*	2017	CLO, DIN, TMX
López, Krainer, Engert, Schuehly, Riessberger-Gallé, and Crailsheim [516]	Sublethal pesticide doses negatively affect survival and the cellular responses in American foulbrood-infected honeybee larvae	2017	CLO
Lu, Warchol, and Callahan [518]	Sub-lethal exposure to neonicotinoids impaired honey bees winterization before proceeding to colony collapse disorder	2014	CLO
Lunardi, Zaluski, and Orsi [520]	Evaluation of motor changes and toxicity of insecticides fipronil and imidacloprid in Africanized honey bees (Hymenoptera: Apidae)	2017	IMI
Manning, Ramanaidu, and Cutler [525]	Honey bee survival is affected by interactions between field-relevant rates of fungicides and insecticides used in apple and blueberry production	2017	ACE
Martin, Fine, Cash-Ahmed, and Robinson [527]	The effect of imidacloprid on honey bee queen fecundity	2018	IMI
Marzaro, Vivan, Targa, Mazzon, Mori, Greatti, Petrucco Toffolo, Di Bernardo, Giorio, and Marton [529]	Lethal aerial powdering of honey bees with neonicotinoids from fragments of maize seed coat	2011	CLO
Matsumoto [533]	Reduction in homing flights in the honey bee *Apis mellifera* after a sublethal dose of neonicotinoid insecticides	2013	CLO, DIN
Matsumoto [534]	Short- and long-term effects of neonicotinoid application in rice fields, on the mortality and colony collapse of honeybees (*Apis mellifera*)	2013	CLO
Medrzycki, Montanari, Bortolotti, Sabatini, Maini, and Porrini [555]	Effects of imidacloprid administered in sub-lethal doses on honey bee behaviour. Laboratory tests	2003	IMI
Meikle, Adamczyk, Weiss, and Gregorc [556]	Sublethal effects of imidacloprid on honey bee colony growth and activity at three sites in the U.S.	2016	IMI
Meikle and Weiss [557]	Monitoring colony-level effects of sublethal pesticide exposure on honey bees	2017	IMI
Meikle, Adamczyk, Weiss, and Gregorc [558]	Effects of bee density and sublethal imidacloprid exposure on cluster temperatures of caged honey bees	2018	IMI

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Studies contributing to pollinator risk assessment, continued

Author	Title	Year	Neonicotinoid(s)
Menail, Bouchema-Boutefnouchet, Smagghe, and Ayad-Loucif [559]	Thiamethoxam (neonicotinoid) and spinosad (bioinsecticide) affect hypopharyngeal glands and survival of *Apis mellifera* intermissa (Hymenoptera: Apidae)	2018	TMX
Mengoni Goñalons and Farina [561]	Effects of sublethal doses of imidacloprid on young adult honeybee behaviour	2015	IMI
Mengoni Gonalons and Farina [560]	Impaired associative learning after chronic exposure to pesticides in young adult honey bees	2018	IMI
Mogren, Danka, and Healy [573]	Larval pollen stress increases adult susceptibility to clothianidin in honey bees	2019	CLO
Mogren and Lundgren [572]	Neonicotinoid-contaminated pollinator strips adjacent to cropland reduce honey bee nutritional status	2016	CLO
Mogren, Danka, and Healy [573]	Larval pollen stress increases adult susceptibility to clothianidin in honey bees	2019	CLO
Moise, Al Marghitas, Dezmirean, and Man [576]	Concerning the effect of imidacloprid on honey bees (*Apis Mellifera Carpatica*)	2003	IMI
Monchanin, Henry, Decourtye, Dalmon, Fortini, Boeuf, Dubuisson, Aupinel, Chevallereau, Petit, and Fourrier [578]	Hazard of a neonicotinoid insecticide on the homing flight of the honeybee depends on climatic conditions and *Varroa* infestation	2019	TMX
Moncharmont, Decourtye, Hennequet-Hantier, Pons, and Pham-Delègue [579]	Statistical analysis of honeybee survival after chronic exposure to insecticides	2003	IMI
Morfin, Goodwin, Hunt, and Guzman-Novoa [583]	Effects of sublethal doses of clothianidin and/or *V. destructor* on honey bee (*Apis mellifera*) self-grooming behavior and associated gene expression	2019	CLO
Morfin, Goodwin, Correa-Benitez, and Guzman-Novoa [582]	Sublethal exposure to clothianidin during the larval stage causes long-term impairment of hygienic and foraging behaviours of honey bees	2019	CLO
Morfin, Goodwin, and Guzman-Novoa [584]	Interaction of field realistic doses of clothianidin and *Varroa destructor* parasitism on adult honey bee (*Apis mellifera L.*) health and neural gene expression, and antagonistic effects on differentially expressed genes	2020	CLO

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Studies contributing to pollinator risk assessment, continued

Author	Title	Year	Neonicotinoid(s)
Naranjo, Pastor, Young, Salazar, Abramson, and Hranitz [594]	A pilot study investigating the effects of sublethal doses of imidacloprid on honeybee larvae: survival and cleaning behavior in nurse bees	2015	IMI
Nauen, Ebbinghaus-Kintscher, and Schmuck [597]	Toxicity and nicotinic acetylcholine receptor interaction of imidacloprid and its metabolites in *Apis mellifera* (Hymenoptera: Apidae)	2001	IMI
Nguyen, Saegerman, Pirard, Mignon, Widart, Thirionet, Verheggen, Berkvens, De Pauw, and Haubruge [616]	Does imidacloprid seed-treated maize have an impact on honey bee mortality?	2009	IMI
Nicodemo, De Jong, Reis, Volpini de Almeida, dos Santos, and Manzani Lisboa [618]	Transgenic corn decreased total and key storage and lipid transport protein levels in honey bee hemolymph while seed treatment with imidacloprid reduced lipophorin levels	2018	IMI
Nicodemo, Maioli, Medeiros, Guelfi, Balieira, De Jong, and Mingatto [617]	Fipronil and imidacloprid reduce honeybee mitochondrial activity	2014	IMI
Odemer, Nilles, Linder, and Rosenkranz [633]	Sublethal effects of clothianidin and *Nosema spp.* on the longevity and foraging activity of free flying honey bees	2018	CLO
Oliveira, Roat, Carvalho, and Malaspina [637]	Side-effects of thiamethoxam on the brain and midgut of the Africanized honeybee *Apis mellifera* (Hymenoptera: Apidae)	2014	TMX
Overmyer, Feken, Ruddle, Bocksch, Hill, and Thompson [643]	Thiamethoxam honey bee colony feeding study: Linking effects at the level of the individual to those at the colony level	2018	TMX
?]paleolog2020imidacloprid	Imidacloprid markedly affects hemolymph proteolysis, biomarkers, DNA global methylation, and the cuticle proteolytic layer in western honeybees	2020	IMI
Papach, Fortini, Grateau, Aupinel, and Richard [649]	Larval exposure to thiamethoxam and American foulbrood: effects on mortality and cognition in the honey bee *Apis mellifera*	2017	TMX
Pashte and Patil [653]	Evaluation of persistence of insecticide toxicity in honey bees (*Apis mellifera L.*)	2017	IMI
Pashte and Patil [654]	Toxicity and poisoning symptoms of selected insecticides to honey bees (*Apis mellifera mellifera L.*)	2018	IMI

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Studies contributing to pollinator risk assessment, continued

Author	Title	Year	Neonicotinoid(s)
Pereira, Nocelli, Malaspina, and Bueno [665]	Side-effect of acetamiprid in adult Africanized honeybee	2012	ACE
Petersheim, Llewellyn, Surmacz, and Hranitz [673]	Motor responses in honey bees are impaired following exposure to sublethal doses of imidacloprid	2018	IMI
Piiroinen and Goulson [676]	Chronic neonicotinoid pesticide exposure and parasite stress differentially affects learning in honeybees and bumblebees	2016	CLO
Pilling, Campbell, Coulson, Ruddle, and Tornier [678]	A four-year field program investigating long-term effects of repeated exposure of honey bee colonies to flowering crops treated with thiamethoxam	2013	CLO, TMX
Pistorius, Wehner, Kriszan, Bargen, Knäbe, Klein, Frommberger, Staehler, and Heimbach [681]	Application of predefined doses of neonicotinoid containing dusts in field trials and acute effects on honey bees	2015	CLO
Pohorecka, Skubida, Semkiw, Miszczak, Teper, Sikorski, Zagibajlo, Skubida, Zdanska, and Bober [710]	Effects of exposure of honey bee colonies to neonicotinoid seed-treated maize crops	2013	CLO
Polk, Bowers, Cakmak, and Hranitz [712]	The effect of imidacloprid on sucrose sensitivity of the honey bee proboscis extension reflex	2014	IMI
Ramirez-Romero, Chaufaux, and Pham-Delègue [726]	Effects of Cry1Ab protoxin, deltamethrin and imidacloprid on the foraging activity and the learning performances of the honeybee *Apis mellifera*, a comparative approach	2005	IMI
Raymann, Motta, Girard, Riddington, Dinser, and Moran [728]	Imidacloprid decreases honey bee survival rates but does not affect the gut microbiome	2018	IMI
Renzi, Rodríguez-Gasol, Medrzycki, Porrini, Martini, Burgio, Maini, and Sgolastra [739]	Combined effect of pollen quality and thiamethoxam on hypopharyngeal gland development and protein content in *Apis mellifera*	2016	TMX
Rinkevich, Danka, and Healy [744]	Influence of Varroa mite (*Varroa destructor*) management practices on insecticide sensitivity in the honey bee (*Apis mellifera*)	2017	CLO

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Studies contributing to pollinator risk assessment, continued

Author	Title	Year	Neonicotinoid(s)
Robinson, Richardson, Dalton, Maisonneuve, Trudeau, Pauli, and Lee-Jenkins [745]	Comparing bee species responses to chemical mixtures: Common response patterns?	2017	CLO
Rondeau, Sanchez-Bayo, Tennekes, Decourtye, Ramirez-Romero, and Desneux [755]	Delayed and time-cumulative toxicity of imidacloprid in bees, ants and termites	2014	IMI
Rossi, Roat, Tavares, Cintra-Socolowski, and Malaspina [759]	Brain morphophysiology of Africanized bee *Apis mellifera* exposed to sublethal doses of imidacloprid	2013	IMI
Rossi, Roat, Tavares, Cintra-Socolowski, and Malaspina [760]	Effects of sublethal doses of imidacloprid in malpighian tubules of Africanized *Apis mellifera* (Hymenoptera, Apidae)	2013	IMI
Rouze, Mone, Delbac, Belzunces, and Blot [763]	The honeybee gut microbiota is altered after chronic exposure to different families of insecticides and infection by *Nosema ceranae*	2019	IMI, TMX
Samson-Robert, Labrie, Chagnon, and Fournier [771]	Planting of neonicotinoid-coated corn raises honey bee mortality and sets back colony development	2017	CLO, TMX
Sanchez-Bayo, Belzunces, and Bonmatin [774]	Lethal and sublethal effects, and incomplete clearance of ingested imidacloprid in honey bees (*Apis mellifera*)	2017	IMI
Sandrock, Tanadini, Pettis, Biesmeijer, Potts, and Neumann [775]	Impact of chronic neonicotinoid exposure on honeybee colony performance and queen supersedure	2014	CLO, TMX
Schmuck, Schöning, Stork, and Schramel [813]	Risk posed to honeybees (*Apis mellifera L. Hymenoptera*) by an imidacloprid seed dressing of sunflowers	2001	IMI
Schmuck, Nauen, and Ebbinghaus-Kintscher [814]	Effects of a chronic dietary exposure of the honeybee *Apis mellifera* (Hymenoptera: Apidae) to imidacloprid	2004	IMI
Schmuck, Nauen, and Ebbinghaus-Kintscher [815]	Effects of imidacloprid and common plant metabolites of imidacloprid in the honeybee: toxicological and biochemical considerations	2003	IMI
Schneider, Tautz, Grunewald, and Fuchs [817]	RFID Tracking of Sublethal Effects of Two Neonicotinoid Insecticides on the Foraging Behavior of *Apis mellifera*	2012	CLO, IMI
Schnier, Wenig, Laubert, Simon, and Schmuck [818]	Honey bee safety of imidacloprid corn seed treatment	2003	IMI

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Studies contributing to pollinator risk assessment, continued

Author	**Title**	**Year**	**Neonicotinoid(s)**
Sgolastra, Renzi, Draghetti, Medrzycki, Lodesani, Maini, and Porrini [826]	Effects of neonicotinoid dust from maize seed-dressing on honey bees	2012	CLO
Sgolastra, Medrzycki, Bortolotti, Renzi, Tosi, Bogo, Teper, Porrini, Molowny-Horas, and Bosch [827]	Synergistic mortality between a neonicotinoid insecticide and an ergosterol-biosynthesis-inhibiting fungicide in three bee species	2017	CLO
Shamim, Decant, Sappington, and Vaughan [829]	Open field feeding study design with *Apis mellifera* to evaluate the whole-hive toxicity of imidacloprid at multiple concentrations in sucrose solution	2014	IMI
Shi, Liao, Wang, Leng, and Wu [839]	Effects of sublethal acetamiprid doses on the lifespan and memory-related characteristics of honey bee (*Apis mellifera*) workers	2019	ACE
Shi, Wang, Liu, Qi, and Yu [841]	Sublethal effects of the neonicotinoid insecticide thiamethoxam on the transcriptome of the honey bees (Hymenoptera: Apidae)	2017	TMX
Shi, Wang, Liu, Qi, and Yu [840]	Influence of the neonicotinoid insecticide thiamethoxam on miRNA expression in the honey bee (Hymenoptera: Apidae)	2017	TMX
Škerl and Gregorc [853]	Heat shock proteins and cell death in situ localisation in hypopharyngeal glands of honeybee (*Apis mellifera carnica*) workers after imidacloprid or coumaphos treatment	2010	IMI
Slowinska, Nynca, Wilde, Bak, Siuda, and Ciereszko [854]	Total antioxidant capacity of honeybee haemolymph in relation to age and exposure to pesticide and comparison to antioxidant capacity of seminal plasma	2016	IMI
Spurgeon, Hesketh, Lahive, Svendsen, Baas, Robinson, Horton, and Heard [869]	Chronic oral lethal and sub-lethal toxicities of different binary mixtures of pesticides and contaminants in bees (*Apis mellifera*, *Osmia bicornis* and *Bombus terrestris*)	2016	CLO

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Studies contributing to pollinator risk assessment, continued

Author	**Title**	**Year**	**Neonicotinoid(s)**
Stadler, Gines, and Buteler [870]	Long-term toxicity assessment of imidacloprid to evaluate side effects on honey bees exposed to treated sunflower in Argentina	2003	IMI
Stanley, Sah, Jain, Bhatt, and Sushil [871]	Evaluation of pesticide toxicity at their field recommended doses to honeybees, *Apis cerana* and *A-mellifera* through laboratory, semi-field and field studies	2015	ACE, IMI, TMX
Straub, Villamar-Bouza, Bruckner, Chantawannakul, Gauthier, Khongphinitbunjong, Retschnig, Troxler, Vidondo, Neumann, and Williams [882]	Neonicotinoid insecticides can serve as inadvertent insect contraceptives	2016	CLO, IMI
Straub, Williams, Vidondo, Khongphinitbunjong, Retschnig, Schneeberger, Chantawannakul, Dietemann, and Neumann [883]	Neonicotinoids and ectoparasitic mites synergistically impact honeybees	2019	CLO, IMI
Suchail, Guez, and Belzunces [886]	Characteristics of imidacloprid toxicity in two *Apis mellifera* subspecies	2000	IMI
Suchail, Guez, and Belzunces [887]	Discrepancy between acute and chronic toxicity induced by imidacloprid and its metabolites in *Apis mellifera*	2001	IMI
Tadei, Domingues, Malaquias, Camilo, Malaspina, and Silva-Zacarin [895]	Late effect of larval co-exposure to the insecticide clothianidin and fungicide pyraclostrobin in Africanized *Apis mellifera*	2019	CLO
Tarek, Hamiduzzaman, Morfin, and Guzman-Novoa [898]	Sub-lethal doses of neonicotinoid and carbamate insecticides reduce the lifespan and alter the expression of immune health and detoxification related genes of honey bees (*Apis mellifera*)	2018	CLO, IMI
Tavares, Dussaubat, Kretzschmar, Carvalho, Silva-Zacarin, Malaspina, Berail, Brunet, and Belzunces [900]	Exposure of larvae to thiamethoxam affects the survival and physiology of the honey bee at post-embryonic stages	2017	TMX
Tavares, Roat, Carvalho, Mathias Silva-Zacarin, and Malaspina [899]	In vitro effects of thiamethoxam on larvae of Africanized honey bee *Apis mellifera* (Hymenoptera: Apidae)	2015	TMX
Tavares, Roat, Silva-Zacarin, Nocelli, and Malaspina [901]	Exposure to thiamethoxam during the larval phase affects synapsin levels in the brain of the honey bee	2019	TMX
Teeters, Johnson, Ellis, and Siegfried [902]	Using video-tracking to assess sublethal effects of pesticides on honey bees (*Apis mellifera L.*)	2012	IMI

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Studies contributing to pollinator risk assessment, continued

Author	Title	Year	Neonicotinoid(s)
Tesovnik, Zorc, Gregorc, Rinehart, Adamczyk, and Narat [904]	Immune gene expression in developing honey bees (*Apis mellifera L.*) simultaneously exposed to imidacloprid and *Varroa destructor* in laboratory conditions	2019	IMI
Tesovnik, Zorc, Ristanic, Glavinic, Stevanovic, Narat, and Stanimirovic [905]	Exposure of honey bee larvae to thiamethoxam and its interaction with *Nosema ceranae* infection in adult honey bees	2020	TMX
Tesovnik, Cizelj, Zorc, Čitar, Božič, Glavan, and Narat [903]	Immune related gene expression in worker honey bee (*Apis mellifera Carnica*) pupae exposed to neonicotinoid thiamethoxam and Varroa mites (*Varroa Destructor*)	2007	TMX
Thany, Bourdin, Graton, Laurent, Mathe-Allainmat, Lebreton, and Le Questel [907]	Similar comparative low and high doses of deltamethrin and acetamiprid differently impair the retrieval of the proboscis extension reflex in the forager honey bee (*Apis mellifera*)	2015	ACE
Thomazoni, Soria, Kodama, Carbonari, Fortunato, Degrande, and Jr Valter [909]	Selectivity of insecticides for adult workers of *Apis mellifera* (Hymenoptera: Apidae)	2009	TMX
Thompson, Coulson, Ruddle, Wilkins, and Harkin [910]	Thiamethoxam: Assessing flight activity of honeybees foraging on treated oilseed rape using radio frequency identification technology	2016	TMX
Thompson, Overmyer, Feken, Ruddle, Vaughan, Scorgie, Bocksch, and Hill [911]	Thiamethoxam: Long-term effects following honey bee colony-level exposure and implications for risk assessment	2019	CLO, IMI, TMX
Thompson, Fryday, Harkin, and Milner [912]	Potential impacts of synergism in honeybees (*Apis mellifera*) of exposure to neonicotinoids and sprayed fungicides in crops	2014	CLO, IMI, TMX
Tison, Rößner, Gerschewski, and Menzel [918]	The neonicotinoid clothianidin impairs memory processing in honey bees	2019	CLO
Tomé, Schmehl, Wedde, Godoy, Ravaiano, Guedes, Martins, and Ellis [924]	Frequently encountered pesticides can cause multiple disorders in developing worker honey bees	2020	IMI
Tosi, Medrzycki, Bogo, Bortolotti, Grillenzoni, and Forlani [928]	Role of food quality in bee susceptibility to fipronil and clothianidin	2012	CLO
Tosi, Démares, Nicolson, Medrzycki, Pirk, and Human [929]	Effects of a neonicotinoid pesticide on thermoregulation of African honey bees (*Apis mellifera scutellata*)	2016	TMX

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Studies contributing to pollinator risk assessment, continued

Author	Title	Year	Neonicotinoid(s)
Tosi, Burgio, and Nieh [930]	A common neonicotinoid pesticide, thiamethoxam, impairs honey bee flight ability	2017	TMX
Tosi, Nieh, Sgolastra, Cabbri, and Medrzycki [931]	Neonicotinoid pesticides and nutritional stress synergistically reduce survival in honey bees	2017	CLO, TMX
Tosi and Nieh [927]	A common neonicotinoid pesticide, thiamethoxam, alters honey bee activity, motor functions, and movement to light	2017	TMX
Tremolada, Mazzoleni, Saliu, Colombo, and Vighi [933]	Field trial for evaluating the effects on honeybees of corn sown Uuing Cruiser(R) and Celest XL(R) treated seeds	2010	TMX
Tsvetkov, Samson-Robert, Sood, Patel, Malena, Gajiwala, Maciukiewicz, Fournier, and Zayed [934]	Chronic exposure to neonicotinoids reduces honey bee health near corn crops	2017	CLO, TMX
Uhl, Awanbor, Schulz, and Bruehl [937]	Is *Osmia bicornis* an adequate regulatory surrogate? Comparing its acute contact sensitivity to *Apis mellifera*	2019	ACE, IMI
van der Steen, Hok-Ahin, and Cornelissen [1001]	The impact of imidacloprid and the interaction between imidacloprid and pollen scarcity on vitality and hibernation of honey bee colonies	2015	IMI
van Dooremalen, Cornelissen, Poleij-Hok-Ahin, and Blacquiere [1002]	Single and interactive effects of *Varroa destructor*, *Nosema spp.*, and imidacloprid on honey bee colonies (*Apis mellifera*)	2018	IMI
Walderdorff, Laval-Gilly, Bonnefoy, and Falla-Angel [1026]	Imidacloprid intensifies its impact on honeybee and bumblebee cellular immune response when challenged with LPS (lippopolysacharide) of *Escherichia coli*	2018	IMI
Wallner [1031]	Tests regarding effects of imidacloprid on honey bees	2001	IMI
Wang, Zhu, and Li [1035]	Interaction patterns and combined toxic effects of acetamiprid in combination with seven pesticides on honey bee (*Apis mellifera L.*)	2020	ACE

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Author	Title	Year	Neonicotinoid(s)
Wessler, Gaertner, Michel-Schmidt, Brochhausen, Schmitz, Anspach, Gruenewald, and Kirkpatrick [1045]	Honeybees produce millimolar concentrations of non-neuronal acetylcholine for breeding: possible adverse effects of neonicotinoids	2016	CLO
Wilde, Fraczek, Siuda, Bak, Hatjina, and Miszczak [1052]	The influence of sublethal doses of imidacloprid on protein content and proteolytic activity in honey bees (*Apis mellifera L.*)	2016	IMI
Williams, Troxler, Retschnig, Roth, Yañez, Shutler, Neumann, and Gauthier [1054]	Neonicotinoid pesticides severely affect honey bee queens	2015	CLO, TMX
Williamson, Baker, and Wright [1073]	Acute exposure to a sublethal dose of imidacloprid and coumaphos enhances olfactory learning and memory in the honeybee *Apis mellifera*	2013	IMI
Williamson and Wright [1072]	Exposure to multiple cholinergic pesticides impairs olfactory learning and memory in honeybees	2013	IMI
Williamson, Willis, and Wright [1074]	Exposure to neonicotinoids influences the motor function of adult worker honeybees	2014	CLO, DIN, IMI, TMX
Wood, Kozii, Koziy, Epp, and Simko [1098]	Comparative chronic toxicity of three neonicotinoids on New Zealand packaged honey bees	2018	CLO, IMI, TMX
Wright, Softley, and Earnshaw [1100]	Low doses of neonicotinoid pesticides in food rewards impair short-term olfactory memory in foraging-age honeybees	2015	IMI, TMX
Wu-Smart and Spivak [1105]	Sub-lethal effects of dietary neonicotinoid insecticide exposure on honey bee queen fecundity and colony development	2016	IMI
Wu, Chang, Lu, and Yang [1102]	Gene expression changes in honey bees induced by sublethal imidacloprid exposure during the larval stage	2017	IMI
Wu, Luo, Hou, Wang, Dai, Gao, Liu, and Diao [1104]	Sublethal effects of imidacloprid on targeting muscle and ribosomal protein related genes in the honey bee *Apis mellifera L.*	2017	IMI
Wu, Zhou, Wang, Dai, Xu, Jia, and Wang [1103]	Programmed cell death in the honey bee (*Apis mellifera*) (Hymenoptera: Apidae) worker brain induced by imidacloprid	2015	IMI

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Studies contributing to pollinator risk assessment, continued

Author	**Title**	**Year**	**Neonicotinoid(s)**
Yang, Chuang, Chen, and Chang [1109]	Abnormal foraging behavior induced by sublethal dosage of imidacloprid in the honey bee (Hymenoptera: Apidae)	2008	IMI
Yang, Chang, Wu, and Chen [1110]	Impaired olfactory associative behavior of honey bee workers due to contamination of imidacloprid in the larval stage	2012	IMI
Yao, Zhu, and Adamczyk [1111]	Responses of honey bees to lethal and sublethal doses of formulated clothianidin alone and mixtures	2018	CLO
Zhang and Nieh [1118]	The neonicotinoid imidacloprid impairs honey bee aversive learning of simulated predation	2015	IMI
Zhu, Yao, Adamczyk, and Luttrell [1120]	Synergistic toxicity and physiological impact of imidacloprid alone and binary mixtures with seven representative pesticides on honey bee (*Apis mellifera*)	2017	IMI
Zhu, Yao, and Adamczyk [1121]	Long-term risk assessment on noneffective and effective toxic doses of imidacloprid to honeybee workers	2019	IMI