Case Study: Neonicotinoids

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About case studies

The Environmental and Occupational Health team responds to specific requests for scientific and technical advice and support from the health care system, the Government of Ontario, and most commonly from Ontario's local public health units. Based on requests received, we have identified questions, issues and topics that may be of relevance to a broader audience. Therefore, we have created the Case Study series to better share information on the diverse environmental health issues we have encountered, and encourage dialogue in these areas.

This response was originally produced in July 2014. The specifics about the location and requestor involved have been removed.

The following was selected as a case study because of the widespread use of neonicotinoids in Ontario.

Background

First introduced in the 1990s, neonicotinoids are a class of highly selective insecticides derived from the insecticide, nicotine.[1,2] Individual neonicotinoids include imidacloprid, clothiandin, thiamethoxam, dinotefuran, thiacloprid and acteamiprid.[2] In 2005, neonicotinoids accounted for approximately 11%–15% of the total insecticide market. With trends of increasing detection of residue levels in food from 4.7% in 2007 to 12.6% in 2010, these results point to an increase in the overall usage of neonicotinoids worldwide.[3,4] Although the usage rates of neonicotinoids in Canada could not be obtained, pesticide sales in Canada report that thiamethoxam and clothianidin were in the top 10 insecticide active ingredients sold in 2010.[5]

Neonicotinoids are mainly used in seed and soil treatment, but may also be directly applied to plant foliage. They have also been widely used in veterinary applications as an effective flea treatment on cats and dogs.[4] Neonicotinoids act primarily as water-soluble plant systemic pesticides, which means that when used as a soil or seed treatment or applied topically, they are taken up by the roots or plant tissues and translocated throughout the entire plant. This protects the plant from piercing-sucking insects such as aphids, leafhoppers, and whiteflies.[3,4] Although these properties of neonicotinoids play a valuable role in crop protection, it is these same features that increase the potential for unintentional exposure to non-target insect species, animals and humans. For this reason, recent Canadian and international attention has targeted the use of neonicotinoids as a potential explanation for a decline in honey bee and other pollinator populations.[6-8]

The following write-up has been prepared to respond to a request regarding current information on regulatory decisions surrounding neonicotinoids in Canada and abroad, and to provide information on the use of neonicotinoids and the potential impacts on food security.

Methods

A literature search on neonicotinoids and food security was conducted through Medline, Academic Search Premier, Environment Complete and Scopus databases using a combination of the following search terms: neonicotinoids, clothianidin, imidacloprid, thiamethoxam, food security, ecosystem, ecology, toxicity and exposure. Grey literature sources were also searched, particularly for information related to the current regulatory measures affecting the uses of neonicotinoids. Results were limited to English language only. Note that only clothianidin, imidacloprid, thiamethoxam were included as search terms rather than all neonicotinoids because they are the most commonly applied neonicotinoids.

Regulation of Neonicotinoids

In 2012, Health Canada's Pest Management Regulatory Agency (PMRA), which is the department responsible for pesticide regulation in Canada, received a significant number of pollinator mortality reports from the main corn-growing regions of Ontario and Quebec. Approximately 70% of the dead bee samples from these regions tested positive for neonicotinoid residues. Based on this information, PMRA determined that current agricultural practices related to the use of neonicotinoid-treated corn and soybean seed are affecting the environment due to their impacts on bees and other pollinators.[9]

On September 13, 2013, PMRA published the Notice of Intent (NOI2013-01) *Action to Protect Bees from Exposure to Neonicotinoid Pesticides*, which states that the likely route of exposure to neonicotinoids was through contaminated dust generated during the planting of treated seeds. Continued reports of high mortality rates in pollinators have caused Health Canada to deem current agricultural practices surrounding the use of neonicotinoids unsustainable. The Notice of Intent states that for the 2014 planting season, several protective measures will be implemented and tracked. These include the use of dust-reducing seed flow lubricants and adherence to safer planting practices. New pesticide and seed package labels with enhanced warnings and updated value information will also be produced. These measures will be evaluated to determine whether there is a continued need for neonicotinoid treatment on up to 100% of the corn and 50% of the soybean seed planted in Canada. [9,10] Results of these measures will be closely monitored as the 2014 planting season progresses, and pending the outcome, further actions may be considered.[10]
In January 2013, the European Food Safety Authority (EFSA) published pesticide risk assessments on three of the most widely used

neonicotinoids (imidacloprid, thiamethoxam and clothianidin) to assess the impact these substances were having on the bee population.[11-13] These scientific reports identified three "high acute risks" for bees:

- exposure to the airborne dust that is mobilized when planting crops such as corn, cereals and sunflowers
- exposure to the residues in pollen and nectar in crops such as canola/rapeseed and sunflowers
- exposure to guttation fluids (guttation is a process in which drops of sap are exuded from, and collect on, the edges of leaves) from corn

The reports suggest that these exposures play a key role in the increase of colony collapse disorder (CCD), which has been seen throughout Europe in recent years.[14]

In response to these assessments, the European Commission has adopted a proposal to restrict the use of imidacloprid, thiamethoxam and clothianidin for two years. During this time period, which began on December 1, 2013, further research is being conducted. The use of these insecticides is restricted on plants and cereals known to attract bees. Restrictions apply to seed treatment, soil application and topical leaf treatment. Exceptions to these restrictions are limited, and include activities such as allowing the treatment of bee-attractive crops in greenhouses or in open-air fields only after flowering has occurred. [11-15]

The scientific conclusions of the United States Environmental Protection Agency (US EPA) regarding the potential for acute effects and uncertainty about chronic risk are similar to those cited in the EFSA reports on imidacloprid, thiamethoxam and clothianidin.[11-14] The US EPA evaluation also makes an effort to address the risk management of neonicotinoids, a significant factor which is not addressed in the EFSA reports. The US EPA has not, as of yet, issued any bans or restrictions on the use of neonicotinoids; however, the agency is currently re-evaluating the insecticides through their registration review process to ensure they meet current health and safety standards.[14] Health Canada's PMRA is currently working in conjunction with the US EPA on the re-evaluation of all uses of neonicotinoid insecticides as part of a larger international project.[9]

Ecosystem Considerations

The concern over the potential effects of neonicotinoids on bee populations has raised questions about indirect effects on other non-target species and overall ecosystem health. To understand the impacts to the environment and overall ecosystem health, researchers have studied the various aspects of the fate and transport of neonicotinoids as well as neonicotinoid toxicity. Subsequently, they have sought to further understand the effect of neonicotinoids on food security. For the purposes of this write-up, food security is defined in line with the World Health Organization's pillars of food security as "food availability where consistently sufficient quantities of food are available."[16]

Environmental Fate and Transport

The persistence of neonicotinoids in the environment is attributed to their chemical and physical properties as shown in studies demonstrating residual concentrations in the environment following application. The soil half-lives of individual neonicotinoids varies considerably. Imidacloprid was reported as having a half-life of 28 to 1,250 days, whereas clothiandin has a soil half-life ranging from 148 to 6,931 days.[17-19] These ranges represent a gap in knowledge and contribute to uncertainty when evaluating these chemicals. Cold soil temperatures common in Canada have been associated with higher soil half-lives.[18] Based on the soil half-lives, it is anticipated that repeated applications of neonicotinoids would lead to an accumulation in soil; however, supporting studies are scarce.[20]

Due to their high water solubility, neonicotinoids have been detected in both groundwater and surface water. The source of these neonicotinoids is likely attributable to spray drift and leaching from soils.[7,19] In a study of wetlands situated near agricultural fields in Canada's Prairie Pothole region, clothianidin was the most commonly detected neonicotinoid in water samples.[18]

Concerns over potential routes of exposure for non-target species have been raised based on the presence of neonicotinoids in soil and surface water. A few direct routes of exposure have been identified, including the ingestion of treated seeds; and dermal contact with, and inhalation of, spray drift during treatment. Indirect routes of exposure include ingestion of impacted surface water, exposure to residues in pollen, and the ingestion of contaminated prey.[8] These indirect routes of exposure represent current gaps in data that are required to understand the impact of neonicotinoids on overall ecosystem health.

Toxicity to Humans and other Vertebrates

Neonicotinoids act by blocking a specific neuronal pathway that is more prevalent in insects than in vertebrates.[4,21] However, if humans are exposed to certain neonicotinoids – imidacloprid, for example, will be absorbed and excreted within 48 hours following ingestion.[21]

In general, standard lethal dose toxicity tests (LD_{50}) have demonstrated the varying lethality of neonicotinoids to birds, rats, mice and aquatic species at concentrations much higher than is required to achieve lethality in insects.[4] Lethal concentrations vary between individual neonicotinoids. For example, as defined by the US EPA, imidacloprid has moderate to high toxicity to birds, moderate toxicity to rats and mice, and practically no toxicity to fish. On the other hand, clothianidin is moderately to practically non-toxic to birds and mammals, and slightly to moderately toxic to fish.[7] Relying on toxicity tests, specifically lethality tests, has been criticized because these types of laboratory conditions do not represent real-world exposure scenarios.[17] For example, concentrations in lakes and rivers have been reported at levels approximately 2 – 7 orders of magnitude lower than lethal laboratory concentrations (the equivalent of 0.00001% to 1%) making it difficult to apply these LD_{50} numbers in a field-type scenario.[7]

However, even concentrations that do not kill insects (i.e., sub-lethal concentrations) may be of ecological significance. The best example of this is the following: Studies on bees that found sub-lethal concentrations produce behavioural effects such as reduced learning, foraging and homing abilities. [8,18,19] These types of behavioural changes are not measured or detected by routine toxicity tests. Without bees acting as a key pollinator species, an estimated 60 varieties of crops would fail to produce fruit.[8] However, in an evaluation of the effect of neonicotinoids on bee populations, authors determined that despite the decline in colonies in North America and Europe, globally managed bee colony stocks have increased by 45% in the last 50 years.[1] This overall increase of stock bee colonies would imply there has been little to no impact on existing crop species yield.

Our ability to determine whether or not neonicotinoids are producing an overall effect on ecosystem health has been reduced by the data gaps affecting our understanding of sub-lethal concentrations, the contribution of indirect exposure pathways to overall neonicotinoid intake, and chronic exposure effects on non-target species.

There is relatively little human health literature on the effects of neonicotinoids at environmental levels. There have been several acute poisoning cases reported following intentional and accidental exposures; however, the amount of ingested insecticide did not prove to be a useful measure for managing toxicity in these cases.[22,23] The details surrounding these poisoning cases, such as exposure dose, are scarce. However, reported symptoms ranged from less severe effects including nausea, headache, dizziness, drowsiness, and abdominal pain to more serious effects such as respiratory effects, seizures, nervous system paralysis, coma and death.[22,23] There were 1,142 neonicotinoid exposure cases reported to the Texas Poison Center Network from 2000-2012 with less than

2% reported as intentional exposure cases. The exposure rate was highest in urban counties at the patient's residence, which the authors attributed to potential domestic garden use of neonicotinoids or exposure to neonicotinoids used as flea control for pets.[22]

Food Security

Despite its ability to effectively control pests, the benefit of neonicotinoids on crop yields versus alternative pest management measures has been debated. For example, canola/rapeseed yields in the U.K. have not changed significantly since 1994, prior to the introduction of neonicotinoids, and neither have soya yields in North America. Meanwhile, neonicotinoid treated seeds were found to produce cost-effective yields of spring wheat in Western Australia.[19] This indicates that the effect on yield may be dependent on the crop itself, with reported increased yields of certain North American crops such as corn.[20] There is a need for further study on whether or not the use of neonicotinoids has successfully increased crop yields and in turn, increased food availability.

With respect to food quality, studies have demonstrated residual concentrations of neonicotinoids in crops including fruits (e.g., apples and grapes) and vegetables (broccoli, bell peppers and cauliflower).[3] The Canadian Food Inspection Agency (CFIA) operates the Food Safety Action Plan, which measures pesticide residues in fruits and vegetables sold intra-provincially (excluding non-federally registered or imported foods) to assess Canadian exposures. From 2009–2010, several pesticide residues (including imidacloprid, clothiandin, thiamethoxam and acteamiprid) were measured in apples, small berries, leafy greens and tomatoes collected in CFIA's Atlantic, Quebec, Ontario and Western regions. Of the sampled neonicotinoids, only imidacloprid was detected in blueberries, blackberries, strawberries, leafy greens and tomatoes. Although residual concentrations of imidacloprid were not provided, the measured residual concentrations were not reported to exceed the imidacloprid maximum residue limits (MRL). The MRL is a level which is used as a compliance measurement, and is typically set at a concentration well below an amount that could pose a human health concern.[24]

Summary

Neonicotinoids are a class of highly selective systemic insecticides used mainly in seed and soil treatment to provide protection from piercing-sucking insects such as aphids, leafhoppers, and whiteflies. Despite their selective toxicity, adverse effects may occur in non-target species. These effects may provide an explanation for the decline in honey bee and other pollinator populations in Europe and North America. In response to these concerns, and until further research is conducted, the PMRA has established protective measures for the 2014 planting season. On December 1, 2013, the European Commission imposed restrictions on the use of three neonicotinoids, imidacloprid, thiamethoxam and clothianidin, for a period of two years. The US EPA has not issued any bans or restrictions during their evaluation period.

To understand impacts on the environment, ecosystem health and overall food security, it is necessary to understand the interaction between the fate and transport of neonicotinoids and their toxicity. Despite what is known about soil half-lives and water solubility, the direct and indirect effects of neonicotinoids under real-world conditions are highly debated. This introduces uncertainty when interpreting the effects of neonicotinoids on non-target species such as bees.

There is a recognized need for further study on whether or not the use of neonicotinoids has successfully contributed to increased crop yields, and in turn, increased food availability. Further study is required to determine if the use of alternative insecticides would be preferable.

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