Scoping a Review of Neonicotinoid Use, Registration, and Insect Pollinator Impacts in Minnesota

The Minnesota Department of Agriculture Pesticide and Fertilizer Management Division

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MINNESOTA DEPARTMENT OF AGRICULTURE
PESTICIDE AND FERTILIZER MANAGEMENT

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https://www.mda.state.mn.us/chemicals/pesticides/regs/pestprodreg.aspx
http://www.mda.state.mn.us/en/protecting/bmps/pollinators.aspx

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Executive summary

The Minnesota Department of Agriculture (MDA) is the lead state agency for pesticide and fertilizer environmental and regulatory functions in Minnesota under the Pesticide Control Law (Minn.Stat. Chapter18B). In addition to functions related to pesticide registration and monitoring, one of the tasks of MDA is to conduct in-depth reviews using a scientific approach to evaluate pesticides in order to better understand Minnesota-specific issues related to pesticides. The scope of these special registration reviews varies depending on the potential education, outreach, and enforcement needs identified by the Department. As such, these reviews are not intended to be redundant of analyses and decisions reached by the United States Environmental Protection Agency (USEPA) during federal registration. Rather, these reviews result in a greater understanding of federal registration concerns and provide a variety of opportunities for action. Outcomes of this review may include: clarification of label provisions and enforcement designed to protect non-target organisms and the environment, targeted enforcement-related education, applicator guidance and social network tools developed to enhance product stewardship, restrictions on or cancellation of products, suggesting research topics that would further the understanding of non-target impacts from neonicotinoids for policymakers, funding agencies, regulatory agencies, etc., and proposing other measures designed to minimize the impacts of pesticide use on human health and the environment. Completion of this in-depth review may take six months or more.

Neonicotinoid insecticides are currently one of the most widely used insecticides in the world because of their potential benefits including potent broad-spectrum toxicity properties possessing contact, oral, and systemic activity. They are effective at very low concentrations, are less toxic to mammals, and are not cross-resistant to previously or still available classes of insecticides including carbamates, organophosphates, and synthetic pyrethroids. However, recent research has suggested potential toxicity concerns for neonicotinoids to various life stages of honey bees, wild bees, as well as other pollinating insects. The concern over the use of neonicotinoid insecticides in relation to insect pollinators led the legislature to request that the MDA report on the process and criteria to be used in a review of neonicotinoid use in Minnesota currently and in the future.

The basic process and criteria the MDA uses to conduct a variety of pesticide reviews has already been established, and the MDA has already reviewed neonicotinoids as part of an emerald ash borer insecticide review (including concerns about pollinator exposure). For these reasons, the Commissioner of Agriculture (the Commissioner) directed MDA staff, on November 5, 2013, to initiate a special review of neonicotinoid pesticides and insect pollinators. This document therefore, serves as the scope of a special review of neonicotinoid pesticides impacts on insect pollinators in Minnesota. The MDA solicited input from and consulted with interested beekeepers and industries. In addition, MDA collaborated with the Department of Natural Resources (DNR), the Minnesota Pollution Control Agency (MPCA), the Minnesota Board of Water and Soil Resources (BWSR) and the University of Minnesota (UMN) to develop this scope to be used in conducting the special review.

As with previous in-depth special reviews of pesticides, the scope of the neonicotinoid insecticide review includes an overview of federal and state pesticide programs, and roles and responsibilities related to the registration and use of neonicotinoids in Minnesota. The scoped criteria of the review are presented below. Each criterion will be explored in relation to Minnesota-specific concerns and opportunities for action.

The scoping criteria include:

- Neonicotinoid background, chemistry, and mode of action;
- Federal and state neonicotinoid registration;
- Neonicotinoid use and sales;
- Neonicotinoid applications and movement in the environment;
- Risks of neonicotinoid use; and
- Benefits of neonicotinoid use.

The MDA made a draft scoping document of the review available for public comment. The comment period closed on May 2, 2014. Following public comments, the MDA and collaborators modified the review scope as appropriate, and is now beginning the review. During the course of the review the MDA will provide information about review related topics through a public listserv and by posting updates to the MDA website. Interested parties may enroll in the listserv through the MDA website. In addition, the MDA may provide status updates through meetings with interested stakeholders. Once the review is complete, the Commissioner will issue a determination of the review's findings along with opportunities for action. The product registrant may request a hearing on certain regulatory actions taken by the Commissioner (Minn. Stat. § 18B.26).

Introduction and background

The Minnesota Department of Agriculture (MDA) is the lead state agency for pesticide and fertilizer environmental and regulatory functions in Minnesota under the Pesticide Control Law (Minn.Stat. Chapter18B). One of those functions is state-level registration of pesticide products approved by the U.S. Environmental Protection Agency (USEPA). In 2006, and in response to a Minnesota Legislative Auditor's report, the MDA initiated an effort to broaden state-level review of pesticide registrations by routinely learning more about new registrations and conducting expanded, in-depth reviews to better understand Minnesota-specific registration issues. The scope of these special registration reviews varies depending on the potential education, outreach, and enforcement needs identified by the Department.

Although prior to the 2006 Auditor's report, the MDA conducted special pesticide reviews while carrying out many of its statutory responsibilities. The MDA's first formal review in response to the Auditor's recommendations was for the corn herbicide atrazine; a multi-agency review comprised of five agency-specific technical assessments addressed human health, the environment, costs and benefits, water quality monitoring, and product labels. Subsequent in-depth reviews have addressed insecticide active ingredients used to control emerald ash borer which included a review of several neonicotinoids and potential pollinator impacts, and a special review of insecticide use related to bed bug control. All of these in-depth reviews led MDA, its collaborators, and stakeholder groups to a greater understanding of the risks and benefits of pesticide product use or generated various voluntary and enforcement-related educational and outreach materials related to human health and environmental protection. For more information on these reviews visit Pesticide Special Registration Review Information

In addition to the in-depth reviews, the MDA also reviews new active ingredients recently approved by the USEPA as well as currently registered pesticides that have significant new uses or have undergone a major label change (19 reviews in 2012-2013). In the process of completing these shorter reviews, the MDA explores a variety of human health and ecological risk issues, and assesses laboratory analytical concerns for tracking potential misuse and non-target impacts. Information on projected pesticide use and efficacy is gathered from University Extension, user groups, and others. Reviews may also include communication with the USEPA or the registrant to request more information about identified concerns.

The concern over the use of neonicotinoid insecticides in relation to insect pollinators led the legislature to request that the MDA report on the process and criteria to be used in a review of neonicotinoid use and impact in Minnesota currently and in the future.

Process

The basic process and criteria that MDA uses to conduct a variety of pesticide reviews has already been established, and the MDA has already reviewed several neonicotinoid concerns as part of its emerald ash borer insecticide review (including concerns about pollinator exposure), for these reasons the Commissioner of Agriculture (the Commissioner) directed the MDA staff on November 5, 2013, to initiate a special review of neonicotinoid pesticides on insect pollinators.

An in-depth, special review is conducted to provide stakeholders and the Commissioner with more information about Minnesota-specific pesticide products and issues. As such, these reviews are not

intended to be redundant of analyses and decisions reached by the USEPA during federal registration. Rather, these reviews result in a greater understanding of federal registration concerns and provide a variety of opportunities for action. Outcomes of this review may include: clarification of label provisions and enforcement designed to protect non-target organisms and the environment, targeted enforcement-related education, applicator guidance and social network tools developed to enhance product stewardship, restrictions on or cancellation of products, suggesting research topics that would further the understanding of non-target impacts from neonicotinoids for policymakers, funding agencies, regulatory agencies, etc., and proposing other measures designed to minimize the impacts of pesticide use on human health and the environment. Completion of this in-depth review may take six months or more.

The MDA has a history of reviewing Minnesota-specific enforcement and other data related to pesticide use and insect pollinators, including endangered pollinator species (Karner blue butterfly) or candidate species (Dakota skipper butterflies and Poweshiek skipper). As noted above, the MDA's special review of insecticide active ingredients used to control emerald ash borer included a review of two of the seven neonicotinoids (imidacloprid and dinotefuran) and potential pollinator impacts. As an outgrowth of that review, the MDA has been collecting and reviewing a significant amount of information and peer-reviewed research related to neonicotinoids and pollinators.

Building off of this information, the MDA solicited input from and consulted with interested beekeepers and industries. In addition, MDA collaborated with the Department of Natural Resources (DNR), the Minnesota Pollution Control Agency (MPCA), the Minnesota Board of Water and Soil Resources (BWSR) and the University of Minnesota (UMN) to develop the scope to be used in conducting the special review.

In-depth reviews of pesticides can include an opportunity for public comment regarding the proposed scope so that interested parties have an understanding of the criteria to be used in conducting the review. For the neonicotinoid review, the MDA made the draft scope of the review available for public comment on March 3, 2014. The comment period closed on May 2, 2014. Following public comment, the MDA and collaborators modified the review scope as appropriate, and is now beginning the review. During the course of the review the MDA will provide information about review related topics through a public listserv and by posting updates to the MDA website. Interested parties may enroll in the listserv through the MDA website. In addition, the MDA may provide status updates through meetings with interested stakeholders. Once the review is complete, the Commissioner will issue a determination of the review's findings along with opportunities for action. The product registrant may request a hearing on certain regulatory actions taken by the Commissioner (Minn. Stat. § 18B.26).

Criteria

The criteria used to conduct the review reflect its scope. As with previous in-depth special reviews of pesticides, the scope of the neonicotinoid review will include an overview of federal and state pesticide programs, roles and responsibilities related to the registration and use of neonicotinoids in Minnesota. The scoping criteria include:

- Neonicotinoid background, chemistry, and mode of action;
- Federal and state neonicotinoid registration;
- Neonicotinoid use and sales;
- Neonicotinoid applications and movement in the environment;
- Risks of neonicotinoid use; and
- Benefits of neonicotinoid use.

Each criterion will be explored in relation to Minnesota-specific concerns and opportunities for action. Preliminary information regarding the scoped criteria is presented below.

Neonicotinoid background, chemistry, and mode of action: Neonicotinoids are systemic insecticides with a structure and mode of action similar to nicotine, a naturally occurring plant alkaloid compound, toxic to humans. Neonicotinoids target the acetylcholine receptors on the insect nerve cells within an

insect nervous system and are potent broad-spectrum insecticides affecting insects through contact and oral exposures. Their action causes excitation of the insect nerves that lead to trembling, shaking, and eventual paralysis, which can lead to death depending on the dose and exposure duration (acute - chronic). Neonicotinoids are effective at very low concentrations and bind at a receptor site specific to insect nerve cells, therefore they are less toxic to mammals and are not cross-resistant to previously or still available classes of insecticides such as carbamates, organophosphates and synthetic pyrethroids.

Introduced in 1991, imidacloprid was the first commercially available neonicotinoid insecticide, and it is currently one of the most widely used insecticides in the world. Currently there are seven neonicotinoid insecticides that are available commercially for use in crop or animal agriculture, urban landscapes, and domestic settings. Structurally, neonicotinoids can be classified into N-nitroguanidines (imidacloprid, thiamethoxam, clothianidin and dinotefuran), nitromethylenes (nitenpyram) and N-cyano-amidines (acetamiprid and thiacloprid). Both nitroguanidines and N-cyano-amidines are widely used in controlling piercing and sucking insect pests that feed on plant fluids and some foliage and root feeding insect pests.

The review will provide an overview of the various neonicotinoid insecticides commercially available. Nitromethylenes are used in controlling only dog and cat insect pests and their use is unlikely to affect insect pollinators; as such, nitenpyram will not be included in the review.

Federal and state neonicotinoid registration: Both federal and state laws govern the registration and use of neonicotinoid insecticides in Minnesota. Most neonicotinoid insecticide regulatory activities in Minnesota rely on guidance developed at the federal level by the USEPA. In the United States, six neonicotinoid insecticides with potential pollinator impacts are registered for controlling agricultural and urban insect pests. Following imidacloprid's registration in 1991, five additional neonicotinoid insecticides (acetamiprid, thiamethoxam, thiacloprid, clothianidin, and dinotefuran) were registered between 1995 and 2002. Currently, imidacloprid is registered for over 140 crop uses in more than 120 countries. More generic products based on imidacloprid have been registered since its patent expired in most countries in 2006.

Because all neonicotinoid insecticides were registered after 1984, they were not subject to specific reregistration requirements outlined in the federal Food Quality Protection Act (1996). However, by law, and for products registered or reregistered after 1984, the USEPA must complete a registration review of pesticide active ingredients within 15 years of the registration to determine whether FIFRA registration requirements are still being met and to determine that there are no unreasonable risks to human health, workers, or the environment when products are used as directed on product labels. The USEPA registration reviews will assess lethal (acute), chronic, and sublethal (low-levels) effects of pesticides on all life stages of the honey bee, as well as effects on colony health in field settings, and would typically result in new data requirements and risk assessment approaches for pollinators. More information on the USEPA's review process can be found at http://www.epa.gov/opp00001/ecosystem/pollinator/risk-mgmt.html

The review will summarize USEPA's existing neonicotinoid registration review activity, including reviews of all major neonicotinoids under accelerated review and scheduled for completion between 2016-2018. The review will also describe how the MDA monitors the USEPA registration schedules for future neonicotinoid products and incorporates related information into new product reviews prior to Minnesota registration. The summary will also note pending legal challenges to neonicotinoid registration.

The review will also seek additional information from neonicotinoid registrants regarding any toxicity testing conducted but not submitted to the USEPA, anticipated label modifications to protect pollinators, pesticide use and stewardship information available to agricultural and non-agricultural pesticide applicators and homeowners, product improvements and new application technologies, and the status of international activity by registrants related to the global issue of neonicotinoids and pollinator impacts. The review will also summarize stewardship and outreach information provided by registrants to end users to protect pollinators from neonicotinoid risks.

Federal ecological risk assessment of pesticides on pollinators – In conjunction with the individual neonicotinoid active ingredient reviews, the USEPA has been working across international borders to revise pollinator toxicity testing for pesticides and degradates of toxicological concern. The current testing paradigm relies on a 3-tiered assessment of laboratory and field data using honey bees as a surrogate organism for all insect pollinators. Significant USEPA and international activity is focused on revising toxicity testing to ensure evaluation of other pollinators, a variety of life-stages, impacts to pollinator food sources, and influence on colony health for social insect pollinators.

The review will include a summary of significant USEPA and international activity focused on revising insect pollinator toxicity testing.

New USEPA labeling requirements on neonicotinoid pesticides to improve protection for bees and pollinators – The USEPA has acknowledged some uncertainties with initial registration of neonicotinoid insecticides regarding their potential environmental fate and effects, particularly as they relate to pollinators. In August 2013, the USEPA revised neonicotinoid labels with new advisory and regulatory language (application restrictions) to further protect bees by prohibiting the use of some neonicotinoid insecticide products on some plant species attractive to bees.

The review will summarize the USEPA label revisions, as well as revisions made by US states and USEPA global review collaborators including Canada, European Union, and Australia. The review will also summarize concerns related to these label changes such as interpretation and implementation of new labels.

New restrictions on use of neonicotinoids to improve protection for bees and pollinators: Minnesota and other locations – In addition to the USEPA, other entities – the Canadian Pest Management Regulatory Agency (PMRA) and European Food Safety Authority (EFSA) — have also placed additional restrictions on the use of neonicotinoids to protect honey bees and pollinators. Many states, including Minnesota, are reviewing the causes of pollinator decline and honey bee deaths as they relate to pesticides. Oregon has placed additional restrictions on the use of neonicotinoids and Minnesota prohibits labeling plants as pollinator-friendly if they have been treated with and have a detectable level of systemic insecticide including some neonicotinoid products.

The review will summarize the current status of neonicotinoid restrictions and advisories in various states in the US, Canada, the European Union, and Australia. The review will also include opportunities for Minnesota-specific label improvements, acknowledgement of other potential beekeeper and landowner responsibilities, and opportunities to increase communication between farmers, beekeepers, and applicators.

Neonicotinoid use and sales: Neonicotinoids are water soluble and are readily absorbed by plants via their roots or leaves. They are systemic and are transported and expressed throughout all parts of a treated plant including roots, stems, leaves, nectar, and pollen. This provides many advantages in pest control and protection to all parts of treated plants; for example, in addition to controlling sap sucking insects they are effective against boring and root-feeding insects, both of which cannot be easily controlled using foliar sprays of non-systemic compounds. Additionally, they are effective at very low concentrations for a prolonged period following planting. For this reason neonicotinoids (primarily imidacloprid, clothianidin and thiamethoxam) are predominantly used as seed dressings to protect a broad variety of crop seedlings, such as corn, soybean, oilseed rape, sunflower, cereals, sugar beets, potatoes etc., at per acre concentrations that are relatively lower than other conventional application methods. In addition, they can be used as foliar sprays on field, horticultural, vegetable, turf, and ornamental crops. They are also used for the treatment of pastures and grasslands, domestic animal pests, and for domestic use against cockroaches and ants. They can be applied as a soil drench or in irrigation water to treat perennial crops such as vines, and they can be injected into tree roots or stems, or sprayed onto bark to protect trees against invasive pests (for example emerald ash borer). A single application can provide protection for several months or years.

Using sales and use data on more than 490 registered neonicotinoid products sold in Minnesota, the review will discuss multiple comparisons between neonicotinoid sales and other insecticides. Release of neonicotinoids into the environment also occurs with seed-treatment of Minnesota crops like corn, soybean, sugar beets, canola, and sunflower. Because current MDA pesticide sales data does not track pesticide use associated with seeds treated outside of Minnesota's borders, the review will include an estimate of the additional mass of neonicotinoids released into Minnesota's environment from neonicotinoid treated seeds. Therefore, the MDA review will combine publicly available information from sales revenue and the estimated use associated with neonicotinoid seed treatments to provide a more complete accounting of statewide neonicotinoid use.

Neonicotinoid applications and movement in the environment: The potential for adverse environmental impacts from neonicotinoid insecticides is under constant evaluation and research by the USEPA, industry, university researchers, the MDA and other organizations. The method and timing of insecticide applications, proximity to sensitive aquatic resources (streams, rivers, etc.) and terrestrial habitat (e.g. honey bee hives and plants that are attractive to pollinators), and soil type at the site of application are a few of the variables that have the potential to influence the environmental fate and potential ecological effects from neonicotinoid insecticide use.

Neonicotinoid insecticides (imidacloprid, thiamethoxam, and clothianidin) are widely used for seed treatment on various crops. Seed treatments prophylactically protect young plants against the entire early-season pest complex (soil, and foliage pests), reduce potential risks to workers, minimize potential runoff to waterways, and lower the overall amount of insecticide usage. However, studies of the uptake of neonicotinoid seed dressings into the target crop suggest that between 1.6 and 20% of the active ingredient is absorbed by the plant, while the remainder enters the soil, is absorbed by neighboring non-target plants, or may leech into water sources. A proportion (<2%) can be lost in planter dust during sowing. The review will summarize information on uptake of neonicotinoids by various plant species.

Neonicotinoids are water soluble and their half-life or persistence in soil varies greatly among the neonicotinoid compounds depending upon the soil type, vegetation, and weather conditions. Loss of neonicotinoids from agricultural soils is presumably via degradation or leaching in soil water. Although, neonicotinoids have been detected in groundwater, streams, storm-water ponds and tidal creeks, the relative importance of neonicotinoid dissipation routes has not been clearly established. The MDA monitors surface water and groundwater for the presence of neonicotinoids. A MDA study has been designed for 2014-2015 that examines wetland water samples for pesticides, including neonicotinoids. A limited number of wetland sediment samples will also be collected for analysis, subject to the development of appropriate MDA laboratory sediment analytical methodologies. To date, the monitoring program has detected neonicotinoid insecticides in groundwater samples at frequencies and concentrations below levels of concern for human health. Almost all surface water samples collected throughout the state have neonicotinoid concentrations below levels of concern for aquatic invertebrates. The review will include an assessment of the partitioning, fate, and transport of neonicotinoid insecticides in the environment based on a variety of use patterns and scenarios, and will include an overview of relevant MDA water quality monitoring data.

Risks of neonicotinoid use: Neonicotinoids in general – and seed treatments in particular – can have important benefits, and can be important components of integrated pest management (IPM). However, they also pose certain risks if used without proper pest histories before seed selection and treatment. Neonicotinoid seed treatment use should be supported through an IPM plan that supports its need. The use of systemic neonicotinoids for prophylactic insect control may contribute to a paradigm that moves away from traditional integrated pest management. IPM is predicated on minimizing use and increasing efficacy of appropriately-timed chemical pesticides via monitoring of pest populations, making maximum use of biological, mechanical, and cultural controls, and only applying chemical pesticides when needed. If used properly, seed treatments can lower non-target exposure and risk compared to soil or foliar insecticide applications. Using neonicotinoid seed treatments in the absence of specific identified pest problems may lead to resurgence of the target pest, replacement by secondary pests, adverse impacts on natural enemies and pollinators, development of pest resistance, and increased costs. The review will include summary information on the management of insect pests, IPM, and other chemical and non-

chemical control methods in various landscape and agronomic settings and their related known or potential insect pollinator impacts.

Given the widespread adoption of neonicotinoids, their systemic activity, their potential persistence in soils, and their potential loss to water resources, many organisms might be exposed to some level of neonicotinoids directly or indirectly. Many studies have examined the toxicity of neonicotinoids to both target and non-target organisms, including mammals, birds, fish, insects, crustacean, mollusks and annelids. Among non-target organisms, beneficial insects (predators, parasitoids, and pollinators) are the most sensitive taxa that are exposed to neonicotinoids directly or indirectly. Furthermore, neonicotinoids can have variable toxicological effects on natural enemies (predators and parasitoids) of target pests; however, their potential long-term, population-level effects on insect pollinators – including honey bees – are uncertain. Although neonicotinoids are less toxic to vertebrates than to arthropods, direct consumption of neonicotinoid treated seeds may expose birds and other taxa to acute or chronic doses**.**

The review will, therefore, summarize these risks, as well as information on neonicotinoid accumulation and persistence in soil, leaching in soil and potential to contaminate wetlands and other water resources.

Risk to insect pollinators – Plant reproduction and seed formation often requires pollination (the process of transferring pollen from a flower anther to a stigma) which can be facilitated by over 200,000 pollinator species including insects, birds, bats, and other animals; however, insects are the most important pollinators. Bees are regarded as the most efficient plant pollinator among the insect species. Honey bees alone pollinate more than $15 billion worth of crops in the U.S. each year. Wild bees contribute more than $3 billion of crop pollination services in the U.S. each year. Other pollinators such as butterflies, moths, flies, ants, and beetles are also vital for the pollination of many cultivated and wild plant species. They play crucial roles both in the production of agricultural and horticultural crops, and in the maintenance of biodiversity and ecological balances in natural ecosystems. The elimination, replacement or reduction of a specific species of pollinator may result in the decline of a specific plant species, which in turn may impact wild animals and humans that depend on those plants. Because butterflies, moths, flies, ants, and beetles do not actively collect pollen as bees do, the extent of pollination services provided by these species are largely unknown.

One of the main advantages of neonicotinoid products is their systemic action. However, this systemic action may expose honey bees and other insect pollinators to contaminated nectar and pollen in treated flowers, or in flowers that take up neonicotinoids applied for purposes other than floral insect control. Most neonicotinoid insecticides are known to be highly toxic to honey bees and bumble bees at very low concentrations. However, limited information is available on the toxicity of neonicotinoids to other pollinator species such as wild bees, flies, butterflies, beetles, etc.

There is also little information on the following: actual concentrations of neonicotinoids found in pollen and nectar of treated crops, how multiple applications affect actual concentration levels of typically treated crops, whether treated plants make up a significant part of a pollinator's diet when other uncontaminated resources are available, and whether typical levels of exposure to treated plants are likely to lead to significant individual- or population-level impacts either directly or indirectly.

While several studies have examined the translocation of imidacloprid from a seed treatment to different plant parts, the majority of these studies fail to accurately relate concentrations found in pollen or nectar, of treated plants, to the actual neonicotinoid concentrations to which pollinators will be exposed over time. Due to the systemic nature of neonicotinoids, pollinators can also be exposed through guttation droplets, honeydew, standing water, and/or sap resin from contaminated plants. However, not all exposure routes are exploited equally and individual- or population-level impacts are still inconclusive and require further studies.

Thus, the review will include an overview of potential direct and indirect effects of neonicotinoid use on insect pollinators, as well as the potential effects of residue accumulation in pollen, nectar, guttation drops, or other pollinator exposure pathways associated with treated plants. The MDA will also summarize the acute (lethal) and chronic (sublethal) effects of neonicotinoids on pollinators.

Direct contact with dust –emitted during the sowing of treated seeds is another route through which pollinators can be exposed to neonicotinoids. Over the last decade several spring bee death incidents, especially in Canada, have been reportedly correlated with planting corn seed treated with neonicotinoids. In these incidents, evidence of neonicotinoids were found in the field as well as in the adjacent vegetation, but the pathways (contact or oral exposure) through which the bees became exposed to the pesticides, were not fully understood.

The review will summarize the issues associated with "planter dust" from neonicotinoid-treated seed as potential risk factor for pollinators.

Neonicotinoids are also used as foliar sprays in field crops, fruit crops (mainly thiacloprid), vegetables, and flowers, which provide an additional route of exposure to pollinators. However, risks to pollinators from foliar spray residues would presumably be similar to risks from other highly bee-toxic chemicals in other insecticide classes such as synthetic pyrethroids, organophosphates, carbamates, etc. In addition, issues related to synergistic effects of neonicotinoids with other pesticides, pathogens, or parasites will be summarized.

The specific risk to insect pollinators through various routes of exposure will be a focus of this review, and will include a summary of research into neonicotinoid risks to a variety of insect pollinator species in crop production and garden/landscape settings, and the related benefits of biodiversity maintenance and ecological balance in natural ecosystems.

Risks to other non-target organisms – The review will also briefly summarize the risks of neonicotinoids to non-target organisms other than insect pollinators in terrestrial, wetland, and aquatic environments.

Benefits of neonicotinoid use: Neonicotinoid insecticides are currently the most widely used class of insecticides in the world and comprise about 25% of the global agrochemical market. Neonicotinoid insecticides have some distinct advantages over other classes of insecticides. They provide very effective control of piercing and sucking insect pests and some difficult to control foliage-feeding beetles that have developed resistance to other classes of insecticides including organophosphates, carbamates, pyrethroids, and chlorinated hydrocarbons. Even though they have been in use for a long period of time (since 1991), relatively little resistance has been reported in crop pests. Therefore, they have become important for the management of insecticide resistance. Neonicotinoid insecticides also suppress the secondary spread of insect-transmitted viruses in various crops. In addition to crop protection, applications of neonicotinoid insecticides in nonagricultural settings such as: urban households, lawns and gardens, and animal health have also expanded in recent years. As previously noted, protecting ash trees from emerald ash borer includes applying neonicotinoids using several application methods, soil-applied, trunk-injected, or basal bark sprays.

Given that neonicotinoids move systemically within the plant they can be applied using a wide range of application techniques at very low dosages. This may help in reducing direct exposure to the applicator and drift in the environment. Neonicotinoids present advantages in pest control including efficacy against boring insects and root-feeding insects, both of which cannot easily be controlled using foliar sprays of non-systemic compounds. Seed treatment provides efficient and prolonged control of insect pests at low dosages when plants are small and most vulnerable to pests. Given that smaller amounts of the active ingredients are used for seed treatments compared to in a field application, theoretically less pesticide is released into the environment, though prophylactic use in the absence of pest pressure can potentially offset this benefit. Since treated seeds are planted in soil, seed treatments have the potential to reduce exposure of pesticides to non-target organisms from direct spray or field runoff.

Neonicotinoids are considered reduced-risk pesticides by the USEPA. They have a selective mode of action targeting the same acetylcholine receptor on the insect nerve cell as nicotine (the active ingredient of tobacco). However, in contrast to nicotine, neonicotinoids do not bind well to the nerve cells of humans and therefore pose little toxicity to humans and other mammals. Other favorable environmental characteristics of neonicotinoids include their ready elimination from the vertebrate body, their relatively

rapid breakdown upon exposure to sunlight, and can be relatively safe to certain natural enemies (predators and parasitoids).

The review will include profiles of the various neonicotinoid insecticides, their benefits, and a summary of the unique nature of neonicotinoids as systemic insecticides (including their use as targeted seed treatments in crop production), their role in managing insecticide resistance and the spread of insect-transmitted viruses in various crops, as well as benefits associated with household, lawn and garden, and animal health use.

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