ALTERNATIVES TO NEONICOTINOID INSECTICIDE-COATED CORN SEED:

AGROECOLOGICAL METHODS ARE BETTER FOR FARMERS AND THE ENVIRONMENT

CENTER FOR FOOD SAFETY

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CONTENTS

EXECUTIVE SUMMARY

Neonicotinoid (neonic) insecticides are heavily implicated in substantial environmental harm to pollinators, aquatic organisms, birds and possibly people. Neonic coated corn seed is the most extensive use of an insecticide on any crop in the United States, affecting close to 90 million acres of farmland, along with the broader environment.

Yet harm from neonic coated corn seed is unnecessary. As this report shows, agroecological and other alternative farming methods that are not highly dependent on pesticides are available and result in high productivity. These methods rely instead on knowledge of the ecology of corn pests and the use of biological diversity to ensure productivity and resilience, while minimizing pollution.

This report is the first detailed analysis of the peer-reviewed research on the efficacy of neonic seed coatings of corn that includes each of the most important early-season pests found in the U.S. Midwest and elsewhere. It is the first extensive analysis of non-insecticidal alternatives to neonics, which are not usually considered in efficacy field trials. Understanding these alternatives is critically important if we are to limit or eliminate the use of prophylactic seed coatings of corn—to the benefit of the environment—while at the same time supporting the vitality of farms. The report also analyzes the reasons for the dramatic exponential increase in the use of neonic seed coatings since the mid-2000s, in order to better understand the reasons for the nearly ubiquitous use of these insecticides on corn.

This report shows that:

1. It is uncommon for neonic seed coatings to increase corn yield, even under current farming practices. Some scientists explicitly recommend against their use as a “cheap form of crop insurance” for growers;

2. The early-season insect pests targeted by neonic seed coatings of corn occur sporadically, and the published peer-reviewed evidence reveals that they infrequently reduce corn productivity in the absence of insecticide use;

3. Industry sponsored analysis that relies heavily on non-peer-reviewed research contains several biases that overestimate the value of neonic seed coatings for improving corn yield. It includes an undisclosed number of field trials designed to encourage higher levels of pests, which exaggerates the benefit of neonic seed coatings compared to typical commercial farms. It also includes an unknown number of trials for the major corn pests, corn rootworms. These pests can cause substantial yield losses if untreated, but there are more effective and more reliable alternatives than seed coatings to control them.

4. There is no reliable evidence that problems from these pests have increased substantially in recent years, contrary to some anecdotal claims. Experiments conducted over the past 15 years have not indicated that these pests have become common problems;

5. This belies the almost ubiquitous prophylactic use of neonic seed coatings. Research has shown that about 71 to near 100 percent of corn are coated with neonics, exposing a huge area of the country to these insecticides. And there is no evidence that the trend for treating the vast majority of corn seed will abate;

6. The conditions that may occasionally favor early-season corn pests can usually be avoided by small changes in farming practices that reduce the occurrence of early-season pest infestations without resorting to insecticides.

7. Some research suggests that neonic seed coatings may sometimes actually decrease yields or reduce profit. This may occur because neonics may reduce the populations of organisms that normally help keep pest insects in check. Farmers may be unaware of this possibility. This important issue should receive additional attention.

8. For all of the reasons stated above, only a limited acreage of corn would be treated with alternative insecticides if neonic seed coatings were restricted. For example, only about 30 percent of corn acres were treated with insecticides

prior to the commercial introduction and rapid adoption of neonic seed coatings, and mainly for pests that are not the primary target of neonic seed coatings. And if ecological means of avoiding or controlling these pests were widely adopted, only a very small percentage of corn acres would rely on other insecticides.

9. Because it has been shown that those alternative insecticides are not more environmentally harmful than neonics, net harm would be greatly reduced with the elimination of prophylactic neonic corn seed coatings.

10. Any means of controlling pests can occasionally fail. The more beneficial social response, if deemed necessary, should be crop insurance for farmers rather than the use of harmful pesticides.

There is not a large amount of peer-reviewed research literature that analyzes the efficacy and yield benefit of neonic corn seed coatings for controlling early-season corn insect pests in the field; and there are even fewer data quantifying the prevalence and impact of these pests on corn yields. In other words, the current justification for the prophylactic use of these insecticides is based primarily on anecdote, or limited scattered research, not extensive published, peer-reviewed science. One purpose of this report is to collect and analyze the available peer-reviewed research and make it available in one place, to present a more coherent and cogent understanding of these issues. The result of this process shows that the early-season pests of corn are not often significant problems on farms. Given the considerable research supporting the high likelihood of extensive environmental harm caused by insecticidal seed coatings, and the effective alternatives that are available, there is no socially or environmentally responsible justification for continuing their unrestricted use.

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As summarized in this report, neonic seed coatings are a prominent example of the reliance on expensive and harmful insecticides for the control of pests as a pale substitute for free biological control provided by advanced farming systems based on the science of agroecology. They are a symptom of even more extensive environmental harm and lack of sustainability caused by industrial farming.

The industrial farming system is antiquated, emerging from earlier industrial and green revolutions, and allows the transnational companies that have near monopoly control over pesticide and commodity seed sectors to acquire excessive profits. The almost ubiquitous coating of corn seed with neonics and other pesticides prior to purchase by farmers by these companies or seed dealers greatly limits the ability of farmers to choose non-coated seed if they prefer it. This allows seed and pesticide companies to benefit from the sale of products, such as unneeded insecticides that prop up the industrial model, at the expense of society broadly and at unnecessary cost to farmers.

Farmers may also see neonic seed coating as a cheap form of insurance to avoid perceived risks or uncertainties from insect pests. Such uncertainties may arise from inadequate or inaccurate information about these pests or viable alternatives to avoid or control them. Supplying that information from reliable, trusted, and independent sources may alleviate those concerns. The limited labor required of farmers to use coated seed, due to application of corn seed coatings by seed companies or dealers prior to purchase, may also contribute to farmer acceptance. Farmers also face institutional challenges that discourage them from adopting farming methods that are better for the environment and rural communities. For all these reasons they need support to end their use of neonic coated corn seed.

This report evaluates some of the social constraints that may discourage policies that would restrict the use of neonic-coated seed, despite their limited benefit to farmers. It also considers policy changes that would help farmers implement ecologically sound alternatives to neonic seed coatings.

Using agroecology approaches to grow our crops rather than industrial methods not only avoids most of the harm of insecticides like neonic seed coatings, but has also been demonstrated to provide profound benefits for water and air quality, reduction of climate change emissions, and increased biodiversity and quality of rural environments and communities.

Some integrated pest management methods that avoid occasional early-season corn pests require only minor changes from current corn production practices. These include monitoring for pests, with insecticide use if needed, earlier weed control or cover crop termination, or minor delays in planting dates. More extensive changes based on the science of agroecology, such as more diverse crop rotations, would bring more dramatic benefits to both farmers and the environment.

Until we recognize the scientific and social irrationality of industrial farming and the harm it causes, and understand that we have viable and sustainable alternatives, we will continue to address the crises of industrial agriculture in a piecemeal way that encourages pesticide use and does not correct the fundamental problems that underlie the current system.

The following recommendations would be important steps toward the elimination of prophylactic neonicotinoid seed coatings and moving toward farming systems that are better for the environment, farmers and their communities.

RECOMMENDATIONS

1. Restrict the use of neonic seed coatings of corn. The published research shows that prophylactic use of neonic corn seed coating is unjustified for its most important purpose of protecting yield. If not eliminated, use should be limited to acres for which heavy infestations of early-season secondary pests occur and are not avoidable or controlled by available non-insecticide methods.

2. Conduct surveys of farmers by USDA/NASS or USDA/ERS or independent university scientists to better understand why, and what percentage of farmers believe they need neonic seed coatings of corn. The data from farmer surveys would help better understand how such farmers can be assisted if prophylactic neonic seed coatings are eliminated. Utilize farmer survey results to actively develop outreach tools that help farmers avoid secondary pest insects, or use alternative treatments to control early-season secondary insect pests. This should be done through USDA, especially through public, independent extension services working with farmers to alleviate concerns about restricting the use of neonic corn seed coatings. It is critical that farmers are integrally

involved from early stages of this work—including decision making—to ensure that the results are of practical value to them.

3. USDA/NRCS should include consideration of early-season secondary insect pests and ecologically sound methods of reducing these pests as part of its Conservation Stewardship Program and EQIP grants, especially those, like longer crop rotations, that have multiple benefits. Such grants would be consistent with the goals of the NRCS.

4. Implement, through USDA/RMA, insurance premium support for the rare cases where secondary pests cause substantial damage to corn yield, and such impacts were unavoidable by other viable approaches, as discussed in this report. Other alternative methods for providing insurance could also be considered. One reason that farmers seem to desire neonic seed coatings, despite the infrequency of damage from the targeted insects, is as a form of "cheap insurance".

5. Conduct additional publicly supported research to fill in holes in our knowledge of early-season secondary insect pests of corn, and to refine agroecological alternative practices to avoid or control them. These should emphasize system-level farming practices that reduce pest numbers in general, as well as providing numerous other benefits to the environment, farmers and society. Research should also be supported that improves scouting and other detection and infestation prediction methods for early-season insect pests.

6. Seed companies should be required to make uncoated corn seed of desirable corn varieties readily available. The Department of Commerce and the Department of Justice should investigate whether illegal monopoly practices have made it excessively difficulty for farmers to acquire uncoated corn seed. The elimination of farmer choice is contrary to principles of a democratic economy.

7. EPA should release its analysis of the efficacy, benefits, and costs of neonic corn seed coatings. It should fully weigh both quantifiable and unquantifiable values in assessments of proposed systemic insecticide products, including at a minimum these foreseeable cost categories:

    - honey bee colony impacts and resulting reduced yields of pollinated crops,

    - reduced production of honey and other bee products,

- harm to other pollinators and other beneficial and non-target organisms
- financial harm to beekeepers and consumers,
- loss of ecosystem services, and
- market damage from contamination events.

EPA should also require verification by independent scientists and economists (preferably published in peer-reviewed journals) for claims of efficacy, crop yields, and economic benefits associated with all products. It should reject applications to register any prophylactic insecticides that undermine basic IPM and agroecological principles, may harm organic farm production, or are not cost-effective, either for the farmer or the nation as a whole.

CHAPTER 1
INTRODUCTION

According to recent data (Douglas and Tooker 2015, US EPA 2017)[1,2], neonicotinoid insecticides, mainly clothianidin and thiamethoxam, are applied to between about 71 and almost 100 percent of corn seed in the United States. This means that this use exposes close to 90 million acres of farmland, and also surrounding environments, to these insecticides. This is the most extensive use of an insecticide on a crop in the United States by a wide margin.

Neonicotinoid use has been linked to widespread environmental harm, and therefore should be replaced with ecologically-sound alternatives. These insecticides harm pollinators that are necessary for full productivity of about 75% of crop species, especially nutritiously important fruits, vegetables and nuts (Klein et al. 2007)[3], and most wild plant species (Ashman et al. 2004)[4]. These pollinators (Godfray et al. 2015)[5] include both honeybees (Krupke and Long 2015, Mogren and Lundgren 2016)[6,7] and wild bees (Woodcock et al. 2016, Whitehorn et al. 2012)[8,9]. Neonic seed coatings have similarly been shown to harm other important beneficial insects, called natural pest enemies (Douglas et al. 2014, Douglas and Tooker 2016, Leslie et al. 2010, Mullin et al. 2005, Seagraves and Lundgren 2011)[10,11,12,13,14] that usually keep destructive crop pests in check in healthy farm ecosystems (Douglas et al. 2014, Douglas and Tooker 2016, Letourneau et al. 2011, Losey and Vaughan 2006)[15,16,17,18]. Neonics have also been implicated in harm to aquatic invertebrates (Morrissey et al. 2015, Van Dijk et al. 2013)[19,20], that are critically important food sources for fish and for providing other ecosystem functions, are linked to declines in farm-associated birds (Hallmann et al. 2014, Mineau and Palmer 2013)[21,22], and may harm people (Cimino et al. 2017)[23]. They have become the most widely used insecticides in the world, and are found almost ubiquitously in our streams (Hladik and Kolpin 2015)[24].

In addition to their high toxicity to insects and other organisms, neonicotinoid insecticides have several properties that can make them particularly harmful. First, they persist for a substantial period of time in the environment, with soil half lives of a year or more, depending on the particular neonic and environmental conditions (Krupke and Long 2015)[25]. Extended persistence of pesticides has been recognized to be undesirable since the long persistence of many organochlorine insecticides was found to contribute to environmental harm in the 1970s. Second, neonics are systemic: they are taken up by and spread throughout the plant, making virtually all plant parts and exudates potentially toxic. Most other widely used insecticides are not systemic. Third, they are highly water soluble, and so they can leach from fields and be transported into streams and groundwater easily. They are therefore found at harmful concentrations beyond agricultural fields (Krupke et al. 2012, Mogren and Lundgren 2016, Hladik and Kolpin 2015, Morrissey et al. 2015, Van Dijk et al. 2013)[26,27,28,29,30]. And fourth, the high toxicity to insects and other invertebrates means that even when spread out and diluted by transport through the plant or in the environment, they will often remain at concentrations that can be lethal or harmful to beneficial organisms. This combination of properties makes neonic seed coatings particularly threatening to the environment.

For all of these reasons, it makes sense to greatly reduce the use of neonic seed coatings in the short term, with a long term goal of eliminating them. However, it is important to know how decreasing or eliminating them would affect corn farming. In particular, it is important to understand whether and how often yield losses may result, and whether there are viable and safer farming practices that could substitute for neonic seed coatings.

Determining whether prophylactic neonic seed coatings of corn are needed based on whether—and if so, how much—they protect corn, and comparing them to other means of protection is the primary goal of this report. In particular, we need to consider not just substitution by other insecticides or toxins, which may also cause environmental and social harm (Douglas and Tooker, 2016)[31], but also viable farming methods that may reduce the need for insecticides generally, and neonic seed coatings specifically.

To determine the justification for prophylactic neonic seed coatings, this report analyzes at length for the first time the peer-reviewed research on each of the most important early-season insect pests that are targeted by neonic seed coatings of corn. In doing so, the agronomic and biological factors that favor or discourage these pests are considered.

Another important consideration of this report is whether neonic seed coatings may be justified for reasons other than yield protection. One important possible reason for using them could be to preserve other desirable methods of insect control. In particular, the report considers whether the use of neonic seed coatings might delay or prevent the development of resistance by corn rootworms to other means of controlling these important pests. Other important considerations for the use of neonics explored in this report are how they fit into current industrial farming systems, and whether alternatives can be practical for most corn farmers.

Our analysis of the science research literature found that there is no good evidence that neonic seed coatings of corn provide needed yield protection on a consistent or even predictable basis. Other alternatives, especially growing corn by using sound ecologically-based farming practices, can reliably provide consistently high productivity and profits (Davis et al. 2012, Lechenet et al. 2014)[a,32,33]. There are also simple farming practices that can be used to avoid harmful infestations of these pests. Systems-based, agroecologocal methods also have the potential to profoundly improve the environment, including water quality and biodiversity, and improve soil fertility which benefits farm productivity and resilience (Liebman and Schulte 2015)[34]. For these reasons, there is no socially acceptable justification for continuing the widespread use of prophylactic neonic seed coatings and the environmental costs incurred from this use.

Finally, prophylactic neonic seed coatings are analyzed in the context of some of the social forces that strongly encourage current industrial corn farming practices that include neonic corn seed coatings. Given the findings of the report that widespread prophylactic use of neonic seed coatings cannot be justified based on yield protection, other reasons for the extensive use of these insecticides are considered. It is important to understand why prophylactic neonic seed coatings are so widely used, if viable and ecologically robust alternatives that can work for farmers are to be implemented. The most likely explanation is found to be monopolistic control of corn seed whereby companies dictate seed coatings, rather than proactive choice by farmers. Several reasons why farmers may accept this situation are also explored, such as risk or uncertainly aversion, and how this may be alternatively addressed.

[a] Research on agroecological methods have not controlled specifically for neonic seed coatings, based on research for this report. Their results have pertained to several different pesticides and other parameters, and therefore can be extrapolated to pesticide use generally. But studies comparing agroecological systems to industrial farming that control specifically for neonic seed coatings are needed.

CHAPTER 2
THE VALUE OF NEONIC SEED COATINGS FOR INSECT PEST CONTROL

A. BACKGROUND: INSECT PESTS OF CORN TARGETED BY SEED TREATMENTS AND THE ARGUMENTS IN FAVOR OF SEED COATINGS

Insects targeted by neonicotinoid seed coatings of corn are early-season pests that attack the corn seed in the soil or the young plant, according to university extension publications (Gray and Steffey 2000)[35] and pesticide product labels (Poncho 600 Label, 2010)[36] which serve as the legal basis for the use of pesticides.

The most often mentioned early-season pests include wireworm species (*Agriotes, Melanotis, Limonius* and *Conoderus* among others), which are the immature forms of click beetles, grape colaspis (*Colaspis brunnae*), corn seed maggot (*Delia platura*), white grub (*Phyllophaga* spp.), black cutworm (*Agrotis ipsilon*) and corn flea beetles (*Chaetocnema pulicaria*). Other secondary pests such as billbugs and stinkbugs can be controlled by rescue treatments rather than prophylactically, and there is little literature on their importance (Gray and Steffey 2000)[37]. For several of the pests not specifically addressed in this report, there is little or no published literature on prevalence or control (Gray and Steffey 2000)[38]. The labeled pests are sporadic, usually considered relatively minor in most locations and most years, and often found only in some parts of corn fields when they occur in economically significant numbers.

By contrast, corn rootworms (primarily western, *Diabrotica virgifera virgifera*, and northern, *D. barberi*) and European corn borer (*Ostrinia nubilalis*) have been consistent major pests in the United States because they are both more prevalent, and cause increased and more widespread damage more frequently (Gray et al. 2009)[39]. Rootworm, also labeled for neonic seed coatings, has historically been well controlled by using sound ecological practices like crop rotations, although rotation resistance now occurs in limited parts of the pest's range in the US. Both are typically controlled by most non-organic farmers in the U.S. by the use of several types of transgenic Bt toxins, and historically by soil-applied insecticide in continuous monoculture corn.

Several potential advantages of seed coatings compared to insecticides applied to the soil include lower volume per area treated, possibly less exposure to farmers and farmworkers, and ability to treat soil-inhabiting pests that could not be controlled by insecticide rescue treatments, if the insects were discovered after planting (e.g. from observed seedling damage). But these potential advantages are offset by high levels of environmental harm over much larger areas when corn seed is routinely coated with neonicotinoids compared to the acreage treated in previous years with applied insecticides. For example, while volume of insecticide per unit area treated is usually lower for seed coatings, the area treated by prophylactic coated seed is much greater than was previously treated by applied insecticides (Douglas and Tooker 2015)[40], therefore exposing a wider area of the environmental to harm (Gurian-Sherman 2015)[41]. Exposure to farmers or farmworkers can also occur through substantial dust released from seed coating at planting (Krupke et al. 2012)[42], or from dust blown from soil due to the persistence of these insecticides. And though rescue treatments (treatment after insect infestations are detected) are not possible for some of these pests, they can be used for most above-ground early-season pests (Gray and Steffey 2000)[43]. Scouting can facilitate decision making about treatment before planting for subterranean pests not amenable to rescue treatments. This would be needed on only a relatively small fraction of the land now exposed to neonicotinoids through seed coatings, if seed coatings were not used. More importantly, agroecological and integrated pest management (IPM) alternatives can usually avoid economically relevant levels of these pests in the first place, thereby avoiding the use of any insecticides in most cases. All these topics are discussed in more detail below.

"But these potential advantages are offset by high levels of environmental harm over much larger areas when corn seed is routinely coated with neonicotinoids compared to the acreage treated in previous years with applied insecticides."

B. BEYOND SEED COATINGS: AGROECOLOGICAL AND INTEGRATED PEST MANAGEMENT (IPM) ALTERNATIVES

To address these issues in this report, we analyzed the science literature to determine 1) whether the pests that are the targets of neonicotinoid seed coatings are important and consistently or predictably harmful, such as might justify prophylactic seed coatings for yield protection, 2) whether neonic insecticide coatings are effective in preventing significant yield loss, and 3) whether there are alternatives to seed coatings that are preferable, especially from the perspective of crop yield and benefit to the environment or public health.[b]

Importantly, the report also evaluates whether these pests can be controlled by the use of agroecological and IPM farming practices that do not rely on the use of harmful insecticides. Unlike industrial agriculture which relies heavily on pesticides, agroecology is based on understanding the interdependence of organisms in farming systems with each other and their environment, as well as the social systems that support or interfere with them. It relies on biodiversity and genetic diversity to protect crops from pests, and builds on indigenous faming systems that have developed in ecological contexts for millennia (e.g. Altieri 2004)[44].

[b] Yield protection is only one measure of value, and is highly problematic and overemphasized in the context of food security (e.g. see A. Sen, 1981. Poverty and Famines: An Essay on Entitlement and Deprivation. Clarendon Press, Oxford). But it is one measure that farmers often consider to be very important.

Various agronomic practices have considerable impact on pests, including those targeted by neonic seed coatings. Where such practices exist, it is important to ask whether they can be effective and profitable, or whether it makes sense to provide programs to assist farmers in implementing them. Where effective methods based on the ecology of the insects and farming systems can be used instead of either seed coatings or soil-applied insecticide rescue treatments, these would be highly desirable due to their broad benefits to the environment and public health.

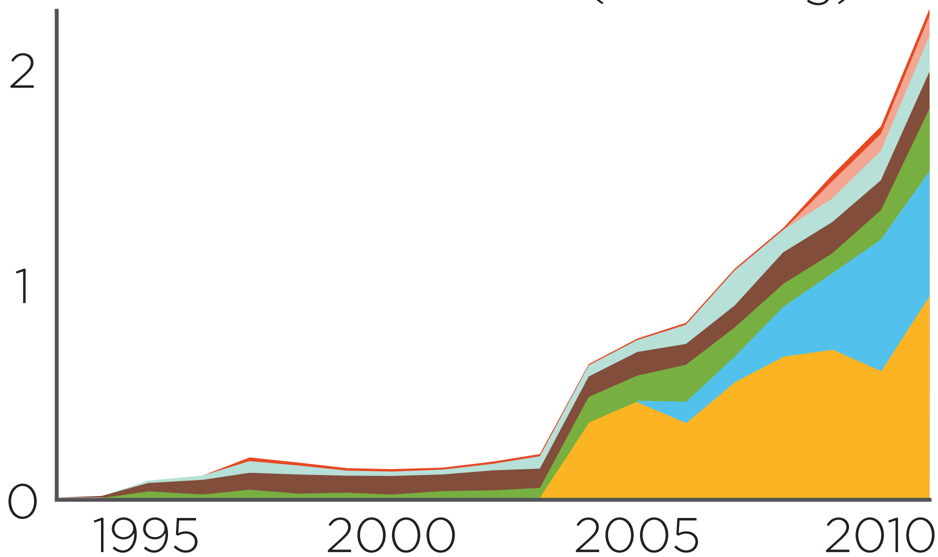
Research on individual early-season pests analyzed below reveals that they usually may be avoided by simple crop management practices based on understanding the ecology of these pests. A later section of the report considers how more extensive agroecological farming can not only reduce early-season pests, but also provide other ecosystem benefits.

The early-season insects that may be the targets of neonic seed coatings include both subterranean and above-ground species. It impractical to treat subterranean pests with insecticides applied to soil after the crop has been planted. Therefore, one possible alternative to neonic seed coatings, rescue treatments using other applied insecticides, are not feasible during the growing season for those pests. However, detection of some of these pests before planting could allow treatment as needed prior to planting, and potentially far less often than is currently the case for neonic seed coatings. The soil dwelling pests considered here typically require more effort to detect, such as by the use of traps or soil cores, prior to planting. However, such tests are generally available. For above-ground pests, rescue treatments can be used.

"Research on individual early-season pests analyzed below reveals that they usually may be avoided by simple crop management practices based on understanding the ecology of these pests."

Those pests that are already well controlled by other methods argue against the need for neonic seed coatings per se for the purpose of reducing or avoiding yield loss. However, other considerations in addition to yield may also be relevant, including: The relative cost of alternatives; their relative risks and benefits to farmers, farmworkers, the general public, and to the environment; and convenience or labor reduction. For example, if rescue insecticide treatments are used instead of prophylactic seed coatings, will those be more or less harmful to the environment and farmer or public health (Douglas and Tooker 2016)[45]? In this example, the less frequent use of rescue treatments must be weighed against their greater volume per use, and their relative toxicity and risk compared to neonic seed coatings.

Neonicotinoid Use (million kg)



Source: Douglas and Tooker 2015

C. THE RISE OF NEONIC SEED COATINGS – WHY NOW?

Neonic seed coatings were virtually unknown before about 2003, but since 2004 their use has increased exponentially so that now between about 71 to almost 100 percent of corn seed in the U.S. is treated with neonic seed coatings (Douglas and Tooker 2015, US EPA 2017)[46,47]. This trend raises several questions about the reasons for the near ubiquity of neonic corn seed coatings that are relevant to the topics addressed by this report. For example, why has the use of these seed coatings started in recent years, and why have they been adopted so quickly and are now so widely used? Is this justified based on yield or crop quality reductions due to the targeted insect pests?

There are probably several explanations for the rapid rise of neonic seed coatings. First, neonics are a relatively new class of insecticides, the first was introduced in the U.S. in 1994 as a sprayed insecticide (Douglas and Tooker 2015)[48]. The systemic nature of neonics also facilitates their use as seed coatings compared to earlier insecticides (which were also occasionally used to coat seeds, but were not systemic).

1. Agronomic Reasons do not Explain the High use of Seed Coatings

Some planting practices have changed over the last several decades, such as increased use of conservation tillage or no-till, and planting corn at higher densities. These practices have been associated with the increase of some crop pests. However, they largely preceded neonic seed coatings by a decade or more. Conservation tillage reached about 30 percent of corn acres by about 1994 and remained flat thereafter through at least 2008, while no-till showed similar trends, remaining under 20 percent (National Research Council 2010)[49]. This was a decade before neonic seed coatings began their exponential rise. Another estimate found about 23.5 percent of corn acres were farmed using no-till practices as of 2005 (Horowitz et al. 2010)[50], compared to the ~70 to almost 100 percent use of coated corn seed.

Increasing amounts of monoculture make corn more vulnerable to several pests. However, corn-soybean rotations still dominate production. For example, monoculture corn increased from 15 to 20 percent in Iowa between 2001 and 2007 (Stern et al. 2008)[51]. While monoculture has increased, that increase represents a small fraction of the acreage treated with coated seed, and neither the increase nor total percent of monoculture corn acres can account for the high percentage of coated corn seed.

> "Occurring almost simultaneously with the swift rise in neonic seed coatings was the 2003 registration of the engineered Bt trait for corn rootworm control from Monsanto (Cry3Bb1, or RootGard) and its rapidly increasing use..."

Occurring almost simultaneously with the swift rise in neonic seed coatings was the 2003 registration of the engineered Bt trait for corn rootworm control from Monsanto (Cry3Bb1, or RootGard) and its rapidly increasing use, followed by several other Bt genes directed at rootworm in subsequent years, with total Bt traits accounting for 76 percent of corn by 2013 (Fernandez-Cornejo 2014)[52,c]. Conventional farmers using these traits in monoculture corn, where rootworm is often a problem, would no longer need to use broad spectrum soil-applied insecticides to control this pest. However, Bt for rootworm does not control the early-season pests that could have previously been controlled by soil-applied insecticides prior to Bt (if the pests were present!). This could possibly leave those acres vulnerable, opening a market for an additional insecticide treatment – in this case, neonic seed coating. But rootworm is not a problem pest on the majority of acres that rotate corn with soybeans or other crops (except where rotation-resistant rootworms were present beginning in the early '90s).

Historically, applied insecticide use for corn covered about 30 percent of acres in the 1990s through 2003 (see Douglas and Tooker 2015), primarily for the control of corn rootworms, and to a lesser extent to control European corn borer, where the latter is not a target of neonic seed coatings.[d] So again, the historical acres treated with insecticides alone cannot explain the much larger area treated with neonic seed coatings. It is possible that some of the acreage treated with soil-applied

[c] USDA does not separately determine the acreage devoted to each Bt trait or gene. However, increasingly, corn varieties contain multiple traits.

[d] The acreage treated for corn rootworm and corn borer may overlap to some extent.

insecticides to control rootworm overlapped with corn that was infested with harmful levels of one or more secondary pests, but there are no data found during research for this report documenting or quantifying this acreage.

In other words, even though many changes in cropping practices discussed above were well underway years before neonic seed coating use began an exponential increase in use, they did not lead to notable increases in soil applied insecticides for early-season pests at the time (e.g. Douglas and Tooker 2015)[53]. Therefore, it is doubtful that the dramatic rise in the use of neonic seed coating could be explained by these changing practices.

Even if it was accepted that most of the former 30 percent of corn acres treated with synthetic insecticides also was infested with high levels of early-season secondary pests—which is highly unlikely given the minor status of these pests—that would leave unexplained the additional 40 to 70 percent of corn acres currently treated with neonics, but previously untreated with other insecticides.

Another factor contributing to the sharp rise in neonic seed coatings could be the trend toward longer-season (later maturing) corn, leading to planting earlier in the season (Gray and Steffey 2000)[54]. This means that on average, soil temperatures would be cooler, slowing germination and early growth, and thereby prolonging the phenology of the crop stages vulnerable to early-season pests. This is widely known to increase the likelihood of damage by pathogenic microorganisms or insects. This effect can be exacerbated by no-till, because this practice does not allow the soil to warm as fast as when its surface area is increased by tillage.

While earlier planting may potentially increase corn vulnerability, early-season insect pests must still be present for them to reduce corn emergence and yield. As will be seen in subsequent sections on early-season pests, infrequent occurrence of these insects is supported by the research literature.

It is also important to note, as will be discussed in greater depth later, that while some historical studies have shown increases in yield over the past several decades coinciding with earlier planting dates due to a longer growing season (Sacks and Kucharick 2011)[55], experimental evidence suggests that delaying planting by a few weeks in the Northern Corn Belt beyond the earliest planting dates does not necessarily reduce yields (Van Roekel and Coulter 2011)[56]. Planting about two to three weeks later than the earliest planting dates would often allow the avoidance or minimization of damage from several early-season insect pests if they are present (see following sections on specific insects). It is recommended in any case that annual planting dates should be determined by actual weather conditions to maximize yield and avoid problems caused by early planting (Coulter 2015)[57].

2. Concentration in the Seed Market and other Economic Factors

In addition to possible farmer-driven interest in seed coatings, there are also market interests at play. The vast majority of seed coatings are applied by the large seed companies or dealers that now control most of the corn seed market (Howard 2015)[58]. Application of neonics to corn seed typically occurs months prior to planting, and prior to purchase by most farmers (Douglas and Tooker 2015)[59]. So unless farmers proactively search for non-coated seed early on, they are unlikely to find it. And even when purchasing early, farmers may not find uncoated seed because several major seed companies apparently do not make uncoated corn readily available (Douglas and Tooker 2015)[60].

Given that the research analyzed here strongly suggests that substantial stand loss in uncoated seed would be unusual, seed companies may extract considerable unjustified profit from farmers through this practice. It is yet another reason why these company practices should be thoroughly investigated, and USDA subsidized insurance provided against loss to secondary pests as an alternative to coated seed.

> **"Given that the research analyzed here strongly suggests that substantial stand loss in uncoated seed would be unusual, seed companies may extract considerable unjustified profit from farmers through this practice."**

Additionally, the added price of the seed coatings is usually simply included as an overall part of the seed cost, and so may not be apparent to farmers. Recent research noted that the cost of neonic seed coatings is not made available to farmers or researchers (Alford and Krupke 2017)[61]. Given dramatically increasing corn seed prices due to genetically engineered traits (Shi et al. 2010)[62], as well as fungicide seed coatings, it may be difficult for farmers to determine the contribution of neonic seed coatings to the cost of corn seed. These aspects of the increased economic concentration of the seed market have made it much harder for farmers to buy uncoated seed, but have nothing to do with whether coated seed is needed to prevent yield or financial loss.

Finally, starting in 2007, corn commodity prices rose dramatically, more than doubling (Trostle 2011)[63]. This may have made it more attractive for farmers to use neonic seed coatings, and accept their cost, to protect more of this higher-value crop. In other words, they may have viewed neonic seed coatings as a kind of "cheap insurance" even if the pests that could be controlled by it were not present often in high numbers (or at the right time of the year) to cause enough harm to justify the cost. High corn prices did not begin until 2007 and 2008, several years after corn seed coating use began its dramatic rise in 2004. So corn cost alone cannot explain the exponential increase in neonic seed coatings. And for the past several years, corn prices have diminished to lower historic levels without apparent reductions in the percent of neonic coated corn seed. It is an open question whether farmers would want to continue to accept the extra cost of these seed coatings if they could more readily acquire uncoated seed.

Consideration should also be given to whether inadequate data on prevalence of the pests or alternatives to seed coatings might induce farmers to accept seed coatings, despite infrequent yield protection. Under such a scenario, farmers may characterize their desire for neonic seed coatings as a situation of "better safe than sorry". This behavior has been observed for Bt technology in order to reduce risk and ambiguity for other corn insect pests (Barham et al. 2014)[64]. These authors note that substantial uncertainties about insect pest risks in particular lead farmers to adopt Bt insect pest protection, and this reasoning may apply to similar perceived value from insecticide seed coatings. However, in contrast to the pests Bt is primarily intended to protect against, there is even less information about the secondary pests targeted by neonic seed coatings, they are more sporadic (less predictable), and cause considerably less overall damage. This could lead to even more ambiguity and uncertainly than for pests targeted by Bt.

The relatively limited relevant information about the pests targeted by neonic seed coatings is in fact supported by the literature search performed for this report. The search revealed that information is not collected in a form readily useful to farmers, and there is very little information readily available on prevalence of these pests. When combined with company claims or advertising[e] suggesting the benefit of coated seed, such unquantified risk may encourage farmers to accept coated seed without adequate data to support the perceived need. Relatedly, the challenges of detecting the presence of target pests, and the possible reluctance to scout for these insects on large farms that value reduced labor costs, may have encouraged farmers to accept a technology that requires no extra labor or time to apply.

[e] One typical example is this Delta Farm Press article from October 28, 2005 (http://www.deltafarmpress.com/pioneer-adds-dynasty-seed-treatment-lineup) in which company representatives claimed substantial value for poncho (clothianidin) corn seed coating. For example: "Utilizing an insecticide seed treatment is a key management tool in protecting seed investments from corn rootworm and secondary insects. With limited or no rescue treatments available, preparation can be vital in protecting corn seedlings."

In sum, the dramatic rise in neonic seed coating use discussed above, leading to a dramatic increase in corn acres treated with insecticide, cannot be explained by increased need to control corn pests compared to the period preceding the introduction of neonic seed coatings. The introduction of farming practices that may have changed pest populations preceded the dramatic increase in neonic seed coatings by a decade or more, and did not lead to notable increases in soil applied insecticide at the time. Nor does analysis of a combination of these factors justify their nearly ubiquitous use. As documented in the sections on early-season pests below, available peer-reviewed research on yield protection shows that these pests remain infrequent and sporadic.

"In sum, the dramatic rise in neonic seed coating use discussed above, leading to a dramatic increase in corn acres treated with insecticide, cannot be explained by increased need to control corn pests compared to the period preceding the introduction of neonic seed coatings."

The default pre-treatment of nearly all corn seed with neonics—and the associated limited opportunity for farmers to purchase untreated seed—is the only practice that can readily account for the treatment of almost all corn acres. Farmers may accept this lack of choice for several reasons, such as uncertainty about the frequency of the pests, reduced labor, and risk or ambiguity aversion, rather than predictable protection of yield. But the corporate practice of pre-treatment of corn seed does not appear to be justified by any pest challenge outlined above.

In particular, and importantly, none of these reasons adequately account for whether these treatments are justified based on losses to pests and cost of the treatment compared to the possible value of corn yield preserved or, especially compared to other alternatives to control or avoid the targeted pests.

Possible additional hypotheses for this large increase, based on actual pest damage and control, could be 1) neonic seed coatings could be dramatically less expensive (including application/labor costs), or 2) dramatically more effective than previous insecticides for treating these pests, making it more economical to treat more acres, or 3) risk to farmers and farmworkers may be reduced or perceived to be reduced compared to other insecticides. Data on these factors for all of the more important early-season pests of corn are limited or not available.

However, peer-reviewed research on efficacy and yield benefits of neonicotinoid seed coatings can act as practical surrogates for determining whether neonic seed coatings make sense in terms of potential economic value based on yield protection.

One significant limitation of neonic efficacy research by entomologists and economists is that it typically does not include alternative methods, other than soil-applied insecticides, that may be more or less effective or provide other benefits. This is a critically important limitation in the available research. Importantly, several of these alternative approaches to controlling or avoiding the pests targeted by neonic corn seed coatings are evaluated in this report.

CHAPTER 3

HARM CAUSED BY EARLY-SEASON INSECT PESTS OF CORN, THE EFFICACY OF NEONIC SEED COATINGS, AND SAFER ALTERNATIVES

The performance of neonic seed coatings for preserving productivity against combined early-season insect pests present in test plots, as well as data on specific pests that are the targets of control by neonic seed coating, are reviewed in this chapter, along with alternative methods to either avoid or limit damage from these pests.

Collectively, the literature on pests analyzed below strongly suggests that these pests, singly or together, only infrequently cause yield damage in the absence of neonic seed coatings. Tests for early-season yield protection from neonic seed coatings may be aimed explicitly at all pests present, as in Cox et al. (2007)[65]. But even for much of the research intended to determine yield protection against specific pests, the protection against other early-season pests may also be included in practice. When experiments test for the presence of a specific pest, other early-season pests may also be present but not detected. The control of all early-season pests that may be present, even if not specifically looked for, adds to the data on the collective importance of these secondary pests. This occurs because most often, early-season pest damage is recorded as reduced crop stand or yield reduction, which could be the result of several early-season pests. For example, Jordan et al. (2012)[66] were specifically interested in annual white grub protection in Virginia. They also looked for wireworms and found their numbers to be too low to cause damage. But they also acknowledge that they cannot rule out the contribution of other early-season pests that they did not specifically measure.

Furthermore, conditions that encourage these pests are generally known, so they can often be avoided by applying this understanding of pest ecology to farming practices. Even without such changes in farming practices, studies conducted in the 2000s indicate that infestations of these pests remain uncommon. Finally, where tested, neonic seed coatings have not shown efficacy high enough to justify their use against some of these pests (and their efficacy against other, even more uncommon, secondary pests has not been specifically tested or reported in the peer-reviewed literature).

A. PEER-REVIEWED RESEARCH AND REPORT METHODOLOGY

The research on early-season pest damage analyzed in this report often measured both stand establishment (a specific indicator of early-season harm), and crop yield. Ultimately, crop yield is more important than stand establishment as a practical matter, and is emphasized in this report. For example, there can be later compensatory growth by corn plants that can make up for some stand losses early in the year. However, other later-season insects or other pests may also affect yield, and need to be accounted for in order for the data in these experiments to be useful. Usually, experimental design controls for these later-season factors, but such controls are never perfect, and so may add some additional experimental error and uncertainty to the results.

Peer-reviewed and academic extension literature analyzed in this report were found by searching Google Scholar using multiple relevant keyword combinations (e.g. names of the pests and corn;

names of specific early-season insects pests of corn; seed treatments and corn), as well as reviewing the literature that cited these primary sources, and reviewing the references cited by the primary and secondary research papers.

Relatively few peer-reviewed studies were found aimed at evaluating the performance of neonic seed coatings against all early-season corn pests present at a field site. The limited number of studies was affirmed by personal communication with several extension entomologists knowledgeable about corn and corn pests (Michael Gray, University of Illinois, 2015, Jon Lundgren, USDA/ARS, 2016, and John Tooker, Pennsylvania State University, 2016). Additional papers were found on the biology and control of various specific early-season pests.

The limited number of papers found is indicative of the relatively low importance accorded to these pests, especially compared to major pests of corn, such as rootworm or European corn borer, for which there is a large research literature. The non-peer-reviewed extension literature more often includes these secondary pests, but generally confirms that they are sporadic and not commonly of economic significance. These publications inevitably are non-quantitative, providing neither the frequency of occurrence of heavy infestations nor the yield loss typically caused by these pests when heavy infestations occur.

B. GENERAL PERFORMANCE OF CORN NEONIC SEED COATINGS

> "Peer-reviewed studies are relatively few, but show that neonic seed coatings are not often useful in preventing yield loss, and are not recommended for use as 'cheap crop insurance' (e.g. Cox et al. 2007)[67] in at least one of the main studies."

Measurement of the prevalence of several early-season insect pests that may be the target of neonic seed coatings requires time, so some studies use corn seedling emergence and stand establishment as proxies for damage by early-season pests. This sometimes includes observation of signs of damage that can be attributed to specific pests. Germination and stand establishment can also be affected by soil-borne pathogenic fungi, so often treatments and experimental controls contain several fungicide seed coatings. Peer-reviewed studies are relatively few, but show that neonic seed coatings are not often useful in preventing yield loss, and are not recommended for use as "cheap crop insurance" (e.g. Cox et al. 2007)[67] in at least one of the main studies. Some studies conclude that these seed coatings could be of value if high levels of the target pests are present, but the studies themselves do not often show improved yield or high infestation levels, or provide data on how frequently high infestation levels occur. A major pesticide industry-sponsored study (Mitchell 2014)[68] shows significant average yield protection, but has several serious limitations that greatly reduce its value for commercial farms. That study is analyzed at length in an effort to understand why it comes to seemingly different conclusions about yield protection from neonic corn seed coatings than the peer-reviewed research literature. Reconciling or otherwise finding

explanations for these differences could allow a more fulsome understanding of yield protection from neonic seed coatings.

Cox and colleagues performed field tests of clothianidin-coated corn at 0.25 mg and 1.25 mg per seed rates (labeled rates) to determine efficacy for controlling early-season pests in silage corn for two years (Cox et al. 2007)[69]. They found that these seed coatings did not provide reliable yield increases against early-season insect pests in their tests, where these insect populations were low. The authors note that early planting dates in the Northeast, where the tests were performed, can exacerbate seedling emergence problems, caused by early-season corn insect pests targeted by neonic seed coatings. Trends toward earlier planting dates have been noted to potentially lead to greater early-season insect damage in other corn production regions, and therefore the research of Cox et al. could be relevant to other regions as well. On the other hand, these experiments were conducted in corn following soybeans, which is noted in the paper to result in lower likelihood of early-season insect infestations, and has also been noted elsewhere (Reeves 1994)[70].

In other words, the economically sound practice of rotating corn and soybeans, which was practiced on an estimated 75 percent of corn acres as of 2006 (Daberkow et al 2008)[71], generally leads to reduced early-season insect pest levels that are below adverse economic thresholds[f]. Crop rotation has also been noted elsewhere to reduce insect infestation levels (Dicke and Guthrie 1988)[72], including early-season insect pests of corn (Reeves 1994). Cox and colleagues (2007)[73] recommended against the use of seed coatings as "an insurance" against early-season pests in the Northeast. It is unclear how

[f] Economic thresholds depend on several changeable factors, including price of the crop and cost of the treatment. For example, a treatment that would be below the economic threshold could be above it at higher crop prices.

well these data would apply to other corn growing regions, although much of the Midwest Corn Belt shares a similar spectrum of relevant pests.

Wilde and colleagues (2004 and 2007)[74,75] tested several neonic (imidacloprid, clothianidin, and thiamethoxam) seed coatings at two rates, against several early-season corn pests, including wireworms, white grubs, and black cutworm and found that both concentrations were sometimes effective at several sites in Kansas.

It was notable that in their 2004 paper these researchers tested seed coatings and soil-applied insecticides in field plots at sites that had a history of these pests, or they artificially infested corn with several of these insect pests in greenhouses. The previous crop (or non-crop) history at the field sites were not reported, despite the importance of previous vegetation and cultivation practices for the presence of these pests. Wireworm, white grub, and flea beetle tests were conducted in fields that were chosen because of previous heavy infestation of one of the pests. Cinch bugs and Southern corn leaf beetles were tested in greenhouses by artificially infesting corn with the insects. In other words, special conditions were chosen, or special sites utilized that enhanced the likelihood of heavy infestations, in order to test efficacy, because adequate presence of these pests could not otherwise be ensured for fields under commercially common cultivation practices. Tests were conducted for three years, beginning in 2000.

Despite the use of sites that where initially chosen for high infestation rates, none of the sites were found to have infestations of these pests in 2001 or 2002, reinforcing observations of the highly sporadic nature of these pests. Even with high initial infestation rates, only 25 percent (3 of 12) showed statistically significant yield improvements over the three years of the tests.

As reported in their 2007 paper, there was no yield advantage for coated seed compared to uncoated seed at a total of 36 sites from 2004 to 2006. As noted by the authors, these sites encompassed a wide range of environmental conditions, and the plots were managed for conservation tillage to maintain organic matter. At all but one site, corn followed a different rotation crop. This supports the common observation in this report that where agroecological practices are used, infestation and yield loss from early-season pests is highly uncommon.

It also must be asked whether the conditions that favor these (or other) insect pests are caused by farming practices needed for acceptable productivity and profit. To the contrary, available research suggests that the conditions that favor these pests can be avoided by a variety of methods, including the use of agroecologically sound farming methods that increase biodiversity and do not rely on insecticides and also have other substantial ecosystem and public benefits. Research suggests that such cropping systems produce equal or higher yields and/or greater profits per acre (Davis et al. 2012, Lechenet et al. 2014)[76,77]. In the infrequent instances where these pests may still cause problems, their presence can often be detected through scouting and traps (Furlan and Kreutzweiser 2014)[78] and treated as needed, rather than prophylactically. Some treatment thresholds have been suggested for several of these pests.

Wilde and colleagues (2007)[79] also conclude that seed treatments may be useful where early-season secondary pests are a chronic problem. But those areas should be a very small percentage of corn acres (as discussed above).

This proposed targeting of chronically infested fields is in stark contrast to current practice, whereby the large majority of corn seed is coated with neonics regardless of pest status. The authors also note that seed coatings could be useful in combinations with Bt varieties that do not control these pests. However, in the absence of substantial infestations of these insects, the results of this study do not justify use of neonics as a default, prophylactic practice.

Alford and Krupke (2017)[80] analyzed the dissipation of clothianidin in corn plants grown from coated seed, and found levels generally too low for effective pest control within about three weeks of planting. They suggest that this rapid loss of effective concentrations of neonic may help explain the inconsistent control often found in the field, especially for corn rootworm in their experiments. They also found no evidence of early-season secondary pests in their field trial in 2014 and 2015, which further supports the infrequent occurrence of these pests.

1. Aginfomatics Report, and General Lessons about the Infrequency of Harmful Levels of Early-Season Secondary Insect Pests of Corn

A study commissioned by the pesticide industry, conducted by Aginfomatics (Mitchell 2014)[81], consists of a meta-analysis of field trials analyzing neonicotinoid seed coating efficacy. Meta-analyses have the value of combining several studies to achieve increased statistical power, but they also necessarily obscure some of the important parameters included in individual studies, but which are not among the limited criteria that are required to be included in all studies. Therefore, important data may be excluded or overlooked in meta-analyses. This is the case for the Aginfomatics meta-analysis.

The Aginfomatics analysis relies heavily on non-peer reviewed research conducted for the industry, or that appeared in compilations of field trials. More than half of their data on neonic corn seed coatings (51.5%) were from industry sources (and it is unclear whether this includes academic trials funded in whole or in part by the industry, which is a common practice). The evaluation of the soundness of these studies, or their particular methodology, does not achieve the level of peer-review. And in the case of industry trials, may not be available to the public.

The Aginfomatics report provides a broad assessment of the efficacy of neonicotinoid seed coatings, but also has several serious limitations that make its results equivocal, and not ultimately dispositive in assessing the value of neonicotinoid seed coatings for the control of early-season secondary pests that are the main targets of these insecticides.

i) Field Trials Often Do Not Accurately Represent Commercial Farming Challenges

As has been widely recognized (e.g. De Janvry et al. 2010)[82], field trials are often not representative of what a farmer may be expected to encounter for several reasons. For example, academic researchers often have more control over the pests and abiotic stresses in small field plots than do farmers, and may use the most effective and advanced methods, that are not always widely used, available or economically feasible for farmers.

> "In other words, artificially heavy infestation may indicate that an insecticide is effective in killing a pest, but exaggerates the likelihood that harmful levels of the pest would be present on typical commercial farms."

Field trials may also be designed for several different purposes that may bias their results. Relevant to the current evaluation, as recognized in passing by the authors of the Aginfomatics report, field trials may be designed to boost pest levels in order to conduct a more challenging test, making them more likely to show treatment effects such as improved yields compared to untreated controls. This kind of testing will give results that are not representative of what farmers typically experience. And in particular, it can suggest greater yield protection and benefit then would typically be encountered on farms. In other words, artificially heavy infestation may indicate that an insecticide is effective in killing a pest, but exaggerates the likelihood that harmful levels of the pest would be present on typical commercial farms.

The reason for conducting tests in the atypical fields that may be heavily infested is that if pest levels are low or non-existent, it is unlikely that an insecticide will reveal any yield difference compared to

a non-insecticide control plot. It is desirable to show how effective the treatment would be if there were actually substantial levels of the pests present, which is presumably when a farmer would need it.[g]

Efficacy trials, including those used to test seed coating insecticides, are routinely designed to encourage high levels of pest infestations (e.g. Wilde 2004, Hammond and Cooper 1993, Cox et al. 2007, Kaeb and Tolefson 2006, Kullik et al. 2011, Estes et al. 2016. For full citations, see appropriate pest sections below), while farmers generally will do the opposite when feasible. Sometimes plots are even artificially infested, if the insects can be reared in a lab or collected (e.g. Wllde et al. 2004)[83].

Estes and colleagues (2016)[84] note field tests conducted in Illinois from 2004 to 2006 that were intended to test the efficacy of different insecticide treatments (soil insecticides and seed coatings) against early-season corn secondary pests. These trials were performed in fields specifically selected for reported high infestation levels of these pests in previous years, but despite this, the researcher found: "However, significant differences among treatments or between treatments and the untreated check in terms of efficacy or yield were observed only infrequently".

These examples provide further confirmation that even when attempting to slant field tests toward higher infestation levels of these pests, yield benefit from neonic seed coatings was seen only infrequently. When placed in the context of the frequency of these pests on typical corn farms, it is

[g] In other words, if there were a balance in field trials between those that attempted to reduce infestation levels and those that attempted to increase them or were neutral in that respect, the net result might be no bias in the mean level of efficacy or benefit. But that is not likely to be the case with sporadic pests.

likely that harm from secondary pests, even when insecticides are not used, would be even lower, and unusual.

Because we don't know how many of the field trials evaluated by Aginfomatics encouraged high pest levels, we don't know how biased the results may be. This differs from the peer-reviewed literature cited in this report, which include such methodological information. Given this uncertainty, and the predominance of encouraging high infestation levels seen in the peer-reviewed literature, the Aginfomatics results cannot be taken as representative of what a farmer could expect, and are likely to substantially exaggerate the efficacy and value of neonic seed coatings of corn.

Countering such bias in test results requires avoiding the inclusion of such tests, or revealing and, ideally, quantifying their biases. This can be done for these sporadic corn pests by including data on the frequency of their occurrence and the damage they cause at various levels of occurrence and under various growing conditions. While neither were done in the Aginfomatics report, the frequency of harmful levels of pest occurrence, and corresponding experimental conditions, are analyzed in the current report.

ii) Including Rootworm Protection Tests Exaggerates Yield Protection

A second limitation of the Aginfomatics assessment is that it does not control for or segregate field tests for protection against rootworm (mostly Western and Northern corn rootworm), the major pest of corn, and common in continuous corn (i.e., corn grown more than one year continuously). For several reasons discussed below, and according to research and extension entomologists, neonic seed coatings should not be relied on to treat rootworm, and are not needed for that purpose (see rootworm section below for references). Practical non-pesticidal methods are available for controlling these pests in most areas.

It is possible that many of the field trials analyzed by Aginfomatics showed yield benefits due to control of rootworm rather than secondary pests (rootworm is considered to be a primary pest of corn in the United States). This is because rootworms are much more common on continuous corn than are secondary pests (even when encouraged), and rootworms are often capable of causing large yield losses. The effects of rootworm might have been controlled in some of the analyzed trials by using corn varieties that contained Bt for rootworm, such as Monsanto's Cry3Bb1 gene. But this trait was not discussed in the Aginfomatics report, and in any case, the first such product was not approved by EPA until 2003, while the field trials that were evaluated by Aginfomatics commenced in 1996.

Corn seed coated with 1.25 mg/seed may have acceptable, though unreliable, efficacy against Western corn rootworm occurring at moderate infestation levels, while the lower rate of 0.25 mg/seed is generally not effective. The report did not distinguish results from different insecticide seed concentrations, but rather averaged them. Therefore, research that used 1.25 mg/seed concentrations of neonicotinoids would not be distinguished from those using lower levels.

Given the high prevalence of corn rootworms in continuous corn, it is possible that most of the positive yield values for neonic seed coatings reported in the Aginfomatics study were the result of control provided against corn rootworm rather than the other early-season pests.

The Aginfomatics study reports an average yield benefit from neonic seed coatings for corn of 17.4% compared to non-insecticide controls. This greatly exceeds the yield value obtained by the available peer-reviewed studies, especially when considering that the early-season insect pests other than corn rootworm often were not present in those studies, and therefore in such environments the seed coatings typically provide no yield benefit.

iii) Insecticide Controls and Other Possible Biases that Exaggerate the Efficacy of Neonic Seed Coatings

The average yield benefit for neonic seed coatings compared to other insecticides in the Aginfomatics report was 4.4%, and should also be qualified by the same concerns as above. In addition, this is a value averaged for all insecticides. But farmers often prefer the most effective insecticides, if they are acceptable for other reasons, such as cost and perceived safety. So this average value may again bias the benefit of neonics compared to the best insecticide options. If farmer preferences for more effective insecticides were taken into account, the relative effectiveness of applied insecticides may be higher. This could reduce or erase the small apparent yield advantage for neonic seed coating. If, to the contrary, more effective applied insecticides are more expensive than less effective insecticides, enough to discourage their use, then the actual yield advantage for seed coatings could be higher.

Probably most importantly, the authors note that many of the non-neonic insecticides used for comparison with neonic seed coatings in the field trials were foliar applications. This is an inappropriate comparison, since foliar applications are intended mostly for later season above-ground pests, not most of the early-season subterranean root and seed pests that are the target of neonic seed coatings. And in fact, subterranean pests, including rootworms, are typically treated with in-furrow, soil applied insecticides. Therefore, these data are invalid comparisons for the purpose of determining the value of neonic seed coatings.

The Aginfomatics study also does not provide any range data for yield benefit, except to say that a few studies that differed from the mean by six or more standard deviations were excluded as outliers. This is an important omission because of the sporadic nature of the pests. A relatively small percent of trials with high yield benefit (but below the six standard deviation cutoff) could skew the overall mean upward substantially. And given the data from other studies that usually showed no yield benefit, this is probably the case for the Aginfomatics study.

"Due to the many substantial limitations in the Aginfomatics report, the results and conclusion from their meta-analysis should not be used to inform farmers or farm policy concerning the benefits of neonic seed coatings of corn in the US."

From a practical perspective, this also suggests that it would be more sensible to try to treat specifically the minority of heavily infested farmer fields after scouting, and to avoid farming practices that encourage heavy pest infestations, than to prophylactically coat most corn seed with neonics. Reporting average data obscures the fact that most fields (according to all published research) do not contain damaging levels of these pests.

Due to the many substantial limitations in the Aginfomatics report, the results and conclusion from their meta-analysis should not be used to inform farmers or farm policy concerning the benefits of neonic seed coatings of corn in the US.

2. Summary and Conclusions from Studies on General Protection Against Early-Season Pests by Neonic Seed Coatings

Peer reviewed research found only occasional yield benefit from neonic corn seed coatings for controlling early-season secondary pests, and then only in experiments that were designed to increase infestation above what farmers would typically experience. By contrast, the study by Aginfomatics, relying on non-peer reviewed and mostly industry funded research, found a substantial average yield benefit for neonic corn seed coatings of 17.7 percent compared to non-insecticide controls, and 4.4 percent compared to other insecticides. Analysis of all of these results suggests some possible reasons for these disparities. The probable reason for at least some of the differences may be explained by: 1) bias toward considerably higher efficacy (yield) than farmers would usually experience because an unknown number of field trials were likely designed to encourage unrealistically high levels of early-season insect pests; 2) that analysis did not separate yield improvements due to protection from the single most important group of U.S. insect pests of corn, corn rootworms, which are more properly treated by other means, or avoided by crop rotation, and for which academic entomologists have said seed treatment should not be relied on (see rootworm discussion below); 3) average values obscure the sporadic nature of these pests, which means that the substantial majority of farmers would get no yield benefit, but incur the additional cost of the seed coatings, while those threatened by unusually high infestation levels have other options (see following sections); 4) neonic seed coatings were often compared to foliar-applied non-neonic insecticides, rather than soil-applied non-neonic insecticides, which biases against the efficacy of the applied insecticides. Therefore, these treatments would not be effective against subterranean pests, while soil-applied insecticides may be, and therefore these tests were an invalid comparison. Because of these issues, the Aginfomatics results cannot be accepted as of practical value to farmers. To the contrary, detailed analysis of specific peer-reviewed studies shows that early-season secondary pests are sporadic and occur at economically important levels infrequently, and that there are effective alternatives available to treat them rather than prophylactic seed coatings.

C. EARLY-SEASON INSECT PESTS TARGETED BY NEONIC SEED COATINGS

As noted above, the main often-mentioned targets of neonic corn seed coatings are wireworms, corn seed maggot, white grub, and grape colaspis. Several other early-season pests may also be the target of seed coatings, especially black cutworms and corn flea beetles. Seed coatings at the high dose are also labeled for corn rootworms. The impact and control of these pests are reviewed individually in the following sections.

> "In this respect, insecticide seed coating technology can be said to encourage undesirable management practices in that considerably more environmentally destructive insecticide is used for no benefit to consumers, the environment, or even farms and farmers."

All of these pests, other than rootworms, are sporadic, and not often encountered at levels that cause economic yield reductions. This is especially true when corn farming is managed in ways that take advantage of current understanding of the ecology of these pests. As is shown below, management methods that are practical and profitable can be used to largely eliminate the threat from these pests without the use of insecticides, applied to the soil or on the seed. This is a critically important point to understand about these pests. Where these best management practices are not followed, it is usually most likely because seed coatings are simpler and more convenient, save labor, or simply because farmers have little opportunity to buy uncoated seed, not because they reliably improve productivity or profit.

In this respect, insecticide seed coating technology can be said to encourage undesirable management practices in that considerably more environmentally destructive insecticide is used for no benefit to consumers, the environment, or even farms and farmers.

The sections below on individual early-season corn pests analyze the available research on prevalence, efficacy of seed coating compared to other alternatives, and the availability of ecologically informed management options.

The pests are placed into one of three subsections, based on whether they cause damage to corn primarily as a subterranean pest, above-ground pest, or rootworm, which is a special case since it is a primary rather than secondary pest.

The main reason to separate above-ground from below-ground pests is that the former can be successfully controlled by rescue treatments after scouting, if an insecticide is deemed necessary. By contrast, subterranean pests cannot be controlled by soil-applied rescue treatments after planting, which makes avoidance through management even more critical as a viable alternative to neonic seed coatings (although, as will be seen, scouting of below-ground pests can allow the successful application of insecticide prior to planting).

1. Subterranean Pests

i) Corn Seed Maggot:

Corn seed maggot (*Delia platura*) is reportedly sometimes a problem for growers after addition of fresh organic matter shortly before planting, such as after the termination of some cover crops,

which encourages egg laying (Hammond and Cooper 1993)[85]. Hammond and Cooper note that "… maggot infestations occur at levels sufficient to cause losses ***only*** when green, living cover crops… ***are incorporated into the soil*** in the spring" [emphasis added]. Therefore, avoiding incorporation of such organic matter largely avoids losses to corn seed maggot. As with other early-season pests, it can kill seeds or seedlings, reducing plant stands, and potentially yield, when favorable conditions exist.

But as with other sporadic early-season insect pests that are the target of neonicotinoid seed coatings, the conditions that encourage the pest can usually be avoided by sound agronomic and agroecological crop management practices. It is also considered to be a greater threat if susceptible crops are planted in succession (Delahaut 2007)[86], including several vegetable crops that are not commonly rotated with corn. However, soybean, a crop commonly rotated with corn, is also susceptible. This points to the need for longer rotations that have been shown to improve productivity of both corn and soybeans and increase farmer profit (Davis et al. 2012)[87]. But it also implicates growing corn in monoculture, an undesirable practice from a number of perspectives, as a factor for increased infestation and damage that can be avoided. As with other minor early-season insect pests of corn, there is inadequate data on its prevalence and impact on commercial farms.

Research has shown that by about two to three weeks after the organic matter is added to soil, the destructive larval stage of the insect has largely passed. Models based on ambient temperature can be used to predict when the greatest populations of breeding adult seed maggot flies will be present, in order to avoid planting during this time period. Adult flies breed for only about three days, which facilitates the ability to avoid mating populations (Hammond and Cooper 1993)[88]. Therefore harm can be avoided, as well as the need for neonicotinoid seed coatings in situations where growers may be concerned about infestations. Harm can also largely be avoided by avoiding application

of substantial amounts of green manure or livestock manure, as well as applying these valuable amendments several weeks before planting.

It should also be noted that despite experimental conditions intended to encourage high corn seed maggot infestation levels, elevated maggot numbers or yield reductions did not occur in soybeans in important research by Hammond and Cooper (1993)[89], regardless of insecticide seed or soil treatment, absence of insecticide, or delay in planting date, over the two years of the experiment. The only statistically significant yield reduction was attributed to high weed infestations in one plot due to failure of the weed control program, not seed maggot. There were some small differences in crop stand, but these were apparently compensated for by growth later in the season that prevented yield differences. Soybean may have somewhat greater capacity to compensate for early-season stand loss than corn (Hicks et al. 1990)[90]. But it is likely that compensatory growth could also have prevented yield reductions in corn if similarly small stand differences occurred in that crop (e.g., Tokatlidis and Koutroubas 2004)[91]. And in any case, later planting dates resulted in the largest crop stand, even without insecticide applications. As with experiments noted above, these experiments further support the sporadic, minor nature of the early-season, secondary insect pests that are the target of neonic seed coatings. These experiments show that even when experimental conditions are deliberately designed to encourage high infestation levels, such pest levels often fail to occur.

Planting early has been a trend to maximize the growing season, especially with longer maturing varieties. However, this also increases vulnerability to early-season pests generally, since cooler early-season soil temperatures increase germination time and slow seedling growth, extending the time that crops are vulnerable to both insect pests as well as pathogens. This can lead to increased reliance on pesticides. The minor occasional advantages of planting progressively earlier should be weighed against the costs to the environment, and the potential impact on highly useful practices such as cover crops, which are known to have potential to improve farm sustainability and environmental quality (McSwiney et al. 2010)[92], and may also increase yield (Miguez and Bollero 2005)[93]. As noted above, the experiments of Hammond and Cooper (1993)[94] provided no yield advantage for early-season planting using insecticides compared to planting several weeks later without insecticide treatments. This has also been seen in the work of Coulter (cited above) more generally.

The caution about possible increased seed maggot infestations corresponding to increased organic matter incorporation in the spring, such as from cover crops, is important because addition of organic matter is valuable for improving soil fertility and generally should be greatly encouraged. However, as noted in other research by Hammond (1990)[95], terminated cover crops that remain unincorporated on the soil surface are largely not attractive to seed corn maggots. Cover crops that remain on the soil surface can have multiple additional benefits, for example in suppressing weeds (Price et al. 2016)[96], lowering soil temperatures later in the season, and conserving soil moisture (Wortman et al. 2012)[97].

The issue of management decisions tailored to cover crop species and management illustrates the need for additional research to better determine effects on early-season pests, as well as extension support to help farmers take advantage of this important practice that is widely advocated and recognized for its many positive attributes.

In summary, while seed corn maggot is one of the early-season pests that is most often mentioned as a potential problem, as with other early pests, there are no data on its prevalence that would legitimize prophylactic corn seed coatings. Furthermore, research and expert opinion has shown that the risk of corn seed maggot injury can be largely avoided by highly beneficial practices—such as crop rotation (Reeves 1994)[98] with non-host crops—that should be encouraged in any case. Damage can also be avoided by planting two to three weeks after incorporation of fresh organic matter, or by leaving terminated crop residues on the soil surface. However, as shown in some of the only peer-reviewed research on this topic, even when crop management conditions were designed to encourage high infestation levels of the pest, over a two-year period, infestations remained low. Given the lack of convincing demonstrations that corn seed maggot is a common problem, as well as the availability of viable and desirable crop management practices to avoid it, there is no reasonable evidence that prophylactic neonic corn seed coatings are needed to prevent significant damage by this pest.

ii) Wireworms

Wireworms are the soil inhabiting larval stage of click beetles, and come from several different genera (*Agriotes, Melanotis, Limonius* and *Conoderus* among others). They are widely distributed in favorable environments and can occasionally be pest problems in corn. As with other early-season corn pests, there are few data on their prevalence in the U.S., but instead considerable anecdote.

Because many species of wireworms have long larval phases, often from three to nine years in the soil, they can be a persistent problem where they occur. However, that also means that once detected, the problem area can be anticipated and targeted, populations monitored using baited traps, and, if needed, treatment prior to crop planting in subsequent years (Furlan and Kreutzweiser 2014)[99].

Similar to other early-season pests, research points to particular, usually avoidable, farm management practices as the predominant reason for occasional infestations. In particular, it is generally found that wireworms are most often a problem when grass crops such as pasture are plowed and corn (or susceptible crops) follow. Soils with high organic content and consecutive and continuous planting of susceptible crops have also been identified as risk factors (Furlan and Kreutzweiser 2014, Furlan 2005)[100,101]. Wireworms at agronomically significant levels can therefore usually be avoided. Crop rotations that avoid continuous susceptible crops, generally a good agronomic practice in any case, can be used to avoid wireworms (Reeves 1994)[102].

"Crop rotations that avoid continuous susceptible crops, generally a good agronomic practice in any case, can be used to avoid wireworms (Reeves 1994)[102]."

While no data for prevalence on U.S. farms was available, work in Europe has shown that wireworms are found at harmful levels in only about five percent of cornfields (Furlan and Krutzweiser 2014)[103]. Extensive data collected over almost 30 years in Northern Italy suggests that only about four percent of corn acreage would contain factors that would lead to yield loss (Furlan et al. 2016)[104]. These authors also cite research consisting of hundreds of field tests that show no significant wireworm yield damage, due to low infestation levels, and growth compensation where some early stand loss occurs.

Where the main two predisposing factors—previous or adjacent grass or meadows and high soil organic content—were not present, this research found less than one percent infestation at economically significant levels (Saussure et al. 2015, Furlan et al. 2016)[105,106]. Although this research was conducted in Europe, there are many similarities in production methods and wireworm species or genera. While different species exhibit varied biology and pest characteristics, the European data applies across the range of genera and species present there, suggesting that it would likely be relevant for the U.S. as well (e.g. Furlan et. al 2016).

Even where easily avoidable risk factors were highest, it is estimated that only 20 percent of such acreage would justify treatment (Furlan et al. 2016)[107]. Therefore, there is no justification for prophylactic treatment of the corn crop in order to address apparently very limited economically significant wireworm problems.

iii) White Grubs

True white grubs (*Phyllophaga* spp.) are larvae of June beetles. As with all other notable early-season secondary pests of corn in the U.S., they only occasionally cause economically significant infestations. And as with other early-season pests, there is limited peer-reviewed research on the prevalence and impact of these insects on corn.

Furthermore, on occasions when white grubs do cause significant yield loss, it is usually in corn adjacent to shelterbelts or woodlots containing willow, poplar or ash tree species, or when corn is planted in converted pasture or rangeland. Research over two seasons on dispersal of adult beetles and infestation of corn showed that 90 percent or more of the beetles deposited eggs within 55 meters of tree sources (Glogoza et al. 1998)[108], and larvae were found only in fields bordering shelterbelts. These authors note that: "Larval populations of *P. implicita* would seldom be expected to exceed treatment thresholds beyond 90 meters from shelterbelts." So even when corn infestation occurs, it is likely to be restricted to the edges of fields, especially the large fields common in the Corn Belt. Some entomologists have reported that occasional infestations occur that are not near shelterbelts or grasslands (e.g. Verenhorst et al. 2015)[109], for unknown reasons. But these have not been quantified and do not seem to contradict the generally infrequent occurrence found in previous research.

White grub larvae also inhabit soil for three years, and first season grubs do not cause economic crop damage. So although, as with other early-season soil pests, rescue treatments cannot be applied, infestation can be detected by soil sample of first year grubs, allowing treatment if needed before possible economic levels of damage during the second and third seasons.

To summarize, white grubs are occasional pests, and their occurrence in significant numbers can largely be predicted, and monitored when they do occur. Therefore, in situations where they may occasionally cause problems, especially adjacent to some tree species, those problem fields can be treated. Extensive prophylactic treatment of seeds is unjustified, especially because even when problems occur, they are often restricted to only a portion of a field. As with other early-season pests, the limited available data suggest that white grub problems are not typical, or can be avoided by avoiding problem conditions. Where that is not possible, selective treatment may be used.

In some regions outside the Corn Belt, annual white grubs (e.g. Japanese beetle larvae), may be more common than true white grubs. For example, Jordan and colleagues (2012)[110] found this to be the case in Virginia. In these experiments, yield protection was found in only 33 percent of fields over a three-year period, with a six percent average yield increase compared to the untreated control. These researchers also collected wireworms, and found their numbers to be too low to cause damage. They also found that scouting for annual white grubs in the fall was generally predictive of economically significant populations the following spring, which would allow farmers to treat only when detected in threatening numbers rather than prophylactically.

iv) Grape Colaspis

Historically, grape colaspis (*Colaspis brunnae*) was associated with sporadic damage to corn, mainly when following red clover in rotation. Reports in the late 1990s suggested some increase in damage, and there was speculation that this insect had adapted to the widespread planting of soybeans, another legume, in rotation corn, leading to increased occurrence (Rice 2003)[111]. Kaeb (2006)[112] noted these reports in the extension literature, but there is little if any documentation of prevalence or level of damage beyond anecdotal reports. These authors also cite historic literature that corn planted under conditions that promote vigorous growth, e.g. avoiding cooler early-spring conditions, do not show serious damage. Furthermore, seed treatment with neonics shows inconsistent control, even where infestations are found. For example, in several years of trials, Kaeb (2006) found no stand or yield decrease in untreated fields selected for previous heavy infestation, although greater plant height was found in treated fields. Plants from treated fields were only two to four percent taller than untreated fields in July. These authors also report results from Shaw in 2001 that found no benefits, including for stand height. The authors conclude that seed coatings were beneficial, despite lack of yield increase, apparently based on speculation that under drier early-season conditions, damaged roots of untreated plants would result in lower yields. However, that was not demonstrated in the field.

Further, in the two years of their field tests (2004 and 2005), few beetles were found in emergence cages, even in control (no seed treatment) fields, despite previous heavy infestation. As with other early-season pests, these results show that even where infestations have been previously seen, they are sporadic and often do not reoccur.

Similarly, several years of trials with soil-applied insecticides in the mid-2000s only infrequently showed any yield benefit, despite targeting fields in Illinois with a history of high infestation levels of grape colaspis (or Japanese beetle larvae) (summarized in Estes et al. 2016)[113]. Although these trials used soil applied insecticides rather than seed treatments, generally these applied insecticides have shown comparable efficacy against soil-borne secondary pests compared to neonicotinoid seed treatments. The main advantage for seed treatments has been convenience and reduced labor requirements rather than reliably higher efficacy.

Estes and colleagues (2016)[114] also saw no yield benefit from soil applied insecticides for grape colaspis and Japanese beetle grubs in trials from 2009 to 2011 for sites not chosen for high infestation levels. However, the authors noted that, "Although these trials were not placed in areas with a history of subterranean secondary pests, the trials were no less likely to have measurable larval populations when compared with other fields in the region." In other words, these trials are representative of what farmers would actually face on commercial farms.

"The main advantage for seed treatments has been convenience and reduced labor requirements rather than reliably higher efficacy."

This paper also notes a number of previous field trials over a period of three years, from 2004 to 2006, aimed at determining the efficacy of various insecticide treatments in fields that had reported high previous levels of secondary pests. The authors found that the various insecticide treatments were only infrequently associated with yield improvements compared with untreated controls.

As with other early-season pests, management of corn production is likely to avoid significant infestations of this pest. First, damage was reported most often with inbred seed corn production,

and therefore would not affect most growers' production crops. Second, grape colaspis seems to be a problem almost exclusively when corn follows certain crops like clover, and perhaps more recently soybeans, in rotation. But it was also never found when corn followed a small grain in rotation (Bigger 1965, reported in Kaeb 2006). Even as late as 1999, it was reported only occasionally when corn followed soybeans, alfalfa or sweet clover (Steffey, reported by Kaeb 2006). Including a small grain in corn-soybeans rotations has been shown to increase yields and profits (Davis et al. 2012)[115].

Taken together, the very limited research on grape colaspis suggests that it remains only an occasional pest, and can usually be avoided by good agronomic practices and generally beneficial crop rotations. Furthermore, even on occasions where grape colaspis is found at levels that may cause some damage, neonic seed coatings generally provided no yield increase.

2. Above-Ground Pests

As noted previously, the above-ground pests discussed below can all be effectively avoided by using appropriate IPM or agroecological practices, or controlled by rescue treatment in the unusual situations where populations of the pest are high enough to require control measures. Because such rescue treatments would occur on drastically fewer acres than are currently treated with neonic seed coatings, and because the environmental toxicity of those rescue insecticides are not higher than for neonics (see later section: "If Neonic Seed Coatings of Corn are Eliminated, Will Other Insecticides Replace them?"), it is highly unlikely that the environmental impacts of such rescue treatments would approach those of widespread prophylactic neonic seed coatings. And importantly, research has shown that agroecological means of avoiding significant infestations of these pests can greatly reduce or eliminate the use of synthetic insecticides while maintaining high yields.

i) Black Cutworm

There have been some reports of increased prevalence of black cutworm (*Agrotis ipsilon*) in recent years, possibly in connection to increases in no-till agriculture over the past three decades. As with other secondary pests analyzed in this report, however, the available research strongly suggests that 1) even under conditions that are expected to foster high infestation rates, economic damage is uncommon; and 2) harm can largely be avoided using best management practices that are ecologically and environmentally sound. Furthermore, academic extension entomologists recommend against relying on seed neonic coatings for preventing significant damage from black cutworm. Finally, unlike subterranean early-season pests, black cutworm feeds above ground, and so is amenable to rescue treatments in the uncommon event that it is needed.

Research in 2011 (Kullik et al. 2011)[116] shows that in only one of six field trials over a two-year period was yield reduction from black cutworm observed, despite these tests being conducted on farms selected for substantial infestations in previous years.[h] This yet again illustrates that even where conditions are considered to be most favorable for infestation (which can usually be avoided), infestations of secondary pests like black cutworm are the distinct exception. Additionally, the low dose of clothianidin (0.25 mg/seed) was ineffective against black cutworm and the high dose (1.25 mg/seed) was significantly less effective than Bt in the only trial where yield loss was observed in the control. Although the authors claim that the low dose may enhance performance of Bt in some cases, it was not the case in their own experiments concerning yield.[i]

Earlier work identified conditions that may enhance infestation of black cutworm (Showers et al. 1985)[117]. Several sets of experiments showed that black cutworm levels could be problematic in no-till fields that were infested with winter weeds. However, when the weeds were killed at least 8 to 14 days before planting corn, black cutworms were rarely a problem. This is because black cutworms apparently cannot feed on dead and dried plant material, and therefore starve prior to corn emergence. Using such ecological information to develop environmentally and economically appropriate farming practices should be highly prioritized over insecticide use.

Kullik and colleagues found a single field test where significant yield reduction occurred in the control plot that had been treated with herbicide on the days that the corn was planted, a practice

[h] The authors reported only two of six field tests in their Table 3. They mention in the text of the paper that there were in fact six field trials, but that only two had infestations of black cutworm when tested (despite a history of infestation). More accurate reporting would have included all six tests in their Table 3.

[i] Kullik et al. write that they used doses of 25 mg/seed and 125 mg/seed. This is 100 fold higher than the legal labeled rate, and we assume here that these designations were a clerical error. If they were accurate, efficacy data from this paper would be irrelevant from a practical perspective, but data on the prevalence of black cutworm would remain of value.

expected to exacerbate black cutworm problems. As the authors acknowledge, cutworms that lose their weed food source simply move to corn seedlings when they are killed shortly before corn seedlings emerge. In other words, it is highly likely that even in the single field trial where cutworm yield reduction occurred in the untreated control, those losses could have been avoided simply by killing the weeds (by whatever methods) two weeks earlier.

Finally, since black cutworm is an above-ground pest, it is feasible to use rescue insecticide treatments to control it. This should be discouraged in favor of ecologically-sound management, in which case the need for rescue insecticide use should be rare. As noted by academic extension entomologists, such treatments, especially granular soil-applied insecticide, are effective (Krupke and Obermeyer 2015)[118]. State-supported pheromone traps, or scouting, can be used to determine whether black cutworms may be a problem (Purdue University Extension)[119]. Entomologists note that reliance on neonics, even to the extent that they may sometimes be effective, is risky because infestation can also occur after the insecticide residue levels become too low to be effective (Krupke and Obermeyer 2015)[120]. These entomologists recommend against reliance on neonic seed coatings to control black cutworm.

In summary, multiple practical agronomic alternatives to neonic seed coatings are available to prevent or control infestations of black cutworm, in the unusual instances where it is a problem. These methods should be highly encouraged. Where they may rarely fail, rescue treatments can be used, and work better than neonic seed coatings in any case. Although costs (e.g. labor) may be somewhat higher for applied insecticide use on a per use basis, it should be considered whether the infrequency of such use may result in lower costs over time compared to the continuous cost of seed coatings applied every year.

ii) Corn Flea Beetles

> **"The large majority of field corn acres, planted for production rather than seed, should be resistant to the most damaging phase of the disease."**

Corn flea beetles (*Chaetocnema pulicaria*) may sometimes reach problem levels after warm winters in the Corn Belt. Extension entomologists have developed a guide for determining the possibility of high beetle numbers based on average temperatures from December – February. Flea beetles are mainly a threat to productivity due to transmission of a bacterial disease called Stewart's wilt, rather than through direct feeding. Field corn varieties are widely available that have resistance to the more-often serious wilting (vascular) phase of the disease, and often have some resistance to the leaf phase, while inbred corn lines used for hybrid seed production, and sweet corn, may be susceptible (University of Illinois Extension)[121]. Kuhar and colleagues (Kuhar et al. 2002)[122] found that control of Stewart's wilt by neonic seed varied and was generally moderate, and considerably lower than was provided by genetic resistance in sweet corn. They also reported some phytoxicity due to imidacloprid seed coatings. The large majority of field corn acres, planted for production rather than seed, should be resistant to the most damaging phase of the disease.

Although corn seed treatments can protect seedling corn (Wilde et al. 2004)[123] it is rarely needed to prevent stand and yield loss due to feeding of the beetles. And because hybrid field corn that is resistant to Stewart's wilt is readily available, this disease is not usually a problem for commodity corn production.

Where avoidance of Stewart's wilt is needed, delaying planting by about two to three weeks, in early May in Iowa, largely avoids feeding by beetles carrying the bacterium (Nutter 2007)[124]. As noted in several sections above, delaying planting by a few weeks also can avoid potential black cutworm and seed corn maggot infestations, often without yield penalty, and is generally beneficial for avoiding early-season insect and fungal pests. Where high levels of corn flea beetles are present, extension entomologists recommend one of many available rescue treatments (Purdue University Extension 2016)[125].

Although the frequency of damaging levels of corn flea beetle in field corn has not been well documented, it is generally predictable, avoidable by sound agronomic practices; and where those rarely fail, effective rescue treatments are available. For all of these reasons, neonicotinoid seed treatments are not needed to protect field corn from flea beetles.

3. Corn Rootworms

Several authors report no significant yield protection value in neonic seed treatments at the lower (0.25 mg/seed) rate, and only moderate and unreliable yield improvement at the higher label rate (1.25 mg/seed) (Cox et al. 2007)[126] for Western and Northern corn rootworms, the most widespread species, and those most prevalent in the Corn Belt. Cox and colleagues note that although neonic seed coatings provided acceptable protection against the moderate infestation levels of their experiments, they are not reliable for controlling Western corn rootworm and recommend against its use as "a cheap insurance policy" in the Northeast for rootworm or secondary pests.

Several field trials in Illinois in 2006 found no significant control of rootworms in heavily infested corn at the high rate of 1.25 mg/seed, and reported that this was consistent with previous tests (Gray et al. 2006)[127]. Similarly, Petzold-Maxwell et al. (2013)[128] did not find significant yield advantage when the high rate of clothianidin seed treatment was used in addition to Bt, or in non-Bt corn. Bt was shown to be more reliably effective.

van Rosen and Ester (2009)[129] summarize the research literature as showing inconsistent protection provided by neonic seed treatment of corn against rootworms. Therefore farmers that rely on these treatments may face substantial yield losses in cases where it fails, which may have been avoided by the use of more effective methods, such as crop rotation where rotation-resistant rootworms are not prevalent.

The unreliability of neonic seed coatings for protection against rootworm is also well summed up by several university entomologists (Obermeyer et al. 2006)[130]. While recognizing that neonic seed coatings are attractive for their convenience and related reasons (that they are "wrapped" directly into the seed), they raise caution about the marginal efficacy of these products: "Using seed-applied insecticides for corn rootworm control in high-risk areas may be a gamble because of the inconsistencies that have been seen in university trials throughout the Midwest. The labels literally state 'protect' or 'protection' from rootworm... not control." They relegate the possible value for rootworm to low or moderate impact areas. However, they also note; "Before deciding to use any of these options, be sure that you actually need it in your growing area – many areas of the state [Indiana] have little rootworm pressure and can get by simply by continuing to rotate corn with other crops in alternating years." This advice to consider the actual situation on the farm is clearly not possible when corn is pretreated with neonics. The field tests conducted by these researchers also found both Bt and soil-applied insecticides performed much better than coated seed for rootworm protection.

Recent research further confirms that neonic seed coatings are not reliable for control of rootworms (Alford and Krupke 2017)[131]. This research measured and modeled the reduction of neonic concentration in corn plants over time, and tested efficacy in fields where rootworm infestations were encouraged by planting late-season corn as a trap crop. They found that even the high dose of clothianidin seed coating provided no yield benefits in two years of trials, and only moderate efficacy in reducing root damage. They suggest that one reason for inconsistent efficacy for neonic seed treatment of corn is reduction of concentration of the insecticide within about three weeks. They also suggest that because of the limitations of these seed coatings, they are unlikely to make economic sense when corn prices are relatively low, as in 2014 to 2016.

They conclude that because of the poor match between the duration of efficacy of neonic seed coatings of corn and the phenology of early-season insect pests, "…coupled with the sporadic occurrence of economic infestations of secondary pests indicates that most US maize producers are unlikely to realize benefits from the NST [neonic seed treatment] approach."

Rootworms are often a problem in continuous corn, and in significant part for that reason, farmers usually rotate corn with non-susceptible crops—particularly soybeans—in the Corn Belt. As noted above, about 75 percent of corn is rotated, mostly in a two-year rotation with soybeans. Crop rotations essentially obviate the need for insecticides to control rootworms–except where rotation resistant rootworms have evolved. These rootworms were selected and flourished in short corn-soybean rotations which are too short to take advantage of most of the benefits or longer crop rotations (Davis et al. 2012)[132]. Although there are uncertainties due to gaps in important data, longer rotations may be considerably less likely to allow the development of rotation resistance (Onstad et al. 2003)[133]. And wheat added to corn-soy rotations has resulted in substantially reduced rootworm damage where rotation resistance is prevalent, to below economic thresholds in some research (Schroeder et al 2005)[134], although these authors caution that wheat may not always adequately reduce damage.

> "Growing corn continuously has long been understood to be inadvisable in its promotion of pests such as rootworm."

Growing corn continuously has long been understood to be inadvisable in its promotion of pests such as rootworm. Even the short corn-soybeans rotation is inadvisable for a number of reasons, from reduced yields, to greater reliance on pesticides, to greater environmental pollution (Davis et al. 2012)[135], and should be discouraged for all of these reasons.[j] Enablement of such generally destructive practices by the use of seed coatings (which are also unreliable for rootworms) or other insecticides should likewise be discouraged in favor of longer crop rotations. In fact, to the extent that arguments are made in support of seed coatings on the basis of higher yield, longer crop rotations are more reliable and more productive, as well as providing multiple environmental and public health benefits (Davis et al. 2012)[136]. As discussed elsewhere in this report, there are several structural, market and policy reasons why farmers may feel compelled to use industrial farming methods, including growing corn continuously. Therefore, efforts to encourage farmers to change their practices must focus on these barriers.

i) Rootworm Resistance Management

As noted above, in addition to yield protection, pest control measures may have other benefits that are important to consider. One hypothetical benefit of neonic corn seed treatments might be the reduction of resistance development by rootworms to other treatments. Rootworm has shown

[j] The corn-soybean rotation has several agronomic advantages over continuous corn, including usually higher corn yields and less need for nitrogen fertilizer use. But compared to longer rotations, it has multiple disadvantages (Davis et al. 2012).

a high propensity toward developing resistance to control methods, and so good stewardship to prevent resistance should be a high priority. However, recent research suggests that the use of neonic seed coatings may actually facilitate development of resistant rootworms (Petzold-Maxwell et al. 2013)[137].

The addition of clothianidin seed coatings to Bt rootworm-protected corn delayed adult emergence from the soil by about 12 days compared to non-Bt corn used as required resistance management refuges. Refuges are intended to supply non-Bt resistant adult rootworms to mate with possible Bt-resistant adults emerging at low frequency from Bt corn.[k] However, the delayed emergence due to seed coating use would likely lead to assortive mating, whereby Bt resistant adults would be less likely to find and mate with non-resistant adults emerging earlier from the refuge. This can substantially increase the probability of resistance emerging to Bt, since it defeats the basic purpose of the refuge. Even when the non-Bt refuge corn seed was also coated with clothianidin, adults emerged much earlier than from seed with both Bt and seed coating. The seed coatings exacerbated differences in emergence dates seen for non-coated Bt vs. non-coated non-Bt refuge corn.

Therefore, using neonic seed coatings on Bt corn, the most effective treatment currently available other than crop rotation, may compromise that control method. Bt is already rapidly succumbing to resistance (Jakka et al. 2016)[138] because it does not provide a high dose and is overused under the promotion of the unsustainable industrial farming model, which eschews agroecological, biologically diverse farming methods like long crop rotations. Use of neonic seed coatings may accelerate this process.

[k] Because Bt toxins active against rootworms do not provide a "high dose" as defined by resistance management models, the refuge strategy is significantly compromised. However, assortive mating due to neonic seed coatings may exacerbate an already problematic situation.

Furthermore, the widespread prophylactic use of neonic seed coatings is more likely to lead to rootworm resistance (as well as other corn insects) to these insecticides than occasional use, for example in response to actual high pest levels (van Rosen and Ester 2009)[139]. Prophylactic use provides continuous high selection pressure, which is known to favor resistance development in general. And rootworms are notable for their propensity to develop resistance to insecticides and even to rotation. Neonic resistance is already emerging in the closely related Colorado potato beetle (van Rosen and Ester 2009)[140]. And seed coatings do not provide a high dose, which is also generally associated with more rapid development of resistance.

"Therefore, widespread prophylactic use of neonic seed coatings for rootworm control may be self-defeating from the perspective of conserving these means of pest control."

Therefore, widespread prophylactic use of neonic seed coatings for rootworm control may be self-defeating from the perspective of conserving these means of pest control. It should also be noted that even where neonic seed coatings are not used to target rootworms, these insects may be exposed inadvertently, and therefore selection for resistance may occur.

CHAPTER 4

IF NEONIC SEED COATINGS OF CORN ARE ELIMINATED, WILL OTHER INSECTICIDES REPLACE THEM?

One important question that has been raised as a caution about reducing or eliminating neonic seed coatings of corn is whether they would be replaced by other insecticides that are equally, or more harmful. As has been discussed throughout this report, however, there are several reasons why this concern has no merit.

First, many fewer acres of corn would be treated with insecticides if the nearly ubiquitous use of prophylactic corn seed coatings ended, and only acres that were actually infested with economically harmful levels of these pests were treated with insecticides. As described in the first chapters of this report, corn acreage with harmful levels of early-season secondary pests is much less than is currently exposed to neonics via coated corn seeds. Although there are inadequate data on the occurrence and levels of these pests in the United States, it is widely understood that they occur only infrequently at high levels. This is also supported by the research analyzed in this report.

A rough approximation of the prevalence of these pests can be derived from consideration of historical acreage treated with insecticides. As noted above, only about 30 percent of corn acres were treated with applied insecticides from the 1990s through 2003 (Douglas and Tooker 2015)[141], and most of those acres were treated for either rootworm or European corn borer. Some acres treated for these pests may have also incidentally controlled early-season secondary pests, but this was likely to have been only a fraction of the total. The fact that there has not been enough research devoted to those pests to confidently determine how often treatment was needed is in itself evidence that they are not important enough to attract more than occasional research efforts.

Furthermore, as seen in the sections on the individual pests, there is no evidence that they have increased substantially. Even in instances where field tests were intentionally designed to encourage high levels of infestation, or where tests were performed in fields that had recent high infestations, the large majority showed no yield advantage when using neonic coated seed compared to untreated controls. This suggests that it is unlikely that more than a few percent of corn acres have infestations of these pests that could justify using neonic coated seeds. This is a small fraction of the current estimates of between 71 to close to 100 percent of acres treated through seed coatings (Douglas and Tooker 2015, US EPA 2017)[142].

In other words, if neonic seed coatings were eliminated, it is likely that only a few percent of corn acres would turn to applied insecticides to treat early-season secondary insect pests (and should not be used to control rootworms). In order for this small acreage to equal the harm from neonic coated seed, the alternative insecticides used on these acres would have to be many times more harmful on a per unit area basis than neonic coated seeds. However, a recent meta-analysis (Douglas and Tooker 2016)[143] found that even the highly toxic synthetic pyrethroids are not more toxic to non-target organisms than neonics. Therefore, it is likely that even if other applied insecticides were substituted for neonics on all of the acres where infestation levels might justify their use, the harm to the environment would be greatly reduced.

But more importantly, we know enough about the ecology of these pests to largely avoid conditions that would lead to heavy infestations. Agronomically sound methods are available to greatly reduce the possibility that these pests would occur in high enough numbers to cause significant crop damage. These methods were discussed in the sections on the individual pests.

Finally, instead of using harmful insecticides as an insurance mechanism, it is more appropriate to use actual insurance for this purpose. First, as suggested by several entomologists, the cost of these seed coatings does not justify occasional value for controlling unusually heavy infestations of these pests.[1] But in addition, this pesticide-based insurance is "low cost" only when we do not consider the heavy costs to the environment. Therefore, the continued use of neonic seed coatings of corn is unjustified, even if some of their use would be substituted by other applied insecticides.

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[1] For example, Cox et al. (2007), explicitly recommend against using neonic seed coatings as a form of crop insurance. Wilde et al. (2007) note that they may be useful where there are chronic infestations of secondary pests (implying that by contrast, they may not be justified otherwise).

CHAPTER 5
POTENTIAL FOR REDUCTION OF CROP YIELD DUE TO NEONICOTINOID SEED COATINGS

Several studies have shown or imply that the use of neonicotinoid seed coatings may reduce yield in some circumstances. Most of these studies analyzed soybeans, but similar effects are likely in corn. Douglas and colleagues (2014) found that slugs, sometimes an important pest of no-till soybeans, corn and other field or forage crops, were largely immune to neonicotinoids, which accumulated in their tissues after feeding on soybean seedlings grown from coated seed. However, ground beetles (carabids), important predators of crop pests in soybeans and corn, were killed when they consumed the contaminated slugs. This led to outbreaks of slugs and a five percent soybean yield reduction in the Pennsylvania tests, compared to untreated controls. This result is additionally important because there are few effective molluscicides available to control slugs, making biological control even more important (Douglas and Tooker 2012)[144].

Mullin et al. (2005)[145] also found high levels of acute toxicity to numerous carabid species compared to untreated controls in laboratory-based bioassays and in microcosms using treated corn seed. As noted by these authors, these important beneficial insects are usually among the species more resistant to most pesticides compared to some other natural pest enemies, so high susceptibility of carabids to neonics is particularly troubling. This is especially so because these experiments were conducted with seed treated at the low coating rate of 0.25 mg/seed, while clothianidin coated corn seed intended to control rootworms and several other pests is treated at the 1.25 mg/seed level. These higher levels may be expected to result in correspondingly higher mortality or morbidity of natural pest enemies.

Ohnesorg et al. (2009)[146] did not observe natural enemy reductions in their research on corn seed coatings. However, more comprehensively, recent meta-analysis of numerous studies identified significant natural enemy reductions associated with neonic seed coatings (Douglas and Tooker 2016)[147].

By contrast other research (O'Rourke et al. 2008)[148] found considerably higher levels of carabids in long (four-year) crop rotations compared to two-year corn-soy rotations. Leslie et al. (2010)[149] found lower activity densities of natural enemies in corn grown from coated seed, and this treatment effect was eliminated in rotated corn. Longer crop rotations (three or more crops) also have consistently had higher corn productivity than corn-soybean rotations that rely more heavily on herbicides and synthetic fertilizers (Gomez et al. 2012, Davis et al. 2012)[150,151], although since many variables differ between these treatments, the increased productivity has not been shown to be due to increased natural pest enemies. Other research (Meehan et al. 2011, Letourneau et al. 2011)[152,153] has shown that higher natural enemy populations are strongly associated with greater productivity or greater biological control potential (Geiger et al. 2010)[154].

In addition to harmful impacts on ground beetles demonstrated above, Seagraves and Lundgren (2011)[155] showed reduced numbers of three other widely disseminated and important protective natural pest enemies in soybeans grown from neonic (thiamethoxam) coated seed.

The use of insecticides such as seed coatings may mask the biological control value provided by natural enemies of crop pests, at the same time that they compromise the potential for biological control by reducing the populations of natural pest enemies.

But natural pest enemies in diverse agroecosystems do not require purchase, unlike insecticides. Therefore, even to the extent that neonic seed coatings may provide some minimal control of pests, they may reduce net profits due to their purchase price compared to relying on natural pest enemies and other processes, discussed in the next section, that control pests without monetary cost to the farmer.

One study modeled the value of natural enemies in five Midwestern states in the Corn Belt as at least $84 million/year for a single important pest of soybeans (Zhange and Swinton 2012)[156], or about $4.20 – $32.60 /ha/year. This model was based on broad spectrum insecticide application, rather than neonic coated seed. But neonics are broad spectrum insecticides for both pests and natural enemies,[m] and as noted above, several researchers have observed substantial natural enemy. Coated seed therefore would likely also cause reduction of income when used prophylactically in the majority of cases where the target pests are not present in numbers that would exceed the economic insecticide treatment threshold that takes into account the contribution of natural enemies.

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[m] Neonics are generally less harmful to non-insect arthropods such as mites and spiders. But because of the large number of insect species that are important natural enemies, we consider neonics to be effectively broad spectrum despite lower toxicity against some natural enemy taxa.

CHAPTER 6
AGROECOLOGY, AND CORRECTING THE MYOPIC FOCUS ON SPECIFIC PESTS

It is understandable that farmers and research scientists would focus on the harm caused by specific secondary pests. When these pests occasionally reach high levels, they may cause large losses of yield and profit. But focusing on individual pests alone does not address the aspects of the farming systems or practices, at the farm or regional scale, which determine the population levels of those pests as well as other environmental impacts.

For example, prevalent monoculture corn farming practices are highly destructive for several reasons, such as high contributions to eutrophication of both fresh and marine water, and substantial emissions of the greenhouse gas nitrous oxide due to heavy dependence on synthetic nitrogen fertilizers. It also often involves reduced addition of organic matter to soil, reducing soil fertility and organic carbon and nutrient recycling on the farm compared to agroecological systems. In the context of this report, they often produce lower corn yields than corn grown in rotation with other crops. It is not fully understood why this is so (Bennett et al. 2011)[157], but reducing pest populations is one of the factors that contributes significantly to higher productivity. Longer crop rotations have been noted for decades to reduce corn pest insects generally, including the pests that are the target of neonic seed coatings (Reeves 1994)[158].

And crop rotation is well understood to control corn rootworms, except where rotation resistance has arisen in recent years (and even in some of those areas, rotation still often works). Unfortunately, there is a trend in U.S. industrial agriculture toward increased monoculture corn rather than longer rotations (Plourde et al. 2013, Stern et al. 2010)[159,160].

Longer rotations in the Corn Belt have been shown to have additional advantages over the common corn-soybean rotation, including substantially reduced pesticide and fertilizer costs, resulting in higher profit margins and greater yield for corn and other rotation crops (Davis et al. 2012, Gomez et al. 2012)[161,162]. In general, increasing the diversity of farming methods is associated with lower synthetic chemical dependence without sacrificing productivity (Lechenet et al. 2014)[163]. Such beneficial results may be missed when focusing on a specific pest rather than on the overall collective impact of all pests, soil quality, and resilience to abiotic factors (e.g. extreme weather) over time.

One often overlooked aspect of farming systems is the importance of biodiversity at the landscape scale in providing natural pest enemies and pollinators for crop protection and production. In this context, the value of natural enemies may be underestimated in the heart of the Corn Belt due to the very low maintenance of diverse uncultivated habitat beyond the farm itself. Research has established greater positive impact of natural pest enemy populations and diversity when uncultivated landscape is available locally and regionally to provide habitat for such organisms (Tscharntke et al. 2005, Gabriel et al. 2006, Gabriel et al. 2010)[164,165,166].

Most experiments testing the efficacy of neonic seed coatings to control early-season pests of corn do not report the landscape characteristics that surround the test plots. However, many of them have been conducted in Corn Belt states that have little uncultivated habitat. And the industrial farms themselves are also diversity-poor ecological matrices (Perfecto and Vandermeer 2010, Tscharntke et al. 2012, Mendenhall et al. 2014, Zalucki et al. 2015, Kremen 2015)[166,167,168,169,170,171], so the populations of natural enemies in industrial corn fields is likely to be especially low, for example when compared to organic farms (Crowder et al. 2010)[172].

Therefore the majority of tests that have been conducted to determine the value of neonic seed coatings may underestimate the potential for biological control in more diverse agroecosystems. Some estimates of increased dependence on insecticides due to loss of natural enemies have been made, and can be substantial (Rusch et al. 2016)[173]. For example, one estimate (Meehan et al. 2011)[174] suggests that farms needed to apply additional insecticides to about 1.4 million ha of cropland, with costs to farmers of about $48/ha, due to inadequate habitat for natural pest enemies in seven Corn Belt states in 2007.

"Therefore the majority of tests that have been conducted to determine the value of neonic seed coatings may underestimate the potential for biological control in more diverse agroecosystems."

We therefore desperately need policies that address the farm landscape beyond single farms, and that incentivize practices that facilitate the large benefits that this brings to farmers and the environment. These policies must recognize the reality that farms are not isolated islands, but part of larger ecological and social communities.

A narrow focus on particular insect pests also neglects negative impacts of neonic and other insecticides on other farm processes and other types of pests. For example, Smith and others (2016)[175] found that harm to weed seed herbivores (often called weed seed predators) may lead to increased weed seed on farms, which could in turn lead to higher herbicide use and thereby higher cost.[n] In other words, natural enemies are not only important for reducing invertebrate pest numbers and impacts, but also the impact of weeds. Significantly, many natural enemies of weed seeds are ground beetles (many carabid beetles are omnivorous, eating insect pests and weed seeds), which have been shown in several experiments to be harmed by neonicotinoid seed coatings, as discussed elsewhere in this report.

"By looking beyond the current narrowly defined and almost exclusive focus on production and cost savings, broader gains can be obtained for the stability of the farm economy and rural society, as well as the environment (Boody et al. 2005, Cochrane 2003)[177,178]."

Finally, the larger impacts of the biologically simplified farming systems that rely on neonicotinoid seed coatings are unaccounted for in a narrow focus on pest control. These include the impact on farming communities and the environment broadly. Among these are the loss of viability of rural towns due to loss of population and jobs, water and air pollution, general loss of biodiversity, loss of soil fertility, and substantial production of greenhouse gasses. All of these important multifunctional values of agriculture (Boody et al, 2005)[176] are ignored by a myopic focus on insect pests alone. By looking beyond the current narrowly defined and almost exclusive focus on production and cost savings, broader gains can be obtained for the stability of the farm economy and rural society, as well as the environment (Boody et al. 2005, Cochrane 2003)[177,178].

[n] The results of this paper were not statistically significant. As the authors note, this could be due to inadequate sample size. So these results should be considered to be preliminary until confirmed or refuted. But when combined with other research noted in this report of the impact by neonic coated seed on weed seed natural enemies such as ground beetles (e.g. O'Rourke et al. 2006), it is not unreasonable to assume that these insecticides may cause some increase in weed numbers and diversity in crop fields.

CHAPTER 7

SOME SOCIAL IMPLICATIONS OF SEED COATINGS

The motivations that drive the use of neonicotinoid seed coatings as they pertain to farming practices and the larger rural landscape need to be understood as part of food and farming systems nationally (e.g. Cochrane 2003)[179] and globally (e.g. McMichael 2005)[180]. In particular, an underemphasized aspect of seed coating technology is that it reduces labor, by avoiding the time involved in applying insecticides in the field, for scouting for insect pests that are the main target of this seed technology, or for management of more complex farming systems that avoid these pests.

And of course, seed companies make additional profit on coated seed. It has long been a recognized part of the business model of pesticide companies to encourage dependence on insecticides. Called the "pesticide treadmill" (Van Den Bosch 1978)[181], that reliance on insecticides instead of biological control supplied in healthy agroecosystems leads to enhancement of pests that were previously insignificant, further reliance on insecticides, resistance development by pests, and replacement with new patented, and therefore more expensive, insecticides.

As noted earlier, farmers also may perceive neonic seed coatings as a relatively inexpensive way to reduce risk, at least as judged by comments of several extension entomologists. Risk reduction is understood to be an important motivation for farmer decision making (Moschini and Hennessey 1999)[182]. Evidence has been provided for risk or ambiguity aversion as one driver of the use of

engineered Bt insect pest protection of corn in the Midwest (Barham et al. 2014)[183]. Arguments about yield may therefore obscure these underlying motivations to use seed coatings as a kind of insurance against uncertain risk.

It is also possible that research on the minimal yield protection afforded by neonic coated seed is not readily available to farmers from trusted sources, or is countered by advertising for seed coatings. For example, we are not aware of previous broad analyses of the minimal value of neonic seed coatings, especially including multiple individual pests and detailed assessment of possible alternatives, such as is contained in this report.

The economic pressure for reduced labor or simplified production systems is in turn motivated in part by pressure to increase farm size—especially in the Corn Belt (MacDonald et al. 2013)[184] —which is facilitated by the ability to farm more acres in less time. The biological and ecological simplification that accompanies this trend, however, exacerbates pest levels and results in a vicious cycle of increasing dependence on harmful chemicals and similar technologies. This has been identified as one consequence of a "technology treadmill" whereby farmers must continuously purchase newer and often more expensive technologies to increase yield or cut costs, while paying increasing land costs, in order to make a profit.

But the large number of existing farms necessitates that while first adopters of new technologies may initially see increased profits, profit margins shrink as most farmers eventually adopt the new technology. Non-adopters that rent land generally lose money and are driven out of business (Cochrane 1993, Levins and Cochrane 1996)[185,186]. Often the remaining farmers buy or lease more farmland and increase their size. The tendency to overproduce, driving down crop commodity prices and profits, has been widely recognized and documented (Ray et al. 2003)[187]. Investment in technologies that facilitate increased farm size such as labor-saving technologies like seed coatings and engineered traits may also lock farmers into simplified farming systems. This can occur through debt, lack of knowledge about sustainable farming systems, and other means, making it difficult to adopt more socially and environmentally beneficial farming methods (Vanloqueren and Baret 2009)[188]. The resulting tremendous harm to the environment and rural society (Lobao and Stofferahn 2007)[189] is in turn the result of this simplified farming system that is, on the other hand, encouraged by the industries that profit from products, including pesticides, which industrial farming systems rely on.

This also means that farmers will require substantial help through policies, incentives, and regulations to move away from destructive industrial farming practices like neonic seed coatings to environmentally and socially sustainable agroecology-based farming systems that are also profitable. Simply relying on the market system will not be sufficient to change farm practices given the broader socio-economic dynamics. Additionally, reliance on self-interested seed and pesticide companies as major sources of information for farmers is unlikely to encourage adoption of environmentally and socially beneficial farming systems that do not rely on company products. Independent publicly supported and trusted sources of information and research are therefore critically needed.

In the case of neonic seed coatings, however, relatively small adjustments to farming practices would be needed to achieve control or avoidance of secondary pests. And even without these changes, neonics are infrequently needed to protect yield. Therefore neonic seed coatings are a particularly good target for changing farming practices toward those based on ecological principles.

"In the case of neonic seed coatings, however, relatively small adjustments to farming practices would be needed to achieve control or avoidance of secondary pests."

The understanding of neonicotinoid seed coatings as part of biological impoverished farming and food systems is important to better understand how to address these problems in the interest of farmers, rural communities, the environment, and society more broadly. For example, while it makes sense from the perspective of farm productivity, profit per unit of land, environmental benefit and so forth to implement agroecological methods to avoid high infestations of early-season corn pests, the increased complexity and slightly increased labor involved goes against the socially and environmentally destructive trends toward increasing simplification and labor reduction per acre that accompany increasing farm size. Only when this larger context is better understood can policies be developed that support farmers, the environment, and rural communities.

CHAPTER 8
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The available peer-reviewed literature demonstrates that prophylactic neonicotinoid seed coatings are not needed to protect corn from yield loss due to early-season insect pests. The available literature on protection of corn from these pests consistently demonstrates that they are not often present at harmful levels. There is not a large research literature on any of these pests, which is to be expected for pests that are not often of economic concern. In fact, the limited amount of research itself is highly suggestive of the minor importance of these pests.

The available research also shows that ecologically based practices can further reduce the possibility of heavy infestations, and in rare cases where this does not work, applied insecticides can be successfully used.

Research has demonstrated that these pests are uncommon despite the frequent use of experimental designs that were intended to increase the severity of these pests. In almost all of the research, scientists grew corn test plots under conditions that have been reported to encourage high early-season pest levels, used plots where high infestation levels had been observed in previous years, or artificially infested crops with the target pests. These are common and accepted practices, because only under moderate to high infestation levels is it likely that enough harm would occur to the crop to adequately test the efficacy of the treatment. However, this does not represent the conditions typically found on commercial farms. Therefore such tests are biased in favor of higher damage from these pests compared to what would typically be found on farms, and overestimate the value of neonic seed coatings for actual farms.

Despite tests that were biased toward higher infestation levels than would commonly be observed on commercial farms, only a relatively small percentage of these tests resulted in improved yields compared to controls where no insecticide was used. Often no yield improvement was observed unless trials were designed to encourage heavy secondary pest infestations, in which yield improvement still occurred in only about zero to 25 percent of this research, depending on the pest and experiment.

There are no data that we are aware of that examines the prevalence of harmful levels of early-season insect pests on farms. While these pests have been mentioned in academic extension entomology documents, and there has been some speculation or anecdote that some of these pests may have increased in frequency in recent years, there is inadequate research or other documentation to support this. We could find no substantive evidence that the levels or frequency of these pests have increased significantly. And in fact, the available peer-reviewed research suggests that these pests have not increased significantly, and remain minor and infrequent pests that do not justify almost ubiquitous prophylactic neonic seed coatings.

A single exception to the peer-reviewed literature is a meta-analysis study of mostly non-peer-reviewed field tests, most of them sponsored by the pesticide industry. This study is unsuitable for determining the realistic yield protection of neonic seed coatings on corn farms. First, the study does not quantify or compensate for the bias in experimental design which is intended to increase pest frequency and levels above those on typical farms, as discussed above. Although mentioned in passing, the study did not adjust for the impact of these biases on its reported results.

"A single exception to the peer-reviewed literature is a meta-analysis study of mostly non-peer-reviewed field tests, most of them sponsored by the pesticide industry."

Secondly, the study apparently includes tests for rootworm control. Although pesticide labels allow for control of this primary major pest of field corn, research and research entomologists consistently recommend against relying on neonic seed coatings for this purpose. Importantly, there are other better, more effective, and more environmentally sound methods of controlling rootworms, especially crop rotations in most of the range of these pests. And corn-soybean rotations are already widely used and practical, although longer rotations should be encouraged. Secondly, there is evidence that use of prophylactic seed coatings for rootworm control could have negative consequences for resistance management designed to preserve current control measures.

It is likely, based on comparison between the results of the industry meta-analysis and the highly contrary findings of the peer-reviewed literature, that the yield protection seen in the industry-supported study is largely an artifact of biased study design and, especially, residual rootworm control, although this is impossible to say with certainty because these concerns were not addressed in the publication. In any case, the peer-reviewed research should take precedent over this study, which relies extensively on non-peer reviewed tests.

Finally, in published studies, moderate control of rootworms was achieved, although unreliably, only when a high dose of 1.25 mg/seed was used. This is five times the dose used to control most secondary early-season pests. If widely used to control rootworm, this could substantially increase the amount of neonics used over a wide area, greatly increasing harm to the environment, including pollinators, natural pest enemies, aquatic invertebrates, birds and other organisms.

A. AGROECOLOGICAL, AND OTHER ALTERNATIVES TO NEONIC SEED COATINGS

For every early-season insect pest targeted by neonic seed coatings, practical alternative, non-chemical methods have been studied based on the biology and ecology of the pests and crops. For farmers concerned about secondary pests, use of these methods should substantially reduce the possibility of harmful infestations, even lower than the already low occurrence of these pests found in the research literature. Implementation of these practices should make significant infestations of these pests highly uncommon.

More broadly, rather than focusing mainly on specific uncommon pests, the use of agroecological principles, informed and optimized by research, has been shown generally to produce yields as high or higher than those of industrial agriculture, with minimal reliance on pesticides.

In fact, there is evidence that using neonicotinoid seed coatings may actually reduce yields in some cases, because of demonstrated harm to important natural enemies that help control most crop insect pests. Although there are not enough data to verify such impacts in corn, the available research is suggestive. More research on this important topic should be conducted to better inform farming practices.

Although agroecological research has not specifically measured the frequency of the minor pests that neonicotinoid seed coatings target, it has shown that regardless of specific pests, high yields and profits are typically achievable. Agroecological systems achieve these results by fostering biological diversity, which breaks pest cycles through crop rotations and cover crops, and provides high levels of natural pest enemies that usually keep pests in check. And when applied on a regional level, these benefits are enhanced.

"Although agroecological research has not specifically measured the frequency of the minor pests that neonicotinoid seed coatings target, it has shown that regardless of specific pests, high yields and profits are typically achievable."

1. Other Available Treatments

For subterranean pests, rescue treatments cannot be used after planting for the rare cases where heavy infestations occur. But scouting can be done for all of these pests. This can be accomplished in cases where farm practices would be most likely to encourage high infestation levels—in other words, they would not need to be done routinely. For some pests, such as corn flea beetle in several states, data are available that can predict years in which heavy infestations may be more common. Several of the more important pests have multi-year life cycles of the harmful larval stage, and therefore scouting can inform treatment for subsequent years.

For above-ground pests, scouting can also be effective, and in the unusual cases where high infestation levels are encountered, rescue treatments are available. In most cases, these are considered to be as or more effective than seed coatings with neonicotinoids.

2. Would Other Insecticides Simply Continue Harm to the Environment if Neonic Seed Coatings were Discontinued?

Pertinent questions have been raised as to whether the substitution of other insecticides for neonic coated seeds would result in as much or more harm as using neonic seed coatings themselves. To the contrary, recent research that demonstrates that seed coatings are as toxic as applied insecticides like synthetic pyrethroids strongly refutes this argument. The analysis in this report shows that insecticides are rarely needed to control early-season corn pests, and that crop loss from these pests can be largely eliminated by using non-chemical methods. While 71 to almost 100 percent of corn acres are exposed to neonicotinoids, only a small fraction of this area would likely undergo exposure to applied insecticides if neonic seed coatings were eliminated. Because neonics are as toxic as applied insecticides, the greatly reduced exposed acreage exposed to insecticides would likely greatly reduce harm.

3. Why Are Neonic Seed Coatings of Corn So Widely Used?

Given that significant harm from the early-season secondary pests is uncommon, why are the large majority of corn seeds coated with these insecticides? Several possible explanations based on changes in pest levels were considered in this report, but none of them was supportable based on available research.

Part of the explanation is likely to be that farmers see these seed coatings as "cheap insurance" even if the pests they are aimed at are uncommon. Inadequate farmer information about the infrequency of early-season crop pests and inadequate information about reliable alternatives may lead to risk and ambiguity (uncertainty) aversion behavior that may favor purchasing coated seed.

Another reason that coated seed may be accepted is that the process of coating is almost always performed by the seed companies or suppliers before the seed is purchased by farmers, so they do not require extra labor on the farm. There may also be increased incentive to be additionally protective of corn seed due to greatly increased seed price since the advent of expensive engineered traits. And when corn prices are high, as they were for several years beginning in 2007, there is additional incentive to "protect the investment in seed" and production. These points were mentioned in several publications on corn seed coatings by entomologists. But those scientists also point out that prophylactic use as "insurance" is not likely to make economic sense.

"Therefore, the monopoly nature of the seed industry has virtually eliminated farmer choice for non-coated seed."

A related issue is that the highly concentrated corn seed market allows virtually no choice about seed coatings by farmers (Douglas and Tooker 2015)[190]. Several of the major seed companies are reported to coat all of their corn seed before sale, not offering uncoated seed. The other major companies coat almost all of their corn seed. Therefore, the monopoly nature of the seed industry has virtually eliminated farmer choice for non-coated seed.

Finally, it is not clear how often farmers are aware of neonic seed coatings, since this is usually part of a package of traits and coatings. More research on all of these possibilities is needed.

Given the increasingly documented harm to biodiversity and possibly to human health from neonicotinoid coated seeds, and the clear tremendous overuse of seed coatings compared to pest pressures and non-chemical alternatives, the continued prophylactic use of neonic coated corn seed is unsupportable in terms of social and environmental impact.

It is also understandable that current large industrial farms are in some ways trapped, or "locked-into" current practices. This is due to the desire or pressure for simplified, labor-saving methods that facilitate increasing farm size, which is in turn driven in large part by national and international farm policies and markets, and labor saving technologies like seed coatings and engineered traits. In particular, the trends toward overproduction and small net profit margins per acre (or even cost of production that exceeds corn prices) must be addressed if corn farmers are to be helped to forego neonicotinoid seed coating and other harmful industrial farming practices.

However, compared to the challenge of changing farming toward agroecological systems that are highly beneficial to the environment, farms, and rural society, the changes needed to avoid early-season secondary insect pests of corn are relatively simple. Therefore ending the use of neonic seed coatings would be relatively easy to accomplish, and is an opportunity to make farming more sustainable.

B. RECOMMENDATIONS

1. Restrict the use of neonic seed coatings of corn. The published research shows that prophylactic use of neonic corn seed coating is unjustified for its most important purpose of protecting yield. If not eliminated, use should be limited to acres for which heavy infestations of early-season secondary pests occur and are not avoidable or controlled by available non-insecticide methods.

> "The published research shows that prophylactic use of neonic corn seed coating is unjustified for its most important purpose of protecting yield."

2. Conduct surveys of farmers by USDA/NASS or USDA/ERS or independent university scientists to better understand why, and what percentage of farmers believe they need neonic seed coatings of corn. The data from farmer surveys would help better understand how such farmers can be assisted if prophylactic neonic seed coatings are eliminated. Utilize farmer survey results to actively develop outreach tools that help farmers avoid secondary pest insects, or use alternative treatments to control early-season secondary insect pests. This should be done through USDA, especially through public, independent extension services working with farmers to alleviate concerns about restricting the use of neonic corn seed coatings. It is critical that farmers are integrally involved from early stages of this work—including decision making—to ensure that the results are of practical value to them.

3. USDA/NRCS should include consideration of early-season secondary

insect pests and ecologically sound methods of reducing these pests as part of its Conservation Stewardship Program and EQIP grants, especially those, like longer crop rotations, that have multiple benefits. Such grants would be consistent with the goals of the NRCS.

4. Implement, through USDA/RMA, insurance premium support for the rare cases where secondary pests cause substantial damage to corn yield, and such impacts were unavoidable by other viable approaches, as discussed in this report. Other alternative methods for providing insurance could also be considered. One reason that farmers seem to desire neonic seed coatings, despite the infrequency of damage from the targeted insects, is as a form of "cheap insurance".

5. Conduct additional publicly supported research to fill in holes in our knowledge of early-season secondary insect pests of corn, and to refine agroecological alternative practices to avoid or control them. These should emphasize system-level farming practices that reduce pest numbers in general, as well as providing numerous other benefits to the environment, farmers and society. Research should also be supported that improves scouting and other detection and infestation prediction methods for early-season insect pests.

6. Seed companies should be required to make non-coated corn seed of desirable corn varieties readily available. The Department of Commerce and the Department of Justice should investigate whether illegal monopoly practices have made it excessively difficult for farmers to acquire uncoated corn seed. The elimination of farmer choice is contrary to principles of a democratic economy.

"The Department of Commerce and the Department of Justice should investigate whether illegal monopoly practices have made it excessively difficult for farmers to acquire uncoated corn seed."

7. EPA should release its analysis of the efficacy, benefits, and costs of neonic corn seed coatings. It should fully weigh both quantifiable and unquantifiable values in assessments of proposed systemic insecticide products, including at a minimum these foreseeable cost categories:

    - honey bee colony impacts and resulting reduced yields of pollinated crops, reduced production of honey and other bee products,
    - harm to other pollinators and other beneficial and non-target organisms

- financial harm to beekeepers and consumers,
- loss of ecosystem services, and
- market damage from contamination events.

EPA should also require verification by independent scientists and economists (preferably published in peer-reviewed journals) for claims of efficacy, crop yields, and economic benefits associated with all products. It should reject applications to register any prophylactic insecticides that undermine basic IPM and agroecological principles, may harm organic farm production, or are not cost-effective, either for the farmer or the nation as a whole.

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