Neonicotinoid Seed Treatments: Limitations and Compatibility with Integrated Pest Management

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Commentary

Neonicotinoid Seed Treatments: Limitations and Compatibility with Integrated Pest Management

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Core Ideas

- Recent educational offerings incompletely addressed neonicotinoid seed coatings.
- These insecticidal coatings are common on corn, soybean, and other crop seeds.
- Current use patterns violate core principles of integrated pest management.
- We present an overview of these products, focusing on some key limitations.
- Deploying neonicotinoids more judiciously will reduce their negative side effects.

Abstract: Educational materials guiding the use of pesticides are often sponsored or co-created by pesticide manufacturers, raising potential conflicts of interest. For example, early in 2017, two registrant-sponsored webinars from the American Society of Agronomy addressed benefits of neonicotinoid seed coatings, which are routinely applied to seeds of many field crops. While these products can protect yield in certain situations, they also carry significant limitations; unfortunately, these presentations avoided such downsides. Here, we provide an overview of key limitations of neonicotinoid seed treatments (NST). First, we address Integrated Pest Management (IPM) and how current use of NST violates its key principles and ignores lessons learned. Second, we address inconsistent yield responses, resistance concerns, and nontarget effects. Third, we return to IPM to discuss how this proven framework can be used to more effectively guide and steward NST to avoid mounting reports of negative side effects.

Ample evidence from a variety of disciplines has demonstrated that industry funding can influence research conclusions in favor of sponsoring companies (Lexchin et al., 2003; Lesser et al., 2007; Lundh et al., 2017). As agricultural scientists, one of our responsibilities should be to strive to minimize biases that may affect our areas of research, influence our perspective on technological advances, or alter our extension-based messaging to farmers or other stakeholders, while maintaining focus on science that improves agricultural production without compromising environmental health. It is this responsibility that motivated us to write this commentary.

We have noticed a trend for educational programming that purports to provide evidence-based guidance on the use of neonicotinoid insecticides but that is sponsored by pesticide manufacturers and presents a one-sided view. For example, early in 2017, the American Society of Agronomy hosted two webinars addressing the use of coatings of neonicotinoid insecticides on seeds of large-acreage crops like corn, soybean, and cotton. (“Neonicotinoid Seed Treatment: The How, What & Why” [Reichart et al., 2017] originally aired on 14 Feb. 2017; “Neonicotinoid Seed Treatment Benefits” [Mitchell, 2017] originally aired on 1 Mar. 2017. One need not have viewed the webinars to understand the points we make here.) Neonicotinoid seed treatments (NST) are marketed to control some early-season insect pests in these crops and have become a focus of debate in recent years in part because of links between their use and negative effects on insect pollinators, including honey bees (Godfray et al., 2014, 2015; Tsvetkov et al., 2017; Woodcock et al., 2017). Bayer and Bayer’s Bee Care program sponsored the webinars, allowing them to be viewed for free. Notably, Bayer is one of the leading manufacturers of neonicotinoid insecticides (Jeschke et al., 2011). The goal of these webinars was to have industry and research experts review questions that included:

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Abbreviations: IPM, integrated pest management; NST, neonicotinoid seed treatments.

"Should seed treatment be used in IPM programs?" and "What are some of the benefits to using seed treatments?" For each webinar, continuing education credits were available for certified crop advisors and certified professional agronomists, indicating that the society saw practical value in the content being offered. Presenters included two Bayer employees and two academics; all offered uniformly positive assessments of NST. Following the webinars, the viewer was left with the impression that there is little room for improvement to the status quo, whereby virtually all corn and the majority of cotton and soybean seeds are treated with NST with little or no regard to pest presence/absence.

As scientists engaged in ongoing research on various aspects of neonicotinoid insecticides, we were disappointed that although offered as educational opportunities, both presentations largely ignored core issues associated with neonicotinoids and failed to acknowledge any of the limitations and challenges posed by widespread use of NST. It is not surprising that Bayer would want to sponsor presentations highlighting benefits of their products, but it is surprising that a major scientific society hosted these webinars under the banner of "professional development without the sales pitch." On the contrary, the research highlighted in the webinars was an incomplete cross-section of available research, and much of it was industry funded.

The purpose of this paper is first to voice a general concern about the potential conflict of interest inherent in industry-sponsored educational materials and second to provide for society members a broader summary of peer-reviewed literature, particularly as it relates to limitations and caveats associated with current NST use. This information should be broadly useful, including for individuals who are interested in this topic but did not view the webinars, because it will provide a perspective on the limitations of NST. We do not rehash the benefits of NST because this information has been highlighted elsewhere (Elbert et al., 2008; Jeschke et al., 2011; North et al., 2016; Hurley and Mitchell, 2017).

We focus in particular on important questions that were raised by the webinar audience—and not adequately addressed by presenters—concerning the role of NST in integrated pest management (IPM), the potential for insecticide resistance, and effects on nontarget species. We highlight IPM as an established framework that although not used currently being used on most acres, can realistically be used to direct use of NST and emphasize how the current industry-mandated use of neonicotinoids ignores the tenets of IPM and the history that led to their development. After addressing IPM, we discuss the widespread use of these products and the evidence for unintended effects both within and outside of cropping systems. The debate about these compounds has become polarized, and there are no simple answers, but stakeholders, including growers and beekeepers, are not well served by a selective tour of research findings that ignores a wealth of peer-reviewed data. We hope to stimulate a robust, informed discussion on the value of these products and their place in current and future agricultural systems.

Integrated Pest Management: A Brief History

The origin of IPM is often traced to 1959, when a team of entomologists introduced its core concepts to the world (Stern et al., 1959). This rigorous, yet simple, evidence-based paradigm was introduced to overcome recurring problems associated with regular, "calendar-based" use of broad-spectrum insecticides, such as dichloro-diphenyl-trichloroethane (DDT) (Stern et al., 1959). These problems included insecticide resistance, residues on crops at harvest, outbreaks of secondary pests, resurgence of primary pests, and nontarget effects on wildlife and humans. This publication introduced the now-familiar concepts of "economic injury levels" and "economic thresholds." It also brought much-needed attention to the importance of natural enemies in maintaining pest populations below economically important levels. Since its introduction, IPM has become synonymous with long-term, sustainable control of pests in agricultural and nonagricultural settings (Kogan, 1998; Sternberg, 2017) and even has been adopted by some medical practitioners to treat human diseases, including cancer (e.g., Gatenby, 2009). Although large field sizes have made some IPM approaches (particularly scouting) challenging for field crops, IPM played a role in production of these crops until relatively recently. At the very least, growers have historically had the choice to opt in or out of insecticide use. As we address below, this is no longer the case, although the reasons for this change are unclear.

Stern et al. (1959) accounted for different severities of pests and commented on appropriate responses to each. They addressed pests that ranged from those that never exceed economic thresholds to those that rarely exceed them ("occasional pests") to those whose populations always exceed economic thresholds ("severe pests"). Fields subject to severe pests tend to require near constant control with insecticides to prevent economic losses (Stern et al., 1959). Notably, the current, widespread use pattern of NST (Douglas and Tooker, 2015) aligns with severe pests, but the risk posed by target pests to crops does not. This disconnect and its repercussions are the focus of the remainder of this paper.

Current Use and Justification for Neonicotinoid Seed Treatments

Neonicotinoids are the most widely used insecticides in the world. The various compounds have some important differences; the nitroguanidine neonicotinoids, including imidacloprid, clothianidin, and thiamethoxam, are the active ingredients most commonly used as seed coatings (Elbert et al., 2008). Until recently, the full extent of their use was unclear because the USDA's National Agricultural Statistics Service has not included seed coatings in their major pesticide survey. Some of our recent work combined data from the National Agricultural Statistics Service pesticide survey with pesticide-use data reported by the USGS and revealed that use of neonicotinoid treatments on seeds of corn and soybean increased dramatically between 2003 and 2011, representing a vast increase in the area of these crops treated with an insecticide (Douglas and Tooker, 2015). By 2011, 79 to 100% of corn acres and 34 to 44% of soybean acres were treated with NST (Douglas and Tooker, 2015), far above the <50% of corn acres and <10% of soybean acres that were typically treated with an insecticide from the 1950s to the 1990s (Osteen and Fernandez-Cornejo, 2013). In other words, much of NST use is on "new acres" rather than displacing acres treated with older insecticide products. After reviewing the literature, we concluded that this large increase in use did not correspond to an equivalent increased risk from target pest species.

Remarkably, even though NST were used on close to 100% of corn acres by 2011 (Douglas and Tooker, 2015), recent data from USGS suggest that the amount of neonicotinoids applied to corn *doubled* between 2011 and 2014 (Fig. 1), despite corn prices falling over that period and acreage remaining fairly stable (USDA National Agricultural Statistics Service, 2017). Because the increased use on corn cannot be explained by expanding treated acres, it must correspond to increasing per-seed application rates. Notably, this increase has come as concerns about nontarget effects and resistance have mounted (details below).

Given the tens of millions of hectares of cropland planted with neonicotinoids annually (Fig. 1), one might expect a multitude of robust datasets demonstrating their benefits in focal cropping systems. However, these datasets are uncommon in peer-reviewed literature. Although some studies have identified benefits (e.g., North et al., 2016; Hurley and Mitchell, 2017), evidence for their value has proven elusive in many, if not most, cases. The hallmark of peer-reviewed studies on NST effects in corn and soybean production is variability in yield and economic effects among fields, years, and regions (reviewed in Douglas and Tooker, 2015; see also North et al., 2016; Hurley and Mitchell, 2017; Krupke et al., 2017a, 2017b). The primary explanation for this inconsistency is that NST mainly target occasional, soil-dwelling pests (e.g., wireworms, white grubs, seedcorn maggot), populations of which are typically low and sporadic over space and time. Surveys indicate that farmers infrequently perceive these pests as important problems (Fernandez-Cornejo and Jans, 1999; Hurley and Mitchell, 2014). A secondary explanation is that the potential for neonicotinoids to benefit the crop is quite low because the active ingredient is only detectable in plant tissues for 2 to 3 wk after planting (Krupke et al., 2017a; Alford and Krupke, 2017). In other words, benefits can only be realized when economically damaging populations of relatively uncommon pests intersect with short-lived insecticides in plant tissues. The current approach is one whereby the targeted pest species tend to be only occasional pests, but the tactic being deployed against them suits severe pests. This use pattern is directly contrary to IPM principles.

Integrated pest management was developed in part because of recognition that indiscriminate use of any pesticide is likely to have unintended, negative consequences, both within and outside cropping systems. Neonicotinoid seed treatments, which are toxic at low concentrations to a broad range of both pest and beneficial insects, are no exception, as discussed below.

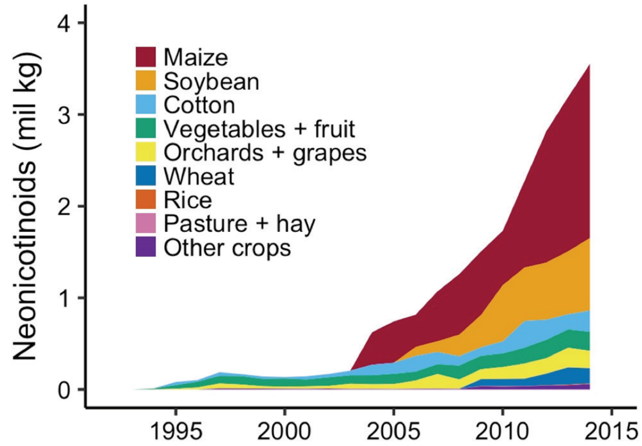

Fig. 1. Neonicotinoid use by crop from 1992 to 2014. Data on crops and active ingredients are for the entire United States, from the USGS National Pesticide Synthesis Project (EPest-High estimate; Baker and Stone, 2015). The *y* axis represents mass of neonicotinoid active ingredient applied in millions of kg.

Unintended Effects of Neonicotinoid Seed Treatments within Cropping Systems

A recent meta-analysis of field studies concluded that NST negatively affect natural-enemy populations similarly to broadcast applications of pyrethroids (Douglas and Tooker, 2016). The long-term implications of such reductions are difficult to predict, but in no-till soybeans in Pennsylvania short-term disruption of biological control by NST benefited slug populations and decreased yield (Douglas et al., 2015). Neonicotinoid seed treatments also have complex effects on crop physiology and defenses (Szczepaniec et al., 2013), which together with effects on natural enemies has likely contributed in recent years to substantial increases in cotton acreage requiring treatment for spider mites (Smith et al., 2013).

Using the same class of insecticides on a large number of acres year after year also exerts strong selection for resistance. In southern states, resistance to NST by tobacco thrips (*Frankliniella fusca*) is widespread, and efforts to forestall resistance and maintain effective thrips control in cotton could lead to a 15-fold increase in active ingredient per acre, eroding grower profit and environmental health (Huseth et al., 2016). While resistance-monitoring efforts are limited, if current use patterns continue, it seems likely that other pest species have or will evolve resistance to NST.

Unintended Effects of Neonicotinoid Seed Treatments in the Broader Environment

Even several years after their introduction as seed treatments, registrant-authored publications presented NST as ideal pest management tools, with high efficacy against targeted pests and low risk for nontarget effects and environmental contamination. Indeed, NST were claimed to "allow for environmentally safe and perfect protection of young plants against insect attack" (Elbert et al., 2008) and were expected to cause no harm to beneficial organisms (Jeschke et al., 2011). This optimism apparently rested on targeted application to seeds, their absorption by roots, and systemic activity in plants.

Subsequent research has revealed a different picture. We will only touch on these issues briefly to define the scope of challenges posed by NST; we direct readers to cited papers for more details.

Following planting, the vast majority of NST does not stay on seeds or in target plants. Some active ingredient is lost during planting due to abrasion of seeds and release of contaminated dust (Krupke et al., 2012, 2017b), but a far larger amount (the majority of what is applied to the seed) is lost due to the high water solubility of these compounds (USEPA, 2003; US National Library of Medicine, 2017). The amount of neonicotinoid applied to seeds that actually gets absorbed by plants is typically about 1 to 10%; the rest remains in soil where it is vulnerable to leaching (Alford and Krupke, 2017; Krupke et al., 2017a).

When leached from crop fields, neonicotinoids enter surface and groundwater at higher frequencies than older classes of insecticides and in concentrations high enough to influence aquatic insect populations (Hladik et al., 2014; Hladik and Kolpin, 2016; Main et al., 2014, 2015; Miles et al., 2017). In turn, reductions in aquatic insect abundance may have cascading effects on insectivorous birds, fish, and other vertebrate wildlife (Gibbons et al., 2015; Hallmann et al., 2014). Moreover, despite lower toxicity of neonicotinoids to mammals relative to older insecticide classes (Tomizawa and Casida, 2005), the risk to humans of neonicotinoid exposure is unclear because so few studies have addressed neonicotinoids and human health (Cimino et al., 2017).

Lastly, a large number of studies have demonstrated how NST can lead to lethal and sublethal effects on wild and managed pollinators (reviewed in Godfray et al., 2014, 2015). Briefly, NST-contaminated planter dust can lead to acute exposure for foraging honey bees (Krupke et al., 2012, 2017b). Wild and managed pollinators can also be chronically exposed to neonicotinoids via pollen and nectar of crops treated with NST and/or wildflowers or weeds growing nearby (Tsvetkov et al., 2017; Rundlöf et al., 2015). Continued, low-level exposure can cause sublethal effects, including increased susceptibility to parasites and pathogens, impaired foraging behavior, and reproductive failure (Henry et al., 2012; Pettis et al., 2013; Tsvetkov et al., 2017). While there are many interacting factors contributing to declines in pollinator populations, available evidence suggests that NST cannot be ignored as a contributing factor. Moreover, despite public pronouncements about commitments to pollinator health in recent years, the main quantifiable response of registrants to mounting concerns associated with NST use has been to apply dramatically more active ingredient to seeds (Fig. 1).

A More Sensible Path

Rather than violating IPM, the emphasis should be on stewardship of NST. Simply put, we support using NST on those acres where damaging populations of target pests are likely to occur. Some of the key risk factors for these pest infestations are known (e.g., Furlan et al., 2017), and guidance on the biology and monitoring of these pests is available through extension publications. Currently, however, such targeted use is impossible because farmer choice is restricted; corn seeds, and increasingly seeds of other field crops, are simply not widely available without NST. Growers effectively receive a mandate to use (and pay for) products that many of them will not need, or benefit from. Indeed, as noted in the webinar on "Seed treatment benefits" (Mitchell, 2017), many growers seem not to know they are using NST, probably because these insecticides are usually part of larger, standard packages of products applied by seed suppliers.

Unfortunately, as addressed above, most current use of NST is not justified under IPM because targeted species are "occasional pests" and economic benefits are inconsistent. Current use of NST—on nearly 100% of corn acres and >50% of soybean acres—far exceeds historic benchmarks for insecticide use in these crops (Douglas and Tooker, 2015). In the decade prior to introduction of NST, only about 35% of corn acres and 5% of soybean acres received insecticides (Fernandez-Cornejo et al., 2014), challenging the notion that NST have simply displaced older insecticide products.

Current use of NST is charting new territory, with most acres of our largest crops being treated with nonselective insecticides without regard for pest populations. The current approach appears not to be driven by the needs of US farmers. Given the value of neonicotinoid insecticides as insect-management tools, we strongly believe that their future use should be stewarded within an IPM framework. Doing so, and thereby greatly reducing the acreage being treated, will maintain the utility and value of these insecticides, while alleviating growing concerns about nontarget effects and environmental pollution.

We hope that highlighting important details not included in registrant-sponsored messaging will provide useful context for society members who want to develop their own positions on NST. More broadly, we encourage the societies to develop conflict-of-interest policies for their educational offerings and hope that future offerings will present a more thorough and critical view of the wealth of literature on various sides of this and the many other complex issues that bedevil production agriculture.

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