Sustainability of Genetically Engineered, Insect-Resistant Crops: A View from the Fringe

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The goal of this paper is to highlight important benefits and limitations of ubiquitous technology-based approaches to pest control that are often utilized outside the framework of integrated pest management (IPM). Particularly in Pennsylvania and other states on the fringe of the Cornbelt, where pest pressures can be lower or different than in large portions of the Midwest, farmers and pest managers would benefit from remembering the tenets of IPM, which involve understanding local pest populations and using appropriate measures to control them when necessary.

Introduction

When viewed from a distance, modern agricultural production can seem very uniform and generic. Particularly for grain and forage crops, there can be a perception that farmers all follow the same script, planting similar crop varieties on similar dates, and using refined management practices that result in ever-improving yields. This perception is perhaps enhanced by looking at large farms, particularly in the American Midwest, that grow grain crops over thousands of acres, dominating the landscape of some midwestern states. Eighty-six percent of land in Iowa, for example, and 75% of Illinois, are planted to just a few crop species, mainly corn and soybeans. These midwestern agricultural landscapes can generally be characterized as having little noncrop habitat and larger farms that grow a relatively limited diversity of crops with little rotation.

By contrast, only 14% of Pennsylvania is planted to crops. Pennsylvania farms are smaller and have smaller average field sizes. Moreover, Pennsylvania crop landscapes are typically much more diverse than most midwestern agricultural landscapes, containing higher levels of crop diversity and substantial areas of noncrop habitat. Also, Pennsylvania farmers tend to be more committed to longer crop rotations and conservation-based farming tactics such as no-till and cover crops. Pennsylvania farms, and those of other mid-Atlantic or northeastern states, are therefore different from midwestern farms that form the heart of the Cornbelt. Pennsylvania is part of what can be considered the eastern fringe of the Cornbelt, and being on the fringe has costs and benefits. One of the costs is that the agricultural industry, particularly the big companies with a national scope, consider Pennsylvania and the Northeast somewhat of a secondary market; therefore, most of their products are designed for the heart of the Cornbelt, but can be used on the fringe. Among the benefits of being on the fringe is that we have lower levels of agricultural intensification, which includes lower concentrations of agricultural fields and more noncrop habitat. From a pest management perspective, lower intensification on the fringe tends to translate to lower, and occasionally different, pest populations challenging our crop fields.

IPM has historically been the dominant framework for developing pest management strategies and tactics and directing pest control decisions. Over the past two decades, however, the agricultural industry has invested in developing tools that allow farmers to protect many acres of crops by planting specialized seeds (and committing to some associated tasks), producing remarkable efficiencies. For instance, weed management was revolutionized by herbicide-resistant crops, which allow herbicides to be sprayed directly over crops. This genetically modified technology has saved farmers untold hours by simplifying weed management, but unfortunately yield improvement has not accompanied the gains in efficiency (Gurian-Sherman, 2009; Shi et al., 2013). In contrast, transgenic, insect-resistant crops (i.e., *Bt* crops) have improved yields slightly while saving farmers scouting time and insecticide costs (Gurian-Sherman, 2009; Shi et al., 2013). Because these transgenic pest management options tend to make farming easier, they have been widely adopted and are now the "default setting" for most US growers. In 2013, transgenic herbicide-tolerant corn accounted for 85% of US acreage, whereas 76% of US corn was planted with *Bt* varieties.

Building upon these seed-based pest management tools, agricultural companies have been adding further pest management options to crop seeds, widening the spectrum of insect pests that seed-based technology can control. Since 2004, the great majority of corn seed sold in the US has been treated with fungicides and/or insecticides to combat early season pathogens or insect pest populations. The insecticides used to coat seeds are from a class of compounds known as neonicotinoids, which are among the most active insecticides yet discovered, but they have been the focus of much attention recently because of their environmental contamination and potential nontarget effects (Bonmatin et al., 2015; Chagnon et al., 2015; Hallman et al., 2014; Hladik et al., 2014; Krupke et al., 2012; Main et al., 2014).

While seed-based insect management options have become standard for many growers, their value depends largely upon the size of the pest populations they are targeting. If weed populations disappear, for example, what value do herbicide-tolerant crops provide? As mentioned above, the fringe tends to have lower, or different, pest populations than the core of the Cornbelt. The goal of this paper is to highlight benefits to be gained by understanding the local pest complex and the threat posed by local pest populations. By highlighting three pest species, we will explore the value and limitations of the current "standard" approaches to pest management.

European corn borer, *Ostrinia nubilalis* (Hubner) (Lepidoptera: Crambidae)

Historically, European corn borer (ECB) has been the most important pest affecting corn production in the United States. ECB is a highly polyphagous pest species that was accidentally introduced into North America in the early 1900s (Vinal, 1917). Prior to introduction of *Bt* corn hybrids, ECB caused crop losses that annually approached $1 billion nationwide and $35 million in the Northeast (Dillehay et al., 2004; Hutchison et al., 2010). In 1996, agricultural companies introduced *Bt* corn hybrids targeting ECB. These hybrids have been widely adopted because they are exceptional for managing ECB: 99.9% of larvae are expected to die when they feed on plants expressing *Bt* toxins (Huang et al., 2011). Because of this strong efficacy, large portions of the Midwest have experienced large-scale reductions in populations of ECB (Hutchison et al., 2010).

With this previous research in mind, and seeking to understand the threat posed by ECB to Pennsylvania corn fields, colleagues and I initiated a three-year study (2010–12) to quantify ECB populations and track the yield and overall economic value of *Bt* and non-*Bt* corn hybrids. We found that *Bt* hybrids continue to provide excellent control of ECB. Moreover, in contrast to a similar study conducted in Pennsylvania in 2000–02 (Dillehay et al., 2004), we found that ECB populations in most of parts of Pennsylvania are considerably lower than ten years ago (Bohnenblust et al., 2014). This population decline may have been caused by widespread adoption of *Bt* hybrids, but our analyses did not detect a relationship between in-field infestations and adoption rates or even features of the landscapes surrounding the fields we sampled. Importantly, our sampling revealed that ECB populations persist in some parts of the state, remaining about the same as in 2000–02 (Bohnenblust et al., 2014). By calculating the economics of production for the different *Bt* and non-*Bt* hybrids studied, we were able to determine that in many parts of the state, particularly where ECB populations were negligible or absent, non-*Bt* hybrids were more profitable, largely because of their lower seed costs. In areas with stronger ECB populations, *Bt* hybrids made more economic sense, but they were not guaranteed to be more profitable, again because of the high seed costs (Bohnenblust et al., 2014).

Given our results, we have been advocating to growers in Pennsylvania that their economic bottom lines could benefit from a better sense of their local populations of ECB. Growers should assess their local populations to know whether or not they are gaining value from planting *Bt* hybrids (Bohnenblust et al., 2014). Blindly planting *Bt* hybrids without regard for the population's size is missing an opportunity to maximize profit while taking advantage of possibly historic lows in pest populations.

Western corn rootworm, *Diabrotica virgifera virgifera* (LeConte) (Coleoptera: Chrysomelidae)

Western corn rootworm (WCR) is currently the most significant corn pest worldwide. The costs of WCR damage and control are estimated to total about $1 billion (Gray et al., 2009). This pest species is extremely adaptable and has evolved resistance to soil-applied insecticides, crop rotation, and, most recently, transgenic *Bt* hybrids (Gassmann et al., 2011, 2014; Gray et al., 2009). WCR is a pest of continuous corn production, and in Pennsylvania and other mid-Atlantic or eastern states, it is easily controlled by rotating corn with soybeans, alfalfa, or other nonhost crops; WCR lays its eggs in corn fields, and when these fields are planted to a nonhost crop the next season, WCR larvae cannot feed and die. Therefore, crop rotation provides an inexpensive, reliable, cultural control alternative to *Bt* hybrids or soil insecticides (Tooker & Difonzo, 2013). Nevertheless, some Pennsylvania farmers who rotate continue to purchase *Bt* hybrids targeting WCR, buying protection from which they gain no value.

In 2014, colleagues and I learned of three farms in Pennsylvania that had greater than expected damage from rootworm larvae to *Bt* hybrids targeting WCR. This damage occurred in fields that were planted to corn for at least three years. We visited these sites to characterize root damage and found more than 2.5 of each plant's 3 nodes of roots chewed away. We also tested the damaged plants with gene check kits (i.e., Quickstix) to confirm they were producing the appropriate *Bt* toxins (they were), and collected adult beetles (Tooker, 2014). With laboratory assays, we are in the process of determining if the beetle populations we collected are resistant to *Bt* hybrids.

From a practical perspective, however, whether these beetles are resistant does not matter; resistant populations are mostly an academic issue. Large populations of beetles are problematic regardless of resistance, and farmers should take definitive steps to reduce their size. Fortunately, in Pennsylvania crop rotation is very effective at eliminating WCR populations; we do not need advanced insecticidal technology to control this pest species. In this case, just understanding biology and rotating to disrupt the pest life cycle are adequate. This is how IPM is supposed to work: use any means necessary, the less toxic or expensive the better. Rotating crops to control rootworm has been my recommendation to any growers who will listen; rotate your crops and the problem will go away.

Gray garden slug, *Deroceras reticulatum* (Müller) (Mollusca: Gastropoda: Agriolimacidae)

The final pest I will consider is slugs, which in Pennsylvania crop fields are a complex of four species, the most damaging of which is the gray garden slug. This pest species, also accidentally introduced from Europe, has been in the US for about 170 years and has become particularly problematic in no-till crop fields. Farmers manage approximately 1.5 million acres of Pennsylvania croplands with no-till, including about 75% of soybean and 65% of corn fields in the state. Slugs, one of the greatest challenges to no-till in Pennsylvania (Douglas & Tooker, 2012), thrive in the stable habitat provided by no-till and benefit from the moisture typical of spring and fall in mid-Atlantic states. In spring, slugs attack corn, soybean, alfalfa, and even canola seedlings, whereas in fall they attack small grains and various cover crop species (Douglas & Tooker, 2012).

Our research has revealed that ground beetles, also known as carabid beetles, and other predators can help control slug populations. In fact, we have found an inverse relationship between slug and ground beetle populations, meaning that when many ground beetles are present, we find very few slugs, and vice versa. This pattern suggests that fostering ground beetle populations should help farmers decrease slug populations. And some of our recent research indicates that this is true, but we also found that seed-applied insecticides can disrupt the benefit of predators for controlling slug populations.

In recent years, neonicotinoid insecticides are becoming increasingly common on corn and soybean seeds. In fact, from 2004 to 2011 the percentage of corn seed in the US that was coated with a neonicotinoid insecticide increased from 0 to about 95% (Douglas & Tooker, 2015). These insecticides layered on seeds are absorbed systemically by plants and run through their vascular tissue, protecting the plants from some early season insect pests for the first few weeks of growth. Unfortunately, slugs also attack early in the season but are not susceptible to these insecticides (recall that slugs are not insects but gastropods, in the phylum Mollusca).

We found evidence that slug populations tend to be worse in corn and soybean fields planted with seeds coated with neonicotinoid insecticides. To explore this potential more closely, we conducted laboratory and field experiments in soybeans. In laboratory experiments, slugs were not affected by neonicotinoids, ingesting plant tissue from soybean seedlings grown from treated seeds as readily as that grown from untreated seeds. We also found that when predators attacked slugs that had fed upon plants grown from treated seeds, they were poisoned or killed (Douglas et al., 2015). In the field, we planted quarter-acre plots with either seeds coated with the neonicotinoid thiamethoxam or seeds without thiamethoxam and tracked plant growth and productivity, slug and natural enemy populations, and predation. This research verified that seed-applied insecticides can indirectly increase slug damage to crops by poisoning insects that eat slugs. In the field, plots with neonicotinoid-treated seed had more slugs, which translated to fewer plants per acre and lower yield (Figure 1).

When we considered the influence of predators on slugs, we found that higher levels of predation were driven by having more slug predators in the plots, but plots planted with

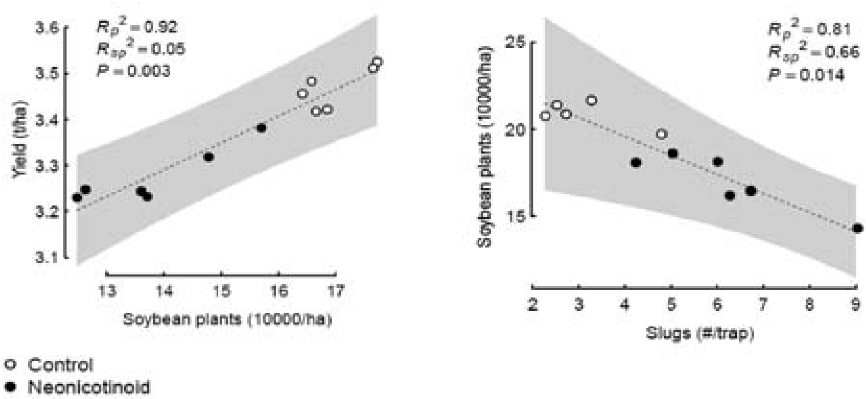

Figure 1. Soybean plots without neonicotinoid seed treatments tended to have higher yield (left-hand panel) because slugs were more abundant in plots with neonicotinoid seed treatments (right-hand panel). Source: Douglas et al., 2015.

soybeans coated with neonicotinoid insecticide tended to have fewer predators and less predation, as measured in the field by a sentinel prey assay; see Figure 2. Moreover, plots with more predation tended to have fewer slugs, but plots planted with insecticidal seed treatments tended to have less predation and more slugs (Figure 2). Overall, in slug-infested plots, soybeans planted with neonicotinoid seed coatings had 19% fewer plants per acre and 5% lower yield. The mechanism responsible began with a lack of an effect of the insecticide on slugs that fed on plants grown from treated seeds. Then, when insect predators ate these slugs, the predators were sensitive to the insecticide now inside the slugs. On average, the slugs contained about 200 parts per billion of neonicotinoid insecticides (Douglas et al., 2015). Importantly, where seeds were planted without the neonicotinoid seed coating, predation of slugs was greater, and yield was higher. These results suggest a major downside to planting neonicotinoid-treated seeds in fields that have significant slug populations. In these situations, the insecticide is doing more harm than good, and a good first step toward pest control in these fields is planting seeds without insecticidal seed treatments.

From these experiments with slugs, we conclude that the default setting of high-input, preventative pest management has a significant downside. Blindly following pest management approaches that were developed with the core of the Cornbelt in mind (not slugs) can be problematic on the fringe, where we have a different pest complex. Our research indicates that growers would benefit strongly from using IPM and managing the pests that they do have, not the pests that they might have. Neonicotinoid seed treatments provide control of secondary pests that may or may not arrive, but farmers tend to know which of their fields have slug problems. In these fields, it is best to use IPM and assess the local populations and respond to them should they become economically significant.

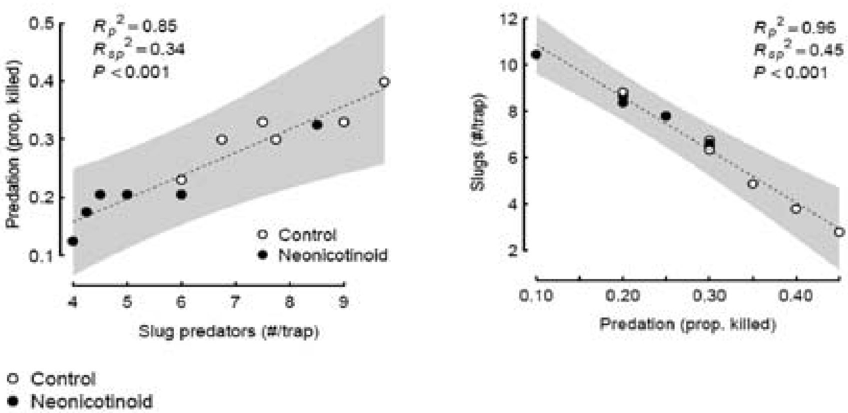

Figure 2. Soybean plots without neonicotinoid seed treatments tended to have higher yield (left-hand panel) because slugs were more abundant in plots with neonicotinoid seed treatments (right-hand panel).
Source: Douglas et al., 2015.

Conclusions

The three pest species I covered here illustrate that the standard prophylactic pest management approach that has been developed for the majority of the Cornbelt has some shortcomings on the fringe. Here, it is best to understand local pest populations, their dynamics, and their biology. By knowing more about pest populations, growers can take advantage of more appropriate control options, minimizing input costs and maximizing profitability. If there are no European corn borer populations in a region, *Bt* hybrids may not be necessary, particularly because some of the other caterpillar pest species that are controlled by *Bt* hybrids tend to be spotty or rare in Pennsylvania and are more economically managed via scouting and rescue treatments. For western corn rootworm, technology does not need to be deployed at all if growers are open to crop rotations that naturally control this pest species in our region. And for slugs, ubiquitous neonicotinoid seed treatments seem to be exacerbating populations by rendering predatory insects less effective, so planting untreated seeds and conserving predator populations can provide an advantage that can resonate to bottom lines (fewer inputs, higher yield, more profit).

Overall, this approach to managing pest populations on the fringe is not pro- or anti-technology. It is just IPM, a knowledge-based approach for managing the pests that growers have, not pests that they may have. This approach is relevant for almost any agricultural system, including the heart of the Cornbelt, but is especially appropriate for growers with smaller fields in more diverse landscapes, such as those found in Pennsylvania and other parts on the fringe of the Cornbelt.

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