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Issue

Softening Shock and Awe Pest Management in Corn and Soybean Production with IPM Principles

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Abstract

The trend in U.S. corn (*Zea Mays*) and soybean (*Glycine max*) crop protection over the past two decades is toward a one-size-fits-all approach that links farmers' insect, weed, and disease management decisions. With re-emerging pest management concerns that include herbicide resistant weeds, Bt-resistant insects, and declines in some pollinator and butterfly populations, it is an opportune time to reflect on how integrated pest management (IPM) principles may be further incorporated into this trend. The purpose of this article is to detail the current trend in corn and soybean crop protection, compare this trend with IPM, and propose ways in which IPM principles can be used to make current corn and soybean crop protection practices more sustainable and resilient.

Key words: disease, insect, integrated pest management, weed

Crop pest management became heavily reliant on chemical pesticides following World War II (Smith et al. 1976). While heavy reliance on this chemical pesticide paradigm increased agricultural productivity through more cost-effective pest management, it was not without adverse consequence including pest resistance diminishing pesticide effectiveness, environmental concerns such as diminished water quality and wildlife abundance, and human health concerns from both acute and long-term exposure to potentially harmful chemicals. Integrated pest management (IPM) received increasing attention in the 1970s as a strategy to reduce the adverse consequences of pesticide use (Kogan 1998). While there is a wide range of evolving definitions for IPM (Bajwa and Kogan 2002), two key elements in these definitions are the more selective use of pesticides and the use of a more diverse range of pest control tactics. Often, in addition to this selectivity and diversity, is the notion of management decisions guided by societal and environmental as well as producer costs and benefits, and long-term as well as near-term costs and benefits. With its holistic and more environmentally sensitive approach to pest management, IPM promotion by the U.S. Environmental Protection Agency's (EPA) is common in its public statements and official rule making (see https://www.epa.gov/safepestcontrol/integrated-pest-management-ipm-principles [accessed 15 March 2018]).

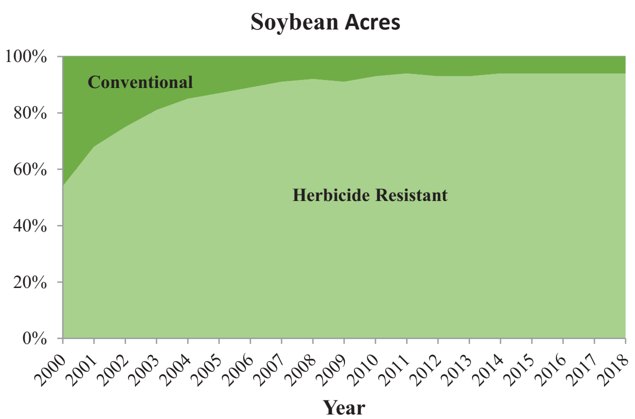
The 1996 commercial introduction of genetically engineered (GE) crop varieties with insect-resistant (IR) traits such as Bt corn (*Zea Mays*) and herbicide-resistant (HR) traits such as Roundup Ready soybean (*Glycine max*) marked the beginning of a significant disruption to the slowly advancing IPM paradigm. This disruption includes the increasing integration of insect, weed, and disease management with GE crops, broad spectrum herbicides, and pesticide seed treatments, which often results in less rather than more selective pesticide use contrary to IPM. Also contrary to IPM in corn and soybean production, the adoption of this new pest management paradigm has been both rapid and widespread, much like the original chemical pesticide paradigm IPM meant to supplant. As with the original chemical pesticide paradigm, the new paradigm has provided a wide range of benefits. However, after less than two decades of extensive use, old problems IPM strove to solve appear to be reemerging (e.g., HR weeds, Bt-resistant insects, and declines in some pollinator and butterfly populations). This re-emergence of old problems is creating an increased urgency to answer a question that has loomed since the first commercial approval of GE crops: How does IPM fit with this new pest management paradigm? (US EPA [1998] offers an early example of how the agency sought a complementary relationship between IPM, Bt corn, and its regulations).

The objective of this article is to assess the extent to which U.S. corn and soybean crop-protection reflects IPM principles. It also ponders the extent to which problems emerging with corn and soybean production are solvable through further adaptation of IPM principles. To accomplish these objectives, we first review recent trends in U.S. corn and soybean pest management and the socioeconomic factors associated with these trends. We then interpret these trends in the context of IPM before proposing strategies for adapting IPM principles to current U.S. corn and soybean production practices. The proposed strategies include thoughts on how the adoption of these adaptations can be encouraged in order to increase the sustainability and resiliency of corn and soybean pest management.

U.S. Corn and Soybean Pest Management Trends

In 2000, the U.S. Department of Agriculture's National Agricultural Statistics Service (USDA-NASS) began using a system with three classifications to track GE crops first introduced in 1996. 'IR' varieties engineered to produce proteins that are toxic to select insect pests but not engineered with herbicide resistance (e.g., Bt corn). 'HR' varieties engineered to withstand the application of certain broad-spectrum herbicides but not engineered to be toxic to insect pests (e.g., Roundup Ready soybeans). 'Stacked gene' varieties engineered to produce proteins that are toxic to select insect pests and to withstand the application of certain broad-spectrum herbicides (e.g., Roundup Ready–Bt corn). Figure 1 shows the remarkably rapid adoption of soybeans with HT traits. Within 5 yr of commercialization, more than half of all U.S. soybean acres had HR traits, whereas in <20 yr, nearly 19 out of every 20 acres had HR traits. While the trend for corn is not quite as impressive, it is still remarkable. Within 5 yr of introduction, 1 out of 4 acres of corn had IR or HR traits and in <20 yr, just over 9 in 10 acres had IR or HR traits. It is also notable how the adoption of these IR or HR traits in corn accelerated around 2005, foreshadowing other important trends that the USDA-NASS classification is too coarse as well as too narrow to reveal (by too narrow, we mean it focuses exclusively on IR and HR traits and no other ways of delivering pesticides).

The first varieties of GE corn produced a single toxin primarily for the control of European and southwestern corn borer (*Ostrinia nubilalis* and *Diatraea grandiosella*). By 2000, some farmers were starting to use 'stacked' GE corn that produced a toxin for corn borer control and had an HR trait, so it could withstand the application of glyphosate herbicide. By 2003, the EPA approved a new IR trait for corn to produce a toxin to control primarily western and northern corn rootworm (*Diabrotica virgifera virgifera* and *Diabrotica barberi*). With the introduction of this new IR trait, 'stacking' could now refer to a combination of IR and HR traits, two IR traits each targeting different types of pests, or an HR trait and two IR traits each targeting different types of pests.



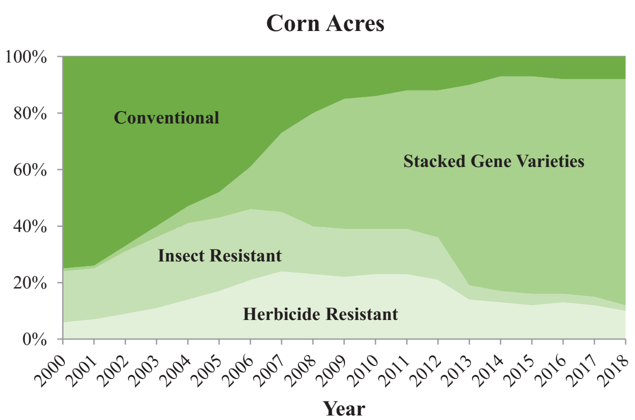


Fig. 1. Adoption rate of insect resistant and herbicide tolerant corn and soybean from 2000 to 2017 (Source: Authors' construction based on publically data—USDA-NASS 2001–2018, usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1000).

Continuing innovation in the chemical and seed industry led next to 'pyramided' IR traits. The distinction between pyramided and stacked IR traits hinges on whether the different toxins produced by a GE corn variety target the same or different types of pest. From a marketing perspective, the seed industry tends to classify types of insect pest as above-ground and below-ground pests. If the toxins target the same types of pests, they are pyramided. Stacked traits target different types of pests. Of course, it is also possible to have both stacked and pyramided traits, which is the current state of the art. For example, DuPont/Pioneer's (Johnston, IA) Optimum AcreMax Xtreme brand corn seed includes two IR traits for corn borer control, two IR traits for corn rootworm control, and two HR traits that allow treatment with two different broad-spectrum herbicides (see Table 1). In addition to corn borer and corn rootworm, Optimum AcreMax Xtreme seed helps control four other species of above ground caterpillar pests. Similarly, Monsanto's (St. Louis, MO) Genuity SmartStax brand has three IR traits for corn borer control, two IR traits for corn rootworm control, and two HR traits, whereas Syngenta's (Greensboro, NC) Agrisure Duracade 5222 EZ1 Refuge has two IR traits for corn borer control, one IR trait for controlling other types of caterpillar pests, two IR traits for corn rootworm control, and two HR traits. Figure 2 shows how extensively planted these stacked and pyramided trait corn varieties were in 2014. Through much of Iowa, Illinois, Michigan, Minnesota, and Wisconsin seed with six different traits could be found. Seed with three to five traits were in much of Kansas, Nebraska, and Missouri. Single to three trait and conventional seed commonly appeared on the fringes of the Corn Belt including much of Indiana, north-central Wisconsin, New York, North and South Dakota, Ohio, and Pennsylvania.

The integration of insect and weed management through the stacking of IR and HR traits is not the end of the story as seed companies have marketed IR traits that control corn rootworm inseparably from pesticide seed treatments. Examples of seed treatments marketed with GE corn seed in 2017 include Bayer's Poncho/Votivo with a neonicotinoid insecticide and nematicide, Monsanto's Acceleron seed treatment with a neonicotinoid insecticide and three different fungicides, and Syngenta's Avita Complete Corn 500 seed treatment with a neonicotinoid insecticide, nematicide, and four fungicides. While soybean IR traits are not available for production in the United States, Hurley and Mitchell (2017) report that half of the soybean farmers they surveyed from 14 of the top soybean producing states in 2013 used pesticide seed treatments.

Crop Protection Trend Benefits

Combining pesticide seed treatments with IR or HR traits provides farmers with seed that has a nearly comprehensive crop protection package built into it—a package Hurley (2016) refers to as 'Shock and Awe Pest Management' or SAPM for short. This package offers a range of benefits to the chemical and seed industry as well as farmers. Seed companies continually adapt the agronomic traits of corn

Table 1. Examples of genetically engineered corn seed brands with insect and herbicide resistance traits and insects it controls or suppresses

Company	Brand	Insect resistance traits	Herbicide resistance traits	Insects controlled or suppressed
DuPont/ Pioneer	Optimum AcreMax Xtreme	Cry1Ab Cry1F mCry3A Cry34/35Ab1	glyphosate glufosinate	Black cutworm (*Agrotis ipsilon*) EUROPEAN corn borer (*Ostrinia nubilalis*) Fall armyworm (*Spodoptera frugiperda*) Stalk borer (*Papaipema nebris*) Sugarcane borer (*Diatraea saccharalis*) southwestern corn borer (*Diatraea grandiosella*) Corn rootworm (*Diabrotica virgifera virgifera* and *Diabrotica barberi*)
Monsanto	Genuity SmartStax	Cry1A.105 Cry2Ab2 Cry1F Cry3Bb1 Cry34/35Ab1	glyphosate glufosinate	Black cutworm Corn earworm (*Helicoverpa zea*) European corn borer Fall armyworm Stalk borer Sugarcane borer Southwestern corn borer Corn rootworm
Syngenta	Agrisure Duracade 5222 EZ1	Cry1Ab Cry1F Vip3A mCry3A eCry3.1Ab	glyphosate glufosinate	Black cutworm Corn earworm EUROPEAN corn borer Fall armyworm Stalk borer Sugarcane borer Southwestern corn borer Armyworm (*Pseudaletia unipuncta*) Western bean cutworm (*Striacosta albicosta*) Corn rootworm

Source: Adapted from DiFonzo (2018).

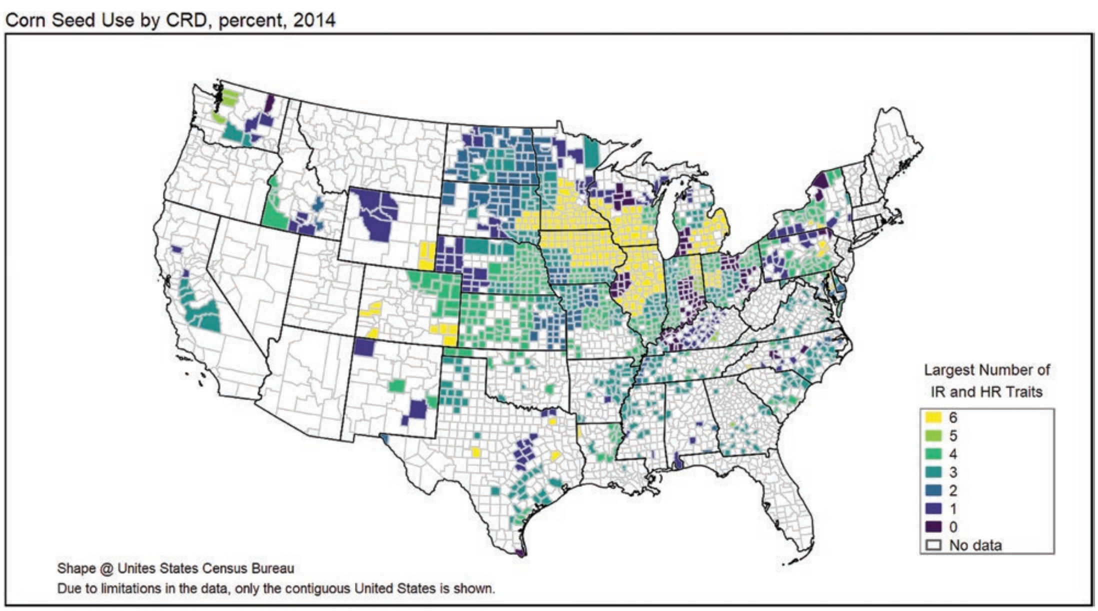


Fig. 2. 2014 crop reporting district distribution of planted corn varieties based on the largest number of genetically engineered insect and herbicide resistance traits (Source: Developed by authors using proprietary GfK Kynetec data, www.gfk.com).

and soybean to better match regional variation in soils and climate. They could also regionally adapt GE crop protection traits, though the cost of offering the complete suite of crop protection traits instead is negligible because once seed is successfully transformed to include GE crop protection traits, scaling up is mostly just a matter of seed replication regardless of whether there is a single trait or bundle of many traits. Therefore, providing farmers with a one-size-fits-all product to meet their crop protection needs makes it possible for the industry to eliminate the added seed production, distribution, and inventory costs that would come with offering multiple combinations of GE crop protection traits. Additionally, selling product with a set bundle of features, some that may be of more limited value, instead of product with fully customized features, makes it possible for seed companies to increase revenue by charging higher prices (e.g., Tjan 2010).

The pyramiding of IR traits in corn has also helped the chemical and seed industry address regulatory challenges. In addition to IR corn, the EPA requires farmers to plant a proportion of conventional corn as refuge for targeted insects to slow the evolution of resistance to the toxins produced by IR traits (Alstad and Andow 1995). As farmer compliance with the EPAs refuge requirements started showing signs of deterioration in the mid-2000s (Hurley 2016), the reduced risk of insect resistance with pyramided IR traits (Ives et al. 2011) made it possible for the industry to argue for and secure regulatory relief. For example, this regulatory relief reduced the required proportion of refuge from 20% to as low as 5% in the Corn Belt. With lower refuge requirements, farmers could protect more of their corn from insect pests, reducing compliance costs and encouraging compliance. More importantly, these changes allowed companies to sell refuge in a bag (RIB) products, which mix conventional seed and IR seed in the bag. These RIB products made complying with EPA requirements compulsory because sorting seed with IR traits from conventional seed out of the bag is not practical (Onstad et al. 2011).

Farmer adoption of GE crops has been found to reduce pest control costs, increase yields, or both (NRC 2010), which helps explain their rapid and widespread adoption. Additionally, crop farm size has bifurcated over time with the number of small acreage farms increasing, and with the acreage operated by large farms expanding rapidly (MacDonald et al. 2013). To survive, many small acreage farmers turn to off-farm employment for supplemental income. Alternatively, larger acreage farmers continue to expand acreage to maintain income in an environment with a shrinking profit margin between per acre crop revenues and production costs. These trends have helped to make time one of the scarcest of farm inputs. With insecticides for the most significant insect pests and resistance to multiple broad-spectrum herbicides built into the seed, farmers can reduce their number of field operations, while also having greater flexibility to more conveniently time those operations. In addition to profitability, these attributes consistently appear as important drivers of pest management decisions (Carpenter and Gianessi 1999, Fernandez-Cornejo et al. 2005, Hurley et al. 2009, Hurley and Mitchell 2017).

The benefits of SAPM have not been confined to the chemical and seed industry or the farmers using it. For example, areawide suppression of corn borer with widespread adoption of Bt corn has been associated with substantial benefits to non-Bt corn farmers (Hutchison et al. 2010) as well as non-corn farmers (Dively et al. 2018). Adoption of IR and HR corn has also been associated with reductions in herbicide and pesticide use (Perry et al. 2016) in addition to other environmental benefits such as reduced greenhouse gas emissions (Brookes and Barfoot 2016).

Reemerging Problems

The rapid adoption of SAPM has corresponded with several concerning trends with pesticide resistance and the environment. For several of these trends, the causal relationship seems transparent. For others, the causal relationship is less definitive.

In the year glyphosate resistant soybeans were commercialized, there were no documented cases of glyphosate resistant weeds in U.S. crop production (Heap 2018). By 2018, there were 17 different weed species with documented resistance to glyphosate in U.S. crop production and at least one documented case of glyphosate resistance in each of 37 different states (Heap 2018). An expert panel assembled by the National Academy of Science to explore the impact of genetically engineered crops on U.S. farm sustainability concluded in their 2010 report that herbicide resistant weeds were a threat to sustainability (NCR 2010). This report led to a series of national workshops and listening sessions on herbicide resistance that culminated with a 15 October 2014 announcement, by the U.S. Secretary of Agriculture, Tom Vilsack, of a plan to release additional resources to address herbicide resistance weeds.

Gassmann et al. (2011) was the first to report the discovery of western corn rootworm in Iowa that were resistant to one of the four types of toxins IR traits produce to control it. These corn rootworms were originally discovered in 2009—a mere 6 yr after the initial introduction of the IR trait. Gassmann et al. (2014) reported the discovery of western corn rootworm in Iowa with cross-resistance to two of the four types of toxins IR traits produce to control it. With Gassmann et al. (2016), Jakka et al. (2016), and Zukoff et al. (2016), there is now evidence from Iowa and Minnesota of various levels of western corn rootworm resistance and cross-resistance to all four toxins IR traits produce to control it. While there has yet to be a published account in the United States of corn borer resistance to any of the toxins IR traits produce to control it, there are anecdotal reports of southwestern corn borer resistance to one of the toxins in Arizona and New Mexico corn production (see public comments submitted to EPA, ID Docket EPA-HQ-OPP-2015-0653-0654). There is also evidence of fall armyworm resistance (*Spodoptera frugiperda*) to this same toxin in Florida and North Carolina corn production (Huang et al. 2014, Li et al. 2016).

The report of sublethal effects of neonicotinoid insecticides on bee behavior (e.g., Cresswell 2011) combined with declining bee populations (Vanengelsdorp 2009) sparked increased regulatory scrutiny of neonicotinoid seed treatments by the EPA in 2013. This increased scrutiny resulted in a 2014 memorandum questioning the economic value to farmers of these seed treatments in soybean production (Meyers and Hill 2014), though Hurley and Mitchell (2017) reports an average value of around $11–12 per treated acre. Also of concern are recent declines in the charismatic monarch butterfly. These declines have been linked to herbicide-tolerant crops, at least circumstantially (Hartzler 2010, Pleasants and Oberhauser 2012). Regardless, the U.S. Fish and Wildlife Service (USFWS) received a petition in 2014 under the Endangered Species Act to protect monarch butterflies (See https://www.fws.gov/savethemonarch/SSA.html [accessed 9 August 2018]). In response, the USFWS is now assessing the status of the monarch with a commitment to issue its findings by June of 2019.

Divergence or Convergence to IPM?

Kogan (1998) and Prokopy and Kogan (2009) envision the evolution of IPM toward its ideal in levels. The EPA views IPM through the lens of a continuum. At its most basic level, individual farmers practice IPM by making field level decisions to control an individual pest species. The monitoring of pests through the systematic measurement of abundance (i.e., scouting) or development (e.g., with growing degree days) and comparison to a treatment threshold calculated based on the cost of treatment relative to the value of the expected reduction in pest losses makes these single and mostly chemical tactics more selective. These decisions, however, do not consider the implications on a farmer's own future pest concerns, let alone neighboring farmers' current and future pest concerns, or broader social and environmental concerns. The benefits captured by this level of IPM are primarily private and immediate, though there can be both adverse and beneficial spillovers to neighboring farmers, society, and the environment.

At the ideal end of the IPM spectrum, stakeholder communities cooperatively manage pest complexes in a broader landscape that includes agriculture. They use a diverse range of tactics that include biological, cultural, and mechanical control as well as selective chemical control guided by pest monitoring. Cooperation and landscape level management make it possible to balance adverse and beneficial spillovers between neighboring farmers, society, and the environment in both time and space. The benefits of this level of IPM are broad and longer term. Given the complexity and coordination involved, it is not surprising that this level of IPM adoption in corn and soybean production did not advance much prior to SAPM supplanting it.

Holding SAPM up to the IPM continuum leads to some hope and some despair. Corn seed planted with a specific IR trait provides near-season long host-plant resistance to select pests. While the host-plant resistance nature and selectivity of the toxin produced by an IR trait are reflective of IPM principles, the season long environmental exposure to toxins regardless of the abundance of the targeted pest is not consistent with IPM principles. Stacking of multiple IR traits erodes selectivity by increasing the spectrum of control, though pyramiding of IR traits adds to the diversity of control tactics. HR traits make it is possible to treat weeds more selectively after scouting for species and size—again in step with IPM. But, the broad-spectrum nature of the herbicides that work with HR crops can result in herbicide resistance among secondary weed species that are currently of little consequence to farmers. Pesticide seed treatments make it possible to further integrate disease with insect and weed control, a goal of higher level IPM, but these seed treatments also result in the prophylactic use of insecticide and fungicide as farmers must choose whether to use them before knowing the significance of their pest threats.

Moving up the IPM Continuum

Understanding the extent to which SAPM is consistent with IPM principles is helpful for considering what opportunities exist to address re-emerging problems in corn and soybean pest management. We now discuss these opportunities in the context of re-envisioning monitoring, expanding the use of multiple tactics, developing new tactics, and fostering coordination among farmers.

Monitoring within season pest abundance or development to guide control actions is currently not feasible with IR traits and seed treatments because treatment decisions come before it is possible to monitor pest abundance or development. Therefore, continuing to use monitoring to do more selective pesticide treatments requires using monitoring to focus more on across season pest forecasts. These forecasts can also be instrumental in guiding chemical and seed companies to do more to tailor regionally the traits and seed treatments offered to farmers, so they match better with the likely pest threats. An example of such a monitoring effort is the Integrated Pest Management-Pest Information Platform for Extension and Education (ipmPIPE) (ipmpipe.org; VanKirk et al. 2012). ipmPIPE originally emerged in 2004 to provide within season monitoring and forecasting of soybean rust (*Phakopsora pachyrhizi*), an invasive pathogen that had the potential to cause significant soybean losses in the United States (Kuchler 1984). While it still serves this function, a reduction in the scope of monitoring efforts occurred as the program identified the limited range of the soybean rust threat and effectively eliminated most preventative fungicide treatments outside this range.

Monitoring need not be limited to pests. The discovery of resistant corn rootworm in Iowa in 2009 was in fields with a history of continuous corn production, a well-recognized risk factor. Tracking what crops are grown where is increasingly possible through satellite imagery (e.g., see Fig. 3). Such information can start to reveal regions of elevated risk for problems like pest resistance. Combining this monitoring information with seed and pesticide sales data would make the identification of elevated risk regions even more precise. With such information, chemical and seed companies as well as farmers can adjust sales or management decisions to lower the risk of problems emerging by switching to management programs that have not been used as intensively. An obstacle to implementing this type of early warning system is that companies are unlikely to share openly sales data for competitive reasons. However, similar information is available from the farmers who purchase the seed and chemicals, making the obstacle one of collecting and aggregating decentralized farmer information. Several third-party vendors are already competing to collect detailed farmer data, aggregate it, and provide services back to farmers to improve their management decisions: Farmer Business Network (www.fbn.com) and Winfield United (www.winfieldunited.com). The extent to which farmers will trust third-party service providers with their detailed production data is unclear, so an alternative model may be necessary—such activities may be viewed within the extension mission of land-grant university system.

IPM promotes cultural, biological, and mechanical practices to reduce pesticide use. SAPM increasingly relies on easily deployed pyramided toxins. While pyramiding toxins is an effective strategy for reducing the risk of resistance, these pyramided toxins often coexist on the farming landscape with single-toxin control tactics, which compromises the benefits of pyramiding. Restricting new commercial introductions of IR traits or seed treatments to pyramids, or requiring the rapid, if not immediate, phasing out of single-toxin IR or seed treatments when pyramids become available can limit these compromises.

Using financial tactics in addition to or instead of cultural, biological, and mechanical tactics offers another way to make pesticide use more selective. Rather than stacking IR traits or applying pesticide seed treatments for the control of minor secondary pests, the indemnification of losses from these pests through crop insurance can still protect farmers without increasing the risk of pesticide resistance. Recent surveys of corn (Sappington et al. 2018) and soybean (Hesler et al. 2018) early-season pests reveal that losses substantial enough to justify management tend to be infrequent and localized, making them good candidates for insurance. Alternatively, adding an IPM endorsement to crop insurance policies that increases insurance premium subsidy rates when farmers implement an approved IPM plan would increase incentives for IPM adoption. If increased crop insurance subsidies are politically infeasible, there are other possible incentives. For example, the 2014 Farm Bill linked soil conservation programs to farmer eligibility for federal crop insurance programs. Similarly, modifying future Farm Bills with IPM requirements to qualify for federal crop insurance programs would again improve incentives for farmers to add more IPM principles to their pest management programs.

Innovation offers additional opportunities to develop new control tactics, but innovation requires investment. There were active research programs on real-time weed detection and discrimination for precision weed management in the late 1990s. This research interest dissipated in the United States when the rise of glyphosate-resistant crops appeared to solve weed management problems

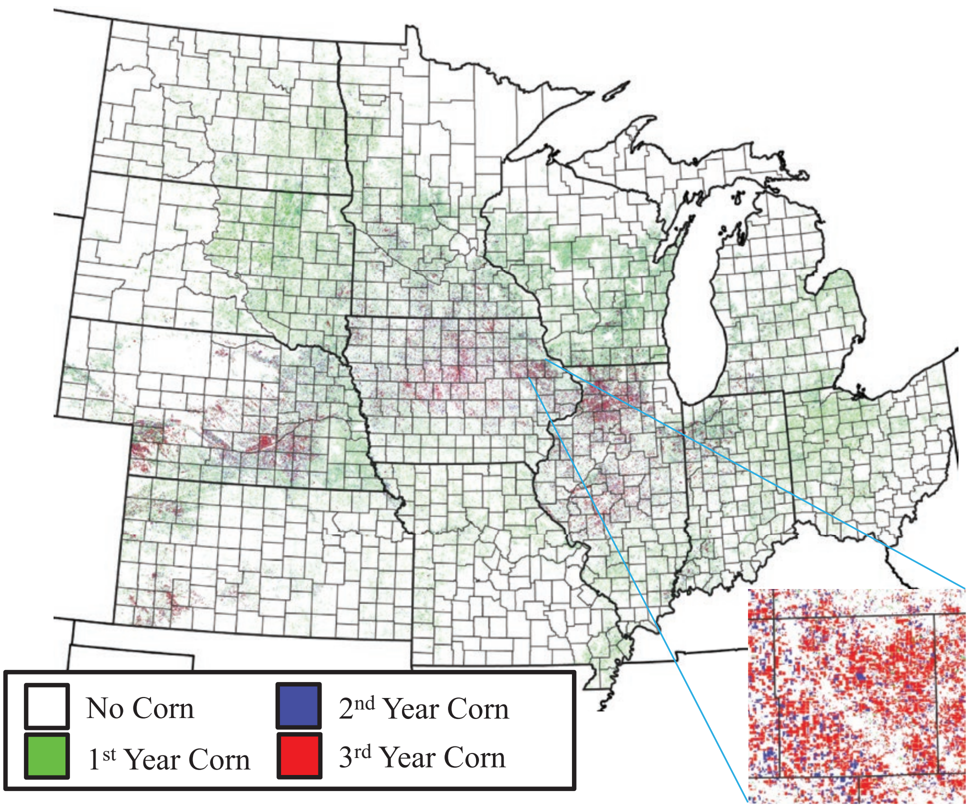


Fig. 3. Continuous corn production in 2012 (Source: Authors construction based on publically available data online at nassgeodata.gmu.edu/CropScape/).

(Bradshaw et al. 1997). However, it is not just interest that dissipated. The public resources funding agricultural research, development, and the land-grant university system have also dissipated (Pardey et al. 2013). While the importance of private investment to the rise of SAPM cannot be understated, the incentives for private companies to support investments with broad industry benefits are weak. As it has become clear that glyphosate-resistant crops were only a temporary solution to farmers' weed management problems, private investment in new tactics appears to be picking up again. Examples of these types of investment are the development of ground-based robotic weeders, unmanned aerial vehicles with optical sensors to monitor pests, and new gene editing technologies for more rapidly and precisely modifying crop traits. While much of the crop trait modification has been focused on the expression of insecticidal proteins for controlling pests, an alternative strategy is the introduction of traits that make it possible for crops to withstand greater stress or pest injury (Peterson et al. 2018). Reaping the rewards of this research is likely to take longer due to a lack of continuing public support when private companies were not so interested.

Achieving greater integration between SAPM and IPM can benefit from the movement to a higher level of IPM with greater cooperation and coordination between farmers, the chemical and seed industry, and other key stakeholders. ipmPIPE and its sister project iPIPE (www.ipipe.org/) rely on being able to establish and maintain networks of individuals who can supply local information on pest threats. This information can then be aggregated to help farmers better manage these pests. However, how farmers then choose to manage these pests is also important. Through more coordinated actions, farmers can avoid repeated and widespread use of the same pesticides, a weakness of current SAPM programs, and an important risk factor for pest resistance. The challenge is how to coordinate farmer efforts. Attempts to coordinate farmers' pest management efforts have met with mixed success. Carlson et al. (1989) and Smith (1998) report on the successes of coordinated farmer programs for eradicating the boll weevil (*Anthonomus grandis*) during the 1970s and 1980s. More recently, Singerman et al. (2017) reports more mixed success in Citrus Health Management Area programs, which are attempting to coordinate Florida orange grower efforts to stop the advance of citrus greening (*huanglongbing*) through the more effective management of the Asian citrus psyllid (*Diaphorina citri*). These efforts can guide the development of institutional relationships that provide greater access to information on key pest threats and coordinate a more effective industry response to these threats.

Concluding Remark

The repeated and widespread use of chemicals to control pests prompted the development of IPM as a more sustainable alternative. As IPM slowly advanced in corn and soybean production, the introduction of and rapid adoption of GE crops, broad spectrum herbicides, and pesticide seed treatments appear to have slowed, if not stopped, this advance. As problems with pesticide resistance and other adverse environmental outcomes re-emerge, it is an opportune time to reconsider how IPM principles can be adapted to help address these problems. Successful adaptation will require special attention be paid to the increased emphasis on integrating farmers' pest management decisions into seed purchases. This integration has made farmers more reliant on the chemical and seed industry for solutions to their pest problems, requiring higher-level IPM principles with greater cooperation and coordination among farmers, the chemical and seed industry, and other stakeholders.

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