Organic Agriculture and Integrated Pest Management:

Synergistic Partnership Needed to Improve the Sustainability of Agriculture and Food Systems

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Foreword

In November 2012, a diverse group of 26 professionals from business, non-profits and governments gathered in Chevy Chase, Maryland to share ideas on how best to improve communication, understanding and outcomes among those working on organic systems and Integrated Pest Management (IPM) in agriculture and food production. Over two days, this group worked through a series of questions and topics, and generated a list of common interests, concerns, observations, resources and next steps.

One of the next steps was to create an ongoing group. This new Organic and IPM Working Group initially convened in August 2013 and continues to provide a forum to exchange ideas; share knowledge and experience; identify and communicate common research, education, policy and regulatory priorities (posted at https://organicipmwg.wordpress.com/priorities/); and pursue opportunities to address needs common to both organic and IPM stakeholders.

This position paper provides background and communicates our Group's shared vision for synergizing organic and IPM efforts to more effectively address threats to human and environmental health, and the livelihood of farmers. Our goals include informing decision makers and key influencers in the public and private sector, including policy makers, researchers, Extension and producers of the need for, and benefits of, achieving this vision. The executive summary is designed to provide a concise overview and may be used as a stand-alone brief.

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Executive Summary

One of the greatest challenges of the 21st century is the need to feed a growing population while improving the productive capacity of agricultural ecosystems, and the health and integrity of surrounding environments for future generations. Integrated Pest Management (IPM) and organic production methods can work together to address this vital challenge. While there are significant differences that need to be understood and respected, the two overlap, with much in common. Both fall far short of potential for adoption, bound by common constraints including inadequate public prioritization and investment.

Despite shared interests and tactics, few leaders and practitioners actively participate in both the IPM and organic communities, foregoing the synergies that could come from exchanging thoughts and ideas, and joint pursuit of common priorities.

Organic and IPM proponents and practitioners share a desire to achieve the benefits greater adoption can deliver. Shared interests include promoting and improving environmental quality, farm economic viability, social equity, and soil and human health. Organic is wholly compatible with advanced, biologically based IPM and most IPM principles and tactics will work in organic systems.

Despite common interests and tactics, few leaders and practitioners actively participate in both the IPM and organic communities, foregoing the synergies that could come from exchanging thoughts and ideas, and joint pursuit of common priorities. Our goals as authors include illuminating ways that organic and IPM can work together to spur further inquiry, discussion and action leading to increased adoption and growth in the benefits more sustainable production systems deliver.

Growing challenges

Human population continues to increase along with expectations for higher quality food and more resource-intensive production including animal agriculture. Many conventional farming practices are a leading source of pollution that threatens the sustainability of food systems and natural resources. Environmental and ecological consequences from current practices include pollution of ground and surface water with sediment, nutrients and pesticides; air pollution; declines in the health of critical pollinators and other beneficial organisms; loss of soil and carbon sequestered in soil; increases in greenhouse gasses; and declines in biodiversity. Losses from insect pests, diseases and weeds persist, along with increased frequency of pest resistance to commonly used pesticides. Yet many prioritize fast, cheap and easy approaches, and share a sentiment that traditional conventional systems are working, with no need to change. Too few research programs at public institutions focus first on understanding the problem and then developing sustainable solutions. Technology is promoted as the answer without addressing underlying fundamental systemic flaws. Public resources for research and education are declining while demands continue to increase for sustainable solutions.

Organic Agriculture and IPM

Both organic and IPM tactics require greater management skill to implement effectively than calendar-based application of inputs. According to a definition adopted by the International Federation of Organic Agriculture Movements in 2008, organic agriculture is “a production system that sustains the health of soils, ecosystems, and people. It relies on ecological processes, biodiversity, and cycles adapted to local conditions, limiting the use of inputs with potential adverse effects. Organic agriculture combines tradition, innovation, and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved.”

Key benefits of organic agriculture

- Fewer adverse environmental impacts.
- Fewer pesticide residues on food products.
- Documented improvements in nutritional quality in dairy, some fruits and vegetables.

Key limitations

- Lower yields.
- Rigorous restrictions on pesticide and fertilizer inputs, which are nearly exclusively limited to substances derived from natural products.

Although IPM is a requirement in the National Organic Program and many other eco-labels, IPM is not a distinct production system. As defined in the USDA National IPM Roadmap, updated in in 2013, IPM is “a science-based, decision-making process that identifies and reduces risks from pests and pest management related strategies. IPM coordinates the use of pest biology, environmental information, and available technology to prevent unacceptable levels of pest damage by the most economical means, while minimizing risk to people, property, resources, and the environment. IPM provides an effective strategy for managing pests in all arenas from developed agricultural, residential, and public lands to natural and wilderness areas. IPM provides an effective, all encompassing, low-risk approach to protect resources and people from pests.”

Key benefits of IPM

- Reduces reliance on single tactics; improves resilience of production systems.
- Can reduce pesticide use, residues, pest damage, production costs and risks, and health and environmental impacts.
- “Big tent” of fundamental principles with flexibility to create new approaches, address any pest complex, and be implemented at different levels along a continuum and adapted to any production goals including organic.

Key limitations

- Benefits and ability to make claims in the marketplace are highly dependent on the extent to which available IPM tactics are adopted, and limited by lack of consumer understanding.

Commonalities and key differences

Organic and IPM researchers, educators and farmers have pioneered and been early adopters of less harmful approaches to pest management. Many organic farmers practiced IPM before transitioning to organic; and certified organic producers are required by the US Department of Agriculture (USDA) National Organic Program (NOP) to integrate IPM practices including cultural and biological controls. A number of practices relied on by organic farmers are becoming more common in conventional farming including cover crops and measurement/improvement of soil health metrics.

Organic benefits from broad consumer awareness and support, price premiums and a clear set of standards included in the NOP. Organic systems are designed to promote biodiversity and soil and plant health. Farm plans describe how the organic approach is to be implemented on each certified farm. When justified, reduced-risk pesticides, largely limited to naturally derived substances, can be used.

IPM is more narrowly focused on pests, and is not an agricultural production system like organic or conventional, but an approach to pest management that can be used in diverse situations and production systems where pests are a problem. IPM has been defined as “a decision-based process involving coordinated use of multiple tactics for optimizing the control of all classes of pests (insects, pathogens, weeds, vertebrates) in an ecologically and economically sound manner.” Different classes of tactics, including chemical, cultural, host resistance and biological methods, are integrated in ways that usually allow production systems to move away from traditional, calendar-based pesticide applications to more ecologically sound strategies. When chemicals are applied, applications are guided using economic and treatment thresholds, based on monitoring and forecasting of pests and beneficial organisms, plant phenology and environmental conditions.

IPM is inherently designed to be applied differently depending on specific conditions including climate, location, weather, crop, pests and beneficial organisms. Eco-label programs that require IPM of participating growers typically specify requirements on a crop and region-specific basis, including prohibitions and restrictions on particular high-risk pesticides.

Approaches to weed management illustrate a difference in perspectives between organic and IPM researchers and educators. Although IPM recommendations include cultural, mechanical and biological practices that are also used by organic farmers, IPM research and education has not focused on reducing synthetic herbicide use as a top priority. To overcome glyphosate-resistant weeds—which for organic farmers are no more challenging than non-resistant weeds—much of the emphasis has been on alternative herbicides, not alternatives to herbicides.

Constraints to greater adoption

Organic and IPM research, development and outreach needs are increasing as demand grows for more production and fewer negative impacts. Yet badly needed systems approaches, which focus on resolving underlying problems, must compete for resources in both public and private sectors against patent and revenue-generating opportunities offered by input product and service development. At the same time, public investment in research and education is declining in real dollars and as a percent of total investment in relation to proprietary private sector research, development and marketing. Although biopesticide market growth is projected to continue to outstrip that of conventional pesticides for the next several years, the organic and advanced IPM input markets remain too small to attract investment in NOP-compliant or other reduced risk products on par with the conventional product market.

Many current public policies and market incentives discourage adoption of practices that may cost more in the short term, yet benefit the environment and agricultural sustainability in the long term. As a result, most farmers focus on maximizing yield and profit; they are not competitive in the marketplace if they unilaterally adopt practices that take into account environmental or social costs externalized by other farmers. Pesticides continue to be relatively easy to use, affordable, widely available and promoted, and employed by nearly all growers. Calendar-based pesticide application schedules require a simplified knowledge base compared to management-intensive organic and IPM approaches. Simplified strategies and externalized costs carry a high price including water pollution, water shortages, climate change and health risks to humans and ecosystems. Improving sustainability will require more than seeking the highest possible yield at the lowest possible cost.

Agriculture delivers many ecosystem services and has potential to deliver many more. If additional farmers are to provide more services to society in terms of soil, water and biodiversity, some form of compensation will be needed as an incentive. Organic and IPM growers must compete with conventional farms' subsidies and externalities that discourage the adoption of more sustainable practices. Policies to internalize these external costs would help encourage the adoption of more sustainable practices.

While market premiums provide incentives for transition and cover at least a portion of the costs of lower organic yields, demand outstrips supply in many organic crops. U.S farmers are missing important market opportunities, and more research and education is needed to overcome yield deficits compared to conventional production. Barriers to increasing organic supply include complexity and costs of organic certification, real and perceived challenges associated with transition to organic, peer pressure, ideological opposition, lack of research and demonstrations, inadequate technical assistance and serious pest management challenges that limit yield and quality under organic restrictions.

Multiple food company quality assurance programs and eco-label certifications require participants to implement IPM tactics. While the term IPM has gained recognition among many wholesale buyers, it is not recognized by retail consumers, and measuring and communicating environmental and health benefits of IPM are in part limited by the lack of a uniform definition of IPM analogous to the NOP standards. Thus IPM is not the leading claim in supply chain programs including those at Sysco, McDonalds, Costco or others, or in eco-labels including the NOP, Eco Apple, Food Alliance, Rainforest Alliance and Forest Stewardship Council. Price premiums in programs other than the NOP are rare to non-existent, negating an opportunity to support reduced-risk tactics that may be more expensive. These programs provide other economic benefits to participating producers including customer retention, and access to new customers and markets.

Common priorities

IPM and organic proponents and practitioners have similar needs for increased resources for research, technology transfer, education, outreach, and public policy and private-sector incentives. Both are interested in reducing production costs and increasing financial incentives for good environmental stewardship. Institutional and individual changes at the implementation and policy levels can encourage sustainable agriculture practices that benefit growers using IPM and organic methods, including a recognition of the similarities and synergies that can result from greater collaboration.

Both communities face unsustainably high farmer retirement rates in the near term, and need new farmer recruitment and education programs. The greatest need is capacity to develop a new generation of researchers and Extension professionals who understand the theory and practice of both IPM and organic agriculture to serve the practical needs of producers and improve sustainability. This is a tremendous challenge during a time of retrenchment in public investment in public and science education.

In addition, all growers need solutions to pest management problems including weeds; diseases such as fire blight of apples and pears, and late blight in tomatoes and potatoes; and newly introduced pests, such as spotted wing drosophila, brown marmorated stink bug and Asian citrus psyllid which spreads the devastating citrus greening disease. Organic growers in particular need NOP-compliant solutions. Low impact solutions, including systems, cultural and biological approaches that are not amenable to intellectual property rights and proprietary revenues, need to be prioritized and incentivized.

Recommendations for action thresholds, or pest population or damage levels at which it makes economic sense to intervene, need to consider variable crop value so they can be readily adjusted by growers to reflect the often higher value of organic crops or the limitations of pesticides allowed for organic production, including earlier application timing or more frequent applications. They need to incorporate abundance of, or potential to introduce, beneficial organisms, which are often key tactics in organic and advanced IPM approaches.

Recommendations

The authors share a common vision of a world where organic and IPM proponents and practitioners work together to improve farm viability, public health and the environment. While we acknowledge differences in production practices, and regulatory and market conditions, those differences allow for fertile common ground. A growing number of consumers and taxpayers are becoming more aware of, and exercising influence over how food and fiber is being produced. Together we can leverage this market and public interest to advance knowledge, science and technology; communicate with one another our successes and failures; combine efforts through mutual understanding of strategies, plans and projects; and effectively evaluate and report needs and progress to farmers, consumers, taxpayers, researchers, educators, policymakers and regulators.

The collaboration between organic and IPM must become a public-private partnership recognizing the need and opportunity for policy and market forces to work together to address these challenges and achieve our goals.

In addition to pest management, by working together and with others, we can also more effectively improve outcomes associated with energy, irrigation and nutrient use for livestock, crops and other plants, which are inextricably tied to air and water quality, and soil, plant, animal and environmental health.

Our key recommendations include:

- Increase public and private support for long-term, interdisciplinary systems research that provides working models and field-scale demonstrations of both organic and advanced IPM systems that farmers, researchers and practitioners can use.
- Facilitate adoption of sustainable practices through publicly funded programs that expand outreach, promote collaboration between IPM and organic proponents, and compensate farmers for ecosystem services provided.
- Eliminate publicly funded programs that encourage unsustainable practices based on maximizing yield and profits at the expense of environmental quality and health.

- Increase public incentives, including pesticide registration improvements for product and service providers to develop, formulate, market and sell more options that are compatible with organic and advanced IPM systems, including biologically based pesticides.

The authors strongly recommend and request that organic and IPM communities commit to work together to achieve these common goals. While organic and IPM share many goals, their needs are not identical but complimentary in many instances. Organic has succeeded largely within the marketplace through consumer choice and marketing efforts, but needs help with transitioning producers to meet the market demand. IPM has a broader acceptance in governmental policy and in conventional farming, but has struggled with creating adequate economic incentives for adoption especially in large-acreage commodity crops. The collaboration between organic and IPM must become a public-private partnership recognizing the need and opportunity for policy and market forces to work together to address these challenges and achieve our goals.

1. Challenges We Face

- A growing population with rising expectations demands increased agricultural productivity.
- Public policy and private-sector decision makers focus on fast, cheap and easy as priorities, and share the sentiment that traditional conventional systems are working, with no need to change.
- Environmental and ecological consequences from current practices include pollution of ground and surface water with nutrients, sediment and pesticides, air pollution, harm to pollinators and other beneficial organisms, loss of sequestered carbon, increases in greenhouse gasses, and declines in biodiversity and soil health.
- Pesticide use poses human health and safety risks to farmers, farm workers, farm neighbors and consumers.
- Substantial losses from pests, diseases and weeds persist, despite billions of lbs. of pesticides used annually. Pest resistance to commonly used pesticides was recognized more than 100 years ago, yet continues to increase.
- Few research programs at public institutions focus first on understanding the problem so as to then develop sustainable solutions; most advance technology as the answer without addressing underlying fundamental problems.
- Public resources for research and education are declining while demands continue to increase.
- Communication and collaboration among organic and IPM leaders falls short of potential to move common priorities forward.

The world faces enormous challenges to grow crops, raise livestock and manage land and other resources to feed, clothe and house the more than seven billion people living on the Earth. These activities, and resulting impacts on our resources and environmental and human health, will intensify as an additional three billion people are expected to be added over the next 50 years. In the effort to produce increasing amounts of food, agriculture threatens to destroy the very resources at its base: healthy soils, water and a stable climate. Farm and ranch land currently cover 40% of the earth's land area, virtually all of the land that is suitable for agriculture.

Clearing land, growing rice, raising cattle, powering irrigation systems and reliance on synthetic fertilizers and pesticides make agriculture the single largest contributor of greenhouse gases. Farming uses 80 to 90% of all the water humans use for any purpose (Foley et al. 2011). Intensification of production has led to increased use of inputs, particularly fertilizers, antibiotics and pesticides. Global pesticide use increased by 53% from 1993 to 2010 (FAO 2015).

The National Water Quality Inventory Report to Congress indicates agriculture continues to be the US's leading source of surface-water pollutants (US EPA 2013a). Animal agriculture was identified as a source for more than 80% of those threats and impairments.

Pest challenges to food and ecological health include weeds, insect, mite, nematode and wildlife pests, plus animal and plant diseases, all causing substantial economic loss despite more than 1.5 million metric tons of pesticides applied to cropland worldwide each year. Crop losses from pests have not decreased as a result of increased pesticide use (Oerke 2006). Development and spread of pest populations resistant to pesticides perpetuates a treadmill of need for new pesticide products and increased pesticide use. The debate between 'land sparing', or increasing production per unit of land to allow other land to be preserved for conservation uses, and 'land sharing', where multiple uses, including conservation, are integrated, oversimplifies both the nature of the problem and potential solutions (Tscharntke et al. 2012). The growing global economy has led to more frequent introductions of pest organisms into new areas with devastating consequences for farmers, crops and other plants in the landscape (Mack et al. 2000, Anderson et al. 2004). Impacts of pest management activities include pesticide residues in farm fields, in ground and surface water and in the food supply, threatening the health of farmworkers, consumers and non-target organisms in the environment (Pimentel 1995).

Poor pesticide-use practices have led to more than 1000 species of insects, mites, plant diseases and weeds developing resistance to pesticides worldwide, generating more than US$1.5 billion in costs per year (Pimentel 2005) including crop loss due to damage by resistant pests, costs of additional pesticide applications required to control resistant pests, and costs associated with bringing new pesticides to market to replace those no longer effective due to resistance. Current estimates are that 237 weed species have developed resistance to herbicides (Heap 2014), with resistance reported in 61 countries and 66 crops to 155 different herbicides.

Pesticide use practices pose environmental and public health problems. The primary populations at health risk are farmers and farm workers due to occupational exposures. An epidemiological review by Mills et al. (2009) suggested that farm workers have elevated risks of brain, cervix, prostate, stomach, lymphatic and bone cancers. Calvert et al. (2008) reported 3271 acute pesticide-related illnesses among farm workers between 1998 and 2005, Bell et al. (2006) suggest reported numbers are likely less than one quarter of actual incidents. A growing body of literature on occupational exposure to pesticides makes it a global high priority (IARC 2014).

Consumers exposed to pesticide residues in food are also at risk. While acute pesticide poisonings of consumers are rare relative to farmers and farm workers, chronic health risks have been linked to pesticides in the diet and in drinking water. These range from cancer to chronic neurological damage and endocrine disruption (Colborn and Carroll 2007, Bergman et al. 2013, Mesnage et al. 2014). The USDA Agricultural Marketing Service conducts limited testing for pesticide residues on produce on store shelves, reporting detectable residues on 65% of conventionally grown fruits and 67% of conventionally grown vegetables in 2012 (USDA 2012). Only a small fraction of fruits and vegetables exceed thresholds for human concern set by the US Environmental Protection Agency (EPA), but these represent billions of servings each year. For example, in 2012, USDA reported 4.2% of domestic peach samples contained residues above levels of concern. Over 2.7 billion lbs. of peaches are consumed annually in the US, representing approximately ten billion servings (USDA ERS 2014b). If 4.2% of those servings contain unacceptable residues, servings above the threshold exceed 420 million. Consumers are justifiably concerned; 60% of US consumers in one 2009 survey rated the presence of pesticides in food products among their highest concerns (Context Marketing 2009).

In a review of monitoring results, one or more pesticides were detected in nearly all fish and surface water samples, and a third of groundwater samples collected between 1992 and 2001 (Gilliom et al. 2007). Seventeen percent of stream samples in agricultural areas exceeded human health benchmarks. In a follow-up study, human health benchmark exceedances declined to 5%, but exceedances for aquatic organism health remained high, declining to 61% from 69% (Stone et al. 2014). Less than half of pesticides in current use with potential to impact aquatic organisms were analyzed. Neonicotinoid insecticides, including imidacloprid, the leading insecticide used worldwide, were not included in the analyses, indicating exceedances are grossly underestimated.

Pesticides can negatively impact soil health. For example, neonicotinoid insecticides can have sublethal effects on earthworms, potentially disturbing soil development and biogeochemical cycling (Pisa et al. 2014). Negative impacts of copper fungicides on soil micro and macroorganisms have been reported (reviewed in Wightwick et al. 2010).

Challenges to adoption and improvement

In applying both organic and IPM practices, growers generally incur increased costs and greater risk of damage relative to conventional production systems. Where IPM reduces pesticide use and saves related costs, or where IPM is subsidized, it is more quickly adopted than in situations where such economic incentives do not exist (Brewer et al. 2004, Martin 1988, Waibel 1990, Orr 2003). Similarly, organic growers, and rarely growers participating in eco-label programs other than organic, can obtain increased prices for their crops, making adoption more economically tenable (Lin et al. 2008, Delbridge et al. 2011).

However the market often fails to provide adequate incentives for growers to adopt organic and IPM practices. In the case of implementing biological control, for example, the cost of beneficial organism releases can be prohibitive compared to pesticide options, and biological options lack the extensive marketing infrastructure that is in place for conventional pesticides. Growers have little incentive to adopt a practice that is more expensive and more difficult to source and/or use. Similarly, there is limited incentive to adopt, and the private sector has little incentive to recommend, a practice that may be perceived as or in fact put production goals at greater risk. For example, an apple grower might have an IPM system available to forecast disease risk. If the system predicts low risk, the grower might choose to skip a fungicide application that would otherwise cost US$40 per acre. However, if the system fails, the grower might lose US$12,000 per acre in crop value. In strictly economic terms, the choice is clear.

Organic crop yields can be lower than those in conventional production, by an average of 19% according to the largest meta-analysis to date which reviewed results from 115 studies (Ponisio et al. 2015). The authors speculate that additional investment in research would reduce yield disparities, based in part on findings that the yield deficit declined to 8-9% for organic systems using crop rotation and diversification. The yield gap depends on a number of factors, and is more pronounced in tropical climates than temperate ones (Seufert et al. 2012, Sooby 2003). Possible factors contributing to the yield gap include lower levels of available nutrients, particularly nitrogen; pest, disease and weed pressure; and possibly ‘organic by neglect’, where inputs are reduced without corresponding efforts to improve soil and ecosystem health, being counted in the statistics for organic together with actively managed organic farming systems.

While funding for organic research has increased over the past 20 years, the share and rate of increase is not proportional to organic agriculture’s growth in acreage and market share (USDA ERS 2014a). The relatively high price of organic food is often cited as a barrier to consumers (Lohr 2001, Luanne 2001, Whole Foods Market 2005, Hartman Group 2012). Yield gaps and higher unit costs of production may be a factor, as well as economies of scale in processing and distribution. Just as environmental costs for conventionally produced foods are externalized, the environmental benefits of organic production are not explicitly recognized in the price farmers receive. At the same time that the need for organic, IPM and other integrated systems research is increasing to meet market demand, budget cuts, retrenchment and a decline in the number of skilled people working in the field are accelerating (Kopp 2009, Green et al. 2011). With the emphasis on privatization, proprietary intellectual property and closed-sourced technologies, research is being directed away from technologies that are clean and green (Lipson 1997, Schmid et al. 2012, Fuglie and Toole 2014). Although biological pesticide growth outstrips that of conventional pesticides, biopesticides represent only 4% of the total pesticide market (Keller 2014). A historic lack of institutional support for organic research and outreach at publically funded universities (Sooby 2003) has put the onus on organic farmers to create viable production systems not widely shared through the Land Grant research and Extension system. Although there have been significant improvements in the past 10 years, continued lack of research capacity may be an impediment to organic not reaching its full potential (OFRF 2012).

Research on IPM protocols has also demonstrated environmental benefits that increase when IPM is practiced at a high level, but most farmers have adopted relatively few of the available IPM practices for a given crop (USDA NRCS CEAP 2015). Current downward trends in public funding for Land Grant institutions including IPM programs and related research and Extension efforts (Wang 2014) will slow IPM adoption, innovation and the associated movement toward reduced pesticide use.

Private pest management consultants and chemical company representatives often fill the void created by too few Extension advisors. The private sector and growers are highly risk averse, and tend to use simple and at least temporarily effective pesticides, rather than develop and adopt new scouting or forecasting methods, or alternatives to pesticides. Chemical company representatives have little short-term incentive to encourage alternatives to pesticides, particularly if their income is based on sales commissions. Long term, however, they risk losing customers if they oversell inputs and fail to maximize bottom-line results.

When functioning as originally intended, Extension serves as both a neutral judge of pest management efficacy and a force for changing agricultural production methods to benefit both producers and the public. Extension and the Land Grant Universities have drifted from engaging in public scholarship to benefit communities, and taken on more market-oriented scholarship. If agriculture is to become truly sustainable, this trend needs to be reversed, and research, education and outreach in the Land Grants and other institutions needs to be refocused on the public good (Peters et al. 2005).

Conventional pesticides continue to be relatively easy to use, widely available and promoted, affordable under the current crop support systems and/or in high value crops. Their use requires a simplified knowledge base compared to organic and IPM, and fit within conventional management systems of the past 60 years to which people are accustomed. In some cases, as with Round-Up Ready crops, pesticides have become an integral part of production systems, generating corporate and producer profits but also causing weed management and environmental issues. The high level of adoption of genetically modified insect and herbicide-resistant corn, soybeans and cotton obviates the use of basic IPM practices such as scouting and thresholds for the pests the crops are engineered to control, despite the fact that an integrated management approach may extend the effective life of these technologies.

Market standards for blemish-free fresh produce drive pesticide use as well, and many applications are made for cosmetic purposes rather than to prevent reduced yield. For example, the apple disease complex sooty blotch/flyspeck blemishes fruit but doesn’t physically damage it, and the blemishes can be wiped off. Yet because blemishing can reduce fruit value by as much as 90%, apple growers in the eastern US apply two to five fungicides a year to manage the disease (Gleason et al. 2011). Growers fear that one mistake may result not only in unacceptable crop damage but weeks, months or even years spent getting a pest outbreak back under control. This makes it more difficult for organic and IPM to gain traction on the ground.

A need for improved communication and collaboration

Despite mutual interests, organic and IPM leaders have rarely communicated on their shared obstacles, opportunities and priorities. The two groups have significant differences in history, philosophy and research, regulation and economic incentives that create barriers to collaboration. The two camps have often competed for the interests of policy makers, funders, practitioners and consumers. Organic and IPM leaders, researchers, educators and users need to communicate and collaborate far better to increase adoption and maximize benefits of ecologically based pest management practices in food production and landscape management. A better mutual understanding of the historical and institutional context in which organic and IPM co-evolved will foster the inherent synergies between organic and IPM systems.

2. Foundations of Organic and IPM

- Organic and IPM share common foundations rooted in ecology and concerns about human, environmental and economic health.
- Organic and IPM concepts challenge tenets of conventional agriculture; IPM focuses on pest management and organic on a broader set of agricultural practices.
- Organic is clearly defined in law; as a concept IPM has multiple broad definitions and is more narrowly described by over 100 crop and region-specific protocols developed by IPM users and other stakeholders.
- IPM and organic methods can address environmental and human health concerns by applying a practical understanding of agroecology to enhance stability, resilience and sustainability in agricultural production.
- Both IPM and organic approaches can enhance and synergize each other through collaboration on research, technology transfer and education to drive more environmentally benign and sustainable crop and pest management tactics.
- Economic, cultural, technical and policy barriers limit adoption of IPM and organic practices, and grower potential to reduce the environmental and health impacts of agriculture.
- A systems approach allows IPM and organic to contribute to ongoing and current challenges.
- Organic and IPM systems may be able to address the difficult trade-offs between food production, environmental quality, human health and food safety by minimizing inputs, improving soil cover, reducing erosion, and building soil organic matter and soil carbon.

Organic and IPM benefits

A well-documented benefit of organic food is reduction in risk of consumer exposure to pesticides in the diet (Baker et al. 2002, Smith-Spangler et al. 2012, Benbrook and Baker 2014). Organic food is significantly less likely to be contaminated with individual and multiple pesticides, and is likely to have significantly lower levels of pesticides than non-organic food including food labeled as IPM grown (Baker et al. 2002). Children who eat organic food have significantly lower levels of organophosphate insecticides in their blood and urine compared with children who do not eat organic food (Curl et al. 2003, Lu et al. 2006, Griffith et al. 2011). Adults consuming organic food have lower levels of organophosphate pesticides in their urine than those who do not (Oates et al. 2014). Reduced dietary exposure to pesticides is not surprising given that USDA regulations require organic farmers to develop a system of cultural practices to manage pests, use pesticides only when cultural practices are not effective, and limit use to pesticides that are generally lower in toxicity and less persistent than pesticides used by non-organic farmers.

Comparisons of nutritional quality are less consistently conclusive than those for residues of pesticides and antibiotics (Smith-Spangler et al. 2012). However, a growing body of literature shows that some organic food can have higher levels of certain specific nutritional components, higher antioxidant levels, and greater nutrient density than some conventionally produced foods (Brandt et al. 2011, Baranski et al.

2014). Organic foods on average also have lower levels of the toxic heavy metal cadmium than conventionally grown foods (Smith-Spangler et al. 2012, Baranski et al. 2014).

Organic also has ecological and environmental benefits including in most cases, greater biodiversity than conventional farms (Hole et al. 2005, Bengtsson et al. 2005). By sequestering carbon in soil organic matter, organic farming practices may also reduce production of greenhouse gases (Gattinger et al. 2012), though this claim is debated (Leifeld and Fuhrer 2010, Leifeld et al. 2013).

Projects conducted by researchers and IPM practitioners over the years demonstrate IPM's potential for reducing pesticide use and/or impacts in a given crop (Reganold et al. 2001, Petzoldt et al. 2000, Petzoldt et al. 2004, Petzoldt et al. 1995). In one example, Peruvian asparagus producer IQF del Peru cut its insecticide and fungicide use by 90% and herbicide use by 75% through the use of IPM strategies (Fernandini 2006). Insecticides containing chlorpyrifos, which is acutely toxic to humans and wildlife, were reduced by more than 90%, replaced by beneficial insect releases and mechanical controls including insect traps. In another example, a survey of 682 grower users of the Network for Environment and Weather Applications (NEWA) reported saving an average of US$19,500 a year per grower in spray costs, and preventing US$264,000 in crop losses as a direct result of using NEWA weather station-based pest forecast models – a core IPM strategy (Carroll 2007). Other examples show farmers saving anywhere from US$25 to US$1000 per acre due to IPM (Benbrook 1996, Mullen et al. 1997, IPM Voice 2012, Farrar et al. 2015). IPM has also been reported to reduce pesticide risk to health and environment, according to models that estimate risks associated with specific pesticides (Kovach et al. 1992, American Farmland Trust 2013).

Assessment tools for measuring the impact of pesticides on human health and the environment are used in IPM recognition and incentive programs including the Environmental Impact Quotient (Kovach et al. 1992), Pesticide Risk Mitigation Engine (Green 2011, American Farmland Trust 2013), and WIN-PST (USDA NRCS 2015). Methods for measuring pesticide impact remain controversial, with challenges to existing methods and approaches (Peterson and Schleier 2014), and continued development of new tools. Sophisticated databases that compile and provide easy access to health and environmental information on individual pesticides, searchable by active ingredient or brand name (Pesticide Research Institute 2014), can assist in identifying less hazardous options. Widely adopted and accepted methods for estimating pesticide impacts are needed to help document environmental and health benefits of IPM adoption and communicate its value.

Analyses of US pesticide use patterns between 1992 and 2005 (US GAO 2001, Epstein and Bassein 2003, Maupin and Norton 2010) showed no significant reductions in pesticide use despite claims that the national goal of 75% adoption for IPM, set by the Clinton administration in 1993, had been nearly met. Because many common cultural practices, such as crop rotation and planting pest-resistant varieties fall under the umbrella of IPM, most farmers use at least one IPM practice, making it possible to meet loosely defined adoption goals without reductions in pesticide use or non-target impacts.

Incremental reduction of pesticide use and rotation of pesticides to delay resistance, without adoption of an ecologically based systems approach to manage pests through non-chemical means, has been called "integrated pesticide management" by IPM practitioners, proponents and critics alike (Altieri et al. 1997, Hill et al. 1999, Ehler 2006). Because there is no clear, uniform definition of IPM and no government regulations limiting use of the term, the distinction between IPM and conventional practices is blurry. As a result, consistent reductions in health and environmental impacts are challenging to document.

Policy, market subsidies and/or other incentives are needed to encourage and help practitioners move further along the continuum of IPM practice adoption. National standards for IPM would be challenging to develop and implement, and could work against the benefits of flexibility inherent in IPM practice.

Historical and institutional contexts of organic and IPM

What is organic agriculture?

Organic agriculture is "a production system that sustains the health of soils, ecosystems, and people. It relies on ecological processes, biodiversity, and cycles adapted to local conditions, limiting the use of inputs with potential adverse effects. Organic agriculture combines tradition, innovation, and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved" (IFOAM 2005).

In the US, organic is a food-labeling term regulated by the US Department of Agriculture [Code of Federal Regulations (CFR), title 7, section 205]. While organic agriculture emphasizes soil, plant, animal and human health, and ecological biodiversity, consumers often focus exclusively on pesticides and mistakenly believe that organic producers do not use pesticides (Williams and Hammitt 2001). The few synthetic pesticides that are allowed have been evaluated for their impacts on human health, the environment and overall sustainability, and undergo a rigorous rulemaking process that includes a review every five years. Naturally occurring compounds with negative impacts are also prohibited. Before any pesticide allowed in organic production may be used, an organic grower must document in their farm plan that alternatives are not effective in the organic system, declare what pesticides they intend to use and get prior approval from their USDA Accredited Certifying Agent.

Organic history

The concept of organic farming developed in the early decades of the twentieth century, with key aspects of its attendant philosophy and practices articulated by Rudolph Steiner, Sir Albert Howard, Lady Eve Balfour, Jerome Rodale and William Albrecht, among others. These authors and visionaries shared a belief in the importance of soil health and fertility as the basis for the health and productivity of plants, animals and humans. Howard, Balfour and others formed the British Soil Association. The term 'organic' was first used by Lord Walter Northbourne to refer to a farming system as an organism, as opposed to a mechanistic collection of resources used to produce food (Heckman 2005).

In the US, Rodale and his successors worked to establish legitimacy for organic methods, republishing classic works by Howard and other pioneering theorists, and producing practical guidance for farmers and gardeners seeking to use them. These efforts were met with open hostility and derision by the agricultural establishment; the editorial stance of Rodale publications reflected this antagonism. Walnut Acres, the first US organic food company, began offering organically produced and processed products in 1946 (DeVault 2006). The first organic certification programs in the US, where grower practices were verified against published standards by on-site inspection, were initiated in the 1970's, primarily through producer-driven organizations working to assure consumers that products were grown using accepted organic practices.

Following Rachel Carson's exposé of the harm inflicted by widely used agrochemicals (Carson 1962), the counterculture movements of the sixties and seventies embraced the organic cause, which further alienated many conventional producers, agribusiness executives and government leaders. It was not until the USDA published its landmark *Report and Recommendations on Organic Farming* (USDA Study Team on Organic Farming 1980) that organic methods were granted serious consideration by a government agency. This recognition was short-lived, and following the subsequent administration's dismissal of Garth Youngberg, the study's lead author, federal support for research, Extension and marketing initiatives expressly related to organic agriculture disappeared (Youngberg and DeMuth 2013). During this time 'sustainable' agriculture became increasingly accepted as an approach to mitigate the health and environmental consequences of prevailing agricultural practices. USDA developed Low Input Sustainable Agriculture (LISA), later replaced by USDA Sustainable Agriculture Research and Education (SARE), and began funding research into practices that were being pioneered primarily by organic farmers.

Prior to government funding for organic efforts, organic advocates relied on private institutions, business and non-profit foundations to support efforts to train practitioners and educate the public about organic methods. Private research institutions conducting organic farming research before federal funding included the Rodale Research Center, the Farallones Institute, the Land Institute, the New Alchemy Institute and the Meadowcreek Project of the Winrock Foundation. USDA's LISA and later SARE programs initiated a trickle of public funding for programs that benefitted organic producers, including IPM. The National Academy of Sciences study *Alternative Agriculture* (National Research Council (US) 1989) highlighted several case studies of farmers successfully using IPM practices, almost all of whom were, coincidentally, producing organically.

While organic certification was voluntary in most US states, it soon became a *de facto* requirement for producers who wished to supply products for the emerging organic industry including staple commodity crops, nationally distributed produce, crops grown for international markets such as the European Union and Japan, and imported products such as coffee and cocoa. The Organic Foods Production Association of North America (OFPANA) sought to harmonize multiple private certification programs and standards. Different sectors within OFPANA, which later changed its name to the Organic Trade Association (OTA), played key roles in lobbying for passage of the Organic Foods Production Act (OFPA) in 1990. There was a lengthy debate over what pesticides and other materials could be used, the time needed for transition before an agricultural site can be classified as organic and the place of agronomic practices in the standards (Gershuny 2014).

The most effective impetus to the passage of the OFPA occurred early in 1989, when the popular CBS news magazine *60 Minutes* aired an exposé (Bradley 1989), based on reports from the Natural Resources Defense Council (NRDC) about the risks of the synthetic plant growth regulator Alar on apples (Sewell and Whyatt 1989). Overnight, supermarkets started featuring displays of 'organic' apples. Consumer and environmental groups concerned about fraudulent claims of organic production quickly formed a coalition that demanded federal regulation of organic labeling, and later teamed up with the grassroots organic farm constituency to both influence the language of the law and advocate for its passage.

The passage of the OFPA as part of the 1990 Farm Bill [7 USC 6501] was followed by full implementation of the National Organic Program (NOP) in 2002 [7 CFR 205]. The NOP evolved over a lengthy 12-year process under the aegis of USDA's Agricultural Marketing Service, which actively involved producers, processors and marketers of organic products, resulting in a consistent national and later international requirements, standards and labeling for organic products. With OFPA and the NOP, organic agriculture finally entered the mainstream.

What is IPM?

As the name implies, Integrated Pest Management focuses on the management of pests, relying on knowledge of biology to make tactical decisions, taking externalized risks to health and environment into account. IPM has many published definitions (reviewed in Bajwa and Kogan 2002); most include using natural or ecologically sound principles or techniques, preventing pests from reaching economically damaging levels, and using multiple chemical, biological and cultural tactics, including host-plant resistance. IPM is not legislatively defined; rather definitions reflect the points of view and philosophies of the diverse organizations and individuals who use IPM.

One widely used definition is:

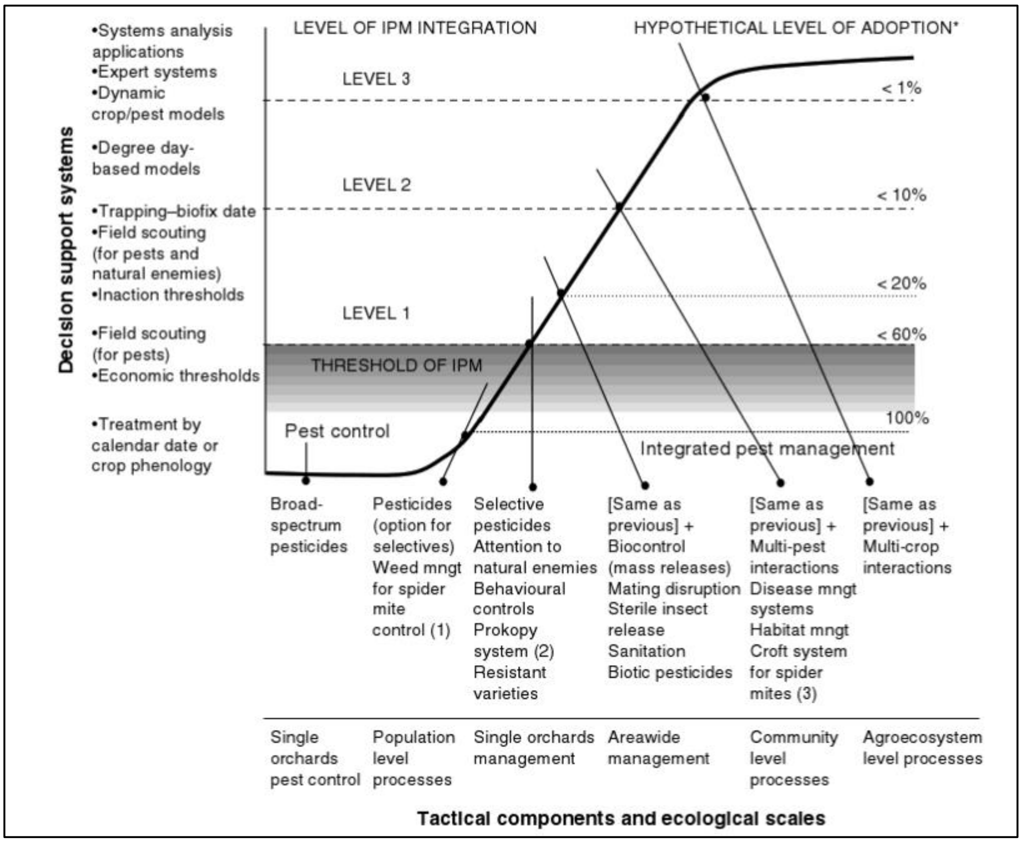
> IPM "is a science-based, decision-making process that identifies and reduces risks from pests and pest management related strategies. IPM coordinates the use of pest biology, environmental information, and available technology to prevent unacceptable levels of pest damage by the most economical means, while minimizing risk to people, property, resources, and the environment. IPM provides an effective strategy for managing pests in all arenas from developed agricultural, residential, and public lands to natural and wilderness areas. IPM provides an effective, all encompassing, low-risk approach to protect resources and people from pests" (USDA NIFA 2013).

IPM integrates multiple management tactics in ways that usually allow production systems to move away from traditional, chemically based management to ecologically sound strategies (MacHardy 2000, Prokopy 2003). When chemicals are applied, the applications are guided using economic and treatment thresholds based on monitoring pest and beneficial organisms, and environmental conditions. (Cooley and Coli 2009). IPM practices are typically crop and region-specific, and are intended to result in effective, timely and affordable pest control while also reducing use of and/or risks of pesticides to health and the environment. IPM can address any pest complex including insects, diseases, weeds, vertebrates and others, and can be adapted to any production goals including conventional, sustainable and organic (Biddinger and Rajotte 2015). IPM can readily evolve to meet new challenges such as food safety (Rajotte 1993). IPM protocols, or collections of practices for specific crops and regions, often include related practices such as irrigation and nutrient management, at least to the extent that they influence pest management. For example, carefully timing irrigation cycles so plant foliage will dry quickly limits potential for plant disease growth and spread.

Some IPM scholars and practitioners see IPM systems as a continuum, moving from calendar-based sprays to the use of scouting and thresholds and eventually to a system in which pesticide applications are rarely needed (Balling 1994, Benbrook 1996), so-called biointensive or biorational IPM (Aluja et al. 2009, Dufour 2001). IPM can also be seen as a series of levels, with practitioners moving from practicing IPM for one pest to integrating IPM into the entire production system, and eventually moving toward the integration of political and societal support and regulation that drives the development of IPM programs (Prokopy 1993). Over time, in theory, IPM should result in reduced pesticide use and impacts if practices are adopted and methods continue to evolve. For example, IPM systems developed for apples in major

US production regions vary from basic to more sophisticated levels, with a concurrent decrease in the percentage of adoption (Fig. 1, Kogan and Hilton 2009).

Figure 1. Kogan and Hilton (2009) illustrate the continuum of IPM practice along two axes, from calendar based, broad spectrum pesticide applications in individual apple orchards, to multiple strategies applied to agroecosystems including multiple crops and using advanced modelling and expert systems.



In spite of these philosophical underpinnings, most IPM definitions do not include specific restrictions on pesticide use, or mandate specific practices that clearly distinguish IPM from conventional production. No practices, except perhaps routine calendar spraying of pesticides, are formally excluded from most IPM definitions, although many market-based programs that include IPM as a component have detailed protocols with specific prohibitions and/or restrictions on pesticides and practices. There is no consensus definition of IPM comparable to the set of Federal standards that define organic. Attempts to compare pesticide use in IPM vs. conventional and organic systems, and to measure IPM benefits on human and environmental health are limited by this ambiguity. It is easy to claim that food was grown using IPM even if very few IPM practices were actually used.

Reduction in pesticide use generally is measured in terms of number of applications and/or the amount of active ingredient applied. Environmental and health risk reduction is estimated using various assessment tools discussed along with IPM benefits below.

IPM history

IPM has roots in scientific understanding of plants, pests and ecology going back to the earliest days of agriculture. As early as 300 BC the Chinese recognized the role of climate in the timing of pest attacks, and were beginning to use natural methods including herbs, oils, and predators and parasites of pests. The first successful biological control program in the US, vedalia beetle to control scale in citrus, began in 1888, the same year the Hatch Act established the Agricultural Experiment Stations as an important research component of the Land Grant University system.

IPM began as a response to pest and environmental concerns resulting from increasing concentration of agriculture and widespread use of pesticides (Stern et al. 1959). In the earliest days of chemical pest control, pesticides were referred to as "economic poisons". Naturally occurring pesticides including arsenic, copper, lead and sulfur prevailed in the 1800s and early 1900s (Gray 1918, Gowings 1959). A mixture of copper sulfate and slaked lime was first used to control downy and powdery mildew in France, and later against other fungal plant diseases (Morton and Staub 2008). DDT was first synthesized in 1874; its insecticidal properties were discovered in 1939. It was used to control lice and mosquitoes during WWII, reducing typhus, malaria and other diseases, for which Paul Mueller was awarded the Nobel Prize in Medicine in 1948. After WWII, various new synthetic pesticides became commercially available and were widely adopted in agriculture as simple solutions to long-standing pest challenges. Given the widespread adoption and perceived success of pesticides, biological control research and implementation was seen as no longer necessary, viable or worth supporting by most Land Grant Universities, private companies or government programs (Perkins 1982). The new age of agrichemicals had arrived, supplanting other methods of pest management.

The uncritical rush to use pesticides was short-lived however. The publication of *Silent Spring* created intense public scrutiny of the impact of wide use of broad-spectrum poisons (Carson 1962) and both public support and research priorities began to shift toward finding safer alternatives. At the same time, researchers recognized the opportunity to focus on keeping pests below damaging levels rather than aiming for complete eradication, motivated in large part by development of wide-spread resistance to chemical pesticides (Rajotte 1993). The earliest references to the term 'Integrated Control' appeared in the entomology literature in the late 1950s in presentations and articles from University of California researchers (Smith and Hagen 1958, 1959; Stern et al. 1959). The term IPM began to be used at Land Grant research institutions during the 1960s

Between 1971 and 1978, the National Science Foundation, USDA and the US EPA provided funding to a consortium of 19 state universities under the Huffaker Project for large scale, multi-disciplinary research in agricultural pest management, which subsequently became the Consortium for Integrated Pest Management or CIPM Project (Frisbie and Adkisson 1985). Based upon these research efforts, USDA later provided funding on a competitive basis for establishing IPM projects throughout the US (Ehler 2006). Early in its development, IPM was considered an aspect of entomology, dealing exclusively with insects and mites, but in the late 1970s the focus broadened to include microbial pathogens and weeds as well (Jacobsen 1997, Kogan 1998). Beginning in 1971 until 2008, significant USDA funding came as Extension formula funds. Competitive research funds flowed through Regional IPM Centers established in 2002. Since 2008, all funds for IPM have become competitive, including the Extension IPM program, as well as the Applied Research and Development Program and Regional Coordination Program, limiting the ability to maintain research and extension infrastructure in every state.

Since the 1980s, the USDA Natural Resources Conservation Service (NRCS) has provided technical and financial assistance to growers and consultants for IPM adoption though their Environmental Quality Incentives Program (EQIP), although less than 1% of EQIP dollars are used for IPM (Nelson et al. 2015). Growers enrolling in the EQIP 595 IPM Standard incentives program work with a certified technical service provider to create and implement an IPM plan that is often based on crop-specific IPM elements or lists of practices (Green and Petzoldt 2009). Before payments are made, growers are required to assess the risk of pesticide applications and IPM plans and implementation records must be approved.

The NRCS Conservation Effects Assessment Program (USDA NRCS CEAP 2010) provides an estimate of IPM adoption. Surveys completed during 2003 to 2006 found low percentages of cropland under a high level of IPM, meaning adoption of multiple IPM tactics to prevent and avoid pest problems. Specifically, the survey found the following use rates: 5% of cropland acres in the in the Ohio-Tennessee River Basin; 5% in the Arkansas White-Red River Basin; 6% in the Great Lakes Region; and 7% in the Missouri River Basin.

3. Organic and IPM in the Marketplace

- The National Organic Program (NOP) and the emerging movement and industry that supported its adoption set the stage for double-digit growth in organic production and products sales, with demand continuing to exceed supply for many organic products.
- Barriers to increasing organic supply include complexity and costs of organic certification, real and perceived challenges associated with transition to organic, peer pressure, ideological opposition, lack of access to solutions, inadequate technical assistance and serious pest management challenges that limit yield and quality under organic practices.
- Marketing IPM-grown food is hindered by low consumer awareness and appreciation for IPM and by the lack of a clear definition of IPM, stemming in part from the crop and region-specificity of IPM tactics.
- Many organizations and eco-labels require IPM practices of participants in certification and/or marketing programs; IPM is behind the scenes in major programs including the NOP, Rainforest Alliance, Food Alliance and Forest Stewardship Council, as well as corporate supply chain programs such as Sysco and McDonald's.
- Market forces that keep organic and IPM from reaching optimal adoption levels can be addressed through sound public policies that remove barriers, recognize practices and reward ecosystem services.

The organic market

While organic practitioners need to understand and implement IPM methods, these are rarely highlighted in organic product marketing. In the effort to create standards that could be applied across all regions and crops, a key decision made by those lobbying for the NOP was to prohibit synthetic crop inputs, with a procedure to make exceptions. This decision, along with others such as the prohibition on use of genetically modified organisms (GMOs), irradiation and sewage sludge, has provided a clear message necessary to build consumer support and awareness in the market, but has also constrained producers.

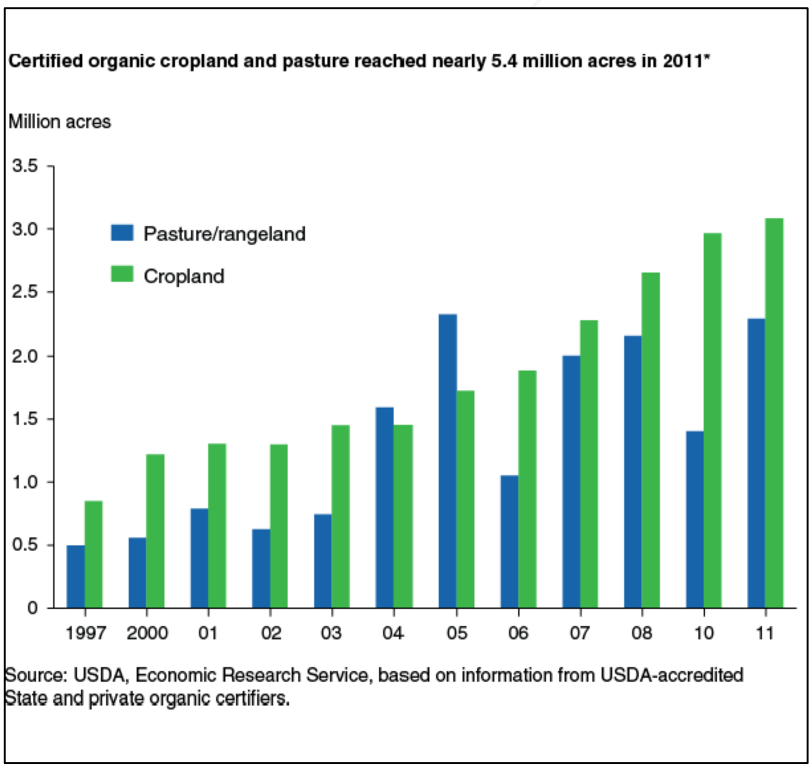
With federal regulation of the organic label, and the marketing and education campaigns that accompanied it, came a surge in demand for organic products in the marketplace, along with greater legitimacy for organic methods within the agricultural research and Extension establishment (Greene 2013, Willer and Lernoud 2014). Funding for organic research, certification cost-share assistance, and other programs have grown significantly in part due to persistent advocacy from organic farm and food organizations. Implementation of the NOP also enabled the National Agricultural Statistics Service (NASS) to begin collecting data about organic practices and sales though the Census of Agriculture, inasmuch as organic producers could be consistently and reliably identified through certification records.

Even before implementation of the NOP, USDA's Economic Research Service (ERS) began compiling information about organic production and sales using survey information collected via private, voluntary certification agencies. The Organic Trade Association (OTA) commissioned market surveys to identify the characteristics of likely purchasers of organic products and other information that would help organic companies target their markets. Promoting organic products generally became a central focus of the trade group, which has no parallel for producers who might wish to promote products under a 'sustainable' or 'IPM' label (Gershuny and DiMatteo 2007).

Organic production and acreage have grown rapidly over the past 25 years since passage of OFPA in the US and parallel regulations by the European Commission, the Japanese Ministry of Agriculture, Forestry and Fisheries, the Canadian General Standards Board and other public agencies throughout the world. The organic market and land in organic production grew at a double-digit pace from the 1980s to the late 2000s, and is still growing faster than the market for food as a whole. For 2011, the most recent year for which there are official data, there were over 5.4 million acres (2.2 million Ha) in certified organic production in the US (Fig. 2, USDA ERS 2013). Between 2002 and 2008, certified organic cropland acreage more than doubled in the United States, and certified pasture grew even faster. These data show that nearly 9% of the vegetable crop acres in the United States, 3% of the fruit and tree nut acres and 4% of the dairy cows were managed under certified organic farming systems in 2008. Global land in organic production was about 92.5 million acres (37.5 million Ha) in 2012 (Willer and Lernoud 2014). Organic food sales in 2014 generated an estimated US$35 billion in revenue (OTA 2015a). Global sales of organic in 2012 were approximately US$63.8 billion (Willer and Lernoud 2014).

Despite all the growth, organic remains a tiny fraction of world and US agricultural production. The US has a total of 844 million acres (342 million Ha) of land in agricultural production, with 0.6% of it organic. Globally, the percent of land in organic production is estimated at 0.9% (Willer and Lernoud, 2014).

Figure 2. Millions of US acres in organic cropland and pasture, 1997-2011.



USDA does not maintain official statistics on US organic retail sales, but information is available from industry sources. Organic products are now available in nearly 20,000 natural food stores and nearly three out of four conventional grocery stores. Fresh fruits and vegetables have been the top selling category of organically grown food since the organic food industry started retailing products over three decades ago, and they continue to outsell other food categories, according to a report by Penton Media (2012). Produce accounted for 43% of US organic food sales in 2012, followed by dairy (15%), packaged/prepared foods (11%), beverages (11%), bread/grains (9%), snack foods (5%), meat/fish/poultry (3%) and condiments (3%). Most organic sales (93%) take place through conventional and natural food supermarkets and chains, according to OTA; the remaining 7% occur through farmers' markets, foodservice and marketing channels other than retail stores.

Exports are a significant factor in organic marketing, with an estimated US$537 million in US exports in 2013 (OTA 2015a). Organic imports in the same year added up to nearly US$1.3 billion. Tropical and subtropical crops, including bananas and coffee, account for a large share of organic imports. Organic soybean exports more than doubled in value to US$90.2 million, and exports of organic rice, wheat and other US-produced staple crops also increased (Greene 2013). Prices for organic products continue to be higher than for their conventional counterparts. Despite price premiums of as much as 200% for some items, organic sales continue to grow among mainstream consumers.

Numerous studies have been conducted on the buying habits and demographics of consumers of organic foods (Whole Foods Market 2005, Context Marketing 2009, Hartman Group 2012, OTA 2015a). Consumers prefer organically produced food because of their concerns regarding health, the environment and animal welfare, and many are willing to pay the price premiums established in the marketplace evidenced by sales growth. Organic products have shifted from being a lifestyle choice for a small share of consumers to being consumed at least occasionally by a majority of Americans. National surveys conducted in 2012 found that 74% of surveyed shoppers bought at least some organically grown foods (Hartman Group 2012). But while certified organic acreage and livestock have been expanding in the United States for many years, domestic production falls short of demand.

The lack of raw organic commodities, such as corn, soybeans and other feed grains, has been identified by OTA as the organic industry’s most critical challenge. Such shortages lead to tight supplies of organic livestock products such as dairy and eggs, among the fastest growing areas of consumer demand (McNeil 2015).

Proposed explanations for the failure of domestic organic production to keep pace with demand despite premium prices include (1) the cost and complexity of organic certification requirements; (2) perceived greater market risks with organic; (3) social and cultural differences between the organic and non-organic communities; and (4) real and perceived production challenges to conversion of conventional acreage to organic. The first three are unique to organic and do not involve IPM to any great degree.

The NOP is actively promoting its 'sound and sensible' initiative aimed at reducing the cost and complexity of the certification process. Federal funding for the certification cost-share program was significantly increased in 2014, providing producers and handlers up to US$750 towards their certification fees (USDA NOP 2015). Nonetheless, obstacles to transition and maintenance of organic production remain, including weeds, plant diseases and newly introduced invasive insect pests which are very difficult to manage with current organic options. In addition, some long-established pests are high risk, recalcitrant or expensive to manage, for example late blight of potato and tomato, cucurbit downy mildew, diabrotica beetles in vegetables, fire blight on apples and pears, and plum curculio on tree fruit.

Organic price premiums can be insufficient to induce risk-averse conventional farmers to make a transition. The requirement of a three-year transition period to organic status following the application of a prohibited substance is a major obstacle. With no price premium for commodities harvested during the transitional period, conversion requires a huge leap of faith for producers who must learn how to eliminate nearly all synthetic inputs, deal with likely yield reductions and hope for an uncertain future reward. Before 2014, crop insurance compensated organic producers at generally lower conventional prices for crop losses, and producers in transition to organic had to use expected yields based on generally higher conventional historical averages (USDA RMA 2013).

Peer pressure and ideological opposition among conventional producers also play a large role in producer reluctance to consider organic production (Theocharopoulos et al. 2012, Press et al. 2014). In addition to the loss of an extensive support system and infrastructure oriented towards conventional farm inputs and market access, a farmer seeking to transition may be viewed with suspicion by family and community members. Organic farmers are in some cases still portrayed in the conventional farm press as faddish, anti-scientific and antithetical to America's obligation to feed the world (Block 2012). Organic advocates working in such communities report frequent disparagement and ignorance about the level of sophisticated science involved in organic management. These critiques are based on a pre-NOP view of organic that for the most part never existed in reality.

IPM in the marketplace

Marketing IPM to consumers is challenged by several factors inherent in the IPM concept. In many ways, strong elements of the IPM approach that are strengths when it comes to production are barriers when it comes to marketing. Most IPM products today are sold to consumers without production claims and without any price premium for several reasons:

- IPM includes a wide spectrum of practices;
- IPM practices can vary from crop to crop, year to year and farm to farm;
- IPM strategies and tactics are selected based on the production system in which they are used, hence IPM used within a certified organic production system would be defined by the requirements of the certification including limited synthetic inputs;
- Outside of a limited number of specific protocols and eco-label programs, IPM does not categorically rule out specific practices or pesticides; and
- Standards for IPM usually have not been developed with input from consumers.

IPM is a continuum that encourages adoption and movement toward better practices, but does not generally exclude even the most basic practitioners from the definition. IPM practices range from low-level tactics to advanced biointensive methods. Many producers, no matter their production philosophy, now use low-level tactics, such as monitoring at least some key pests and monitoring weather. Biointensive IPM employs a wide array of non-chemical, biological, cultural, host resistance and new technological strategies such as mating disruption, predator and parasite release, and internet-based decision support and trapping. The biointensive end of the spectrum is closely aligned with organic practices, while the more basic, widely used practices have become broadly used in conventional agriculture, making it difficult to distinguish differences.

Further, IPM practices can vary within a single farm, between crops and from year to year depending on pest pressures, weather, crop varieties and other factors. This makes it an effective and responsive approach for producers, but doesn't lend itself to black and white guarantees for consumers, and has led to a downgrading of ratings on eco-labels that use IPM as a requirement on the eco-label ratings website maintained by Consumers Union at www.greenerchoices.org.

IPM does not generally rule out entire categories of practices or substances, including the application of synthetic chemicals. This makes it hard to guarantee a checklist of 'no X used' or to generalize in simple sound bites to reassure consumers of exactly how the products are grown across multiple crops and farms. Because IPM is so broadly applied, a community of advocates and practitioners has not coalesced to push for limits to the definition of IPM, or for marketing strategies and regulation.

Especially in the last 15 years, increasing consumer awareness of pesticide concerns and agriculture's recognition of the need to move toward more sustainable practices have led to a variety of efforts to include IPM in marketing programs, both to educate consumers and to reward growers who are taking these extra measures. Most have been implemented with IPM in the background behind labeling and promotion campaigns that emphasize locally grown and broadly defined sustainability benefits.

The New York State IPM Program and the Massachusetts IPM Program began recognizing growers for practicing IPM in the late 1980s (Grant et al. 1990, Anderson et al. 1996). In New York, Wegmans regional supermarket chain was interested in communicating to consumers that fruit and vegetable suppliers were using IPM practices, in part to help address consumer concerns about pesticide use. In Massachusetts, the USDA Soil and Water Conservation Service (now NRCS) was interested in providing financial assistance for IPM. Because most farmers use at least some IPM practices, the question "how much IPM is enough for recognition?" quickly arose. Protocols consisting of crop and region-specific lists of IPM practices were developed in conjunction with growers, university researchers and Extension personnel. These programs prioritized practices and assigned points to each one. Growers maintained records to document their use of practices, and these were verified through examination of grower records, including on-farm visits. Growers participating in the development of the IPM Elements used in the New York State IPM/Wegmans IPM marketing partnership set a bar for qualifying for IPM labeling at 80% of the points available for a given crop. Massachusetts Partners with Nature required growers to achieve 70% on similar IPM Guidelines developed for that program (Anderson et al. 1996). Growers in both states used this recognition in their direct and wholesale marketing.

These two early programs attempted to educate the public about the benefits of IPM as well as provide farmers with a mechanism to be recognized for high-level IPM adoption by government incentive programs, commercial buyers, direct-to-consumer marketing and the public. Surveys conducted during the course of these programs indicated that while initial consumer recognition of the term IPM was low, after explanations of IPM were provided, consumers indicated an increased willingness to purchase food grown using IPM practices (Hollingsworth et al. 1993, Pool 1997).

Multiple factors contributed to a gradual end to these two programs including lack of consumer response; insufficient infrastructure for crop and region-specific protocol development and third-party verification of grower records; no price premium for IPM crops; reluctance by retailers to create a third category on already crowded shelves; concern by organic proponents that another option would undercut the newly emerging organic position; increasing visibility and credibility of the organic label; and resistance from growers who believed labels drew attention to their use of pesticides. In addition, growers, even those using IPM, became concerned that these programs made clear that growers were using pesticides, and some growers resented the implication that conventional production was somehow unsafe. Of the Massachusetts farms that could have participated in Partners, at most only 53% did. The Massachusetts Dept. of Food and Agriculture pulled support in 1999 citing “low participation” (Cooley and Coli 2009). Reports have not been published comparing pesticide use between growers qualifying for either label to non-participating growers.

Later eco-label programs have shifted toward including IPM practices in a wider suite of sustainability practices including pollinator protection, energy and water conservation, greenhouse gas reduction and recycling. These programs do not use the term IPM on the label, eliminating the barriers of lack of public recognition of and resonance with the term IPM, and the need to associate the word “pest” with the purchase of food. These programs include Rainforest Alliance, Food Alliance and the Forest Stewardship Council, certifying 40 million acres of production in the US and 376 million worldwide (IPM Institute 2012), with forest product certification accounting for 34 million of the US acres and 367 million acres internationally. This approach has helped differentiate IPM practices under the umbrella of broader claims and brands, rather than creating a new IPM certification in a marketplace that is already crowded with claims and labels. Links to programs are provided on the IPM Institute web site: http://www.ipminstitute.org/links.htm. Certification programs are also available for IPM practitioners in a range of settings, including facilities and grounds management.

One example, Eco Apple, is a certification program administered by Red Tomato, a marketer of sustainably-grown local produce (http://www.redtomato.org/eco-apple/). Eco Apple growers are certified by the IPM Institute, which provides third-party verification of practices for a number of eco-labels and sustainability programs. Eco Apple protocols were developed and are reviewed annually by researchers and growers. The protocol classifies pesticides as traffic-light ‘green’, ‘yellow’ or ‘red’ colors based on several types of toxicity criteria and the potential for resistance development:

- *Green* – use with justification, e.g. trap captures or weather-based thresholds;
- *Yellow* – use with justification and/or restrictions when green list or other alternatives are not adequate; and
- *Red* – do not use.

The Eco Apple protocol prohibits use of more than thirty pesticides approved by US EPA for apples, many of which are widely used in typical commercial production.

IPM is an adaptive approach that allows adoption at many points along a spectrum. It is inherently designed to be applied differently depending on specific conditions, climate, location, crop, pests and timing. For these reasons, a set of standards based on specific substances and requirements, such as one modeled on the NOP regulations, could hold back continuous improvement of IPM practices. However, the principles underlying IPM are consistent across uses at all levels and circumstances. Eco Apple and other successful programs have identified ways to verify application of these principles and communicate them credibly to consumers, differentiating products grown using advanced IPM practices from more basic, conventional practices. Such differentiation and consumer awareness is essential to support growers in finding a foothold in the marketplace.

The increasing consumer awareness of and concern about food quality has in large part driven the growth of eco-labels and organic production. Assuming this growth continues, consumers and wholesale buyers will want more clarity in production practices used for food and other agricultural products. Technology enables tracking of food to the level of individual fruits and vegetables, facilitating the process of connecting food to a grower through the supply chain. Whether eco-labels which incorporate advanced IPM succeed in this marketplace will depend on consumers' ability to understand them and consumer confidence that a given label means high-quality, healthful food grown in a sustainable way. Both consumers and growers, organic and conventional, have an interest in developing this agriculture as the fate of the planet depends on it. IPM and organic practices currently offer a good start, but sustainable agricultural systems will depend on collaboration between these two approaches as well as major investment in research and education for their development.

4. Overcoming the Barriers to More IPM and Organic

- Organic and IPM adoption and benefits remain far short of potential.
- Organic and IPM research, development and outreach face competition from public and private sector efforts that result in sales revenue to manufacturers, distributors and retailers; systems approaches do not necessarily generate revenue opportunities.
- A 'bigger is better' mentality, and short-term goals of maximum yield and profit, without consideration of external costs to health and environment, are not sustainable.
- Most researchers focus on a narrow aspect of the whole, and fail to consider impacts of their research at the agroecosystem level.
- Certified organic growers are accountable to a legislatively defined standard with third-party oversight. In contrast, only a minority of IPM growers participate in programs that verify a high-level IPM performance.
- Conventional farmers who apply excessive inputs are seldom held accountable, although corporate sustainability efforts are increasing pressure on all growers to improve.
- New and redirected investments are needed in farmer-oriented, systems-based research and demonstrations appropriate to regional conditions to make transformational rather than incremental gains in addressing pressing health and environmental concerns. A few model funding programs and funded projects illustrate this potential.

A new approach

By any measure, organic and IPM adoption fall far short of their potential. Less than 1% of US cropland is certified organic (USDA ERS 2013). Only about 10% of cropland benefits from a high level of IPM practices (USDA NRCS CEAP).

The most daunting barriers to greater IPM and organic adoption are not concepts, definitions, standards or consumer demand. IPM tactics and organic systems face similar and overlapping production challenges that can be addressed by an approach to pest management that is not overly dependent on chemicals. Instead, the most significant barriers are declining public research, Extension and education funding and under-valuing by major universities and institutional research and educational programs.

An ecological approach to pest management is at a disadvantage when competing for attention with private sector, product-focused research, development and marketing. External costs in environmental degradation are not included in the pest and crop management decision process. Widespread pest resistance to pesticides is a symptom of overreliance on pesticides and of the lack of integrated approaches that include cultural, biological, host resistance and new technology for decision support.

The situation is illustrated in these comments on weed management.

> *"Unfortunately, the knowledge infrastructure needed to practice Integrated Weed Management (IWM) in the future may be atrophying. Although seed and chemical companies can generate enormous revenues through the packaged sales of herbicides and transgenic seeds, the IWM approaches are based on knowledge-intensive practices, not on salable products, and lack a powerful market mechanism to push them along."* (Mortensen et al. 2012)

Ward et al. (2014) provided a broad critique of weed science centering on the tendency for weed scientists to remain highly isolated from other disciplines, focusing solely on weed management to the detriment of a more fundamental understanding of ecological and evolutionary theory. That critique failed to address a primary flaw shared by pest disciplines in general: the retreat from systems thinking towards a model where inputs are purchased to treat symptoms rather than addressing the systemic causes of pest problems. Organic and advanced IPM models on the other hand, look beyond symptoms and apply deeper understanding of theoretical underpinnings, a broader vision including prevention and avoidance and biological solutions to pest problems, and increased collaboration across diverse disciplines. While inputs are used by both organic and advanced IPM producers, pesticides are not the first line of crop protection, but are instead a complement to a systems approach. Finding a balance between a systems approach and input-based models can be challenging when external pressures for and incentives from product sales dominate the process.

Long-term shifts in production strategies and techniques are influenced by research priorities, both privately and publicly funded. The organic sector has been unable to support the large-scale, long-term research needed for developing sustainable farming systems in part because the output of that research is publicly accessible knowledge and not a product that can be sold. Ideally, the Land Grant system would provide such public-sector research and education. Yet with decreased public funding, Land Grant universities turn to patents to generate support for their programs. It's impossible to patent a cover-cropping practice that will, for example, decrease soil pests. So rather than do research on cover cropping systems, a scientist may choose to identify the active components that suppress pests, patent them and sell the rights to a company that can market it. Actually growing and incorporating a cover crop might improve several aspects of soil health, including organic matter as well as beneficial microbes, but selling a pest suppressing chemical makes money.

When funding sources narrowly focus on one area, innovative systems thinking is often sacrificed. A long-term systems approach to research is needed if transformative change rather than incremental change is to happen. Many of the beneficial impacts of both organic and IPM approaches can only be realized if the entire growing environment, including the soil, evolve to deliver valuable ecosystem services that include biocontrol of pest populations. Significant adoption of such a systems approach depends on the combination of public funding with private investments in research that is independent of the need to sell products or services. Indications are that state and federal grants are unlikely to increase substantially in the near future (National Science Board 2012, Green et al. 2012). Therefore, a new model is needed that balances private revenue support with public sector funding for experiments that take a long-term systems approach. Organic Research and Education Initiative (OREI) federal grant program is evidence that positive impacts can be gained with this type of funding partnership. Significant capacity including faculty, post-doctoral associates, graduate students and experimental acres has been built for organic systems with the help of OREI. While this investment is undersized for the need, it does suggest that reorientation of public dollars can have a meaningful impact.

Expanding adoption

In today's agricultural production systems, it is challenging to produce a crop, protect health and environment, remain financially viable and be socially responsible, regardless of the production system used. Human behavior and a focus on short-term economic gains often supersede health, environmental and social considerations. One example of this kind of thinking can be seen in the conventional food industry presenting larger serving sizes to increase sales (Young and Nestle 2002). Human health is thus put at risk through obesity and greater susceptibility to heart and other diseases.

This neglect of health, spurred on by the desire for more, is also apparent in our current agricultural cropping systems. Conventional agronomic research focuses on increasing yields, often by relying on increased inputs and intensive management. A primary reason for broad adoption of chemical-intensive strategies is the widespread expectation of top yields and economic returns without regard to externalized environmental and health costs, and the business model that promotes this focus. When implemented by farmers who seek to maximize short-term profits and who are not expected to pay for those external costs, the resulting environmental impacts include hypoxia in the Chesapeake Bay, Great Lakes and Gulf of Mexico, groundwater contamination by nutrients and pesticides, and unacceptable levels of soil erosion.

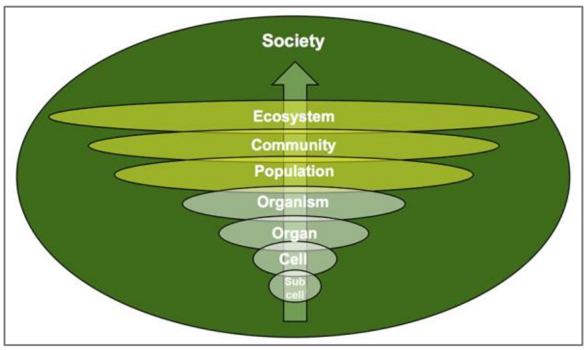
This approach to crop production has come at a huge cost to biodiversity and soil health (DeLong et al. 2015) and has led to calls for a return to whole-farm strategies to manage pests. In order to improve soil health, new, biologically focused systems of production need to be investigated and pursued. Because biological reference points fluctuate greatly over space and time, regional and ongoing research will be key to understanding how to best achieve economically sustainable results for farmers.

To overcome these challenges, alternate funding strategies need to be instated through the public sector. A new paradigm of farming systems research with broader goals beyond yield enhancement will require a substantial public investment. Private research and product development companies will continue to produce necessary input products; these need to be incorporated into sustainable systems as appropriate, and not promoted and used regardless of external costs.

Beyond yield: Compensating environmental and societal benefits

Agricultural methods that conserve or improve natural resources and that aim to balance economic, environmental and social priorities should be valued more than they currently are. Systems that focus on one priority such as short-term yields are rarely if ever sustainable over time. Approaches that incorporate and integrate a wide range of practices and goals in addition to economic success, notably environmental and societal sustainability, are more complex, and more costly and take longer to fully develop. But as a society we have generally valued short-term economic success and ignored or discounted contributions to long-term sustainability.

Figure 3. Levels of agricultural research from the sub-cellular to ecosystems, ultimately impacting society (Stockbridge School of Agriculture).



There is a tendency among most people to focus on the short-term and familiar. This is true of agricultural scientists who tend to focus on their own areas of expertise. Much agricultural research is at the organism, organ, cellular, and/or sub-cellular and genetic levels. Most agricultural researchers have been trained to take an organism apart to understand it from the perspective of their own discipline. To develop sustainable agricultural systems, each individual field of study must be understood as part of an integrated whole (Fig. 3).

It will be increasingly important for agricultural researchers, as well as policy makers, to understand the interactions of various levels of biology in the context of whole ecosystems. Agriculture inherently involves social science, as well as populations and communities of organisms, including humans, interacting in complex ecosystems. Interactions between components across different scales in a system over time create emergent properties or behaviors that may not be predictable. Systems ecology is a scientific discipline that offers a framework for understanding relationships within complex agricultural systems from the sub-cellular to the ecosystems level, and the emergent properties that often come from them.

This type of systems ecology has been proposed as a sustainable way to protect crops from pests (Lewis et al. 1997). Instead of understanding the underlying causes of pests and engaging in preventive measures, most strategies have focused on a single pest, a single crop and a single 'silver bullet' solution. A total systems approach applies ecological principles to manage pests, weeds and diseases. Cultural and biological practices, such as crop rotation, intercropping, beneficial organism releases, cultivation practices, mating disruption and other non-biocidal interventions are used to protect crops, with biocides used in exceptional cases if at all. Such an approach requires looking beyond maximum yield and short-run profit to the benefits beyond the farm over a long horizon.

Farmers are, of course, central to agroecosystems. Whether a farmer/grower considers himself or herself to be conventional, to be using IPM or to be a certified organic producer, too often the yield of their crop is their sole measure of success. For sustainable agriculture to thrive, growers must value additional measures of success. Improved soil health, reduced greenhouse gas emissions, reduced energy consumption, decreased pesticide use, community vitality and other societal and environmental metrics need to be teamed with economic success.

The long view

Over 35 years of data from Rodale Institute's Farming Systems Trial, Iowa State's Long Term Agroecological Research experiment and USDA's Beltsville Maryland Farming Systems Project provide extensive information supporting the idea that statistically equal yields can be obtained in agronomic crops while improving sustainability indicators.

The USDA Regional IPM Centers have funded over 1200 studies since 1996 that show the environmental and associated human health benefits of diversifying pest management techniques using IPM. As discussed above, IPM practices tend to form a continuum, from using none to biointensive, with the biointensive most likely to improve the health of agroecosystems (Philips et al. 2001).

Advanced IPM, with multiple crops grown in rotation using a variety of cultural, biological and technological tactics, with chemical applications based on thresholds and scouting, addresses sustainability issues and is most likely to fit in organic systems. In organic systems, growers must have knowledge of the biology and seasonal differences that exist for producing crops without the extensive use of synthetic inputs that incur external costs. This approach focuses on prevention, keeping ahead of pest outbreaks using a variety of methods that are not focused solely on external inputs. It also provides societal benefits and ecosystem services.

Yet our society largely ignores these benefits and focuses on short-term economic gain. The present food system encourages growers to exploit cropping systems by implementing practices that reap large yields, but degrade soil health and pollute the environment without significant financial consequences. If a crop failure occurs, taxpayer-subsidized insurance will make up the losses. The costs of modern high-input monocultures are truly externalized, born by society as a whole.

At the same time, we require those farmers using advanced IPM and organic methods to pay extra for certification and inspections. No growers are rewarded for the ecosystem services they may be providing.

In short, the economic incentives are upside down. Growers should be rewarded for using sustainable practices, and the costs of unsustainable methods quantified and factored into investments in incentive programs. For example, farmers who use cover crops that build soil health, sequester carbon and nitrogen, and suppress pests should get tax relief or a direct payment.

With the many global challenges faced by society, a new approach is needed for agricultural and other managed landscapes. Both organic and IPM farming practices have much to contribute to shaping this new approach. Compensating farmers for ecosystem services requires not just innovative agricultural practices, but also restructuring markets to reward the public benefits provided (Schmid et al. 2012). In response to public demand and the need to ensure long-term viability, large corporations, smaller companies and even local restaurants are working with growers to produce crops and/or manage resources in a more sustainable way. Examples include the Potato Sustainability Initiative, an effort started by McDonald's in 2010 with now multiple potato buyers and more than 500 US and Canadian potato growers participating, the Sysco IPM/Sustainable Agriculture Initiative, with more than 80 food processors and 5000 growers participating worldwide, and Responsibly Grown, launched by Whole Foods Market for its produce supply chain in 2014. Additional examples include Field to Market, Stewardship Index for Specialty Crops and the Sustainable Agriculture Initiative, broad collaborations including academics, corporations, non-governmental organizations and public agencies to develop science-based approaches to implement and document improvements in sustainability metrics.

Programs and protocols like these are needed to move agriculture away from a destructive system to a regenerative one that repairs our soils and begins to build environmental and human health into food production. Transformational thinking, not just incremental change, is needed if we are to make meaningful advances in our management of essential natural resources: soil, water, energy and labor.

Currently, organic products command premiums in the marketplace because consumers increasingly demand them. To a lesser extent, consumers have sought out eco-label products. But while consumers are becoming more aware of how their food and fiber are being produced, their preferences are slow to be translated into government policy.

Government programs and the federal farm bill subsidize and hence encourage current production models. With public support, government can rework subsidies and related programs to move agriculture toward using practices that contribute to a sustainable future. These dollars should fund research, including regionalized farmer-oriented, long-term experiments. They should fund demonstration sites and educational opportunities to break down barriers to adoption of sustainable methods. They should make the public more aware of the critical issues surrounding agricultural sustainability and food, and improve consumer access to affordable food products produced sustainably.

5. Moving Forward

- IPM and organic have many similar needs for increased resources in research, education, Extension, technology transfer, and public and private sector incentives.
- Both groups of practitioners have an interest in reducing production costs and tapping into market incentives for environmental stewardship.
- Organic production falls short of demand, indicating that sustainable agriculture is a growth area and that consumers will support policies that encourage IPM and organic farming.
- Institutional and individual changes at the implementation and policy levels can encourage sustainable agriculture practices that benefit organic and IPM growers.

Common needs

Pests challenge all farmers, organic or not, and those who work in different agricultural production systems share common aspirations. Many IPM techniques apply equally to conventional or organic farms. Organic farmers have been early adopters of many IPM methods, such as releases of beneficial organisms, habitat management to encourage beneficial insects, mass insect trapping and behavioral modification of insects using pheromones. At the same time, the IPM community has learned from organic agriculture, especially its emphasis on long-term cultural practices. Indeed, many IPM specialists and researchers engage with the broader idea of integrated crop management. Many previously 'organic' practices are finding their way into conventional farming, evidenced by the increasing frequency which with cover crops, soil health, water quality and sustainability are covered in the mainstream ag press. When it comes to managing pests, IPM is a method that can fit a grower's organic farming goals and be useful in encouraging conventional growers to use more sustainable methods.

While organic farming and IPM have obvious synergy, both the organic and IPM communities, including Land Grant scientists, educators, promoters and growers, have not fully embraced their common interests nor engaged the synergism an improved collaboration would provide. A first step in building these collaborations is to identify areas of mutual interest between organic communities and other growers, then refocus research, education and outreach, both within and outside the USDA and Land Grants to address them.

Research

Although IPM and organic farmers face many of the same pest problems, their economic situations and the technologies that they have at their disposal are not the same. To build beneficial collaboration it is necessary to look at where the two overlap. For example, organic farmers have consistently listed weed management as their top research priority, while weed management generates significant external and on-farm costs in conventional agriculture.

In spite of its importance, IPM programs have generally not given weed management the same attention they have given insects and diseases. For example, IPM has not implemented threshold or degree-day models to manage weeds to the extent that it has to manage insects and diseases. While IPM recommendations acknowledge cultural, mechanical and biological practices that are available to organic farmers, little IPM work has gone into the elimination or even the reduction of herbicide use. With the emergence of glyphosate-resistant weeds (which for organic farmers are no more challenging than non-resistant weeds) the emphasis has been on alternative herbicides, not alternatives to herbicides. An approach to herbicide-resistant weed management that does not rely on herbicides would benefit both organic and non-organic farmers. Some organic farmers have developed very successful weed management systems with the tools available to them. Still, organic growers would like more research done on herbicide alternatives, and have identified soil and nutrient management, tillage and cultivation practices, natural herbicides, particular problem weeds, flame weeding and no-till without herbicides as high priorities (Baker and Mohler 2014). Such research would reduce the reliance on herbicides seen in current IPM programs.

A basic tenet of IPM, the economic threshold, should be more rigorously researched. Given diminishing returns, maintaining a weed-free field throughout an entire season may not be worth the costs. Some ‘weeds’ actually provide ecosystem services by cycling nutrients, providing beneficial habitat and maintaining soil structure. Both organic and IPM farmers would benefit from economic models that account for the total costs associated with the control of weeds, and a quantification and valorization of the ecological benefits provided by weeds.

Beyond weeds, most organic farmers share specific important pest problems that challenge all producers. Newly introduced exotic pests, such as spotted wing drosophila (SWD, *Drosophila suzukii*), brown marmorated stink bug (BMSB, *Halyomorpha halys*) and Asian citrus psyllid (*Diaphorina citri*) threaten organic and conventional crops alike. SWD, BMSB and the Asian citrus psyllid are responsible for growing economic losses in the US due to crop loss and management costs. Overall pest management costs on susceptible crops have risen 15 times since SWD arrived. In 2010, BMSB caused US$37 million in apple crop losses in the mid-Atlantic region (Leskey et al. 2012). Crop damage due to BMSB was reported in 17 states in 2014 (Northeastern IPM Center 2015), up from ten states in 2013. In the case of the Asian citrus psyllid, the vector of the bacteria that cause citrus greening, also known as huanglongbing (HLB), pesticidal approaches alone have been ineffective in stopping the spread of the disease. As a result, farmers are experimenting with non-pesticidal techniques to improve plant nutrition and the natural immunity of citrus trees (Stansly et al. 2014).

While introduced pests present particular problems, losses from pests in general continue to be a rising threat to the food supply and economic viability of farms. Pesticides alone do not solve the problem. Despite a 2200% increase in pesticide use in the United States over the past 75 years, to 1.1 billion pounds annually (US EPA 2013b), pest organisms account for enormous losses to US agriculture, estimated at US$137 billion in annually losses (Pimentel 2001).

Applied entomologists have long known that broad-spectrum insecticides often create new pest problems because they destroy the balance between plant pests and their natural enemies. This secondary pest problem is not nearly as common in organic systems. Because organic farmers are generally required to use less toxic and more specific insecticides, beneficial populations are rarely reduced the way that they are on conventional farms. IPM systems are generally designed to preserve beneficial organisms by using selective insecticides, adjusting timing of application and improving the habitat for natural enemies.

Alternatives to antibiotics to control fire blight (*Erwinia amylovora*) in pome fruit is a major concern of organic apple producers and a growing concern of conventional producers. Organic farmers in the US are now no longer able to apply antibiotics to crops, following standards developed previously in the European Union and Canada. Pathogen resistance to streptomycin has reduced its efficacy, increasing conventional farmer interest in alternatives as well, largely to preserve the efficacy of the remaining antibiotics. While biorational pesticides against fire blight are generally not as effective as antibiotics, they can be used in conventional management programs to reduce resistance selection pressure. Both organic and conventional growers can use decision-support models to determine the need for treatment.

Another priority of organic farmers is the development of alternatives to copper for the management of late blight (*Phytophthora infestans*) in tomatoes and potatoes. Cultural practices; breeding, selection and development of horizontally resistant varieties; nutrition management; induced immunity; systemic-acquired resistance; and biological control through the introduction of antagonist or hyperparasites appear to be the most promising avenues of research. However, much of the research that takes place is on a 'silver bullet' input-substitution approach.

Education

As the farming population ages, the next generation of farmers will need to have a very different set of skills than has been required in the past. Farming has become more information intensive. Constant messages to buy into cheap, fast and easy solutions abound. Unlike previous generations, beginning farmers often do not have farming backgrounds. On the one hand, this appears to be a daunting challenge, where sometimes even the most basic skills need to be learned. On the other hand, these new farmers are not bound by tradition, family expectations or peer pressure to maintain a certain set of practices. As such, new farmers may be more willing to experiment and innovate.

Extension

Organic farmers historically have not relied on Extension for advice, with many thinking that Extension was unwilling or unable to address their needs (Papendick et al. 1980). There are a number of reasons for this. One is that Extension agents often have been unfamiliar with organic practices and standards. Efforts to train Extension staff have improved the situation somewhat, but there remain a number of Extension staff uninterested in serving organic farmers. No recent study of Extension's capacity and willingness to serve organic clients appears to have been conducted, but some farmers still report a reluctance by Extension to give advice on organic practices. Part of this may be due to the influence of conventional commercial agriculture. Extension recommendations often are reduced to input substitution without an understanding that the restrictions on pesticide use in organic standards greatly limit pesticide interventions. Extension recommendations for action thresholds, or levels at which it makes economic sense to intervene to address a pest problem, rarely consider variable crop value, and so cannot be adjusted by growers to reflect the often higher value of organic crops. Thresholds frequently do not incorporate presence, abundance or potential to introduce beneficial organisms, which are often the backbone of organic and advanced IPM systems. Additional training and funding to increase organic expertise and reinforce the synergy between organic and IPM practices would be beneficial.

Technology transfer

Many of the tools that provide options for organic farmers as well as farmers using advanced IPM are not commercially available or practical to apply. Biologically based approaches are often in the public domain, and companies are not interested in commercializing them if they are not able to obtain intellectual property rights and a monopoly on a product. While the organic market niche is growing, it is often perceived as too small for input suppliers to formulate specific products that comply with organic standards. In several cases, formulated products have an active ingredient that complies with the organic standard, but non-active ingredients—euphemistically known as 'inerts'—do not comply. Not only must the active ingredients meet the OFPA's rigorous criteria to protect human health and the environment, the inerts must be classified as 'minimum risk' (List 4) by the EPA, unless otherwise specified (USDA NOP 2011). Many products with compliant active ingredients but non-compliant inerts were formulated prior to implementation of the NOP. The objective was to maximize efficacy, rather than to minimize risk or impact on human health and the environment.

The Inter-regional Research Project on Minor Uses of Pesticides (IR-4) program, in a new approach to identifying research priorities, held their first biopesticides workshop in 2014 and now recognizes organic farming as a minor use separate from various crops. Follow-through will require organizing organic farmers to participate in the process effectively, and to work with the pesticide registrants, researchers, Extension and suppliers in a way they have not done before.

Although the supply and variety of products available has been increasing, the agricultural supply sector continues to have a marketing opportunity to develop, formulate and sell additional NOP-compliant products, which can also serve IPM and conventional customers. Suppliers can be given incentives to provide fee-based services, including scouting, soil and yield mapping, and custom operations using specialized equipment that may be impractical for individual farmers to acquire.

Strategies

The long-term viability of farmers depends on their ability to manage operations efficiently in a productive way, and to generate sufficient income through marketing and protecting the natural resource base upon which their livelihood depends. Organic agriculture continues to rely on a premium price, but in the long run, organic farmers will need to close the yield gap and lower costs of production to remain competitive.

Holistic approaches to farm management require a higher level of awareness of pest biology, nutrient cycling and ecosystem interactions, and result in a different set of options and decisions than an approach that involves delivering a prescribed amount of synthetic fertilizer and choosing a pesticide to control a pest. Emphasis is on prevention and anticipating problems rather than reacting to crises. Organic farms are required to have a system plan that is approved by the Accredited Certification Agent. In the case of pest management, producers are required to think through the weeds, pests and diseases they face and spell out how they will manage those production challenges using biological, cultural and mechanical approaches. Similarly, growers at the high end of the IPM adoption spectrum are implementing systems for preventing pest outbreaks that rely on sophisticated knowledge of pest biology and ecological interactions. Increased research and outreach attention to crop production systems theory and practice will better prepare farmers to transition to more sustainable practices.

Organic farming is market-driven, responding to consumer demands for healthy food that does not pollute the environment. While there have been numerous attempts over the years to develop an IPM label, marketing has not been the foremost concern driving the adoption of integrated techniques. The organic market continues to grow at a double-digit rate. Supply is not keeping up with demand, and there is an opportunity to transition more farms to organic. Farmers using advanced IPM who are interested in a premium market are likely to have an easier time making the transition to organic. Market-based programs and other certifications that incorporate substantive IPM practices into their standards and requirements will also help to drive IPM and organic practice adoption. Increased consumer recognition of the environmental and health benefits of crops grown under high-level IPM practices and other incentives are needed to move more farmers along the IPM continuum.

Policies

Policymakers and funders often see IPM and organic as mutually exclusive separate silos. This is a misperception in that IPM is not a separate production system, but an approach that is required in the NOP and can be used in multiple production systems. Corporate as well as government policies need to change perspectives. A 'least-toxic' IPM approach will serve wholesale buyers and consumers who want to purchase products that are safe for themselves and the environment. Where possible, manufacturers should formulate pesticides that have both active and inert ingredients allowed for organic production. A number of pesticides have active ingredients that are allowed for use in organic production, but because the registration process takes so long and costs so much, companies are reluctant to re-register a product with a new formulation that is less toxic or complies with organic standards. One possible reform is a streamlined process for a less toxic formulation to be registered for free if a more toxic formulation is withdrawn.

Institutional and individual changes are needed to implement programs that serve the mutual interests of IPM and organic producers, as well as the interests of other stakeholders who want to reduce the environmental impacts of agriculture. These changes will require a new set of governmental, institutional and company policies; building the capacity needed to conduct research, develop tools and techniques, and deliver new technologies; and communication between the organic and IPM communities at all levels to build trust and understanding of mutual concerns and interests. Broadening the IPM concept to incorporate nutrient management practices, as in Integrated Crop Management, would fill a void in many Land Grant University research and Extension programs where there is no parallel formal program with a mission to reduce risks from nutrient management practices on farms and non-farm managed landscapes.

Land Grant universities are expanding their certified organic acreage, but the amount of land that is available to conduct organic farming research is still relatively limited. More researcher-farmer partnerships are needed for both organic and IPM approaches to provide demonstrations that have credibility with producers beyond controlled experiment stations that do not provide what many see as 'real world' results. Conventional and IPM research facilities can be transitioned to organic with the opportunity to conduct experiments on the dynamics of transition. These studies can provide valid results that can help transitioning organic farms understand the ecological processes that take place. However, to be valid, the methodologies should replicate the transition of operating farms as closely as possible. The bigger challenge with capacity building is developing the human resources needed. A new generation of researchers and Extension staff need to be trained to understand the theory and practices of both IPM and organic systems to serve the practical needs of producers and improve sustainability.

Organic and non-organic producers have a lot in common, yet often do not interact. Building bridges between the organic and integrated communities will take time and trust-building. The Organic and IPM Working Group is one step toward expanding and deepening that communication and building that trust. Opportunities for collaboration, exchange of ideas and exploration of common goals will continue to emerge as communication increases, and we hope this white paper will be the beginning of many productive conversations to that end.

Conclusion and recommendations

Agriculture faces many challenges that require an understanding of the systemic nature of the problems, rather than simply responding to symptoms. The organic and IPM communities can work together to address these challenges and develop and increase adoption of solutions. To do so efficiently and in a timely manner will require changes in policies and the marketplace. The key policies we recommend are:

- Increase public and private support for long-term, interdisciplinary systems research that provides working models and field-scale demonstrations of both organic and advanced IPM systems that farmers, researchers and practitioners can use.

- Facilitate adoption of sustainable practices through publicly funded programs that expand outreach, promote collaboration between IPM and organic proponents, and compensate farmers for ecosystem services provided.

- Eliminate publicly funded programs that encourage unsustainable practices focused on maximizing yield and profits.

- Increase public incentives, including through pesticide registration improvements, for product and service providers to develop, formulate, market and sell more options that are compatible with organic and advanced IPM systems, including biologically based pesticides.

These policy proposals all need further work to develop them as viable options. The organic and IPM communities are committed to working together, whatever past difference there have been and whatever future challenges remain. With policies conducive to promoting organic and IPM systems, together we can address the serious challenges we face to feed the world without destroying it.

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