Conceptual Framework for an Iowa Pest Resistance Management Plan

Resistance management is the effort to slow the development of pest adaptation to chemical, genetic and agronomic control practices; foster methods of early, resistance detection; and mitigate resistance as it arises.

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EXECUTIVE SUMMARY

Resistance management (RM) is the effort to slow the development of pest adaptation to chemical, genetic and agronomic control practices; foster methods of early, resistance detection; and mitigate resistance as it arises.

An outcome of a January 2015 meeting, entitled "Resistance Management: Whose Problem and Whose Job," included a call for developing a state-wide, voluntary, pest resistance management (RM) plan. The meeting was attended by representatives from across Iowa's agricultural community. Subsequently, Iowa's Agricultural Strategic Thinkers Acting Together Effectively (Iowa AgState) concurred the time was right for preparing such a plan. A task force of representatives, from a cross-section of Iowa AgState organizations, consortia of agricultural pest management technology providers, the Iowa Department of Agriculture and Land Stewardship (IDALS) and Iowa State University College of Agriculture and Life Sciences (ISU/CALS), was formed to develop a conceptual framework for the plan. This paper, authored by the task force, provides a framework that can serve as the foundation for developing an Iowa RM plan during 2016.

<u>Leaders and Partners</u>
Successful implementation of the RM plan will require a "champion" and it is suggested the Secretary or Deputy Secretary of IDALS serve in that role. The development and implementation of a statewide, voluntary, RM plan ultimately requires strong leadership and partnerships from Iowa's farmer, commodity, agricultural retailer, crop adviser, and crop consultant organizations and pest management technology providers, in association with IDALS and ISU/CALS. The RM plan could be coordinated by IDALS, which would also be responsible for apprising the Environmental Protection Agency and the United States Department of Agriculture of the plan and its implementation. ISU/CALS would continue to develop and compile the science on pest resistance and RM strategies, including economic implications, and could be the hub for developing outreach materials for the agriculture community.

<u>State of the Science to Support RM</u>
Common themes concerning resistance development and management in insects, weeds and pathogens are evident; however, specific details vary across pests and pest management practices. Resistance management practices should include a diverse combination of crop rotations, effective use of different pesticide modes of action, seed with stacked native and biotechnology-derived traits, and mechanical controls in the context of diligent use of integrated pest management (IPM). IPM includes scouting to assess pest pressure and monitoring for early detection of poorly performing pest management technologies. Employing these RM practices are likely to increase input costs, time commitments and production complexity in the near term, but long-term productivity and profitability will likely be higher due to the reduced rate of pest resistance development.

Research surveys show that Iowa farmers and agricultural stakeholders are aware that pest resistance is a problem, and they are concerned. They also share the belief that multiple stakeholders bear responsibility for RM and proactively taking action. The surveys suggest there is common ground on which to build coordinated approaches to RM.

To facilitate the development of an Iowa RM plan, knowledge and understanding of current and potential science, technology and production agriculture management solutions as well as applied socioeconomic analyses of different pest resistance problems and RM practices is needed. These analyses will help to better understand current RM options and the perceived and actual costs, and short- and long-term benefits of RM practices, as well as reveal which RM practices provide the most significant return on investment.

Critical Features of a Plan

The nature of pest RM requires a plan that incorporates a long-term, integrated approach to pest management, and its costs and benefits. The goal of the plan is to document and promote holistic and integrated management solutions that will effectively and sustainably control pests, and postpone or delay resistance development, foster methods of early detection, and then mitigate, to the extent possible, the spread of pest resistance. Framing and messaging the plan and its goal of promoting R&D investments and extending the long-term viability of effective pest management technologies will be critical. Other key elements of the plan will likely need to address education and outreach, incentives, financing and lease agreements, monitoring implementation and results, and governance.

Ultimately, the actions of individuals will be the key facet of the Iowa RM plan, but achieving the desired outcomes of these actions may require community-based approaches. The proposed framework suggests some options for defining communities, discusses the need for leaders within communities and stresses the importance of coordinated efforts of all stakeholders.

Recommendations and Considerations for Implementation

Development and implementation of the Iowa plan would be facilitated by IDALS and ISU/CALS. Critical to implementation of a state RM plan is long-term engagement of the Iowa agricultural community and allied industries. The paper proposes a framework that links production decisions and pest management strategies and costs with human behaviors, including land owners', farm operators' and agriculture financing entities' decisions and investment strategies for land-management practices, and delayed development of pest resistance. The roles for each sector of Iowa agriculture within this framework are outlined. Plan implementation will be based on an evolving state of the science and will leverage existing partnerships, networks and roles within Iowa communities. The Iowa plan should facilitate recognition of individuals, leaders and 'champions' who emerge.

Conceptual Framework for an Iowa Pest Resistance Management Plan
December 18, 2015

1. INTRODUCTION AND BACKGROUND

January 30, 2015, State-wide Meeting:
The impacts of pest adaptation to chemical, genetic and agronomic control practices concern many sectors of the agricultural community. Due to growing concerns and the changing national regulatory framework to address pest resistance management (RM), Iowa State University, College of Agriculture and Life Sciences (ISU/CALS) and the Iowa Department of Agriculture and Land Stewardship (IDALS) facilitated a one-day meeting on January 30, 2015, to discuss RM options in Iowa crop systems. The meeting included representatives from the Iowa community of farmers, agriculture support networks, and pesticide and biotechnology companies. Planning for the workshop included input from Iowa farm organizations, cooperatives, agricultural retailers, certified crop advisers, independent crop advisers, land management firms, and pesticide and biotechnology companies. The meeting summary report can be accessed at: http://www.ipm.iastate.edu/content/pesticide-resistance-workshop-2015.

The major recommendations from the meeting included:

- Developing a statewide, voluntary, RM plan coordinated by the State that includes broad participation from all sectors of Iowa agriculture
- Establishing a unified, consistent message to increase awareness for action
- Sharing of meeting outcomes by each meeting participant within their organization

Meeting participants concluded that developing an Iowa RM plan was a high priority. It was suggested that development and implementation of a plan be facilitated by the state (perhaps in a manner similar to the Iowa Nutrient Reduction Strategy) and bring together broad participation across the agricultural community. It was noted that development and implementation of such a plan would require strong leadership from Iowa's farm owners and operators, commodity, agriculture retailer, crop adviser, and crop consultant organizations, and pest management technology providers, in association with the State and ISU/CALS. It was further noted that a plan, with clearly defined objectives and roles across all sectors in agriculture and flexibility for different parts of the state, could minimize the potential for regulatory intervention.

Meeting participants also discussed some initial perspectives on the tactical aspects of implementing an Iowa RM strategy. For example, it was deemed critical to include socio-economic analyses to inform problem definition and potential solutions. Identifying potential funding options for developing and implementing the plan, and establishing effective means to deliver information and tools to individuals and communities were also emphasized.

While building a coalition of organizations to work with Iowa to develop an RM strategy may take some time, meeting participants indicated that increasing awareness of the need to take action could be addressed immediately. In this regard, the need to develop and deliver a unified message and increase outreach to farm owners, including absentee land owners, and operators, especially short- and long-term renters, and their advisers was stressed.

Finally, the participants noted that it was essential that they take back to their organizations the messages from the day's meeting. This was viewed by several participants as the key immediate next step to help increase awareness of the issue and for organizations across Iowa to explore the potential development of a State RM strategy.

June 19, 2015, AgState Meeting:
On June 19, 2015, ISU/CALS and IDALS met with Iowa's Agricultural Strategic Thinkers Acting Together Effectively (Iowa AgState) to discuss the January 30th meeting recommendations. At the June meeting it was agreed that a task force be formed to prepare a conceptual framework for an Iowa pest RM plan and report back to AgState and leadership of related organizations in December 2015. Assuming agreement on the conceptual framework, with modifications as recommended, the plan itself would be developed during 2016.

Task Force:
The task force was formed in September 2015, with representatives from the Agribusiness Association of Iowa, Agricultural Biotechnology Stewardship Technical Committee, Iowa Corn Growers Association, Iowa Chapter of the Society of Farm Managers and Rural Appraisers, Iowa Farm Bureau Federation, Iowa Institute for Cooperatives, Iowa Soybean Association, Resistance Action Committees, and Practical Farmers of Iowa. The task force efforts were facilitated by representatives from ISU/CALS and IDALS/Pesticide Bureau. Contributors to this framework document are listed in Appendix A.

2. PREPARING THE FRAMEWORK

The task force met by teleconference and in person during September, October and December, 2015. Task force deliberations involved a review and discussion of the January 30, 2015, meeting summary (see Appendix B) and relevant scientific literature (see REFERENCES).

The task force prepared the proposed conceptual framework through written contributions of individual members and group discussions. The framework represents a consensus of the task force; however, in some instances the group noted where different options or approaches should be considered as the conceptual framework evolves into a state plan.

3. IOWA PEST RESISTANCE MANAGEMENT PLAN PARTNERS

The development and implementation of an Iowa RM plan requires strong leadership from Iowa's land owners, farmer, commodity, agriculture retailer, crop adviser and crop consultant organizations, and pest management technology providers, in association with the IDALS and ISU/CALS. Specific recommendations for different sectors within the agricultural community are anticipated, e.g., crop protection companies and retailers may be encouraged to create internal incentives for promoting RM, provide common/consistent messaging and advice, and ensure sufficient supply of products are available that support diverse modes of action and/or crop rotations; farmers may be asked to participate in demonstrations, provide data and feedback on feasibility of practices, and lead and promote peer-to-peer discussions on the issue; and ISU/CALS should be relied upon to continue to develop and compile data on resistance and RM practices, including economic feasibility, and be the hub for identifying and developing outreach materials the agricultural community can employ.

The management plan, with clearly defined roles across all sectors in agriculture, would need to be coordinated by IDALS. In turn, IDALS would be responsible for apprising the Environmental Protection Agency (EPA) and the United States Department of Agriculture (USDA) of the plan and its implementation to minimize the potential for regulatory intervention.

In summary, all of the following will have important roles to play in the successful implementation of an effective RM plan in Iowa:

- Iowa agricultural organizations
- Row-crop farmers, including land/farm owners and farm operators/renters
- Independent and certified crop advisers
- Seed, crop protection, technology/service, fertilizer providers, ag retailers
- Land owners, land managers
- Urban and rural community members
- EPA and USDA

4. STATE OF THE SCIENCE

In preparation for the January 30, 2015, meeting, background papers (http://bit.do/state-of-the-science) were developed that addressed the state of the science concerning western corn rootworm resistance to Bt traits, weed resistance to herbicides, and pathogen resistance to genetics and fungicides in Iowa and surrounding states. The background documents also included a summary of socio-economic issues.

A brief synopsis of these background papers, updated as appropriate, is provided below. Several common themes concerning resistance development and management in insects, weeds and pathogens are evident; however specific details vary across pests and pest management practices. For example, less complicated pest management technologies reduce time and costs, but if the same technology is used over multiple seasons, the likelihood of resistance development increases. With resistance development there can be increasing costs and complexity for pest management and reduced productivity over time.

RM practices include, but are not limited to, crop rotations, technology diversity, mechanical control methods, and diligent use of integrated pest management (IPM), including scouting for pest pressure and early detection of resistance by observing poor performance of targeted-pest management. For RM efforts to be effective the appropriate suite of practices needs to be employed. While employing RM practices increases input costs in the near term, long-term productivity and profitability will likely be higher due to the reduced likelihood of resistance development and its associated costs of pest management and/or reduced yields.

There can be situations where RM can be relatively simple, straightforward and successful when practices employed by individual farmers are not influenced by practices employed by their neighbors – typically in situations where resistant pests are immobile and do not infest neighboring farm fields. In cases where a resistant pest is mobile and it can infest neighboring farmers' fields, the coordinated RM practices by farmers can help ensure that all in the community will benefit from the longer-term productivity and profitability associated with delayed evolution of pesticide resistance.

4.1 Insect resistance

Insect pests have repeatedly demonstrated an ability to evolve resistance to insecticides, including insecticidal proteins derived from the bacterium *Bacillus thuringiensis* (Bt), which are used in genetically modified crops. Western corn rootworm is among the most serious pests of corn in North America, and Bt corn is currently used to manage this pest (Gray et al. 2009). The first commercially available Bt hybrids for management of rootworm were grown in 2003 and produced Bt toxin Cry3Bb1, and subsequently three additional Bt toxins have been commercialized for management of rootworm: Cry34/35Ab1, mCry3A and eCry3.1Ab. Beginning in 2009, severe feeding injury to single-trait Cry3Bb1 corn was observed in Iowa, and subsequent bioassays revealed that this feeding injury was associated with Bt resistance (Gassmann et al. 2011). These fields, with Cry3Bb1-resistant western corn rootworm, had a history of continuous corn cultivation and three or more years in which Cry3Bb1 corn was grown. Additionally, these fields were associated with feeding injury to Bt corn of greater than one node of root injury, which translates to an average yield reduction of 17 percent (Dun 2010). In 2011, cases in Iowa of severe feeding injury to Bt corn by western corn rootworm expanded to include mCry3A corn. Subsequent bioassays found resistance to both mCry3A corn and Cry3Bb1 corn, and cross-resistance between these Bt toxins (Gassmann et al. 2014). More recently, cross-resistance was found among all Cry3 toxins targeting western corn rootworm, these include Cry3Bb1, mCry3A and eCry3.1Ab, which represent three of the four Bt traits (Jakka et al. 2016). In Iowa, and elsewhere, most western corn rootworm populations appear to remain susceptible to Cry34/35Ab1 (Gassmann et al. 2011, 2014; Jakka et al. 2016). However, in 2013 western corn rootworm were collected from four field in Iowa that suffered greater than a node of feeding injury to Cry34/35Ab1 corn, and subsequent bioassays revealed that rootworm populations from these fields displayed incomplete resistance to Cry34/35Ab1 corn (Gassmann et al. 2016).

> *Resistance management is the effort to slow the development of pest adaptation to chemical, genetic and agronomic control practices.*

Adult western corn rootworm exhibit limited dispersal, traveling less than 40 meters per day; however, longer-distance dispersal also occurs. This limited adult dispersal facilitates resistance evolution if a farmer uses the same management tactic continuously, because adult female rootworm tend to oviposit eggs into the same field from which they emerged, completing their entire life cycle in a single field. Initially, resistance is expected to exist in a patchwork among fields, occurring in fields where the same management practices have been used repeatedly (Gassmann et al. 2011). Over time, however, the movement of Bt-resistant adults across the landscape can lead to the presence of Bt-resistant western corn rootworm, and substantial feeding injury to Bt corn, in fields without a history of continuous use of the same Bt trait and continuous corn cultivation (Gassmann et al. 2014). As a result, although an individual farmer may bear the immediate costs when a population of Bt-resistant western corn rootworm evolves, there is the potential for resistance problems to expand and affect farmers in the broader landscape if appropriate actions are not taken.

To delay the evolution of Bt resistance by western corn rootworm, farmers should plant non-Bt refuges and apply IPM by rotating among a variety of tactics, including crop rotation, Bt traits and soil-applied insecticides. Crop rotation is an effective IPM tool for western corn rootworm because rootworm larvae cannot survive on soybean roots, and as a result, rotating fields out of corn production breaks the lifecycle of western corn rootworm and is highly effective at reducing pest abundance. Because of the widespread resistance to Cry3Bb1, mCry3A and eCry3.1Ab corn by western corn rootworm in Iowa, it is advisable for farmers to use corn pyramided with Cry34/35Ab1 and either Cry3Bb1 or mCry3A.

In addition to cases of Bt resistance by western corn rootworm, this pest has also developed resistance to cultural control through crop rotation in Illinois, by ovipositing outside of cornfields, and resistance to adult management with pyrethroids in Nebraska and Kansas (Spencer and Levine 2008, Pereira et al. 2015). In Iowa, northern corn rootworm displays resistance to crop rotation though extended diapause, overwintering in the soil for multiple years (Krysan et al. 1986). Although, historically found in northwestern Iowa, rotation-resistant northern corn rootworm now extends into the eastern half of Iowa (Dunbar and Gassmann 2013).

In contrast to western corn rootworm, European corn borer has been managed successfully with Bt corn since the 1990s, with no documented cases of Bt resistance in Iowa or elsewhere in the United States (Siegfried and Hellmich 2012). The greater mobility of adult European corn borer compared to western corn rootworm, and consequently greater mixing of populations from refuges and Bt fields, is likely an important factor contributing to this effect. Additionally, Bt toxins targeting European corn borer are high dose, killing both susceptible individuals and individuals that are heterozygous for resistance. Finally, pyramided Bt corn targeting European corn borer was brought to the market before any cases of resistance occurred, which has probably helped to maintain Bt susceptibility in this pest.

Resistance to conventional insecticides by soybean aphid has yet to be documented in Iowa. However, extensive reliance on conventional methods to manage this pest, including neonicotinoid seed treatments and several classes of foliar insecticides, are placing intense selective pressure on this pest to develop resistance (Ragsdale et al. 2011). Recent control failures of foliar pyrethroid insecticides in southwestern Minnesota may be a harbinger of insecticide resistance developing, although more research is required to determine whether resistance is present (Koch et al. 2015). Additionally, there are biotypes of soybean aphid that are adapted to aphid-resistant soybeans in North America (Ragsdale et al. 2011). However, such cultivars are not widely used due to limited commercial availability (McCarville et al. 2012). The extent to which these biotypes will affect future use of aphid-resistant soybeans is not clear, and is an active area of research.

Other pests of relevance to soybean production in Iowa include two-spotted spider mite and bean leaf beetle. Two-spotted spider mite, although primarily a problem in soybeans during extended dry-periods, is a pest that has repeatedly demonstrated an ability to evolve resistance, with documented resistance to more active ingredients than any other arthropod (Van Leeuwen et al. 2010). Insecticide resistance by bean leaf beetle has not been documented in Iowa, although reduced susceptibility to pyrethroids has been found for some regions of the southern US (Musser et al. 2012).

Cases of resistance to Bt crops, conventional insecticides and cultural control by pests in Iowa and elsewhere illustrate the potential for insects to adapt to management practices through the development of resistance. By applying a diversity of management tactics, selection for resistance to any single tactic will be reduced and the evolution of resistance delayed. In general, farmers can slow the development of resistance by insects through a diversified management approach and the judicious use of insecticides.

4.2 Weed resistance

The scientific literature is replete with papers on herbicide resistance in weeds. Research describing evolved resistance to herbicides represents the major component of the weed science effort nationally and internationally. Areas of interest include the specific mechanisms by which weeds evolve resistance to herbicides, the implications of multiple resistances, the genetics of herbicide resistance, and the impact of herbicide resistance on weed fitness.

A project sponsored by the Iowa Soybean Association (Owen et al. 2015) to assess herbicide resistance in Iowa has provided a clear picture of existing resistances in waterhemp, marestail/horseweed and giant ragweed. A high percentage of Iowa fields have herbicide-resistant waterhemp, with a majority of the populations demonstrating multiple resistances. The most common multiple resistances in waterhemp is to Herbicide Group (HG) 2 (ALS inhibitor herbicides), 5 (PSII inhibitor herbicides), and 9 (EPSPS inhibitor herbicides). A small percentage of waterhemp populations have resistance to 5 herbicide groups. Evolved resistance in waterhemp to HG 14 (PPO inhibitor herbicides) and 27 (HPPD inhibitor herbicides) is increasing rapidly. Recently, resistance to HG 4 (auxin herbicides) has been reported in Illinois and Missouri waterhemp populations. Clearly HG 4 resistance as well as resistance to HG 14 and HG 27 are serious threats in Iowa.

All of the weeds in Iowa with evolved resistance to herbicides are annual and are well adapted to current production agriculture systems. Once established in a weed population, the resistance remains despite the fact that the HG in question has not been used recently. Herbicide resistance in all HGs is likely nuclear and the trait(s) that codes for herbicide resistance is dominant or semi-dominant. In the current Iowa crop production system, the risk of herbicide resistance is generally high and will soon become a serious, widely distributed problem in most Iowa fields. A number of predictive models have been developed to assess the evolution of herbicide resistance in a number of weed species. However, they have not been widely applied in weed management decisions. A significant economic impact is expected, but this is difficult to estimate, as are social impacts in cases where resistant weeds are mobile and can move into neighboring farmers' fields. Strategies for driving broader application of predictive modeling and similar tools will be presented later in this document.

In a general sense, weed management has not changed greatly over the last six decades. Current strategies include chemical-based approaches (often used due to cost and convenience), cultural, mechanical and, to a lesser degree, biological. The emphasis has been on chemical strategies and, given the unprecedented adoption of genetically engineered crops with tolerance to glyphosate, biotechnology traits, and chemistry combinations, almost to the exclusion of mechanical and cultural strategies. Options to address the burgeoning problem of evolved resistance to herbicides are understood but poorly accepted by Iowa farmers. One key to managing herbicide resistance is to diversify weed management practices beyond using herbicides.

4.3 Pathogen resistance

Like insects and weeds, plant pathogen populations can evolve due to selection pressure from pesticides or crop resistance. How quickly this shift occurs depends on the genetics of the pathogen and the choice and use of the pesticide or crop variety. There are numerous examples in the literature of pathogens evolving resistance to fungicides within a couple of growing seasons. For example, the cereal powdery mildew or, closer to home, the frogeye leaf spot fungus, are resistant to strobilurin fungicides. There are very few choices of fungicides available to farmers. Similarly, there are a limited number of sources of host plant resistance for fungal pathogens and soybean cyst nematode (SCN).

It is increasingly understood that evolution of resistant pests is both a biological and social problem.

When pathogen resistance develops, it is usually not as obvious as with Bt-resistance, where lodged corn is evident; or herbicide resistance, where weeds are easily visible growing over the intended crops. Damage from many pathogens is generally more subtle and sporadic. Crops may be less vigorous, stunted or deformed, discolored, senesce earlier, or just have lower yields.

The sources of resistance for SCN include: PI88788, Peking and PI 437654 (Tylka and Mullaney 2015). It is important to note that 97 percent of commercially available soybean varieties use PI88788. Repeated use of soybean varieties with the same source of resistance can result in SCN populations developing increased levels of reproduction on that source of resistance. There is evidence of this happening with PI88788 resistance in Iowa. Therefore, soybean varieties with resistance from different sources should be grown to slow the evolution of SCN resistance to soybeans with PI88788. In addition, there are chemical and biological options, as well as some cultural practices, which farmers can consider as components of a RM strategy and as components of an integrated approach to managing SCN and other nematode problems.

The most common foliar fungicides currently registered for use in Iowa include only a few classes of fungicides: strobilurin (FRAC Code 11), triazoles (FRAC Code 3), and SDHI (FRAC

Code 7) fungicides. The FRAC Code of a product is based on the mode of action of the fungicide. To reduce the risk of fungicide resistance developing, fungicides belonging to different FRAC codes should be used in an integrated or rotating fashion to manage crop disease. Many of the commercial products combine two or more fungicide classes (FRAC codes).

Seed treatment fungicides include the same classes as the foliar fungicides, but also include a few additional classes such as: phenylamides (FRAC Code 4), thiazole carboxamide (FRAC Code 22), phenylpyrrols (FRAC Code 12), and methyl benzimidazole carbamates (FRAC Code 1).

To reduce selection for fungicide resistance, farmers should use products in combination with other disease management practices such as disease resistant varieties, rotation and other cultural practices, such as varied tillage, planting dates, plant populations and row spacing. Moreover, a fungicide should be applied only when needed, early in disease development, and at full label recommended rates. Some fungicide-use advisers have emphasized that broad prophylactic application of fungicides can promote overall plant vigor and increased yields. Farmers should be cautious of this practice, as it may contribute to more rapid fungicide resistance development. Monitoring for pathogens or specifically for certain strains of pathogens that are insensitive to the targeted management (variety or fungicide) is often time consuming and requires trained personnel. However, farmers and agronomists can monitor and address selection for pest resistance by scouting for disease after a fungicide application is made. If the disease does not appear to be controlled by the fungicide, it should be investigated.

Fungicide resistance has been reported in numerous disease-causing pathogens of crops including frogeye leaf spot of soybean. The pathogen that causes frogeye leaf spot is genetically diverse, and strains have been found in the Midwest that are insensitive to strobilurin fungicides. This disease is consequently a model system for developing an RM-monitoring plan.

4.4 Sociological considerations

It is increasingly understood that evolution of resistant pests is both a biological and social problem. Dealing with resistance will require substantial changes in management strategies. Failure to act in the short term will likely lead to much greater costs in the long term (Jussaume and Ervin 2014). Behavioral responses to problematic situations, however, depend in large part on beliefs about whether a problem exists and the degree to which it poses risks (Nigg and Mileti 2002). In other words, people change their behaviors only if they believe that (1) a problem exists and (2) that it represents a threat.

Accordingly, a first step toward addressing the problem of resistant pests is the development of an understanding of beliefs and perceived risks by farmers and stakeholders. Survey research in Iowa in 2012 and 2013 documented that 82 percent of farmers agreed that they were concerned about herbicide-resistant weeds becoming a problem and 62 percent were concerned about Bt-resistant insects becoming a problem in the areas where they farm (Arbuckle 2014). Importantly, very few farmers were confident that new technologies would be developed to help manage resistant pest populations. Further, farmers surveyed also understood that the way pest-management technologies are used has a major impact on the rate of resistance evolution, and they viewed RM as a community problem involving multiple stakeholders (e.g., farmers and the private and public sectors).

> *While employing RM practices increases input costs in the near term, long-term productivity and profitability will likely be higher due to the reduced likelihood of resistance development.*

Similar (though less methodologically rigorous) surveys of representatives from three Iowa stakeholder groups—agricultural retailers and advisers, farmer and commodity associations, and pesticide/biotechnology companies—indicated that these stakeholders are also highly aware of and concerned about pest resistance. Results from a non-random sample of representatives from these stakeholder groups showed that they are concerned about pest resistance; believe that farmers' actions play a major role in the evolution of resistance; understand that farmers look first to agricultural retailers for information to help them make pest management decisions; and believe that multiple stakeholders, including farmers, private firms, and public universities and agencies bear responsibility for RM.

In short, survey results showed that Iowa farmers and agricultural stakeholders have similar perspectives on pest resistance and RM. They believed that resistant pests are a problem, and they are concerned. They also share the belief that multiple stakeholders bear responsibility for action. Taken as a whole, these survey results suggest there is much common ground on which to build coordinated approaches to RM.

4.5 Economic considerations

All pest management and RM decisions have long-term socioeconomic implications that need to be better understood across the agricultural sector. Most decisions involving variable production inputs are made on an annual or short-term basis. Research is needed to determine to what extent the returns outweigh the costs. It has become more evident that the economics of pest management need to be treated as a long-term decision. Initially, pest management efficacy or "killing effectiveness" is a fixed stock like any nonrenewable natural resource. Efficacy can be depleted or exhausted through resistance development by overuse of a pest management technology. Only with judicious use of a combination of RM practices can the efficacy (or economic value) of pest control practices be sustained over the long-term. Once resistance evolves and efficacy is depleted, susceptibility cannot be restored or renewed for a particular pest control chemical or trait. The only alternative at this point is to develop a new product or trait or better, to use a combination of RM practices to achieve a degree of pest control, albeit at a higher cost. Included in the long-term socioeconomic implications should be spillover of resistant pests into neighboring farms that are external to the individual farmer's pest management cost decisions, but impose a social cost, and possibly a financial cost, to their neighbors. RM practices have to be built on goals of maximizing long-term net benefits to both the farmer and neighboring farmers and improving long-term net benefits to the farm community (Miranowski and Carlson 1986).

To facilitate the development of an Iowa RM plan, applied socioeconomic analyses of different pest resistance problems and RM practices are needed. These analyses will help to better understand the perceived and actual spillover costs, and short- and long-term benefits and costs of RM practices, as well as reveal which RM practices provide the most significant return on investment. For example, Miranowski and Lacy (2015), Livingston et al. (2015), and Arbuckle (2014) help shed light on this issue.

A community-based RM approach will yield greater benefits when a farmer's pest management practices lead to spillovers on neighboring farmers and members of the community. For a spillover, the pest has to be relatively mobile and the resistance problem has to be transferred with the mobile pest. If seeds from a resistant weed travel from a farmer's field to a neighbor's field, the neighbor may incur significant costs if unable to control the weed. Alternatively, if a farmer's Bt-resistant western corn rootworm beetles travel to the neighbor's field, the neighbor may be able to manage the pest if using a crop rotation that breaks the cycle. The first case may realize significant community benefits from intervention. The second case may only cause significant root injury to a neighbor's field the following year if the neighboring farmer is planting continuous corn. The western corn rootworm spillover is more likely in areas with a prevalence of continuous corn and use of the same Bt trait (Gassmann et al. 2011).

It is important to point out that the initial adoption of RM practices may improve long-term net benefits but reduce short-term net benefits. Both individual farmers and neighboring farmers in the community will be better off in the long term with RM practices. At the same time, even though longer-term net benefits may be improved by RM practices, it does not ensure that all farmers will adopt RM practices. Some may even sacrifice short-term benefits for simplicity, time-savings, convenience, and other behavioral reasons. Commodity prices, yield risk, and uncertainty may further drive the short-term focus. Subsidized crop insurance is designed to offset short-term price and yield uncertainty, but it may actually cause some farmers to focus more on short-term net benefits and discourage adoption of RM practices (unless they are a condition of receiving indemnity payments). A community-based approach needs to recognize these challenges as well as farmers' willingness to cooperate to control pests (Stallman and James 2015) when considering options for addressing them as a community.

4.6 Regulatory and policy considerations

EPA and state pesticide agencies have a potential regulatory role to address resistance development and management under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). At both the state and federal level there is increasing attention to RM. The extent to which current regulatory approaches are effective and the extent to which adjustments may be needed in terms of education and/or increased regulatory requirements are being evaluated. There is a general sense that regulatory agencies will continue to support enhanced education and training.

For conventional pesticides, federal pesticide labels approved by EPA often include advisory language regarding RM. Combined with state pesticide applicator training and pesticide stewardship training, this advisory language has generally been the extent of regulatory oversight to date. For Plant Incorporated Protectants (e.g., Bt), EPA has required RM practices (e.g., refuges) through conditions of registration. EPA is currently asking public comment on greater specificity to management requirements for Bt corn traits. For herbicides registered for use with herbicide tolerant crops, EPA is initiating an approach to implement RM practices through enforceable or advisory language on Federal labels and through conditions of registration placed on the herbicide registrants.

Through the Plant Protection Act, USDA's Animal and Plant Health Inspection Service must determine if traits imparting herbicide tolerance or resistance can be deregulated. As part of this decision, USDA undertakes an environmental assessment under the National Environmental Protection Act (NEPA) for all proposed de-regulations. To date, the USDA decisions have included an assessment of herbicide resistance development and management within the NEPA analyses; however, since EPA, under FIFRA, is responsible for determining conditions under which herbicides may be registered, USDA has determined it does not have regulatory authority to directly address RM practices in its deregulation decisions. Consequently, USDA's role in RM is generally one of advancing research, incentives and outreach to promote RM practices.

The nature of RM requires the Iowa plan to incorporate a long-term, holistic approach to pest management.

The expansion of subsidized crop insurance under the 2014 Farm Bill safety-net legislation may be creating a potential disincentive for adoption of RM practices, unless RM practices are required to receive indemnity payments for crop losses (Miranowski, Ernst and Cummings 1974). If the deductible portion of the yield loss is small, it may create a disincentive to adopt more costly RM practices in controlling or managing pests. Unfortunately, no research studies have yet looked at the potential impacts of expanded use of subsidized crop insurance on RM.

5. CRITICAL FEATURES OF AN IOWA PEST RESISTANCE MANAGEMENT PLAN

5.1 Holistic and long-term approach

The nature of RM requires the Iowa RM plan to incorporate a long-term, holistic approach to pest management. It could begin with a clear overview of current issues and realistic future threats and timeline, followed by embedding the importance and essentials of RM into the broader topic of IPM. Key concepts include challenges due to a lack of IPM in row-crop agriculture, the need for a more holistic and ecosystems approach to pest management, and the need to move from a short-term to a long-term and more community-focused approach when making farm management decisions. Plan management should complement other sustainability plans, such as preventing soil erosion, preserving water quality, enhancing pollinator and wildlife habitat, and managing nutrients (Nutrient Reduction Strategy), to the extent possible. There may be instances where some recommended RM practices (e.g., tillage) and other conservation practices (conservation tillage) may need to be modified to best optimize attainment of multiple sustainability objectives.

5.2 Framing and messaging

Once RM issues and risks are clearly described, the plan needs to plainly state that the development of resistance does not indicate a failure of the RM plan. When a RM plan is implemented, it will not necessarily prevent resistance. The goal of the plan is to postpone or delay resistance, foster methods of early detection, and then mitigate resistance as it arises.

The RM plan also needs to anticipate new technologies, even if these new technologies appear to be strong RM candidates. The plan needs to emphasize that IPM and RM dovetail together and form the core of the plan, both for current and future technologies.

Key elements of the plan are a common message and a state champion. A champion for this plan might be the Secretary or Deputy Secretary of IDALS. Iowa State University and IDALS will provide guidance on RM to the implementation drivers.

5.3 Incentives

Helping land owners, especially absentee land owners, and farm operators, especially short-term lessees, understand the rationale and importance of investing in short- and long-term RM strategies is a critical first step to a successful RM plan. Promoting or incentivizing long-term sustainable pest management approaches for people and organizations will be critical. Existing or new USDA programs could play a role in this regard. Perhaps USDA's Natural Resource Conservation Service and/or the Farm Service Agency EQIP and CRP programs could be structured to help defray input costs associated with RM practices. In addition, USDA's crop insurance policies could be re-evaluated to help support RM. The plan could explore ways to incentivize pest management technology through USDA by a pest management credit and the possibility of selling the credits.

The plan could address what happens to sustainability of a pest management technology if there are no incentives or when incentives go away. There will be a need to avoid the pitfall of the nutrient reduction strategy where people held off on participation until incentives were in place. It will be important to recognize people who are currently using sound RM strategies. It will be necessary to provide incentives not only for people establishing new RM practices, but also for those who have already been employing sound RM approaches. RM must be an on-going effort, not a one-time cost share that has worked for some programs. Transparency for participants in the plan may be helpful to foster wider participation.

5.4 Agricultural financing and lease agreements

Another critical piece of the plan is financing. Currently, operating loans may include only a small amount of money for pest management. For example, $20 per acre for an herbicide program may not allow for a sound RM plan. Changes in how operating budgets are financed and negotiated could also take a long-term view. The state RM plan needs to communicate the central idea of investing more now to ensure an economically-viable future. This may entail an educational program that includes stakeholders and influencers and extends to land managers, landlords/land owners, bankers, loan officers, and attorneys who draft rental agreements, who are all within the suggested "community" (see *Defining Communities* below).

Committing to a sustainable and holistic approach creates a challenge to build the importance and essentials of RM into the broader topic of pest management, along with all other considerations, operations and players that have a role in agriculture production, i.e. farmers, land owners, Certified Crop Advisers (CCAs), independent crop advisers, cooperatives, applicators and companies. Everyone needs to begin, if they have not already, thinking of managing/delaying pest resistance as part of their overall strategy and operations for pest management. These ideas also potentially extend to land managers, lawyers and land management companies. How do farm managers reward good RM practices? How do we address the potential problems that arise with cash rent? Should land managers require RM as part of a lease agreement, for example, by documenting use of multiple modes of pesticide action by renters?

Because the RM plan will emphasize the need to move from a short-term approach to a long-term approach, a standard "sustainability clause" could be added to all financially-related agreements for growers. It could be a consideration for each agreement to make funding or future rights-of-rental dependent on appropriate management of the land (soil, water, nutrients, and pests). Any element, like weed or rootworm resistance, could devalue the land and should potentially be considered. There are examples of such land devaluation in other cropping systems, e.g., resistant ryegrass in Australian wheat. Regardless, standard rental agreements may need to be revised to incorporate RM. There is a standard form that is used by attorneys when land is rented. This default form needs to be updated to include recommendations regarding RM.

The state RM plan needs to communicate the central idea of investing more now to ensure an economically viable future.

At the very least, farm owners and operators should be made aware of how pest resistance affects yield and value of grain (e.g., quality, docking, test weight). It may be incorrectly assumed that most farmers have a high degree of flexibility to influence these desired changes. Due to operating loan restrictions, land rental agreements, local farm competition, or loyalty to specific traits or chemistry providers, farmers may base their decision more on these external influencing factors than on considerations about specific pests or sustainability.

5.5 Individual- and community-based approaches for RM

The actions of individuals will be key components of an RM plan, but achieving the desired outcomes of these actions will require community-based approaches. There may be incentives for good RM but key inhibitors are the potential near-term input costs to individuals and communities. Incentives to good RM may include concern of additional regulation, but more importantly, the development of resistance means that farmers will lose efficacious technologies and pest management costs likely will increase. Although individual farmers where resistance first arises will most likely experience the most severe financial effects, neighbors also will experience problems due to pest movement. As a result, there are incentives to approach RM at the community level and the individual level. Consideration should also be given to state border communities where adjacent farms across state lines may not be part of the plan, discouraging adjacent Iowa communities from participation.

5.5.1 *Defining communities*

The community's size and the associated management recommendation should reflect the nature of the pest, resistance attributes, and the size and scope of the risk. The size and composition of the community could be small or large depending on the pest, the current situation, the stakeholders, and the potential risk.

Weeds are ubiquitous and resistance is widely spread across the state. Thus, the "size" of a community could be relatively small or large compared to other pest complexes. Communities based on weed species may work for giant ragweed and Palmer amaranth, but the ubiquitous distribution of waterhemp, and to a lesser degree marestail/horseweed, make community size more a factor of smaller scale. For marestail/horseweed the community designation could be the tillage system.

Western corn rootworm resistance is spreading but currently somewhat localized and some opportunity exists to provide a supportable and logical recommendation for community size.

Diseases can be transient, sporadic and resistance to fungicides and nematicides has yet to be described in Iowa, however, SCN has developed resistance to some host-plant varieties. A statewide community for SCN resistance management may be appropriate as SCN populations are relatively sedentary with respect to field-to-field distribution and movement. On the other hand, a tailored approach to managing the selection for virulent populations of SCN on resistant soybean varieties is necessary. For other pathogens, communities may be formed based on the distribution of these pathogens. For example, white mold is most prevalent in northeastern Iowa while gray leaf spot is most common in southern Iowa. By contrast, northern corn leaf blight is found throughout Iowa. Thus, disease communities need to consider environmental factors that increase the risk of disease (e.g., soil type, precipitation and temperatures during the growing season, and crop rotation).

Factors to be considered when areas within the state may benefit from more tailored, community-based approaches, may include differences in farm size (and associated issues of time management, movement of equipment, off-farm employment), rental vs. owned land, use of custom applications/harvesting, cropping with or without animal enterprises, soil types, tillage, weather, and other cultural practices that vary within parts of the state and across years. IPM and RM strategies need to match those different conditions and practices, and provide farmers and land owners flexibility to match their situations.

5.5.2 *Implementation drivers*

One feature of the state plan might be a community-based farm organization that facilitates the involvement and direction of key stakeholders including bankers, absentee land owners, and land management firms. If someone is going to do business in the community, they need to understand the sustainability goals that go along with being a member of the community. Rather than focus on the farmer (or person who manages the farm), the focus should be within the community. Perhaps a community-based group such as bankers, land-management firms, and insurance agents could work together to establish community-based sustainability goals, balancing short-term individual gains with long-term community and environmental benefits. It needs to be understood by all that the actions of any one farmer or collective group of farmers may impact the overall community.

A pilot effort for a community-based approach or a phased-approach to statewide implementation could be employed and address questions such as: At what scale does influence happen? Who are the stakeholders and influencers? How do we address contrasting pest management approaches when land is rented versus owned? Can the end user influence how pests are managed?

There is a strong argument to use CCAs as one of the primary implementation drivers (influencers) of this plan. There are 1,400 CCAs spread across the state. Other potential implementation drivers are farm organizations, sales people, technology providers, agronomists, product support personnel, commodity groups, and cooperatives. The stakeholders and influencers extend to bankers, land managers, land owners, and attorneys who draft rental agreements. As part of a community-based plan, sales representatives from company technology providers in the state of Iowa could be charged with upholding the sustainability principles created by the community. Technology providers could build a reward system for their sales representatives who help their customers build longer-term systems solutions for pest management and RM for their farms. A potential conflict among technology providers may be anticipated when a RM recommendation reduces the opportunity to sell their products.

5.5.3 Tools for community leaders

RM communities will emerge around the state as a result of the state RM plan and there will be a need to provide tools for the community leaders so they can be successful in their leadership role. There will also be a need for a source with the most up-to-date information on RM practices. The plan will need to address how best to meet these needs.

5.6 Monitoring for results

Monitoring and scouting of pest populations will be a necessary feature of the state RM plan. The RM plan should leverage existing policies for monitoring resistance and use outcomes to determine if targets are being met.

Reporting of data and information should be voluntary and aimed at educating the community. If the community is educated and can help farmers make appropriate decisions, rather than the government or a particular company, there may be more trust and transparency within the community.

Participants in the RM plan will need to have information about the presence of resistance. There needs to be some type of reporting or pest survey to measure outcomes. Growers will need some type of mechanism to share information if they have problems. Can a reward or benefit for sharing information be provided or articulated by the state plan? If farmers can share information to a trusted forum where they know they can get good advice or help, they may volunteer potential pest management problems being experienced.

Can farmers be provided with a way to document that they are following an RM plan? Farmers following RM plans will provide an example to others, and adherence to RM plans will likely be important information for regulators. As a result, it is important to recognize and highlight individuals in the community who are adopting good RM practices. Recognition of those following RM plans could follow the example of a program such as Master Gardeners, where people receive certification and provide some number of hours of outreach within the community; or the Iowa Farm Environmental Leader Award, where individuals are recognized as model practitioners of sound stewardship. Another example is the Soybean Rust First Responders program, created by ISU/CALS and the Iowa Soybean Association, which prepared Iowa soybean farmers for the arrival of soybean rust (Robertson and Tylka 2007). Farmers and agricultural advisers who participated in the training were recognized as "First Responders."

The actions of individuals will be key components of an RM plan, but achieving the desired outcomes of these actions will require community-based approaches.

Types of monitoring to be implemented to inform a RM plan will differ for different types of pests. Some aspects of monitoring are more logically incumbent upon a farmer or their crop adviser and other types of monitoring are more appropriate for the pesticide registrant or other parties. Registrants could support local scouting; support development of public domain technology that reduces scouting input costs such as remote sensing, precision agriculture and localized treatment options, grain sampling systems for weed seed identification; and perform follow-up scouting in response to unexpected crop injury from a pest normally controlled.

More specific questions include when and what type of scouting is most effective. For example, to manage weeds (resistant or otherwise), early is better. Scouting for weeds in crops in the V2-V5 stages of development is optimal because a suite of weed management options (herbicides or mechanical) is still in play.

To assess weed resistance, monitoring in August/September, prior to harvest, is the optimal time, but likely only effective in soybean. Other pest complexes have different considerations. Scouting for diseases, for example, is optimal in corn at R3-R5 and soybeans at R5-R6. In the case of corn rootworm, scouting for unexpected injury could include an assessment of risk factors; e.g., continuous corn with same Bt trait, late planting the previous year, lodging, high adult population density, informal root evaluations, and water stress (Andow et al. 2015).

In general, routine monitoring is unlikely to detect pest resistance when it first arises because of the scale over which a product is used and the necessarily limited number of samples that may be collected and tested for resistance. Poor performance of a technology in the field is often the most useful initial indicator of evolved resistance. However, care must be taken to rule out alternative causes of poor field performance; e.g., disease samples could be sent to the ISU/CALS Plant and Insect Diagnostic Clinic to assess pathogen sensitivity to a fungicide. Once a resistance issue has become more widespread, either at a local or regional level, more routine monitoring may be useful of characterizing the extent of resistance.

A key question is how does monitoring information develop into action and RM implementation.

Additionally, once the plan is implemented it is possible for certain RM technologies that confirmation testing could overwhelm current state and private testing facilities. The cost of confirmation of pest resistance will undoubtedly increase with successful plan implementation and must be considered.

5.7 Adaptive management approach

Monitoring for outputs (e.g., assessing the level of farmer and other sector participation in a RM effort) and outcomes (e.g., assessing unexpected injury and/or resistance) to assess effectiveness will help inform when modifications to practices are needed. Clearly a process for communicating unexpected injury or resistance when detected will be needed. For example, the zero tolerance program in Arkansas for Palmer amaranth provides an example of using monitoring data to inform modification of practices (See http://www.uaex.edu/publications/pdf/FSA2177.pdf). Importantly, this effort has waned due to the retirement of the "champion." Invasive weed and pest eradication programs are also illustrative of community-based features for programs with coordinated, adaptive practices undertaken by farmers and others in the crop production system.

5.8 *Governance of a voluntary RM plan*

While some resistance scenarios may lead to community-based, 'local' RM approaches, these community-based efforts need to be nested within a state-wide effort that maximizes use of cross-cutting knowledge and resources. Communities may need to be local in some cases, but concepts, plans and efforts can and should be coordinated statewide to allow for consistency. Consequently, IDALS would play a critical role within the state to ensure the voluntary RM programs are performing in a manner consistent with the relevant federal pesticide registration decisions. IDALS would also be the interface with EPA to ensure that the relevant federal registration decisions (i.e., labels and conditions of registration) appropriately reference Iowa's state RM plan, providing Iowa farmers who voluntarily participate in the state RM plan regulatory assurances.

EPA may be less likely to invoke mandatory RM requirements if viable state-based RM programs are developed and implemented. Features of a state RM plan and practices required through Federal labels and/or EPA's conditions of registration would be similar, if not identical; however, a state plan could have a greater degree of localized flexibility and adaptiveness than could be attained through a national, regulation-based RM scheme. For a state RM plan to be accepted by EPA as an alternative to a federal regulatory approach, the RM practices, monitoring and adaptive approaches would likely need to result in outcomes (i.e., rates of resistance development) consistent with FIFRA cost-benefit determinations in the specific registration decisions.

6. RECOMMENDATIONS / CONSIDERATIONS FOR PLAN IMPLEMENTATION

Critical to implementation of a state RM plan is long-term engagement of the Iowa agricultural community and allied industries. To accomplish this, the implementation framework needs to consider an integrated approach for communications across specific sectors. Plan implementation should build upon the science described in Section 4 of this paper and consider a tiered approach for outlining and communicating different inputs, human behaviors, land-management strategies, and outcomes for delaying resistance. The logic model below assumes an approach where plan development and implementation is facilitated by IDALS and ISU/CALS to help ensure communication and coordination across the agriculture industry, farmers and farm managers, landowners and the general public.

Proposed Logic Model for Coordination across Sectors

Inputs	**Human behavior (Activities)**	**Land Management Industry Practice & Crop Production**	**Pesticide Resistant Population Outcomes**
Ag Industry– Retail Sales, Allied Supplier Organizations, Industrial and Private Agronomists, Scientists, Academic Centers of Influence, Certified Crop Advisers, Independent Crop Consultants			
Development of educational tools and programs (IPM upgrade – new messaging in line with current day practices) Central website for providing access to RM resources with links to established relevant resistance websites Use science-based approach & assessment for public access Socioeconomic analysis – demonstrate cost of	Tiered communications approach – target information flow at the point of University Extension-to-Agribusiness Identify institutional/market structures that can lead to promotion of practices that lead to pest resistance Survey of recommended practices: -Adequacy of University resources to meet needs of Agribusiness &	Increase the inclusion of Mode of Action on all pesticide labels Agribusiness may not promote practices that lead to pest resistance More fields are scouted to identify possible resistant pests Technologies will be developed to identify possible resistant pests Invest in development of more efficient & cost-	Minimize the development and spread of pest resistance Preserve crop production technologies for farmers Reduce the economic impact of pest resistance – *trends* Measurement of plan effectiveness Consideration of tangent geographic zones relative to plan implementation, regular plan

RM (short & long-term costs) Coordinate with & support 'Touchstone' or technical resource groups addressing pest resistance (Take Action, CropLife, Weed Science Society of America, American Phytopathological Society, Entomological Society of America, National Commodity Groups, etc.) Pursue alternative funding sources for incentivizing farmers to adopt RM practices (lease agreements, product line specific program coordination, Farm Bill, other) Reward for CCA – IPM test Specific links to technology providers to be defined	address questions in field -Awareness of RM practices -Interest in implementing RM practice Support RM workshops and meetings (AAI Showcase, ICM, ISA Soybean Research Conference, Crop Advantage, Corn Growers Crop Fairs, Soybean Grower Meetings) – identify key network players and "Champions" Identify "Influencers" within the existing Agribusiness community. Provide means for coordination across Ag sectors and association with state RM plan Compilation and review of available information	effective monitoring techniques will be adopted to confirm resistant pests Develop a site to map baseline of resistant pests, possible forecasting or grade of selection pressures Establish procedures for admission of pest resistance reporting (USDA reports/sites, private sources, and other data. Need consistency for IA map- baseline)	upgrades, ability for participation across state lines, etc.
Farmers, Farm Managers, and Land Owners --			
Engage educational outreach Provide existing/optional RM practices	Tiered communications approach – target information flow at the point of Farmer – to-Agribusiness	Land rent leases include resistance stewardship plans Increase the number of farmers using RM practices	Minimize the development and spread of pest resistance Preserve technologies available to farmers

Scenario-based socioeconomic analysis to demonstrate cost of RM (short & long-term costs)	Survey of recommended practices: -Availability and efficacy of RM tools -Awareness of RM practices -Interest in implementing RM practice -Communications about RM practices with Agribusiness Identify *Local* and *Community* "Champions" Provide means for coordination across Ag sectors and association with state RM plan		Minimize the economic impact of pest resistance – *field results/examples* Maximize the technology lifecycle for farmers
General Public --			
Campaign or development of messaging that communicates safety, healthy food, and sustainability Engagement of youth curriculum: FFA, 4-H, university students, community college students, apprentice programs	Identify networks – both farm/ag and general public for messaging Monitor response and adapt to address concerns & questions early on	Outreach & Education	Develop safer, healthy, sustainable, and affordable food Promote sustainable food production practices

Pest resistance issues are not new topics and much of the Iowa agricultural community is well aware of the need for RM practices. The implementation framework for the state plan should draw on the wealth of expertise from inside the state and beyond. Starting points may stem from research findings, possibly a science-based assessment for Iowa, and/or build upon RM plans, strategies/conceptual frameworks that are in place with other organizations or touchstones such as:

- Take Action

- Weed science societies (Weed Science Society of America, North Central Weed Science Society, Northeastern Weed Science Society, Southern Weed Science Society and Western Society of Weed Science)
- Plant Management Network
- American Society of Agronomy
- Certified Crop Adviser boards
- Resistance Action Committees (insecticides: IRAC; herbicides: HRAC; fungicides: FRAC)
- Integrated Pest Information Platform for Extension and Education (iPIPE).

Opportunities to inform the logic model and build a strong implementation framework for Iowa relies upon recognition of, and balance with, others working on RM practices.

Strong leadership in the agricultural community is needed from within each sector identified in the logic model. The implementation framework should facilitate recognition of individuals, and support leaders or 'champions' that emerge in the area of RM. It is these individuals who can operate on both local and community levels, and who are essential to achieving long-term goals of an RM plan.

In addition, real-time feedback regarding agricultural communities' and the general public's reactions to socioeconomic analyses contain great value in understanding why certain RM practices may be adopted and why other practices may not be so widely adopted.

Additional considerations of the implementation framework might focus on coordination with entities that could serve as "influencers," a role that can support, in some capacity, efforts put forth by champions at the local and community levels. Several Iowa-based organizations are already engaged in the topic of RM, including those represented at the January 2015.

Finally, the implementation framework should take into consideration existing organizations, current roles and networks within the Iowa community, resource/time allocation, and opportunities for future funding – all of which, may assist in providing opportunities for future leadership and further facilitation and support of the plan framework.

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APPENDICES

Appendix A. Task Force Contributors to the Conceptual Framework Document

- Ed Anderson, Iowa Soybean Association
- J. Gordon Arbuckle, Jr., Iowa State University, College of Agriculture and Life Sciences (ISU/CALS)
- Amy Asmus, Agribusiness Association of Iowa
- Steven Bradbury, ISU/CALS
- David Ertl, Iowa Corn Growers Association
- Jim Gulliford, Soil and Water Conservation Society
- Kim Heckert, Iowa Institute for Cooperatives
- Aaron Gassmann, ISU/CALS
- Ben Gleason, Iowa Corn Growers Association
- Ed Kordick, Iowa Farm Bureau Federation
- John Miranowski, ISU/CALS
- Daren Mueller, ISU/CALS
- Micheal Owen, ISU/CALS
- Gretchen Paluch, Iowa Department of Agriculture and Land Stewardship, Pesticide Bureau
- Clint Piltcher, Agriculture Biotechnology Stewardship Technical Committee
- Larry Pohlman, American Society of Farm Managers and Appraisers, Iowa Chapter
- Peter Porpiglia, Resistance Action Committees
- Alison Robertson, ISU/CALS
- Greg Tylka, ISU/CALS

Appendix B. January 30, 2015, Resistance Management Meeting Recommendations for a State Resistance Management Plan

(see Appendix B in http://www.ipm.iastate.edu/content/pesticide-resistance-workshop-2015)

- **Develop a state-wide resistance management strategy**
  - State ownership to minimizing regulatory intervention by EPA
  - Coordination should be at state level (perhaps modeled like the Iowa Nutrient Reduction Strategy); realize one size does not fit all; i.e., resistance management plans could be different across the state
  - Requires strong leadership and coordination within and across organizations
  - Not bottom up or top down approach - it needs to work for farmers and be sustainable and cohesive
  - Broad participation
  - Coordinated approach with industry
  - Defined roles for all sectors in agriculture
  - Include: weeds, insects, pathogens, economics, society, community, culture, geography, climate, cultural and management practices
    - Other examples may be instructive to forming a state resistance management program e.g., boll weevil (but pest specific), Australia glyphosate resistance (but different socio-economic/regulatory environment); citrus greening in Florida
  - Care in public communication of the plan; need to establish progress first
- **Potential tactical aspects of developing and implementing a state resistance management strategy**
  - Socio-economic dimensions of problem and solution; understand and evaluate incentives – economic, personal and social
  - Appeal for simple solutions and need to address 'old school' versus new generation pest management approaches – both will likely play a role
  - Broaden definition of 'community' to include precision agriculture and financial institutions
  - Role of check-off or other mechanisms to provide funding
  - Delivery of information and tools will be a key aspect
- **Awareness and opportunity to take action**
  - Near term- Need to provide unified message on resistance management for the state
  - How to ensure resistant management is a priority on farm for all organizations?
  - Education across groups; key role for ISU/CALS extension to be a hub of information to support farmers and their advisers
    - Education/Outreach could include:
      - CCA education
      - Pesticide Certification Education
      - Other audiences
- **Critical for meeting participants to take messages from the meeting to constituent groups now**