Report of the Second Resistance Management Workgroup to EPA's Pesticide Program Dialogue Committee (PPDC)

Submitted to PPDC at the Fall 2024 Meeting, November 13-14, 2024

Table of Contents

Glossary

Following is a list of technical words used in this document, along with definitions, in order to optimize the readability of this report.

- *Consumer surplus* – the difference between what consumers would be willing to pay for a good or service and what they actually do pay. Changes in consumer surplus are a standard metric used in economics to measure consumer benefits or losses from market changes

- *Diffusion of innovations* – the process by which new ideas or practices (i.e., innovations) are communicated through certain channels over time, and are either adopted or rejected by, member of a social system over time (per Rogers 2003)

- *Integrated pest management (IPM)* – an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties (per University of California 2024)

- *Mode of Action (MoA)* – series of events that takes place at the cellular or molecular level after an organism is exposed to a pesticide. In other words, the mechanism by which a pesticide kills an organism

- *Pesticides* – any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest

- *Producer surplus* – measures the net returns producers receive from supplying products, e.g., in an agricultural context this is equivalent to farm income

- *Selection pressure* – an evolutionary force that causes a particular phenotype (observable characteristics of an individual) to be more favorable in certain environmental conditions

- *Site of Action (SoA)* – specific cellular or molecular processes targeted by a pesticide. Synonymous with “MoA”

- *Vector borne diseases* – diseases that result from a pathogen transmitted to humans and other animals by blood-feeding arthropods (e.g., mosquitoes, ticks)

Executive Summary

The development of resistance amongst pests – whether they be animals, insects, fungi, microbes, pathogens, or weeds – to pesticides poses serious biological and economic problems across agriculture, human health care, and environmental conservation efforts. Resistance is often described as a "wicked" problem because it has multiple complex causes and does not lend itself to simple or straightforward solutions (Gould et al. 2018; Jussaume and Ervin 2016; Shaw 2016). This workgroup views the serious threat that resistance poses to these key sectors of our society as being analogous to EPA's oft-cited comment that failure to comply with Endangered Species Act obligations threatens the conventional use of many pesticides. If we collectively do not prioritize and devote the resources necessary to more effectively manage resistance, then pesticides will no longer effectively control the intended target pests, thus threatening agriculture, public health, and entire ecosystems.

Because of the far-reaching potential for serious impacts from pesticide resistance, any hope of proactively avoiding or delaying the development of resistance, and of successfully limiting the spread of resistance once it develops, requires complete and broad engagement from all stakeholders. Affected parties who must play significant roles include not only federal and state governments, but also pesticide registrants, pesticide applicators and many other stakeholders from agriculture, natural habitat management and health care industries.

Pesticides are an important tool for managing any pest and form a key component of integrated pest management (IPM) programs, and the loss of any component can imperil the success of an entire IPM program. It is the view of this workgroup that IPM principles offer the greatest promise for avoiding/delaying resistance and managing it when it does occur, and so these principles are reflected throughout this report.

In this context, this workgroup offers the following recommendations for consideration and action by EPA (*note that these are ranked in ascending order with respect to the workgroup's assessment of the relative number of obstacles to EPA's implementation of these recommendations. Recommendations that the workgroup believes are the highest priority – regardless of feasibility – are noted in bold*):

<u>*Minimally Challenging*</u>

- **EPA should take maximum advantage of the scientific expertise provided by existing professional society liaisons, especially with regards to BMPs for pesticide resistance management, and explore whether there are additional professional societies with which EPA should establish relationships.**

- **EPA should explore opportunities for future collaboration with Resistance Action Committees (RACs) on pest-specific resistance management standard practices, and**

explore grant programs that could foster innovation in resistance management, including community-based resistance management networks.

- **EPA should more actively coordinate with both federal partners (such as the USDA) and external stakeholder groups already actively engaged in pesticide resistance management education and training; this should include discussing with grant-offering groups opportunities for prioritizing innovative pesticide resistance management research.**

- EPA should critically assess whether existing regulatory incentive programs for non-conventional pesticides (including bio-pesticides, organic pesticides and biological control agents) are effective, and whether novel incentives (e.g., expanded voucher programs) could better promote the development of new non-conventional pesticides and pesticide devices that have IPM and resistance management benefits.

- **EPA should expeditiously publicize the updated process for the FIFRA 25(b) minimum risk pesticide submission process.**

Moderately Challenging (some time or resources required)

- EPA should collaborate with regional IPM centers to support the development of and/or updating of Crop Profiles (CPs) and Pest Management Strategic Plans (PMSPs) with specific information on potential costs of resistance.

- EPA should develop and strengthen partnerships with external organizations and parties to help foster innovation in the development of non-conventional pest control devices and products.

- EPA should create a classification committee in the Biopesticides and Pollution Prevention Division (BPPD) to help guide uncertain non-conventional pesticide cases through the registration process; this committee would operate prior to the new active ingredient submission process.

- EPA should explore opportunities for supporting the development of pesticide resistance surveillance tools.

- EPA should include registrant-submitted data on pesticide resistance submitted per FIFRA 6a2 in the public Incident Data System (IDS) website.

Very Challenging (significant time or resources required)

- EPA should request the development of a National Road Map for Pesticide Resistance Management under the auspices of the Federal IPM Coordinating Committee (FIPMCC).

- **EPA OPP should create a new position (or devote a partial full-time equivalent (FTE) towards a new position) of the Resistance Management Coordinator, who would be responsible for leadership within and outside EPA on pesticide resistance management issues.**

- EPA should quantitatively account for resistance management implications in pesticide registration and cancellation decisions, and create a pesticide-specific priority system for doing so.

- **EPA should collaborate with federal partners, academia, agricultural retailers, agronomist/consultants, and RACs to develop standardized checklists for cases of suspected resistance that could be used as a decision support tools by growers and other pesticide users and explore whether these checklists could be developed into thresholds that could be used to aid in the collection of data on cases of suspected resistance.**

1. Introduction.

1.1. Scope

This report pertains only to pesticides whose uses are regulated by the Biological and Pollution Prevention Division (BPPD), the Pesticide Re-evaluation Division (PRD), and the Registration Division (RD). Therefore, they are not intended to address resistance issues related to products solely regulated by the Antimicrobials Division (AD) of the Office of Pesticide Programs. The workgroup developed this caveat to acknowledge assertions by some members of the PPDC that the target organisms for pesticide uses regulated by AD are sufficiently different so as to warrant separate and more focused work outside of this workgroup.

There is indeed considerable ongoing work by registrants and other stakeholders on the issue of managing antimicrobial resistance, including efforts to develop protocols to predict and understand bacterial resistance to microbicides that are under development by the International Organization for Standardization (ISO). Additional research is underway by the European Union (EU) and has been discussed at the Organization for Economic Cooperation and Development's (OECD) Working Party on Biocides.

Because this report does not specifically address resistance issues related to products solely regulated by AD, we leave here for discussion by PPDC two options for possible next steps:

- Option 1: PPDC could form a new workgroup to focus only on antimicrobial resistance issues that affect the products regulated by AD.

- Option 2: Instead, PPDC could simply allow ongoing antimicrobial resistance management efforts to continue, with the informal suggestion made that AD should ensure that its staff are engaged in and fully participating in these external antimicrobial resistance efforts and participating in the proposed interagency framework on antimicrobial resistance.

1.2. What is pesticide resistance?

Over the years the scientific community has come to appreciate that the development of pesticide resistance is much more complicated and sophisticated than once thought. Resistance to almost any pesticide can develop in any given pest population when it is exposed repeatedly to pesticides with the same "mode of action" (also known as "site of action"). The development of such resistance is a natural and inevitable outcome of evolutionary selection pressures that favor survival until reproduction, but scientists have documented that in some organisms, the development of resistance is not quite as linear or predictable as once thought.

1.3. Who is affected by pesticide resistance?

Simply put, we are all affected directly or indirectly by the development of pesticide resistance. Whether it is resistance to pesticides used in agriculture that leads to increased food prices, resistance to pesticides amongst insect or vertebrate vectors of human and livestock diseases, resistance to antibiotics that can negatively impact human health, or risks of increased exposure to pesticides from the mismanagement of resistant pests, we are all touched by pesticide resistance. As such, while this report necessarily focuses on this workgroup's recommendations for actions that EPA could take to improve its existing efforts to promote resistance management, all of us must appreciate that we all have an equally vital role to play in tackling pesticide resistance management.

The members of this workgroup urge readers to consider what work they and their organization can do to support EPA's implementation of the recommendations in this report, and what else you can do to work in parallel to EPA to constructively manage pesticide resistance. We are running out of time in some cases to successfully manage resistance in some pests. The proliferation of resistant microbes, insects, and weeds requires us all to consider systemic changes in how we produce food, how we manage ecosystems, and how we manage pesticide resistance alongside public health concerns. We will all bear the costs if growers are unable to sustainably manage herbicide resistance in weeds, or if public health professionals are no longer able to keep vector-borne diseases under control in urban areas or control pathogens in health care settings.

EPA should play a central role in addressing resistance, given its statutory authority to license and regulate pesticides in the United States. It is important to acknowledge that EPA has made strides in its efforts to further resistance management. While this workgroup applauds EPA for what it has already done, the recommendations in this report (not to mention those of the first

Resistance Management Workgroup, highlight the need for more action by EPA to help successfully address pesticide resistance going forward.

1.4. PPDC Resistance Management Workgroup 1.0

EPA's Pesticide Program Dialogue Committee (PPDC) first approved the formation of a resistance management-focused workgroup at the Fall 2020 meeting, with the following charge questions:

- Are there current EPA policies that positively or negatively affect conventional pesticide resistance management? What policies could be re-worked to more positively address resistance management?
- Are there current industry programs that positively or negatively affect conventional pesticide resistance management? Would EPA have a role in those programs, and what might that be to positively influence industry?
- Are there incentives (for registrants or pesticide users) that could be considered related to conventional pesticide regulation that might positively affect resistance management? Are there other ways in which the agency can work with stakeholders (e.g., growers, commodity groups, academics) to cooperatively address resistance management?
- Are there elements from EPA's *Bt* plant incorporated protectant (PIP) resistance management program that could be used in conventional pesticide resistance management?

After working on these issues for a year the first PPDC Resistance Management Workgroup recommended that:

1) EPA should explore changes in pesticide labels to make them more uniform across manufacturers. Labels need to contain clear and concise language so all needed information to implement resistance management is easily found and understood by end users such as crop consultants, pesticide decision makers, and commercial and private pesticide applicators.
2) EPA should conduct a thorough review of EPA policies and regulations that impact resistance management and remove contradictions and situations that hinder effective resistance management to the maximum extent possible.
3) EPA should expand collaboration and outreach efforts with other federal agencies and convene panels of relevant stakeholders to address specific priority issues and questions associated with resistance and resistance management.
4) EPA should explore how it can encourage proactive pesticide resistance management and prevention programs in cooperation with industries and universities through cooperative agreements, updated training materials, and grant programs.
5) EPA should explore the creation of incentive programs for assistance to pesticide users and their educators in overcoming the hurdles associated with resistance management,

in particular incentives to researchers, users and supplies for accurate early detection and timely adoption of regionally specific resistance management actions.

The PPDC Resistance Management Workgroup 1.0's final report and recommendations were presented at the May 2022 PPDC meeting. OPP leadership responded to the workgroup's recommendations at that same meeting with a request for further assistance in prioritizing these recommendations, and in developing suggestions that could help EPA implement "low hanging fruit" amongst the workgroup's recommendations. It is remarkable that OPP desires this second workgroup to assure policy development and implementation.

1.5. PPDC Resistance Management Workgroup 2.0

At the May 2022 PPDC meeting the following charge questions were approved as the basis for a second PPDC Resistance Management Workgroup:

- Assist EPA in developing implementation strategies from the first workgroup recommendations.
- Develop a framework for the quantification of risks and benefits from resistance to conventional pesticide active ingredients.
- Explore leveraging IPM strategies for resistance management.

As this workgroup has carried out our deliberations, we have been sure to keep in our minds that EPA has relatively limited authority in this domain. EPA arguably has only a few regulatory tools by which they can affect pesticide resistance management, namely pesticide labels themselves and the terms and conditions for the registration of those pesticides. However, beyond these few regulatory tools, EPA also has a major role to play in supporting education, outreach and coordination with other federal, state, and tribal authorities, as well as extension advisors and growers, to support resistance management activities. Our recommendations address both how EPA could improve the accounting for resistance management in the context of its limited regulatory tools, and how EPA could improve its existing education, outreach and coordination work related to pesticide resistance management.

In light of these overarching considerations, and in response to this workgroup's charge questions, we recommend the following overarching recommendation themes (*organized within the context of the original charge questions for this workgroup)*:

- Assist EPA in developing implementation strategies from the first workgroup recommendations.

  Recommendation Theme #1. EPA should strengthen partnerships within and outside the federal government, including through the creation of a new Resistance Management Coordinator position to lead these efforts.

- Develop a framework for the quantification of risks and benefits from resistance to conventional pesticide active ingredients.

  Recommendation Theme #2: EPA should integrate resistance cost/benefit assessments into their decision making on pesticide registrations.

  Recommendation Theme #3: EPA should work with pesticide registrants and external stakeholders to improve the rigor and transparency of resistance data.

- Explore leveraging IPM strategies for resistance management.

  Recommendation Theme #4: EPA should explore opportunities for removing regulatory barriers to alternatives to conventional pesticides.

Additionally, we note that the highest priority recommendation of the first Resistance Management Workgroup was label reform. This iteration of the PPDC Resistance Management Workgroup has deliberately not continued to work on this specific recommendation given the ongoing work of PPDC's Label Reform Workgroup, which as we understand it specifically includes new language on resistance management.

As our workgroup discussed the charge questions and how to arrive at consensus recommendations, a central theme that emerged and ended up forming the thesis of our recommendations was the integral relationship between pesticide resistance management and Integrated Pest Management (IPM). It's important to note that as we discussed IPM in the context of this report we did so with the following definition in mind:

> *"IPM is an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Pest control materials are selected and applied in a manner that minimizes risks to human health, beneficial and nontarget organisms, and the environment (University of California 2024)."*

This workgroup also appreciates that the application of IPM can vary for different types of pests, and as one example acknowledges the growing body of literature and practice on Integrated Weed Management (Norris 1999; Norsworthy et al. 2012; Sanyal et al. 2008; Swanton and Weise 1991).

1.6. Interconnectedness of resistance management and Integrated Pest Management (IPM)

Pesticide resistance is frequently described as a classic example of a "wicked problem" in that there are no singular causes or solutions. To acknowledge this, the workgroup puts forth the premise that IPM principles offer a path forward to sustainably managing pesticide resistance.

To build on the understanding of pesticide resistance as a "wicked" problem, though, we must briefly consider the root causes of pesticide resistance. The increasing reliance on a very limited number of pesticidal modes of action to control pest populations is a clear primary driver of pesticide resistance (Thia et al. 2023). There are, however, other factors that have arguably exacerbated the spread and impact of pesticide resistance, such as the reduction of natural enemies of pests, a rapidly changing increasingly unpredictable legal and regulatory landscape with regards to pesticides, and a complex web of socio-economic factors. All of these confound pest management decision making (Dentzman 2021; Sun et al. 2017). To acknowledge the myriad factors that drive pesticide resistance and hinder management of resistance, it was recognized as early as the 1970s that IPM offered an optimal approach to addressing pesticide resistance management. Indeed, it is suggested that IPM and resistance management are twins, with the importance of the former rising from the growing failure to effectively curtail the latter.

The focus on IPM resulted in widespread research that was translated into successful programs through EPA, USDA and CDC, as well as other federal agencies and departments (Kogan 1998; Olsen et al. 2003). However, many of these programs were temporary in nature (as many federal programs are); these early efforts offer examples though of how strong federal investment in IPM programs can benefit agricultural production systems and health care systems alike. Commonalities amongst these early and successful programs included emphasis on optimizing the judicious use of pesticides (i.e., using these tools only when necessary), and model programs for the diffusion of IPM research and knowledge via existing and experienced change agents. It is this last point that this workgroup built on for our first recommendation, which centers on building on existing relationships within and outside of the federal government to further work on resistance management.

2. Recommendation #1: EPA should strengthen partnerships within and outside the federal government, including through the creation of a new Resistance Management Coordinator position to lead these efforts.

The establishment of groups coordinating IPM work, both within EPA and the broader federal government and external to the federal government, has resulted from the decades-long history of IPM-related work in the U.S. This workgroup proposes that EPA should focus on better leveraging internal and external relationships and partnerships to further EPA's understanding of resistance management. EPA needs to proactively engage with federal and external stakeholders, understand what they are already doing related to pesticide resistance management, and identify novel opportunities for collaboration moving forward. These stakeholders are often experts in outreach and education, so the experience and knowledgebase of practitioner-facing stakeholders will be critical to make collective progress on resistance management. The appointment of a specific Resistance Management Coordinator within EPA's Office of Pesticide Programs would enhance EPA's ability to implement this first recommendation.

2.1. Leverage existing external partnerships and relationships

2.1.1. Professional scientific societies

EPA has already established close working relationships with several professional societies, including via the appointment of specific liaisons from the American Phyto-pathological Society (APS), the Entomological Society of America (ESA), and the Weed Science Society of America (WSSA). For these three societies, the appointed liaisons coordinate work with EPA on scientific matters related to the control of weeds, insects, and plant pathogens. The presence of these existing relationships between EPA and APS, ESA, and WSSA highlight the expertise that these societies and their members offer on pest management issues, including on resistance management and IPM. EPA should take maximum advantage of this valuable scientific expertise and their capacity to communicate with other experts on resistance management science.

Management of pesticide resistance is complicated and requires inter-disciplinary knowledge. As such, we would strongly encourage EPA to reach out to and establish liaisons with other professional societies whose expertise in social sciences and collaborative decision making could benefit our collective progress on resistance management. A few examples of such professional societies include the Agricultural and Applied Economics Association (AAEA), the American Public Health Association (APHA) and the American Rural Sociological Society (RSS).

Specific topics that we recommend that EPA discuss – on an ongoing basis – with existing and new professional societies are:

- Whether professional societies have Best Management Practices (BMPs) or recommendations for pesticide resistance management in their discipline that EPA could adapt and integrate into PRN or label updates. Additionally, could EPA and professional societies better coordinate on outreach and communication materials related to pesticide resistance management?
- How EPA might support and encourage the development of decision support tools to help farmers assess the benefits and costs of resistance management on their operations. Examples of these tools include the University of Arkansas Palmer Amaranth Management (PAM) (Lindsay et al. 2017) or the Ryegrass Integrated Model RIM in Australia (Lacoste and Powles 2014).
- Encourage the development of quantitative field-level "action thresholds" that would serve as the baseline applied definition for "resistance" with respect to registrant's adverse incident reporting obligation under FIFRA 6a2.

Recommendation 1.1: EPA should identify whether there are additional professional scientific societies with particular expertise and knowledge in pesticide resistance management, or scientific outreach and extension activities, that it could establish a formal relationship with through the appointment of a liaison to OPP.

Recommendation 1.2: EPA should take maximum advantage of the scientific expertise provided by the professional society liaisons to bring their members' knowledge of resistance frequency, recommended management practices, and barriers to adoption of resistance management practices, so as to inform EPA's regulatory decisions. The agency should use these connections to gain insight with regard to BMPs specific to insecticides, fungicides, and herbicides, as well as with regard to extension outreach on resistance management, including the development of grower decision support tools.

2.1.2. Resistance Action Committees (RACs)

The RACs include the Herbicide Resistance Action Committee (HRAC), the Insecticide Resistance Action Committee (IRAC), and the Fungicide Resistance Action Committee (FRAC). These industry associations are administered by CropLife International and have extensive technical expertise on resistance management, resources and capabilities for outreach and education, and a history of collaboration with both EPA (and other federal partners) and academics on resistance management.

Recommendation 1.3: EPA should explore opportunities for future collaboration with RACs on pest-specific resistance management standard practices, and explore grant programs that could foster innovation in resistance management, including the development of local field-level action thresholds to assist grower decisions and community-based resistance management networks.

2.1.3. Work with other external stakeholders to support resistance management education and outreach and develop grant programs that could be used to promote innovation in resistance management activities.

Besides professional scientific societies and the RACs, there are many other organizations outside the federal government already actively engaged in resistance management across disciplines and sectors. These include groups such as the American Mosquito Control Association (AMCA), the Biological Products Industry Alliance (BPIA), the IPM Institute of North America, the National Alliance of Independent Crop Consultants (NAICC), the various commodity organizations, and similar groups who engage with farm workers and with urban pest management issues.

The largest group of key external collaborators are academics, especially those with extension-oriented appointments who provide valuable insight to assist EPA and other professionals. In addition, the USDA-funded but independently operated Regional IPM Centers are important intermediaries between extension pest management specialists across the U.S. and federal agencies. The IPM Centers produce Crop Profiles (CPs) and Pest Management Strategies Plans (PMSPs), which can be critical sources of information for EPA on crop production practices and pest management issues, including resistance management. See Recommendation 2.3 for a related specific suggestion on how EPA could work with Regional IPM Centers to improve the coverage of resistance management in CPs and PMSPs.

In addition to key expertise on education and outreach, there is also a long history of grant funding provided by some of these external organizations to promote IPM and other innovations. Some examples include: 1) annual grants funded by the Regional IPM Centers that funds projects focusing on leveraging IPM for pest-resistance management; 2) annual grants funded by commodity organizations; and, 3) the Center for Regulatory Science in Agriculture, which supports innovative agricultural research and training programs, including those touching on resistance management.

Recommendation 1.4: EPA should more actively coordinate with other external stakeholder groups already actively engaged in pesticide resistance management education and training; this should include discussing with grant-offering external stakeholders opportunities for prioritizing innovative pesticide resistance management research, especially on topics with relevance to EPA's regulatory authorities.

2.2. Leverage and expand on existing internal (i.e., within the federal government) partnerships and relationships.

2.2.1. Coordinate with grant-offering agencies to prioritize innovative pesticide resistance management research.

Innovation and research to advance resistance management, like IPM in general, has to be supported primarily by the federal government, simply because there's little short-term financial gain to be had but enormous longer-term costs to our society and economy if pesticide resistance management efforts are unsuccessful. This is the classical common pool resource problem associated with the "wicked problem" discussed earlier. As such, it is imperative that EPA and other federal agencies that provide funding to support research and implementation projects coordinate and prioritize innovation in research to support pesticide resistance management. Perhaps even more importantly is the need for research to understand barriers to and drivers of implementation of pesticide resistance management. To some degree we can argue that we already collectively understand the basics of how to manage pesticide resistance in various disciplines, but we continue to fail at acknowledging and studying why resistance management efforts continue to fall short even when we understand what to do.

There are numerous federal agencies and departments with whom EPA could better coordinate to ensure that pesticide resistance management becomes a more consistent funding priority, these include the Centers for Disease Control (CDC), National Institute of Health (NIH), National Science Foundation (NSF), the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, and USDA's National Institute of Food and Agriculture (NIFA).

This workgroup would argue though that simply coordinating with other federal agencies and departments to ensure that pesticide resistance management is a funding priority falls short of reflecting the major threat that failing to make progress on resistance management poses.

Therefore, this workgroup makes several more specific and far-reaching recommendations to better lay the groundwork for EPA and other federal agencies to take serious steps on coordination on pesticide resistance management.

2.2.2. Work with federal partners on the Federal IPM Coordinating Committee to develop a National Road Map on Pesticide Resistance Management, one Component of Which is the Formation of Centers for Excellence for Research and Practice of Resistance Management.

2.2.2.1. Build on existing participation in FIPMCC

The Federal Integrated Pest Management Coordinating Committee (FIPMCC) provides leadership, management, and coordination on pest management issues, including Integrated Pest Management (IPM) and resistance management (USDA 2020). The committee is composed of representatives of federal agencies with IPM research, implementation, or education programs but also includes public and private sector participants as appropriate, such as the USDA-funded Regional IPM Centers.

2.2.2.2. Initiate the development of a National Road Map for Pesticide Resistance Management.

As an existing active member of FIPMCC, EPA should request that FIPMCC ask for volunteers to work on the development of a National Road Map for Pesticide Resistance Management. This effort could look to several existing documents as precedents:

- National Road Map for Integrated Pest Management, the goal of which *"is to increase the adoption and efficiency of effective, economical and safe IPM practices"* and is *"facilitated through information exchange and coordination among federal and non-federal researchers, educators, technology innovators, IPM practitioners and service providers, including land and natural resource managers, agricultural producers, structural pest managers, and public and wildlife health officials* (FIPMCC 2018)*."*
- National Public Health Strategy to Prevent and Control Vector-Borne Diseases in People, which is guided by the stated vision of *"A nation where vector-borne diseases no longer threaten the health of people* (US DHHS & CDC 2024)*."*
- USDA Strategy to Address Antimicrobial Resistance, the purpose of which is to *"serve as a guide to USDA agencies and their collaborators on priorities to accelerate our understanding of an minimize the risk from antimicrobial resistance* (USDA 2023)."

While this workgroup does not wish to pre-suppose the focus or contents of the National Road Map for Pesticide Resistance Management, we suggest that EPA and the other federal partners who participate in the FIPMCC consider the following:

- Whether the creation of Centers of Excellence for Research and Practice of Resistance Management – modeled after similar Centers of Excellence (CoEs) created and managed by US CDC – could help to form a centralized system of federally-led research, education and training on pesticide resistance management issues. Rather than creating new entities, we would recommend that FIPMCC consider leveraging existing experts already working on this topic housed within CDC's Centers of Excellence, EPA's Office of Research and Development (USEPA/ORD), USDA's Agricultural Research Service (ARS), or even the Regional IPM Centers.

- The Road Map should include discussions on how to manage the intersections of pesticide resistance management with other current pressing issues, including risks to the effectiveness of human and animal drugs posed by certain pesticides (USEPA 2023), and trade-offs between pesticide resistance management and compliance with the Endangered Species Act (ESA).

Recommendation 1.5: EPA should actively engage with federal grant-agencies and advocate for the prioritization of innovative pesticide resistance management research and management programs, especially on topics with relevance to EPA's regulatory authorities.

Recommendation 1.6: EPA should request the development of a National Road Map for Pesticide Resistance Management under the auspices of FIPMCC.

2.3. Devote specific OPP resources towards resistance management

The recommendations proposed thus far for action by OPP are extensive, and will require additional resources to come to fruition and be successful; again, we acknowledge though that the burden of greater resources and commitments needed to tackle pesticide resistance management falls on all of us collectively and not just EPA.

Therefore, this workgroup also proposes several recommendations regarding how EPA could re-allocate existing resources to better benefit pesticide resistance management, and how EPA could optimally devote new resources to help achieve the goals set out in these recommendations.

2.3.1. Explore whether additional investments in existing IPM programs could allow these programs to better support progress on pesticide resistance management.

Within OPP's Biopesticides and Pollution Prevention Division (BPPD) there already exist funding and staff resources focusing on IPM, both within the Environmental Stewardship Branch and the Center for IPM. One activity some of the workgroup members undertook was to assess the current activities and strategic plans of these offices within BPPD, in part by having a dialogue with BPPD IPM-focused staff on the following questions:

1. What are the current IPM, volunteer/non-regulatory (e.g., IPM Center and/or PESP) related activities in BPPD which could augment Agency efforts to implement pesticide resistance management?

2. Is there a current strategic plan that can demonstrate success that specifically addresses the national implementation of volunteer/non-regulatory IPM (e.g., IPM Center and/or PESP)?

3. Who coordinates that plan or activities with the Regions and/or other Offices (e.g. OAR) regarding the consistent implementation of IPM?

4. How does the Pollution Prevention Act apply to IPM in relation to BPPD?

Responses to these questions are summarized in more detail in Appendix I. Generally, this dialogue was instrumental to the development of the following recommendations. Our workgroup further suggests that BPPD consider whether its existing IPM-focused programs, including regular webinars[1], could more inclusively address the utilization of IPM for pesticide resistance management.

It would be important, however, for EPA BPPD to recognize key differences in pest resistance management with conventional pesticides compared to Plant Incorporated Protectants (PIPs) and clearly address these differences, as well as the different approaches to resistance management required by each pest group, in their programs.

To support these efforts this workgroup requests that EPA evaluate whether existing funds could be re-allocated to support the expansion of existing IPM-specific activities and roles to include pesticide resistance management. In particular, the workgroup respectfully suggest that the existing Pesticide Environmental Stewardship Program (PESP) could focus moving forward on resistance management through IPM, including through its grants program (which awarded $780,000 not quite 18 months ago).

2.3.2. Appointment of a new resistance management coordinator position

For this first recommendation to be optimally effective, this workgroup recommends that a central point person within EPA be tasked with the responsibility of managing and enhancing the existing relationships and partnerships outlined above. Therefore, this workgroup recommends that EPA demonstrate its commitment to addressing pesticide resistance, and promoting more sustainable management of pesticide resistance, by devoting the resources necessary to fund one staff member who would be appointed to the role of "Resistance Management Coordinator." A legacy plan ought to be put in place to ensure the continuation of resistance management work at EPA should this designated individual need to be replaced.

The Resistance Management Coordinator would be responsible for leading the effort to improve coordination on resistance management issues within EPA. Having a committed individual who has clear responsibility for coordination of internal capacity would greatly improve the EPA's ability to respond and be proactive in addressing resistance management. The Coordinator

[1] https://www.epa.gov/ipm/upcoming-integrated-pest-management-webinars

would also manage collaboration with federal partners on resistance management issues, including through FIPMCC.

EPA interacts with external groups regularly on resistance management issues, including professional societies and the RACs. The EPA Resistance Management Coordinator would be the Agency point person responsible for coordination and information exchange with these external stakeholders. The Coordinator could assemble information obtained through these external interactions for use by EPA divisions to guide their assessments of new registrations and registration review. Also, the Coordinator could lead EPA's efforts to develop a framework to assess how a pesticide, as potentially labeled, will fit into IPM programs designed to address resistance management and asses whether the pesticide, as labeled, would actually be effective in the field to address resistance. This information will also be valuable input for Workgroup Recommendation #2, which is to conduct more quantitative benefit-cost assessments for resistance-related impacts of regulatory actions.

Recommendation 1.7: EPA OPP should create a new position (or devote a partial full-time equivalent (FTE) towards a new position) of the Resistance Management Coordinator, who would be responsible for leadership within and outside EPA on pesticide resistance management issues.

3. Recommendation #2: EPA should integrate resistance cost/benefit assessments into their decision making on pesticide registrations.

There are long-established tools that economists have used to estimate the impacts of pesticide cancellations. These tools can be fruitfully applied to measuring resistance management benefits and costs. Benefit-cost analysis for resistance management is complicated by intertemporal considerations. Managing resistance often entails short-run costs, while the resulting benefits accrue only in future years. The net benefits of resistance management depend crucially on how fast resistance would occur absent management and how many years the resistance management strategies delay resistance onset. Economists have used both sophisticated bio-economic models and simpler-to-implement ad hoc models to account for these critical timing issues. Each approach has relative strengths and weaknesses. There is scope for combining methods, using simpler methods if justified and resorting to more complex methods if not. Additional details on a possible approach for conducting pesticide resistance cost/benefit analyses is presented in Appendix II.

It is quite feasible to conduct benefit-cost analysis of resistance management policies for individual compounds or classes of compounds. It is not feasible, however, for EPA to conduct such analyses for every pesticide (or even large numbers of them), and so we offer some suggestions for the creation of a prioritization scheme.

Recommendation 2.1a: EPA should formally account for resistance management implications in pesticide registration and other regulatory decisions.

Every registration or cancellation decision is going to have implications for resistance management. Simply noting this fact in decisions is not especially helpful in accounting for the role of resistance management. The following information would be helpful for EPA to explicitly consider in its decisions:

- How does registration or cancellation affect the diversity of effective MOAs that are available?
- If use of a compound were cancelled, what would growers most likely use instead?
- What is the resistance status of these other compounds (e.g. is there already resistance in certain states and cropping systems)?
- How much would the increased use of substitute compounds increase their likelihood of facing resistance problems?
- How do the costs per acre of applications of substitute compounds compare with the compound under consideration?
- Are there studies of yield performance of substitute compounds relative to the one under consideration? If yes, what are the estimated yield differences?
- For new compounds being considered for registration, do they increase the existing diversity of effective MOAs? Would they alleviate specific pre-existing resistance problems? How might they ward off potential resistance problems?

Recommendation 2.1b: EPA should create a priority system to identify specific pesticide active ingredients for which benefit-cost analysis of resistance management would be carried out first.

Priority could be given to pesticide and cropping system combinations where:

a) There is a lack of economical substitutes for the compound that may face resistance,
b) The national value (both in an economic and a social valuation context, e.g. public health benefits of mosquito control) of uses in aggregate (and potential economic impact) is large,
c) Specific target pests controlled by the active ingredient have an outsized negative impact,
d) The percentage-change in production and income from resistance costs are relatively large; e.g., for many specialty crops, resistance could generate large percentage losses, even though the crop is a small share of national total sales or acreage; or,
e) Active ingredients pose relatively higher risk for resistance to evolve more rapidly, or primary target pests of an active ingredient have characteristics that make them particularly prone to developing resistance.

Other considerations might include how pesticide usage or resistance in one cropping system might spill over to other cropping systems. An example was concern over how *Bt* corn and *Bt* cotton might affect resistance to foliar *Bt* sprays in organic vegetable crop production. Some of the information needed to set these priorities would include sales volumes, the area treated, the share of sales volumes, and the share of the area treated (shares would provide some information about the availability of substitutes). Much of this information could be gleaned from materials supplied by registrants, as they must document how their compounds are improvements over systems that exclude their products.

Recommendation 2.2: Collaborate with regional IPM centers to support the development of and/or updating of Crop Profiles (CPs) and Pest Management Strategic Plans (PMSPs) with specific information on potential costs of resistance.

These documents are natural places to collect and report such information. There was an initial round of extensive reporting on the heels of the Food Quality Protection Act (FQPA). In the last decade, however, the number of CPs and PMSPs has dropped off considerably (Boudwin et al. 2022). EPA and USDA are often able to get useful information on typical specialty crop production practices from CPs and PMSPs, but these documents could better focus on resistance management practices and EPA could help the regional IPM centers with cost benefit analyses that could be incorporated into these documents. This recommendation builds on suggestions made in Recommendation 1.4.

4. Recommendation #3. EPA should work with pesticide registrants and external stakeholders to improve the rigor and transparency of resistance data.

There are currently limited sources of quantitative data on the occurrence and spatial distribution of pesticide resistance; this is in sharp contrast to the sophisticated and comprehensive surveillance of antimicrobial resistance to animal and human drugs through the National Antimicrobial Resistance Monitoring System (NARMS)[2]. Sustainable management of pesticide resistance is arguably impossible without public access to high quality data on pesticide resistance cases to support both grower decision-making and also to inform state and federal pesticide regulatory efforts. Better pesticide resistance data could be used by regulatory authorities both to support Section 18 Emergency Exemption petitions and to aid regulatory discussions with regards to the implications of potential mitigations.

There continues to be a disconnect between the timescale at which pesticide users recognize and must react to suspected pesticide resistance, and the timescale necessary to fully confirm resistance using established scientific protocols. EPA should engage with stakeholders already working on the development of standardized checklists in cases of suspected resistance to better understand the implications of this asynchrony for regulatory and policy purposes. In the context of agriculture, many agronomist/consultants already utilize versions of these checklists

[2] https://www.fda.gov/animal-veterinary/antimicrobial-resistance/national-antimicrobial-resistance-monitoring-system

to screen for suspected resistance, and there has been some work done already to codify these into standard indicators of possible resistance, e.g., Norsworthy et al. (2012) for weeds:

- *"Failure to control a weed species normally controlled by the herbicide at the dose applied, especially if control is achieved on adjacent weeds;*
- *A spreading patch of noncontrolled plants of a particular weed species; and,*
- *Surviving plants mixed with controlled individuals of the same species."*

Recommendation 3.1: EPA should collaborate with federal partners, academics, agricultural retailers, agronomist/consultants, and RACs to develop standardized checklists for cases of suspected resistance that could be used a decision support tools by growers and other pesticide users, and explore whether these checklists could be developed into thresholds that could be used to aid in the collection of data on cases of suspected resistance.

Recommendation 3.2: EPA should explore opportunities for supporting the development of pesticide resistance surveillance tools.

As of mid-2023 EPA began sharing pesticide incident data publicly via the Incident Database System[3], and the underlying data should include any adverse incident reports submitted to EPA by pesticide registrants that involve cases of pesticide resistance. These data are currently the best available data on the spatial distribution of resistance, and so we strongly suggest that EPA undertake any necessary steps to ensure that these data are included and clearly identified in IDS.

Recommendation 3.3: EPA should include registrant-submitted data on pesticide resistance submitted per FIFRA 6a2 in the public Incident Data System website.

5. Recommendation #4: EPA should explore opportunities for removing regulatory barriers to alternatives to conventional pesticides.

A foundational tenet of IPM is the combination of biological, cultural, mechanical, and chemical pest control methods, with the acknowledgement that appropriate combinations of these various types of control methods works better than any single control method on its own (University of California 2024). While increasing the effectiveness and durability of pest control is a key goal of IPM, alternating and/or combining types of pest control methods also "*reduce(*s*) the evolution of pest resistance to pesticides and other pest management practices*" (FIPMCC 2018).

The availability of effective physical, biological, and any other non-conventional pesticide pest control measures and devices is critical to achieving this foundation of IPM, and is a core statutory obligation of EPA. It is important to remember that under the Federal Fungicide, Insecticide and Rodenticide Act (FIFRA), EPA has broad authority to license both "pesticides"

[3] https://ordspub.epa.gov/ords/pesticides/f?p=359:1::::::

and "devices,"[4] both of which are commonly used components of IPM. Therefore, EPA can improve its support of IPM by (1) encouraging the development of alternative pest control products and methods through appropriate regulatory incentive programs and partnerships, and (2) streamlining the process for FIFRA registration or 25(b) exemptions for biological control agents, and novel or atypical biopesticides.

5.1. Encourage the development of alternative pest control products and methods through appropriate regulatory incentive programs and partnerships.

To encourage the development of non-conventional pest control products or devices, EPA should:

1. Develop regulatory incentive programs to encourage the development and dissemination of non-conventional pest control devices or products. EPA can work together with pesticide registrants and equipment manufacturers to achieve this. For organic pesticides and bio-pesticides there are already reduced registration requirements in terms of fees and testing requirements (compared with conventional pesticides), but EPA could explore providing additional opportunities (e.g., through expansions of its Reduced Risk Program for conventional pesticides[5] or the Vector Expedited Review Voucher Program[6]) for these non-conventional pesticides to offer registrants a more rapid path to commercialization. With regards to devices[7], the past few years have seen an explosion in the marketing of air purification devices, seed destruction equipment and electric weeding machines, with little awareness by the equipment manufacturers that these devices are regulated by EPA. To bring stability to the marketplace this workgroup would propose that EPA actively engage with this community of manufacturers and work collaboratively with them to improve clarity regarding regulation of these products.

2. As stated earlier in Recommendation #1, EPA should strengthen external partnerships with groups that can help to promote the development and dissemination of non-

---

[4] FIFRA Sec. 2 [7 U.S.C. 136] Definitions:
- Device: *"The term 'device' means any instrument or contrivance (other than a firearm) which is intended for trapping, destroying, repelling, or mitigating any pest or any form of plant or animal life (other than man and other than bacteria, virus, or other microorganism on or in living man or other living animals); but not including equipment used for the application of pesticides when sold separately therefrom.*
- Pesticide(s): *"The term 'pesticide' means (1) any substance or mixture of substance intended for preventing, destroying, repelling, or mitigating any pest, (2) any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant, … ."*

[5] https://www.epa.gov/pesticide-registration/conventional-reduced-risk-pesticide-program#:~:text=OP)%20Alternative%20Status-,What%20is%20the%20Conventional%20Reduced%20Risk%20Pesticide%20Program%3F,environment%20than%20existing%20conventional%20alternatives.

[6] https://www.epa.gov/mosquitocontrol/vector-expedited-review-voucher-verv-program#:~:text=Under%20the%20Vector%20Expedited%20Review,or%20other%20insecticide%2Dresistant%20mosquitoes

[7] https://www.epa.gov/pesticides/pesticide-devices-guide-consumers#:~:text=It%20is%20generally%20unlawful%20to,%C2%A7%20152.25%20).

conventional pest control devices or products. These partners may include the Regional IPM Centers, land grant university cooperative extension programs, and other academic institutions (e.g., the Center of Excellence for Regulatory Science in Agriculture at North Carolina State University and Louisiana State University).

Recommendation 4.1: EPA should critically assess whether existing regulatory incentive programs for non-conventional pesticides (including bio-pesticides, organic pesticides and biological control agents) are effective, and whether novel incentives (e.g., expanded voucher programs) could better promote the development of new non-conventional pesticides and pesticide devices that have IPM and resistance management benefits.

Recommendation 4.2: EPA should develop and strengthen partnerships with external organizations and parties to help foster innovation in the development of non-conventional pest control devices and products.

5.2. Streamline the process for FIFRA registration or 25(b) exemptions for biological control agents, and novel or atypical biopesticides.

Building on the previous recommendation and suggestion, arguably the biggest incentive EPA has at its disposal for non-conventional pesticide and pesticide devices is the addition of a specific product or device to the list of "Minimum Risk Pesticides" under FIFRA 25(b). Barriers exist to registration for novel and atypical biopesticides, innovative pesticide devices, and biological control agents, all of which represent important alternatives to conventional chemical controls. Although there is already a reduced list of testing requirements for microbial pesticides (relative to conventional pesticides), existing regulatory requirements represent a hurdle to the wider use of these products, which arguably offer outsized benefits relative to very minimal real risks. As such, a more streamlined process for 25(b) exemption for such products is urgently needed.

To accomplish this goal, EPA should:

1. Provide guidance, including detailed expectations, for the FIFRA 25(b) minimum risk pesticide submission process. In 2021, EPA requested[8] public comments and suggestions on the petition process for FIFRA Section 25 exemptions. Process improvements following that request for input is still needed. In some cases, conventional chemical alternatives exist that do not have a clear pathway to FIFRA registration (e.g., due to lack of commercial viability) and do not appear to require FIFRA registration due to their risk profile. In these cases, a pathway to FIFRA exemption under 40 CFR 152.25[9] is needed. The most recent addition[10] to the 25(b) minimum risk pesticide list followed a review

[8] https://www.regulations.gov/docket/EPA-HQ-OPP-2020-0537
[9] https://www.ecfr.gov/current/title-40/chapter-I/subchapter-E/part-152/subpart-B/section-152.25
[10] https://www.epa.gov/pesticides/epa-adds-chitosan-list-active-ingredients-eligible-minimum-risk-pesticide-exemption

process that took four years. Biological control agents are exempt[11] from FIFRA regulation with the following exceptions: eucaryotic microorganisms, including protozoa, algae, and fungi; procaryotic microorganisms, including bacteria; and viruses. For these types of biological control agents, there may not be a clear path for a FIFRA Section 3 registration and there is no precedent for FIFRA 25(b) exemption. In that regulatory environment, these important conventional pesticide alternatives can remain out of reach for pesticide users, hindering IPM and resistance management. EPA should develop a more efficient process and provide guidance for FIFRA 25(b) exemption petitions for all types of pesticides, including biological control agents.

2. Create a classification committee in the Biopesticides and Pollution Prevention Division (BPPD) to guide uncertain cases through, and prior to, the new active ingredient submission process. Registrants intending to submit novel biopesticides to EPA for FIFRA registration can face uncertainty in whether their product will be classified as a biochemical or microbial pesticide, what data requirements will apply, and how to adequately fulfil those requirements. Those uncertainties can result in regulatory delays and barriers to entry in some cases. For example, fermentation products may have different materials that go into the fermentation media relative to the output that make it unclear how to classify the product and what needs to be tested. BPPD should create a committee to deal with these uncertain cases so that a consistent decision process is followed, and a point of contact exists outside of the risk management branches. This type of committee could serve a purpose internal to BPPD similar to the bio-classification committee that determines whether a submission would be handled by BPPD or the Registration Division.

Recommendation 4.3: EPA should expeditiously publicize the updated process for the FIFRA 25(b) minimum risk pesticide submission process.

Recommendation 4.4: EPA should create a classification committee in the Biopesticides and Pollution Prevention Division (BPPD) to help guide uncertain non-conventional pesticide cases through the registration process. This committee would operate prior to the new active ingredient submission process.

[11] https://www.ecfr.gov/current/title-40/chapter-I/subchapter-E/part-152

6. Bibliography

Boudwin R, R Magarey, and L Jess. 2022. Integrated pest management data for regulation, research, and education: Crop Profiles and Pest Management Strategic Plans. Journal of Integrated Pest Management 13. https://doi.org/10.1093/jipm/pmac011.

Carlson G. 2008, January 1. The use of economic benefit models in estimating the value of triazine herbicides. *In* The Triazine Herbicides – 50 Years Revolutionizing Agriculture. Lebaron H, J McFarland and O Burnside, Eds. San Diego: Elsevier. Pp. 153-162.

Carpenter J, L Gianessi, and L Lynch. 2000, February. The economic impact of the scheduled US phaseout of methyl bromide. Washington DC: National Center for Food and Agricultural Policy.

Cho C, Z Brown, K Gross, and D Tregeagle. 2024. Developing practical measures of the price of pesticide resistance: A flexible computational framework with global sensitivity analysis. Journal of the Agricultural and Applied Economics Association 3: 212-227.

Dentzman K. 2021, March-April. Community management of herbicide-resistant weeds in the Pacific Northwest. Crop & Soils 54: 8-13.

Fernandez-Cornejo J, S Jans, and M Smith. 1998, October. Issues in the economics of pesticide use in agriculture: a review of the empirical evidence. Applied Economic Perspectives and Policy 20:462-88.

FIPMCC. 2018, September 21. A National Road Map for Integrated Pest Management. Washington, DC: U.S. Department of Agriculture, Office of Pest Management Policy, Federal Integrated Pest Management Committee (FIPMCC). https://www.usda.gov/sites/default/files/documents/IPM-Road-Map-FINAL.pdf. Accessed April 2, 2024.

Frisvold G, M Bagavathiannan, and J Norsworthy. 2017, June. Positive and normative modeling for Palmer amaranth control and herbicide resistance management. Pest Management Science 73:1110-20.

Frisvold G and J Reeves. 2008, March 15. The costs and benefits of refuge requirements: the case of Bt cotton. Ecological Economics 65:87-97.

Gould F, Z Brown, and J Kuzma. 2018. Wicked evolution: can we address the sociobiological dilemma of pesticide resistance? Science 360: 728-732.

Hurley T, B Babcock, and R Hellmich. 2001. Bt Corn and Insect Resistance: An Economic Assessment of Refuges. Journal of Agricultural and Resource Economics 26: 176–194.

Jussaume R and D Ervin. 2016. Understanding weed resistance as a wicked problem to improve weed management decisions. Weed Science 64: 559-569.

Kogan M. 1998. Integrated pest management: historical perspectives and contemporary developments. Annual Review of Entomology 43: 243-270.

Lacoste M and S Powles. 2014. Upgrading the RIM model for improved support of integrated weed management extension efforts in cropping systems. Weed Technology 28: 703-720.

Laxminarayan R and R Simpson. 2002. Refuge Strategies for Managing Pest Resistance in Transgenic Agriculture. Environmental and Resource Economics 22: 521–536.

Lichtenberg E, D Parker, and D Zilberman. 1988, November. Marginal analysis of welfare costs of environmental policies: the case of pesticide regulation. American Journal of Agricultural Economics 70:867-74.

Lindsay K, M Popp, J Norsworthy, M Bagavathiannan, S Powles, and M Lacoste. 2017. PAM: decision support for long-term Palmer amaranth (Amaranthus palmeri) control. Weed Technology 31: 915-927.

Liu S and G Carlson. 1996. Ex Ante Estimation of Substitutes Resulting from a Pesticide Cancellation. Review of Agricultural Economics 18:537-46.

Liu S, G Carlson, and D Hoag. 1995, July. Trade-off analysis of herbicide withdrawals on agricultural production and groundwater quality. Journal of Agricultural and Applied Economics 27:283-300.

Livingston M, G Carlson, and P Fackler. 2004. Managing Resistance Evolution in Two Pests to Two Toxins with Refugia. American Journal of Agricultural Economics 86: 1–13.

Livingston M, J Fernandez-Cornejo, G Frisvold. 2016. Economic returns to herbicide resistance management in the short and long run: the role of neighbor effects. Weed Science 64: 595-608.

Miranowski J and K Lacy. 2016. When do resistance management practices pay for the farmer and society? The case of western corn rootworm. AgBioForum 19: 173-183

Mitchell P. 2014, November. Market-level assessment of the economic benefits of atrazine in the United States. Pest Management Science 70: 1684-96.

Monjardino M, D Pannell, and S Powles. 2003. Multispecies resistance and integrated management: a bioeconomic model for integrated management of rigid ryegrass (Lolium rigidum) and wild radish (Raphanus raphanistrum). Weed Science 51: 798-809.

NAPIAP. 1993. The Importance of Pesticides and Other Pest Management Practices in U.S. Cotton Production. Report No. 1-CA-93. Washington, DC: United States Department of Agriculture, National Agricultural Pesticide Impact Assessment Program (NAPIAP).

Norris R. 1999. Ecological Implications of Using Thresholds for Weed Management. *In* Expanding the Context of Weed Management. D Buhler, Ed. Philadelphia, PA: Haworth Press, Inc. Pp. 31-58.

Norsworthy J, S Ward, D Shaw, R Llewellyn, R Nichols, T Webster, K Bradley, G Frisvold, S Powles, N Burgos, W Witt, and M Barrett. 2012. Reducing the Risks of Herbicide Resistance: Best Management Practices and Recommendations. Weed Science 64: 31-62.

Olsen L, F Zalom, and P Adkisson. 2003. Integrated pest management in the USA. *In* Maredia, K, D Dakouo, and D Mota-Sanchez, Eds. Integrated Pest Management in the Global Arena. CABI International. https://www.cabidigitallibrary.org/doi/epdf/10.1079/9780851996523.0249.

Osteen C. Commodity and Chemical Assessments. 1992. *In* Proceedings of the National Pesticide Impact Assessment Workshop, February 26 and 27th, 1992. J Toth, Jr., Ed. Raleigh, NC. Pp. 659-60.

Qiao F, J Wilen, and S Rozelle. 2008. Dynamically optimal strategies for managing resistance to genetically modified crops. Journal of Economic Entomology 101: 915-926.

Rogers E. 2003. Diffusion of Innovations, 5th Ed. New York, NY: Free Press. 541 pp.

Sanyal D, P Bhowmik, R Anderson, and A Shrestha. 2008, February. Revisiting the perspective and progress of integrated weed management. Weed Science 56: 161-167.

Shaw D. The “wicked” nature of the herbicide resistance problem. Weed Science 64: 552-558.

Sun H, T Hurley, K Dentzman, D Ervin, W Everman, G Frisvold, J Gunsolus, R Jussaume, J Norsworthy, and M Owen. 2017. Economic and behavioral drivers of herbicide resistance management in the US. Economics Faculty Publications and Presentations 81. https://pdxscholar.library.pdx.edu/econ_fac/81.

Sunding D. 1996, November. Measuring the marginal cost of nonuniform environmental regulations. American journal of Agricultural Economics 78:1098-107.

Swanton C and S Weise. 1991, September. Integrated weed management: the rationale and the approach. Weed Technology 5: 657-663.

Taylor C, R Lacewell, and H Talpaz. 1979, July. Use of Extraneous Information with an Econometric Model to Evaluate Impacts of Pesticide Withdrawals. Western Journal of Agricultural Economics 1:1-7.

Thia J, J Maino, A Kelly, A Hoffman, and P Umina. 2023. Expanding risk predictions of pesticide resistance evolution in arthropod pests with a proxy for selection pressure. Journal of Pest Science 96: 1199-1212.

University of California. 2024. What is Integrated Pest Management (IPM)? Davis, CA: University of California, Statewide Integrated Pest Management Program. https://ipm.ucanr.edu/what-is-ipm/. Accessed March 27 2024.

USDA. 2020. History of the Federal Integrated Pest Management Coordinating Committee (FIPMCC). Washington, DC: United States Department of Agriculture (USDA), Office of Pest Management Policy (OPMP). https://www.usda.gov/sites/default/files/documents/20201110-FIPMCC-History.pdf. Accessed April 2, 2024.

USDA. 2023. USDA Strategy to Address Antimicrobial Resistance. United States Department of Agriculture (USDA), Office of the Chief Scientist (OCS). https://www.usda.gov/sites/default/files/documents/amr-2023-strategy.pdf. Accessed April 2, 2024.

US DHHS & CDC. 2024. The National Public Health Strategy to Prevent and Control Vector-Borne Diseases in People. Washington, DC. United States Department of Health and Human Services and the Centers for Disease Control and Prevention. https://www.cdc.gov/ncezid/dvbd/pdf/VBD-National-Strategy-508.pdf. Accessed April 2, 2024.

USEPA. 2016. Guidelines for Preparing Economic Analyses. Washington, DC: United States Environmental Protection Agency, Office of Policy, National Center for Environmental Economics. https://www.epa.gov/environmental-economics/guidelines-preparing-economic-analyses-2016. Accessed May 5, 2026.

USEPA. 2023. Pesticides: Concepts for a Framework to Assess the Risk to the Effectiveness of Human and Animal Drugs Posed by Certain Antibacterial or Antifungal Pesticides. Washington, DC: U.S. Environmental Protection Agency (USEPA). https://www.regulations.gov/document/EPA-HQ-OPP-2023-0445-0013. Accessed April 2, 2024.

Weersink A, R Llewellyn, and D Pannell. 2005. Economics of pre-emptive management to avoid weed resistance to glyphosate in Australia. Crop Protection 24: 659-665.

Acknowledgements

This workgroup would like to acknowledge the engagement by and efforts of the following members over the past two years:

Elyssa Arnold, USDA Office of Pest Management Policy [§]
Amy Asmus, Asmus Farm Supply, Inc.
Derek Berwald, US EPA OPP Biological and Economic Analysis Division [§]
Aradhya Chandrashekar, Bayer Crop Sciences & HRAC
Ian Clark, Clark Farms
Larry Dallas, Illinois Farm Bureau
Katie Dentzman, Iowa State University
Cameron Douglass, USDA Office of Pest Management Policy *
Steve Eskelsen, Adama
George Frisvold, University of Arizona [§]
Dawn Gouge, University of Arizona
Rebecca Haynie, CropLife America
Will 'Skee' Jones, Environmental Protection Network
Elizabeth 'Libby' Karn, US EPA OPP Biological and Economic Analysis Division [§]
Marc Lame, Indiana University
Nikhil Mallampalli, US EPA OPP Biological and Economic Analysis Division *
Janet McAllister, US Centers for Disease Control and Prevention
Patricia Prasifka, Corteva
Caydee Savinelli, Syngenta
Jill Schroeder, New Mexico State University & WSSA
David Shaw, Mississippi State University
Layne Wade, GrowWest

* Workgoup chairs
[§] Recommendation discussion group leads

Appendix I. EPA/OPP/BPPD Responses to PPDC Resistance Management Workgroup 2.0's IPM Sub-group Questions

1. What are the current IPM, volunteer/non-regulatory (e.g., IPM Center and/or PESP), activities in a BPPD which could augment Agency efforts to implement pesticide resistance management?

   BPPD has limited capacity to augment Agency efforts to implement pesticide resistance management through non-regulatory efforts for non-Bt plant-incorporated protectant (PIP) pesticides. The division would consider any collaborative opportunities around resistance management that would fit within current resources and leverage existing outreach and education expertise.

   Existing efforts include:
   - *The Center for IPM, which has four staff who have some capacity to support resistance management outreach efforts; this group also hosts the IPM webinar series, which has been very successful;*
   - *The Pesticide Environmental Stewardship Program (PESP), though resource limitations have substantially scaled back activities of this group, especially related to resistance management activities. In 2022 PESP allocated $780,000 in grants to six different projects, namely:*
     - *University of Tennessee: Creating a National Framework for Delivering and Assessing Pollinator Protection Trainings*
     - *Oregon State University: Delivering Herbicide Resistance Training Through Web-Based and In-Person Workshops to Pacific Northwest Agricultural Professionals*
     - *University of Florida: Integrating Pest and Pollinator Management Strategies for Ornamental Plant Production*
     - *University of Vermont: A Smart, Sensible and Sustainable Approach to Neonicotinoid Seed Treatments*
     - *Purdue University: Implementing Arthropod IPM on Watermelon Farms for Pollinator Protection*
     - *West Virginia University: Improving Knowledge about Integrated Pest Management and Pesticide Safety*

2. Is there a current strategic plan that can demonstrate success that specifically addresses the national implementation of volunteer/non-regulatory IPM (e.g., IPM Center and/or PESP)?

   There is no current BPPD strategic plan addressing national implementation of non-regulatory IPM; past strategic plans on IPM focused primarily on schools. However, there were relevant activities reflected in recent BPPD workplans, including in FY24: oversight of PESP grants; IPM webinar series; cross-office and regional outreach support; ombudsman *services for BPPD; and, contract oversight/COR services for BPPD. Past non-regulatory efforts included the Strategic Agricultural Initiative, IPM in Schools program, and IPM for structures, agriculture, and vector management. Each of these attained some level of success while identifying the need for ongoing federal investments to implement and sustain non-regulatory IPM.*

3. Who coordinates that plan or activities with the Regions and/or other Offices (e.g. OAR) regarding the consistent implementation of IPM?

   BPPD's Environmental Stewardship Branch has historically maintained engagement with OAR and EPA's Office of Children's Health Protection (OCHP), but this coordination is limited. OAR and OHCP have sought to include IPM in their outreach activities. BPPD is exploring new opportunities, especially around extramural programs. There is ongoing regional coordination with regular engagement between EPA Region staff and IPM center staff, and past National Program Managers (NPM) guidance to the Regions supported IPM-centric programs.

4. How does the Pollution Prevention Act apply to IPM in relation to BPPD?

   EPA's broad mandate to "… support the adoption of IPM …" comes from FQPA (U.S. Code Title 5, Section 135r-1), and EPA's Office of Pollution Prevention and Toxics (OPPT) has specific agency responsibility for managing EPA's Pollution Prevention Act funds (PPA). Historically PPA programs and funding have been used by OPPT to evaluate risks associated with new and existing chemicals and explore ways to prevent and reduce pollution. To date there has been no crossover specifically of PPA programs run out of OPPT, and IPM programs, which historically are run out of OPP/BPPD.

Appendix II. Additional Details on a Pesticide Resistance Cost/Benefit Analysis Framework

What to measure?

The benefits of resistance management are the avoided costs of resistance. What then are the costs of resistance? Usually, growers must shift to control tactics that (a) are less effective at optimizing yields, (b) less effective at maintaining crop quality, (c) more costly to use, or (d) combinations of all three. Costs of resistance in the first year of field failures can be substantial, as growers make expenditures on tactics that prove ineffective, are "caught by surprise," and must incur additional, unplanned expenses to protect their crops. Additional social costs can occur if producers shift to substitute compounds with greater *environmental or human health risks*. Resistance to one MOA can reduce the diversity of effective tactics and lead to heavier reliance on other MOAs and, in turn, hasten resistance to *those* MOAs. If these avoided costs are the benefits of resistance management, what are the costs of resistance management? These are often quite similar in nature to the costs of resistance. Growers must shift to tactics that are less effective, more costly, or both to maintain the efficacy of existing MOAs.

How can one translate these effects into economic values for benefit-cost analysis? A direct consideration is the effects on farm income (producer surplus). Growers may have lower sales revenues from lower yields or receive lower prices if crop quality is reduced. Further, their production costs may increase. Next, there are effects on consumers (consumer surplus). Consumers face losses because less of the agricultural commodity is available (some consumers must do without). Then, what *is* available in the market may now have a higher price. Consumers may also lose from lower product quality. There are standard and established economic methods for estimating how changes in pesticide availability or effectiveness affect producer and consumer surplus.

How might one evaluate effects on environmental or human health risks? One could compare risks under three scenarios:

1. Risks before resistance occurs – these would be the risks associated with the use of the current pesticide (at risk for resistance),
2. Risks once resistance occurs – resistance to one pesticide may increase reliance on other pesticides, which will have their own, different risk profiles,
3. Risks if resistance management is implemented and resistance is avoided – this could include risks associated with other pesticides in an effort to diversify pesticide-based control; it could also include risk changes if non-chemical methods are part of the resistance management strategy.

Estimates of different risk factors for different compounds would be available from pre-existing risk analyses conducted for product registration (and any subsequent risk analyses). One *could* attempt to estimate economic values for these risks. This would involve exercises to monetize health risks or non-market valuation techniques to estimate economic values of changes in environmental quality. Again, there are commonly used economic approaches to assigning economic values to health risks and changes in environmental quality. Compared to estimating changes in consumer and producer surplus, there is less consensus among economists about the appropriateness of some of these approaches. Alternatively, one could present direct estimates of risk trade-offs to decision makers without assigning dollar values to these. The economic impact estimates for producers and consumers could be combined with risk information to estimate the cost-effectiveness of risk-reducing options (Osteen 1992). For example, without assigning a dollar value to a particular risk, one could estimate that "risk X could be reduced by Y percent at a cost of Z dollars."

In principle, one could compare the path of producer surplus, consumer surplus, and environmental and health risks over a multi-year time horizon with and without resistance management practices in place. The net benefits of adopting resistance management practices hinge on two questions of timing. When would resistance develop absent the proposed resistance management strategies? How long might the resistance management strategies be expected to delay the onset of resistance?

Steps to measuring the costs of resistance

The costs of resistance are similar to the costs of pesticide cancellations. As such, resistance costs can be estimated in ways similar to estimating cancellation costs. There are long-established methods that economists use to estimate costs of cancellations. If a compound is cancelled, producers must shift to different compounds or to non-chemical control methods.

These alternatives may

a. be more costly,
b. provide less yield protection (affecting production),
c. provide less quality protection (affecting price),
d. have potentially greater environmental or human health risks, or
e. combinations of these four problems.

The first step in quantifying cancellation (and therefore resistance) costs is to identify substitute control methods and quantify their production performance. This can be done via expert opinion surveys or interviews of growers, crop advisors, pesticide dealers, applicators, extension advisers, commodity group representatives, produce packers and distributors, and university researchers (Sunding 1996). This information can be supplemented with data on historical market shares of products with similar applications. Simulated impacts may be based on assessments of the single, best substitute, analytical models, or field trial and demonstration farm data. For substitute compounds, environmental and human health risk profiles are usually available from pre-existing risk assessments of these compounds.

A next step is to use changes in production attributes of substitute control measures as inputs into partial budgeting models or regional or national commodity supply and demand models

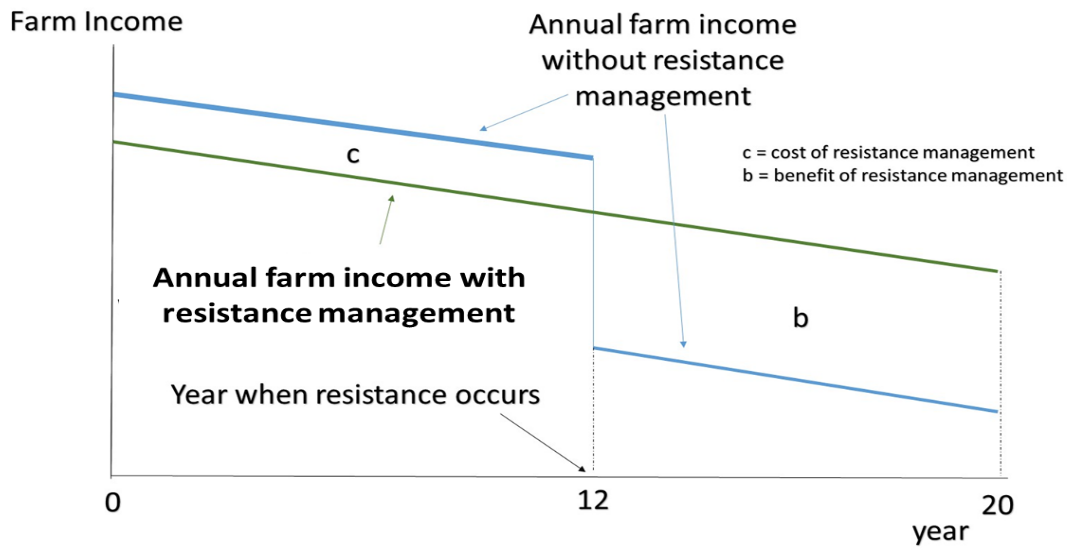
(Carlson 2008; Carpenter et al. 2000; Fernandez-Cornejo 1998; Liu and Carlson 1996; Liu et al. 1995; Mitchell et al. 2014; NAPIAP 1993; Taylor et al. 1979). Partial budgeting models can capture changes in yields and per acre costs, keeping price fixed, and may be appropriate for effects confined to regions that do not account for a large share of national production. For larger-scale impacts that could affect national prices, market supply and demand models are more appropriate. Yield and per acre cost changes can enter into these as supply curve shifts. Changes in quality would be modeled as demand curve shifts. Shifts in supply and demand curves translate into changes into production, prices, and separate dollar-valued impacts on consumers and producers. Past research suggests the costs of cancellations can vary significantly across different crops and regions (Lichtenberg et al. 1988; Sunding 1996). Such variation is also likely to occur in the case of resistance.

Steps involved in quantifying resistance *management* costs are similar to quantifying costs of resistance. Resistance management usually involves adopting alternative chemical or non-chemical treatments. These are often similar to alternatives that growers would resort to after resistance occurs. Again, estimates of effects of the alternatives on yields, product quality, and per acre costs would need to be estimated. These changes could then be inputs into partial budgeting or regional or national commodity supply and demand models. Environmental and human health risk profiles could be obtained from pre-existing risk assessments.

It is possible, in principle, to conduct a benefit-cost analysis of resistance management policies. Usually, resistance practices lead to lower short-run returns, but by delaying resistance, can provide larger returns over a longer time horizon. In a supply-demand framework, resistance management may generate small, negative short-run supply shocks in order to avoid larger, negative long-run supply shocks. One could conduct standard multi-year benefit cost analysis and estimate the net present value and benefit-cost ratios for resistance management following EPA principles and guidelines (USEPA 2016). There is a long history of estimating the impacts of pesticide cancellations. The National Agricultural Pesticide Impact Assessment Program (NAPIAP) (disbanded in 1998) involved collaboration between the USDA and land-grant universities to estimate costs of pesticide cancellations to aid EPA regulatory decision making. Many of the methods used to evaluate pesticide cancellations could be readily applied to measure effects of resistance.

An additional complication for assessing the benefits and costs of resistance management are intertemporal differences in benefits and costs. Resistance management often entails short-run costs, but longer-term benefits. There are standard methods outlined in the EPA principles and guidelines for discounting future costs and benefits (USEPA 2016). **Figure 1** illustrates costs and benefits of resistance management over time. To simplify matters we assume resistance to this pesticide affects an area small enough so that there are no national market price effects. We then ignore price effects on consumers and only consider effects on farm income. We consider a 20-year time horizon. The path of discounted farm income without resistance management is shown by the broken blue line. Without resistance management, we assume that resistance would occur after 12 years. The blue income line falls after year 12 because resistance lowers farm income. Annual farm income with resistance management practices in place is shown by the green line. Under each strategy, future farm income is discounted. The process of discounting literally places less weight on benefits and costs that occur farther in the future relative to the near term.

Figure 1. Benefits and costs of resistance management over time.



Before resistance, income under resistance management is lower (perhaps because farmers are using more diverse tactics that are less profitable in the short run). The green line lies below the blue line. In year 12, after resistance occurs, income is higher under resistance management (green line now above the blue one) because resistance has been avoided. In this example, annual returns are lower under resistance management before year 12, but greater after year 12. The cost of resistance management is shown by area c. This is short-run income foregone by managing resistance. The benefit of resistance management is shown by the area b. The net benefit of resistance management is b – c.

In this example, it is assumed that resistance management prevents resistance from occurring for at least eight years longer than if were not implemented. From Figure 1, one can see that the size of b (benefits) relative to c (costs) will increase if the year of resistance occurs earlier and that they will decrease if resistance occurs later than year 12. The long-term, net benefits of adopting resistance management practices thus hinge on (a) when resistance would occur if the resistance management were *not* adopted, and (b) by how many years do the resistance management practices delay the onset of resistance? Different approaches have been used to address questions (a) and (b). One is to use bioeconomic modeling that integrates economic decision-making with the path of resistance over time (Cho et al. 2024; Hurley et al. 2001; Laxminarayan and Simpson 2002; Livingston et al. 2004; Livingston et al. 2016; Monjardino et al. 2003; Qiao et al. 2008). Another is to make assumptions about the year of resistance onset with and without resistance management, and then to estimate net benefits based on different assumed values. The date of resistance onset may be based on external biological models (Weersink et al. 2005; Miranowski and Lacy 2016) or ad hoc assumptions (Frisvold and Reeves 2008; Frisvold et al. 2017). This first approach has a stronger scientific grounding but requires a significant amount of data and modeling capacity. Findings may not be generalizable to other production settings. Applying this approach over a large number of settings would have significant time and resource costs.

The second approach – simply assuming different dates of resistance onset -- is much simpler to implement. Benefit and cost estimates can be derived simply in Excel, for example. This approach lends itself to conducting sensitivity analysis – examining how changes in a host of assumptions about the timing of resistance onset, costs of alternative pest control strategies, consequences of resistance on yields, costs, prices, the rate of discount, and other factors affect the long-run net benefits of resistance management. Yet, results based on ad hoc assumptions about resistance timing would be harder to defend and so, may be less useful to decision-makers.

One approach might be to combine approaches. Start with analysis based on simple, ad hoc assumptions about the timing of resistance. Then conduct sensitivity analysis to see how much timing assumptions affect the benefit-cost ratio of resistance management policies. If the net benefits of resistance are large and are relatively insensitive to assumptions about resistance timing, then the simple approach may suffice. If, however, net benefits of resistance management are highly sensitive to small changes to the timing of resistance, this would represent a case were more rigorous bio-economic modeling is warranted. A number of economic studies have estimated net benefits of resistance management strategies. Many have focused on the costs and benefits of refuge policies for Bt crops (Hurley et al. 2001; Laxminarayan and Simpson 2002; Livingston et al. 2004; Frisvold and Reeves 2008; Qiao et al. 2008), while others have examined herbicide resistance in weeds (Monjardino et al. 2003; Weersink et al. 2005; Miranowski and Lacy 2016; Livingston et al. 2016; Frisvold et al. 2017).