AgInfomatics

The value of pyrethroids in U.S. agricultural and urban settings:

Executive summary

2017

This report series, researched and produced by AgInfomatics, LLC, is an independent and comprehensive analysis of the economic and societal benefits of pyrethroid insecticides (bifenthrin, cyfluthrins, cyhalothrins, cypermethrins, deltamethrin, esfenvalerate, fenpropathrin, permethrin, and tefluthrin). The research was sponsored by the Pyrethroid Working Group, an informal association of firms marketing products based on the above pyrethroid active ingredients. These products are used in agricultural, structural and landscape applications.

AgInfomatics, an agricultural consulting firm established in 1995, conducted an analyses exploring the answer to the question: *What would happen if pyrethroids were no longer available or restricted beyond the current situation?* Comparing this hypothetical future to the economics associated with current applications allowed AgInfomatics to derive an estimate of the value of pyrethroids.

This estimated value was based on robust quantitative and qualitative study methods including econometrics, modeling of insecticide use, crop yield data, market impacts, surveys of growers, surveys of professional applicators and in-depth case studies. All these data sources and methods were used to triangulate on the above question.

The value of pyrethroids in North American agriculture and urban settings

Reports include:

1. Executive summary
2. Methods and assumptions for estimating the impact of pyrethroid insecticides on pest management practices and costs for U.S. crop farmers
3. Summary of the use of pyrethroid insecticides by U.S. crop farmers and the impacts of non-pyrethroid scenario on insecticide use and farmer costs
4. Estimated yield benefits and efficacy of pyrethroid insecticides for major U.S. crops based on a meta-analysis of small plot data
5. Use and value of insect management practices in U.S. alfalfa corn, cotton and soybean production
6. Value of pyrethroid insecticides to urban pest management professionals
7. An economic assessment of the benefits of pyrethroid insecticides in the U.S.
8. Case studies of pyrethroid use patterns and potential impacts of regulatory changes on production of high value fruits and vegetables in primary U.S. production states
9. A case study of pyrethroid use patterns and potential impacts of regulatory changes on the control of mosquito vectors in Florida

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1.0 Introduction

This document provide an executive summary to a research project on the value of pyrethroid insecticides in both on agricultural and urban settings in the United States. The project generated eight other reports totaling more than five hundred pages, and so this executive summary also serves as a guide to the findings and content of these other reports. The overall project research strategy was to use a triangulation approach that involved examining the question of the value of pyrethroids using multiple methods and approaches at different scales and based on different types of data in order to develop a more robust assessment. This report attempts to summarize the main findings in only a few pages. The evidence, the data and analytical results, and the methodological details supporting the summary statements can be found in the individual reports.

Overall, these reports demonstrate the tremendous value of pyrethroid insecticides to U.S. society in both agricultural and non-agricultural settings. The culmination of several reports projects that the use of pyrethroids in crop production generates an annual economic benefit of $1.6 billion for U.S. society. Consumers capture most of this benefit as lower prices for foods such as meat, dairy and eggs, as well as fruits and vegetables such as tomato, potato, citrus and sweet corn. The primary source of these benefits arise from protecting yields, with about half of this $1.6 billion benefit generated by yield gains in commodity crops, such as corn and soybean and the other half in specialty crops, such as tomato, potato, citrus and sweet corn. Though not explicitly quantified in this project, the contributions of pyrethroids to resistance management are another important source of value emphasized by farmers in telephone surveys and case studies. Pyrethroids are a low cost and effective, broad-spectrum class of insecticides to use in rotation with other more costly and selective insecticides to not only protect crop yields but also to manage insect resistance.

Pyrethroids are also a critical element in protecting human health from harmful pests. The control of mosquitoes, fleas and ticks would become much more difficult, even as disease transmission by these pests increases. Even before the Zika virus, over 50,000 cases of human disease were reported annually in the U.S. from these pests. Another major use of pyrethroids is controlling damaging pests found in lawns, gardens, and the larger urban landscape. For example, homeowners spent over $4.5 billion last year in an attempt to control pests that have been introduced to the U.S. A large percentage of professionals in these industries used pyrethroids to manage cockroaches, ants, mosquitoes, bed bugs and flies in homes, schools, hospitals, restaurants and other businesses. Without pyrethroids, cost increases and decreases in customer satisfaction are a major concern because pyrethroids are a low cost and effective class of insecticides. These professionals also emphasized their usefulness for managing resistance since relying on fewer modes of action would accelerate the development of insect resistance.

The remainder of this report provides more context for the project as a whole and a more in depth-review of each report and its respective main findings. First, the reasons driving the project are summarized, and the project team and the overall project research strategy is described. Next, a single para-

graph overview of each report is provided to give a broad overview of the project as a whole. Finally, each report is summarized over multiple pages, with a final concluding section to summarize the pyrethroid project's take home message. A key point to note is that this report focuses primarily on the main findings and only provides a brief overview of the methods and data used for each report. The data and analytical results and the methodological details supporting these summary statements are provided in the individual reports.

2.0 Why the reports?

AgInfomatics LLC was responsible for providing a comprehensive analysis of the socio-economic benefits of pyrethroid insecticides used in agriculture and urban settings in the U.S. to contribute to the broader policy debate regarding this class of insecticides. The overall research strategy was built on two foundational concepts: use of methodological triangulation and a counterfactual scenario. These approaches were selected because use of pyrethroid insecticides in the U.S. is diverse, complex and dynamic. Establishing the value of these compounds requires multiple methods operating at different scales, all focused on the core value question. Value will become apparent under a counterfactual scenario when assuming pyrethroids are no longer available, and all the repercussions of the adaptations and impacts to this hypothetical situation emerge. Capturing these diverse side effects and impacts requires using multiple methods for a more robust assessment of the value of pyrethroids in their many uses.

The function of these reports is to inform discussions regarding policy that may influence the use of the following pyrethroid active ingredients: bifenthrin, cyfluthrins, cyhalothrins, cypermethrins, deltamethrin, esfenvalerate, fenpropathrin, permethrin and tefluthrin. Public policy is a guide to a future action designed to achieve specified objectives. If a future action is going to restrict access to pyrethroids, then these reports will provide some of the likely socio-economic outcomes of that action. Much of the media coverage of pyrethroids has focused on costs (perceived or real). What has been lacking is a robust assessment of the ***value*** of pyrethroids in their current uses. It is possible that this void exists because of the challenges presented in characterizing this widely used group of chemicals with diverse use patterns. The purpose of this series of AgInfomatics reports is to provide an estimate of the benefits of pyrethroids in the U.S.

AgInfomatics is an independent agricultural research firm located in Madison, Wisconsin. The principals of AgInfomatics are Dr. Peter Nowak, who specializes in measuring the adoption of agricultural technologies, and Dr. Paul Mitchell, an agricultural economist who is acknowledged as the foremost authority on the economics of pesticides in modern agriculture. As the project was implemented, additional experts were brought into the project as sub-contractors. The AgInfomatics team on the benefits of pyrethroids project included:

- Dr. Terry Hurley, Professor of Applied Economics at the University of Minnesota-St Paul, specializes in the valuation of non-market goods and services.

- Dr. Jeff Wyman, Professor Emeritus of Entomology at the University of Wisconsin-Madison is a vegetable entomologist who provided leadership and conducted the case studies within agricultural and human health systems for the project.

- Dr. Deana Knuteson, academic researcher, department of Horticulture at the University of Wisconsin-Madison, works with farmers and agricultural groups on pest management and sustainable practices. She was responsible for compiling and interpreting small-plot and insecticide use data.

- Dr. C. Robert Taylor, Professor Emeritus of Agricultural Economics at Auburn University, is the developer of AGSIM, the economic impact simulation model of the U.S. agricultural economy used to calculate the market-level benefits of pyrethroids for this project.

3.0 Research strategy

A counterfactual logic guided the overall analysis on assessing value of pyrethroids. In layman's language, the basic approach involves developing a non-pyrethroid scenario of what agriculture and urban applications would be like without these pyrethroids and then examining differences between the counterfactual scenario and the current system. Bryne (2016) discusses the counterfactual imagination as being based on *what if ?* questions, such as *What if we could no longer use pyrethroids?* As noted by Markman and McMullen (2003):

> *For counterfactuals to help prepare for the future, they require not only a simulation of a possible alternative as if it were true but also an evaluative comparison of the alternative to the current reality to work out the difference between the two.*

In this case, the difference between current uses of pyrethroids and a hypothetical future without pyrethroids represents the costs and benefits of this class of insecticides. In addition to extensive GfK Kynetec data, growers and professional pest applicators were asked to hypothetically remove pyrethroids from their current pesticide management strategies. Data on the actual insecticides used in crop production, plus asking growers and professionals to assume they no longer had access to pyrethroids, allowed AgInfomatics to identify likely substitutions, adjustments, gains and losses in the metrics of commercial agriculture (e.g., yield) and other impacts related to human safety and the environment (Ferraro, 2009).

This type of counterfactual analysis is common in economic and political arenas where it is necessary to assess the likely impacts of proposed policies and regulations (Mitchell, 2014; Moschini et al., 2000; Falck-Zepeda et al., 2000; Price et al., 2003; Courtois, 2010). Cowan and Foray (2002) note that counterfactual conditional statements are ubiquitous in any scientific endeavor, and they discuss the strengths and pitfalls of this approach.

Counterfactual methods have recently been used to evaluate multilateral trade policy (Anderson et al., 2016) and the probable health impacts of food safety interventions (Wang, 2016). The counterfactual analysis for this project addresses the question, *What if pyrethroids were no longer available in the U.S.?*

More than counterfactual logic is needed to elucidate the value of pyrethroids; it also requires a sophisticated methodology. AgInfomatics selected a multi-method strategy of data triangulation to provide the most robust answer to the counterfactual question (Denzin and Lincoln, 2000; Campbell and Fiske, 1959). Data triangulation means using multiple methods to 'triangulate' on the same phenomenon or question. Denzin (1978) referred to four types of triangulation, all of which were employed in this study:

1. **Data triangulation** means using different sources of data, such as from small-plot experiments, grower surveys and case studies, to focus on the pyrethroid value question.

2. **Investigator triangulation** means using investigators from different disciplines (e.g., entomology and economics) to collaborate in data collection, analyses and reporting.

3. **Theory triangulation** means interpreting the data from different perspectives or theories, such as addressing both farm production economics and the environmental benefits of avoiding pest resistance.

4. **Methodological triangulation** means using more than one method to gather data addressing a common issue (e.g., qualitative case studies and quantitative economic modeling to understand why a particular insecticide is used). Another form is to use insights from qualitative techniques to develop appropriate quantitative strategies.

For the analysis of pyrethroids, qualitative techniques were used to define the scope of the challenges associated with managing the pests that can impact human health. Recording the experiences and applied knowledge of those taking on these challenges provides in-depth perspectives that are not possible with just statistical analyses or data summaries. The same could be said of the urban pest management professionals who must balance the process of managing pests, maintaining customer satisfaction and navigating business realities. According to Denzin (2012):

The combination of multiple methodological practices, empirical materials, perspectives and observers in a single study is best understood as a strategy that adds rigor, breadth, complexity, richness and depth to any inquiry.

Reaffirming Denzin's observation, there are two key advantages to data triangulation. First, measuring the same phenomena using different methods enhances the **validity** of the results by eliminating bias and potential alternative explanations of the research question. As Weick (1969) states:

We typically need multiple methods or techniques which are imperfect in different ways. When multiple methods are applied, the imperfections in each method tend to cancel one another.

Second, methodological triangulation also provides an opportunity to explore unanticipated findings when there is some divergence in the results of different methods. Triangulating methods does not mean all the methods generate consistent results, but differences or nuanced discrepancies may lead to further understanding of the phenomena being investigated. Working to understand why different methods may generate different outcomes increases the **credibility** of the analysis.

Overall, close to 60,000 records from GfK Kynetec on agricultural pest management collected in 2012, 2013 and 2014 went into the analysis. These data were complimented by telephone surveys of almost 1,500 growers of key agricultural crops regarding their pest management strategies. A professional marketing firm with extensive national and international experience in agriculture conducted this survey. Fifteen in-person interviews with growers and consultants of essential specialty fruit and vegetable crops were also conducted to gain an in-depth understanding of the motivations behind the pest management strategies of farmers. Next, data from nearly 3,000 small plot research studies were analyzed to provide hard data on the efficacy of different insecticides. Another web-based survey was conducted with almost 300 pest management professionals who work with urban residential, business and food establishments to learn how these professionals deal with pest management for these diverse clients. The importance of pest management was amplified from fifteen in-depth, face-to-face interviews with the professionals in Florida responsible for protecting human health from mosquitoes and other pests that may serve as vectors of diseases to humans. Finally, a review of the scientific literature was conducted to augment and corroborate the conclusions developed from the above sources. All of these sources of information were 'triangulated' onto the question regarding the value of pyrethroids.

4.0 The methods

A data-driven approach was employed to specify current crop production systems and hypothetical non-pyrethroid alternatives. These data were derived from GfK Kynetec, peer-reviewed literature, extension publications, and efficacy and yield trials by public institutions. AgInfomatics staff then refined these alternatives based on an array of sources, including the knowledge of those involved in day-to-day insecticide use decisions — crop advisors, scientists and extension professionals working at leading land grant universities, purveyors of plant protection products and services, growers, and agency staff charged with human health protection. The economic analysis focused on determining the monetary benefits derived from yield gains and cost benefits of pyrethroids. The survey of growers also examined non-monetary benefits derived from insecticide use, such as human safety, convenience, resistance management and consistency of control.

In these reports, data triangulation involved the following methods and techniques:

- **Partial budget analysis:** A partial budget analysis is a simple tool used to estimate the financial gains or losses due to a change in a farm system. In this case, AgInfomatics examined a hypothetical change in the pest management system. Partial budgeting can only examine two alternatives, which in this case was pest management with and without pyrethroids.

- **Partial equilibrium analysis:** As the name implies, partial equilibrium analysis bring supply and demand into balance for one specific market. It does not consider interactions with other markets for substitute or complementary goods but rather holds these constant for the analysis. It is a common tool used in the market outlooks and policy impact studies.

- **Multi-market equilibrium model:** These complex and sophisticated models account for a wider range of changes and interactions in the economy when a new policy or technology is introduced. The yield and cost impacts due to a change in pesticide regulations can change the equilibrium market price and quantity for the targeted crop. In addition, other crops not directly affected by the policy can be impacted because the relative profitably changes for crops that compete for the same acreage. Multi-market equilibrium models capture the interactions between crop markets and estimate the impacts of changes in one crop market on equilibrium prices and quantities in other markets. This project uses AGSIM (Taylor, 1993), a model based on econometrically-estimated dynamic supply and demand equations for major field crops. AGSIM has been used by academic and government analysts to examine a wide variety of agricultural policies, including those related to pesticides (Mitchell, 2014; Ribaudo and Hurley, 1997; Taylor et al., 1991; U.S. EPA, 1997, 2002).

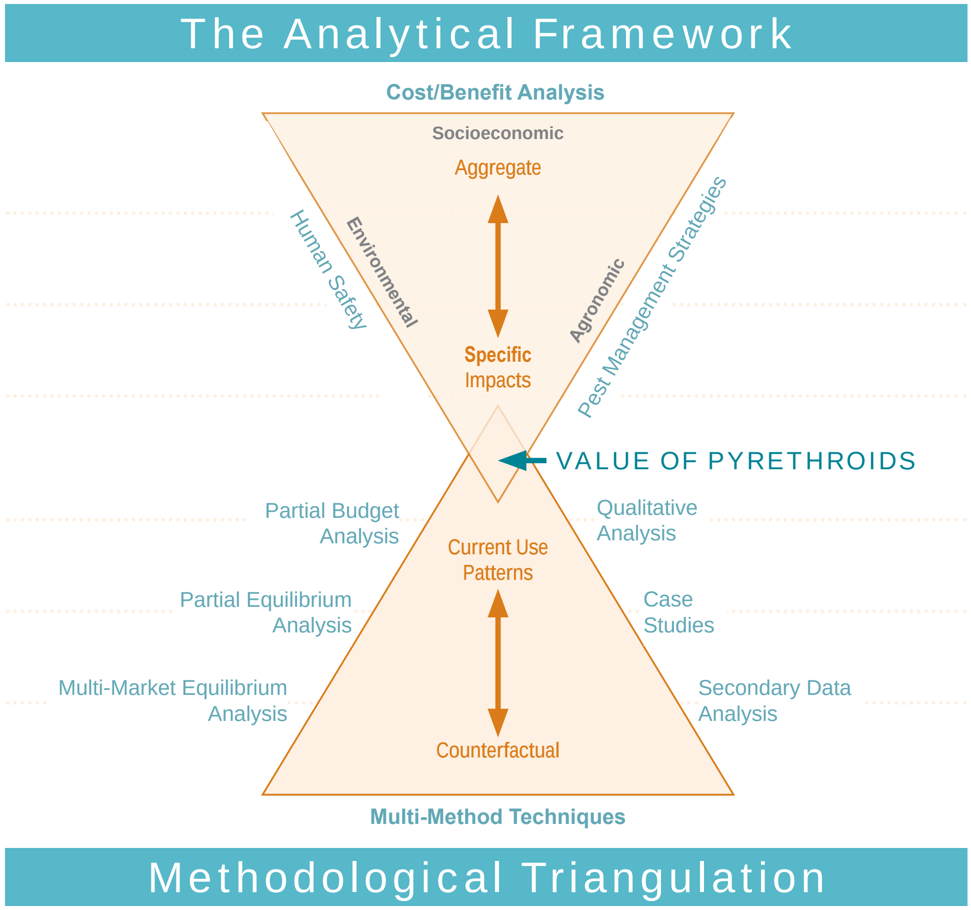
- **Case studies:** A case study is an empirical, in-depth, descriptive analysis and investigation of a specific situation. The advantage is the richness and elaboration in gaining an understanding of the specific phenomena being studied in a real-life context, while the disadvantage is the time and costs it takes to produce this outcome. Case studies give an in-depth understanding of a particular situation but do not generalize results beyond that situation. The method is often used in the evaluation of a new policy or regulation (Buzby et al., 1995; Johnson et al., 2012).

- **Survey research:** There are many types and degrees of sophistication in survey research. Commonalities include the selection of individuals from a larger population using a specific and often a probability-based method, a set of standardized questions, statistical analysis and some level of generalization to the larger population. This study surveyed growers of select crops and members of two professional pest management associations to estimate the value of pest management and pyrethroids and to better understand the non-monetary benefits of pyrethroids.

- **Secondary data analysis:** Secondary data analysis, sometimes called meta-analysis, takes advantage of the wealth of information that already exists. In this case, prior research included small plot studies of product efficacy by land grant universities and published in journals, *Arthropod Management Tests,* university reports and extension bulletins.

Figure 1 graphically illustrates the relation between the research design and the methods employed in establishing the value of pyrethroids in agricultural and urban settings.

FIGURE 1. The analytical framework used in the studies



5.0 Overview of the reports

A total of nine reports were produced, including this executive summary. Each report provides sufficient detail allowing it to stand alone, although a comprehensive understanding of the value of pyrethroids in the U.S. will be based on reading all the reports. These nine reports are first listed and briefly summarized, followed by a longer summation of their key features and findings in the next section. The reports resulted from an in-depth investigation over a 16-month period by AgInfomatics. Research methodology, analytics and documentation are designed to meet or exceed the standards of peer-reviewed publications.

1. The value of pyrethroids in U.S. agricultural and urban settings: Executive summary

The first report (this document) summarizes the other eight reports examining the value of pyrethroids. The importance of both counterfactual logic and methodological triangulation is discussed within the context of scientific analysis and examining the impact of new policies and then the

highlights of the remaining reports are presented in this summary of the overall study.

2. Methods and assumptions for estimating the impact of pyrethroid insecticides on pest management practices and costs for U.S. crop farmers

The first report is an extensive documentation of the methods used to develop the impact of the non-pyrethroid scenario on insecticide use on the following 14 major crops: alfalfa, citrus, corn, cotton, potato, rice, sorghum, soybean, spring wheat, sugar beet, sunflower, sweet corn, tomato and winter wheat. The process is based primarily on the GfK Kynetec pesticide use data (widely recognized as among the best survey-based data on agricultural chemical use, having been collected annually for almost 50 years). The report uses cotton as the example crop to illustrate and describe the process and then provides the same results for the other 13 crops in an extensive appendix.

The report first summarizes insecticide use for each crop based on the 2012-2014 three-year average of treated acres for foliar-applied and soil-applied insecticides, and the primary targeted pests for pyrethroids. For the non-pyrethroid scenario, the process then reallocates these pyrethroid treated acres to non-pyrethroid alternatives based on market shares by target pest, with adjustments for differences in average application rates and the number of applications for each alternative active ingredient. The final output for each crop is the total change in insecticide treated acres by active ingredient, pounds of each active ingredient applied and farmer pest management costs for the non-pyrethroid scenario.

3. Summary of the use of pyrethroid insecticides by U.S. crop farmers and the impacts of the non-pyrethroid scenario on insecticide use and farmer costs

Because the second report is quite lengthy and technical, this report is an extensive executive summary of the main findings of the second report, combined with some interpretations of the implied benefits of pyrethroids and cross-crop comparisons. The emphasis of this report is on illustrating the key role that pyrethroids fulfill in pest management for these 14 crops based on the current insecticide use data and changes in insecticide use and farmer costs if pyrethroids were not available.

4. Estimated yield benefits and efficacy of pyrethroid insecticides for major U.S. crops based on a meta-analysis of small plot data

A meta-analysis is a statistical tool to systematically integrate results across multiple studies to focus on a single research question. By increasing the number of cases and the conditions surrounding the analysis, one increases the statistical power of the resulting analyses. All studies included in the meta-analysis are screened to meet explicit inclusion criteria associated with the methodology and the substantive issue. In this case, the meta-analysis assembled yield and insecticide efficacy data from small plot experiments representing 4,453 observations. Experiments were included only if they had pyrethroid treatments and collected at least one measure of yield or efficacy relative to an untreated control. In total, data were assembled for 335 site-years for 14 major U.S. crops: soybean, corn, alfalfa, citrus, cotton, potato, rice, sorghum, sugar beet, sunflower, sweet corn, tomato, spring wheat and winter wheat. The meta-analysis focused on estimating the yield advantage or the efficacy advantage of pyrethroid insecticides relative to both no control and to non-pyrethroid alternatives. The efficacy advantage focused on reductions in measures of pest population, crop damage or increases in crop health metrics.

5. Uses and value of insect management practices in U.S. alfalfa, corn, cotton, and soybean production

A national farmer survey of corn, soybean, cotton and alfalfa farmers in the U.S was conducted to measure the value of plant-applied-protectants with an emphasis on pyrethroids. The survey was also designed to measure the non-monetary benefits of pesticides while accounting for farm characteristics. A professional market research firm (Market Probe) with an expertise in farmer surveys was contracted to conduct the surveys between February and June of 2016. The sample design was based on 400 completed farmer surveys for each crop, with respondents selected with a sample proportionate to insecticide use by state for each crop.

The survey instrument elicited information on 2015 insect management practices, pest management concerns, the sources of insect management information and the most important considerations when choosing which pest management practices to use. Farmers who reported using certain insect pest management practices in 2015 were also directly asked to choose the monetary value of the benefits the management practice provided to them. Multiple regression analysis was used to evaluate how insect pest management and the value of insect management varied by farmer and farm operation characteristics. Simulation methods were used with regression results to estimate the amount of crop acreage that was operated with pest management practices and the aggregate value that pest management provided to farmers.

6. Value of pyrethroid insecticides to urban pest management professionals

A survey of the membership of the National Pest Management Association (NPMA) and National Association of Landscape Professionals (NALP) was conducted to gain insights from urban professionals on the value of pyrethroids. These professionals not only have knowledge of current pest management strategies but also understand the implications of a counterfactual scenario in which pyrethroids were not available.

The survey solicited information on the roles and industry experiences of respondents. Urban professionals were asked about the types of insect pests managed by their businesses and how these pests are managed. They were asked about their perceptions of how lost or reduced access to pyrethroid insecticides would impact their businesses under a counterfactual scenario. Finally, survey participants were asked to characterize their

businesses in terms of the number of employees, gross sales and types of customers serviced. Factor analysis was used to explore how types of considerations faced in pest management decisions differed by the characteristics of the business. Regression analysis was used to determine how the characteristics of the individual's business, industry experience and considerations for pest management were related to their perceptions regarding lost or reduced access to pyrethroid insecticides.

7. An economic assessment of the benefits of pyrethroid insecticides in the U.S.

This report uses the multi-market equilibrium model AGSIM for commodity crops and partial equilibrium models for specialty crops to estimate the market-level benefits that use of pyrethroids generates. These complex and data-intensive models are often used in ex-ante (before the fact) policy evaluations because they integrate across all consumers and producers to estimate aggregate economic benefits. Key inputs for this analysis include the yield advantage and cost advantage of pyrethroids for each crop. The yield advantage was based on the yield and efficacy meta-analysis (Report 4) and the cost advantage was derived from data on the costs of pyrethroid alternatives for each crop (Reports 2 and 3). In addition, a large amount of historical market, economic and crop acreage data that characterizes the U.S. agricultural sector was used to estimate the models. Using a counter factual approach, the estimated economic benefits generated for the U.S. economy by the use of pyrethroids is about $1.6 billion per year.

8. Case studies of pyrethroid use patterns and potential impacts of regulatory changes on production of high-value fruits and vegetables in primary U.S. production states

AgInfomatics team members conducted farmers interviews to develop case studies describing pest management strategies farmers currently use and what farmers thought would happen under a counterfactual non-pyrethroid scenario. In terms of crops and regions, these case studies include fresh market tomato and sweet corn in Florida, California almonds, potato and process sweet corn in Washington, and potato and process sweet corn in Wisconsin. The written case studies summarize the salient findings, but the interviews with growers were recorded and transcribed by a professional transcription firm.

9. A case study of pyrethroid use patterns and potential impacts of regulatory changes on the control of mosquito vectors in Florida

Just as for the agricultural case studies, interviews focused on how insecticides were used in current mosquito management efforts and then shifted to adaptations that would be required under a counterfactual non-pyrethroid scenario. AgInfomatics team members interviewed several individuals in Florida associated with control of mosquitoes. These included staff in the Indian River Mosquito Control District; a representative of the American Mosquito Control Association; a representative of the University of Florida Research, Extension and Education organization; a staff member of the USDA/ARS Mosquito and Fly Research Unit; a representative from the Department of Defense's Global Vector Management Liaison with Deployed War-Fighter Protection Program; a member of the Department of Entomology at University of Florida; an entomologist at the University of Florida in the Emerging Pathogens Institute; a staff member of the Navy Entomology Center of Excellence in Jacksonville; and a staff member of the Department of Entomology and Nematology at the University of Florida.

6.0 Summary of each report

2. Methods and assumptions for estimating the impact of pyrethroid insecticides on pest management practices and costs for U.S. crop farmers

The overall goal of this process was to reallocate crop acres with pyrethroid insecticides to non-pyrethroid alternatives. The primary data were the GfK Kynetec insecticide use data for 2012 to 2014. In recent years the size of the agricultural sample has been based on approximately 20,000 interviews. Interviews employed in-person and telephone techniques, as well as mail and web-based questionnaires. In addition to growers, GfK Kynetec also collects data from processors, packinghouses, crop consultants, custom applicators and retailers. In 2012, approximate sample sizes were 4,300 each for corn and soybean, 2,200 for winter wheat, 2,000 for alfalfa, 1,350 for cotton, 1,000 for spring wheat, 800 for sorghum, 400 for sugar beet, 375 each for potato, rice and sunflower, plus pesticide use for about 40% of citrus acres, 35% of tomato acres and 30% of sweet corn acres. Approximately the same sample sizes were used for the 2013 and 2014 data.

The GfK Kynetec data employed in this analysis for each crop include planted acres, total area treated, base area treated, total pounds applied, and farmer expenditures. For each crop, these were available by active ingredient and categorized into either a foliar system or a soil system based on the application method and included target pest information as well. Planted acres are the number of acres planted; base area treated is the unique number of these planted acres treated with an insecticide once or more, and total area treated are the number of acres treated with insecticides, potentially the same acre more than once. Insecticide treated acres are categorized as either foliar-based systems or soil-based systems based on GfK Kynetec data that specifies target pest, application method (e.g., broadcast, aerial or in-furrow application) and timing of the application. Seed treatment acres are excluded because the focus is on pyrethroids, and pyrethroid seed treatments are not used in these crops. Foliar-based systems are used for all the crops examined in this analysis, while soil-based are used only for corn, cotton, potato and sugar beet.

Cotton is used to illustrate and describe the overall process; results for the remaining crops are reported in summary tables in an extensive appendix. For each crop, the initial step is to determine when and how pyrethroids are used for what pests. For cotton, the annual average for 2012-2014 was 5.3 million acres treated with foliar pyrethroids and 14.6 million acres treated with foliar non-pyrethroids applied. The comparable figures for soil-applied insecticides were 0.2 million cotton acres treated with pyrethroids and 0.6

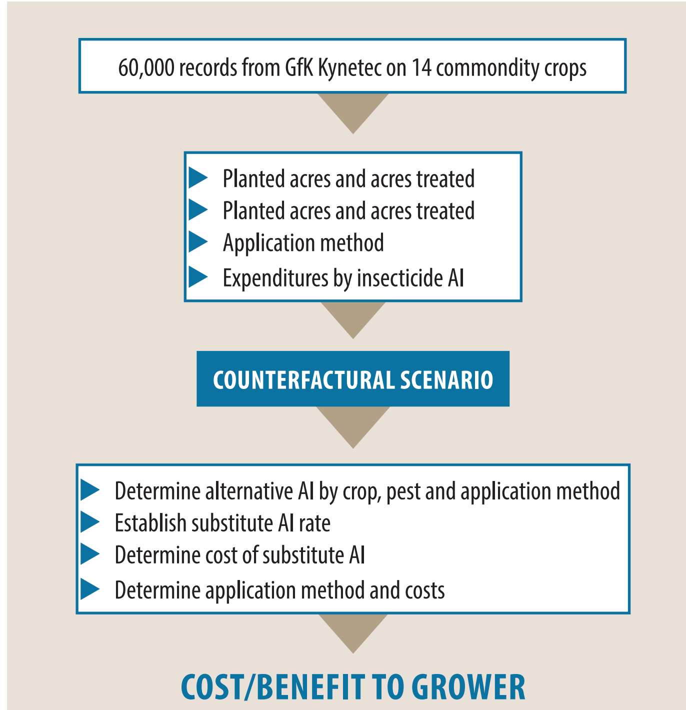
million acres treated with non-pyrethroids. The 5.4 million acres treated with foliar-applied pyrethroids and 0.2 million acres treated with soil-applied pyrethroids are reallocated to non-pyrethroid altnreives for the counterfactual scenario. These initial data summaries for each crop also indicate current usage patterns and the overall importance of pyrethroids in insect management for each crop.

Developing an alternative scenario begins by identifying the major target pests for acres treated with insecticides, separately for foliar- and soil applications and the share of these targeted acres that each active ingredient (AI) captures. For cotton, there were 72 unique target pests and 98 different active ingredients. To reduce the complexity, all pyrethroid AIs were combined into one group, and non-pyrethroid AIs were only included if they were used on at least 1% of the cotton acreage. This process reduced the number of non-pyrethroid AIs to 15 for foliar systems and four for soil-based systems. Similarly, target pests were grouped according to entomological taxonomy, and only groups targeted on at least 1.5% of all treated acres were maintained. For cotton, this process resulted in six target pest groups (fleahoppers, lepidopterans, mites, plant bugs, stink bugs, and thrips). The data showed that stink bugs are the primary target of pyrethroid insecticides in foliar-based systems, with a 44% share of all foliar pyrethroid treated acres, while lepidopterans are overwhelmingly the primary target pest in soil-based systems, with an 86% share of pyrethroid treated acres.

Next, pyrethroid treated acres are then allocated to non-pyrethroid alternatives based on the shares of treated acres each non-pyrethroid had for each target pest. For example, of all the non-pyrethroid treated acres using foliar applications targeted at stink bugs in cotton had 1/3 using one AI and 2/3 using another, then the pyrethroid treated acres targeted at stink bugs in cotton would be reallocated to 1/3 to the first AI and 2/3 to the second. The number of applications was adjusted to equal the average for the new AIs to reflect differences in the efficacy of AIs and the applications rates were the averages for the new AIs, not the pyrethroid application rate. Finally, grower insect management costs were calculated using the average costs for the new AIs and application costs to reflect the new number of applications. Figure 2 illustrates this process.

The counterfactual scenario requires substituting another insecticide for current pyrethroid applications. Several key assumptions were made to develop this scenario. First, the analysis assumes that growers would continue to use pest control on pyrethroid-treated acres. Second, pyrethroid treated acres in a foliar-based system remain in a foliar-based system and simply switch to a non-pyrethroid active ingredient. Similarly, pyrethroid treated acres in a soil-based system remain in a soil-based system. Scouting costs do not change since the grower is already scouting, and the insecticide application frequency is adjusted to reflect differences in field half-life and efficacy for the alternative active ingredients. Any changes in grower costs reflect the net difference in insecticide costs and the net change in application costs resulting from changes in the average number of applications. As noted, the analysis based on GfK Kynetec data in cotton had to account for 72 different target pest species, 98 different active ingredients and 11 different application methods. The analysis was structured to initially examine

FIGURE 2. Analytical processes used in Report 2: *Methods and assumptions for estimating the impact of pyrethroid insecticides on pest management practices and costs for U.S. crop farmers*



the target pest(s) and the method of application (foliar or soil) in order to ascertain the most likely non-pyrethroid insecticide selected.

To give some sense of the results, for the 2012-2014 period, there were 5.5 million acres treated with pyrethroids in cotton or about 29% of all cotton treated acres. Under the counterfactual scenario, acres treated with organophosphates increased by 3.5 million and by almost a half million for neonicotinoids. Acres treated with assorted other insecticides increased by 0.86 million under the counterfactual scenario.

A key implication that will be noted on multiple occasions is the increased probability of resistance emerging under the non-pyrethroid scenario. The 2012-2014 average shows that cotton farmers rely primarily on three modes of action (pyrethroids, organophosphates and neonicotinoids), which decreases to two modes of action for the non-pyrethroid scenario. The removal of pyrethroids takes away an important tool growers are using to delay resistance.

Next, a partial budget analysis estimates the impact on grower costs of the reallocation of pyrethroid-treated acres to non-pyrethroid insecticides. This cost analysis for the non-pyrethroid scenario was based on only two costs: the costs of the substitute active ingredient used to control pests and changes in application costs due to a different number of applications used. A partial budget analysis holds many other factors constant, which in this case includes crop and insecticide prices, and the existing spectrum of pests. Pest resistance is also assumed to remain at 2012-2014 levels, meaning no need for increased rates or applications. It also assumes that lower cost methods of managing insect pests will not be developed or applied.

The replacement costs for the non-pyrethroid insecticides exceeds that of the pyrethroids for both foliar- and soil-based systems since in general, pyrethroids are a relatively lower cost class of insecticides. However, the application costs for the non-pyrethroid scenario in cotton are lower since the total treated acres decrease about 684,000 acres. This decrease in acreage means that aggregate farmer costs decrease by almost $1.9 million. Yet as noted in the full cotton analysis, the fact that pyrethroid insecticides are used on such a large portion of cotton acres is evidence that the source of their value is something beyond cost since they are slightly more costly than the non-pyrethroid alternatives. The primary purpose of this report is to describe the process and report the technical results. The interpretation and discussion of those results is provided in the report 3.

3. Summary of the use of pyrethroid insecticides by U.S. crop farmers and the impacts of the non-pyrethroid scenario on insecticide use and farmer costs

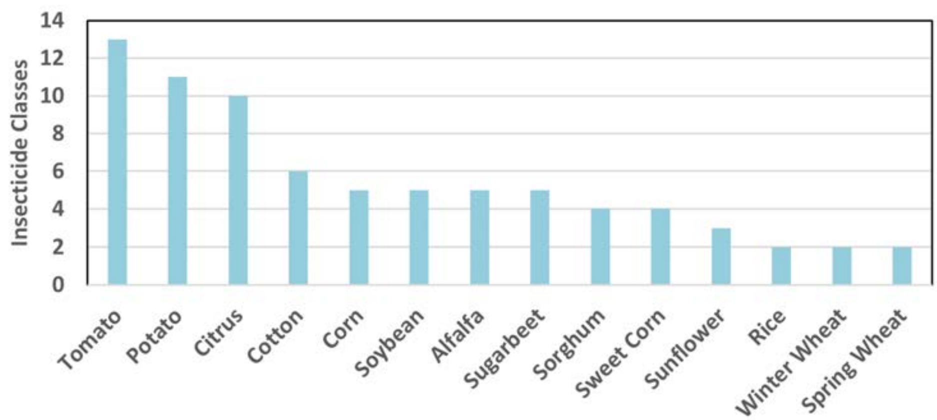
This report first focuses on providing a broader summary of the use and importance of pyrethroids for insect management in 14 crops based on the analysis described and reported in the report 3. Secondly, this report describes the broader implications of the non-pyrethroid scenario to elucidate some of the more indirect benefits of pyrethroid insecticides.

From 2012 to 2014, the annual average acreage treated with pyrethroids for these 14 crops was almost 50 million acres or 53% of the more than 93 million acres treated with any foliar- or soil-applied insecticide. Four crops had pyrethroids used on more than 70% of their insecticide treated acres: rice, sunflower, corn and winter wheat, while sweet corn, soybean, sorghum, and spring wheat used pyrethroids for 50 to 70% of their treated acres. Crops using pyrethroids on 30% or less of their insecticide treated included cotton, tomato, potato and citrus, with sugar beet an intermediate case with 43% of treated acres using pyrethroids. Across all 14 crops, pyrethroids represented just under half (49%) of all foliar insecticides and just under three-quarters (72%) of all soil-applied insecticides. Corn and soybean each have over 14 million pyrethroid treated acres the largest among these crops, while cotton was third with 5.5 million pyrethroid-treated acres. Total treated acres alone, however, does not capture the importance of pyrethroids in these crops.

Data on the number of pyrethroid applications per crop, target pests, number of insecticide classes used per crop and the cost advantage of pyrethroids relative to alternative insecticides round out information on pest management prior to constructing the non-pyrethroid scenario. In terms of the number of pyrethroid applications, sweet corn stands out with an average of more than three per planted acre, with citrus and tomato the next largest with 1.2 to 1.3 pyrethroid applications per planted acre, and all other crops have less than one. These data are additional evidence of the importance of insect management and pyrethroids for these crops. For insecticide modes of action (Figure 3), farmers use 10 to 12 on crops such as tomato and 4 to 6 for cotton, corn, soybean, alfalfa, sugar beet, sorghum and sweet corn. However, farmers only use 2 or 3 for sunflower, rice, spring wheat and winter wheat. For these crops, a major concern for the non-pyrethroid scenario is that farmers would rely on too few modes of action, raising serious resistance management concerns.

The cost data show that pyrethroids have a substantial cost advantage relative to the alternatives. The pyrethroid cost advantage exceeds $12 per treated acre for tomato, for foliar applications on potato and for soil applications on sugar beet. For citrus, soil applications in sweet corn and corn, and foliar applications in sugar beet, the pyrethroid cost advantage ranges from $8 to $10 per treated acre. Finally, the top five target pest groups for pyrethroid applications were lepidopterans, stink bug, aphids, corn rootworm and beetles, which accounted for 69% of all pyrethroid treated acres. In other words, roughly seven out of ten times when a pyrethroid is applied, it is targeted at one or more of these pest groups.

FIGURE 3. Number of insecticide classes used by crop



The counterfactual scenario projects a number of changes in pest management for the crops analyzed. First, 49.6 million acres treated with pyrethroids are replaced with 47.5 million acres treated by non-pyrethroids (Table 1), so that insecticide treated acres change from 89.2 million to 87.1 million. As Table 1 shows, these aggregate numbers do not reflect the specific changes for each crop. Treated acres decreased for most crops when replacing pyrethroids with non-pyrethroids, except treated acres increased for sugar beet and sunflower and remain unchanged for citrus, sweet corn and tomato. This 2% decrease in aggregate insecticide treated acres occurs because the average number of applications is slightly fewer for non-pyrethroids compared to pyrethroids. Replacing pyrethroids with non-pyrethroids has by far the largest impact on the use of organophosphates. The projected increase in treated acres for this insecticide class is from 34.7 million acres to 57 million acres, a 155% increase. The replacement of pyrethroids with non-pyrethroids increases the total pounds of insecticide applied, with 3.3 million pounds of pyrethroids replaced by 23.9 million pounds of non-pyrethroids, a 63% increase. Organophosphates are projected to make up 17.7 million pounds of these 23.9 million new pounds applied.

The non-pyrethroid scenario impacts farmer costs for pest management in two ways — costs to buy alternative, non-pyrethroid AIs (typically higher) and application costs that for most crops decreased due to treating fewer crop acres. Table 1 reports the net change in total costs by crop, both in total and per treated acre, with most of the cost impacts due to higher costs

TABLE 1. Summary of the non-pyrethroid scenario for the 14 crops

Crop	Pyrethroid Treated Acres	Non-Pyrethroid Replacement Acres	Net Change in Grower ---Pest Management Costs--- $ Total	$/Treated Acre
Alfalfa	2,972,708	2,483,779	$275,696	$0.09
Citrus	1,010,250	1,010,250	$10,259,493	$10.16
Corn	14,237,234	13,983,516	$103,050,775	$7.24
Cotton	5,529,920	4,651,174	-$1,897,107	-$0.34
Potato	718,122	712,280	$9,096,627	$12.67
Rice	1,105,696	1,036,013	$4,095,086	$3.70
Sorghum	688,697	618,736	$138,398	$0.20
Soybean	14,869,265	14,746,451	$16,393,389	$1.10
Spring Wheat	1,517,493	1,356,756	-$1,320,091	-$0.87
Sugar Beet	362,985	386,935	$4,245,028	$11.69
Sunflower	1,428,502	1,495,290	$5,201,905	$3.64
Sweet Corn	1,942,574	1,942,574	$16,170,934	$8.32
Tomato	483,248	483,248	$6,108,529	$12.64
Winter Wheat	2,735,074	2,480,800	$578,553	$0.21
All 14 Crops	**49,601,766**	**47,526,354**	**$172,397,213**	**$3.48**

for alternative AIs. Of the total $172 million increase in pest management costs in aggregate, the largest is $103 million for corn, with about $16 million each for soybean and sweet corn and about $10 million for citrus. Once expressed as a cost increase on a treated acre basis, the cost impacts fall more noticeably on the specialty crops, with cost increases of more than $12 per treated acre for potato and tomato, almost $12 per acre for sugar beet and more than $10 per acre for citrus. The cost impact is small for some crops and even negative for a few (spring wheat and cotton), implying that farmers derive benefits for the use of pyrethroids other than cost savings, such as increased yield.

4. Estimated yield benefits and efficacy of pyrethroid insecticides for major U.S. crops based on a meta-analysis of small plot data

The most valuable insecticides provide effective pest control that translates into enhanced yields at reasonable costs. As a result, substantial scientific effort focuses on collecting data to evaluate the efficacy of insecticides under field conditions. Replicated and randomized small plot field experiments are a common experimental design, with some sort of untreated control. Collected data include measures of pest population densities, crop injury, crop health and/or yield. Effective pesticides reduce pest populations, decrease crop injury and/or improve crop health, and potentially, these enhancements increase crop yield. Conducting small plot experiments to collect data of this sort is a common activity for land grant universities and other researchers.

The AgInfomatics team assembled data for these 14 crops from published small plot experiments, mostly conducted at land grant universities. Overall, more than 500 site years of data were assembled, generating more than 4,000 observations of pest population densities, crop injury, crop health or crop yield for pyrethroid insecticide treatments versus untreated controls and/or other insecticide treatments. A site-year is a set of replicated trials conducted at a single site in a single year with an untreated control. Multiple observations can be generated at a single site-year because multiple treatments may be evaluated, plus multiple experiments may be conducted at the same site in a year.

The meta-analysis of these data uses the treatment averages across the replicates at each of these site years and treatments to examine the efficacy and linkage between pest control and crop yield for these 14 crops. The report summarizes the data and methods and the main findings. More data were available for corn and soybean, and so those data were analyzed using more involved methods than for the other crops. As a result, the report contains three sections, one for soybean, one for corn and one for all other crops; this summary maintains these sections.

Overall, this meta-analysis finds that pyrethroid insecticides are among the most efficacious insecticide classes used commercially to manage a wide range of pests in a variety of crops. In most pest-crop systems examined, pyrethroids are the most efficacious insecticide class or are equally efficacious to other classes used. Superior efficacy generally translates to higher yields, but this connection is highly variable due to the natural variability in pest-crop systems. Because pyrethroids are generally a lower cost insecticide class, they are typically economically competitive with other insecticide classes because of their efficacy and associated yield benefits. As a result, pyrethroids are an effective and economical insecticide class that provide monetary benefits for many farmers and in the longer term, they provide low cost options for rotating or mixing insecticide classes for managing insect resistance to multiple modes of action.

The U.S. is the world's largest corn and soybean producer, annually producing 30 and 35% of global output for each crop, and they are the top two crops in the U.S in terms of planted area and crop value. In 2014, the farm gate value of soybean was almost $40 billion, while corn was almost $53 billion, together comprising 62% of the value of all crops produced in the U.S. As expected, a number of pests have emerged for these crops, but two insect pests that receive the most grower attention are the soybean aphid and corn rootworm larvae. As a result, a substantial amount of data exists for small plot experiments focusing on these pests in corn and soybean.

Soybean

Soybean aphids are quite small and hundreds or even thousands can infest a single plant. Because aphids cause direct damage by piercing the plant and sucking plant juices on a regular basis and the effects on the plant accumulate over time, entomologists use cumulative aphid days (CAD) as the measure of soybean aphid pressure. Aphid populations per plant are counted on different days, and the CAD between any two days is the aver-

age aphid population for the two sample dates multiplied by the number of days between the two sample dates.

A bio-economic model was used for the meta-analysis, linking CAD without treatment (CAD_0) to CAD with treatment (CAD_{seed}, CAD_{foliar}), and then to yield and profit (Figure 4). Efficacy was the linkage between CAD with and without treatment — how much each treatment reduced CAD. The yield benefit of a treatment was then determined by how much the treatment decreased CAD — the larger the decrease in CAD, the larger the yield benefit. The meta-analysis estimated parameters for this model using small plot studies that collected CAD and yield for both treated and untreated plots. Data were assembled from 118 site years for studies conducted from 2002 to 2015 in 10 states, generating a total of 588 observations of foliar insecticide treatments and 225 observation of insecticide seed treatments.

The meta-analysis estimated the average percentage reduction in CAD for each treatment. On average, pyrethroids reduced CAD 12 percentage points more than foliar-applied non-pyrethroid insecticides and 35 percentage points more than seed treatments. These results indicate that foliar-applied pyrethroid insecticides are the most effective insecticide for controlling soybean aphids in soybean in the U.S. This increased efficacy translated into increased yields. The yield advantage of a foliar-applied pyrethroid was 0.7% compared to a foliar-applied non-pyrethroid and 3.75% compared to a seed treatment.

A Monte Carlo analysis linked these efficacy results to yield and profits for five different Midwestern regions. Under typical cost assumptions, foliar-applied pyrethroids are the most valuable soybean aphid control option available to Midwestern soybean farmers under a wide range of reasonable assumptions for yield, price, aphid pressure and costs. However, yield, price, aphid pressure and cost assumptions exist for which seed treatments or leaving soybean untreated can also be the most profitable, implying that U.S. soybean growers will find the flexibility valuable of having all three treatment options available.

Corn

Corn rootworm and European corn borer are the two most problematic corn pests in the U.S. Rootworm larvae feed on corn roots (often hundreds or even thousands per plant), causing crop injury and yield loss. Soil-applied insecticides and rootworm Bt corn are commonly used to manage corn rootworm larval injury, with use of soil-applied insecticide increasing due to the emergence of rootworm resistance to Bt toxins. On the other hand, European corn borer and other lepidopteran pests of corn are primarily and effectively managed by corn borer Bt corn, though foliar-applied insecticides, including pyrethroids, are used by a few. As a result, the meta-analysis focuses on rootworm management using soil-applied insecticides.

Because many rootworm larvae can infest a single plant, and they live below-ground, rootworm pressure is assessed using the node injury scale (NIS), which measures the amount of root feeding by rootworm larvae. As a result, many small-plot experiments collect data on the NIS and yield for

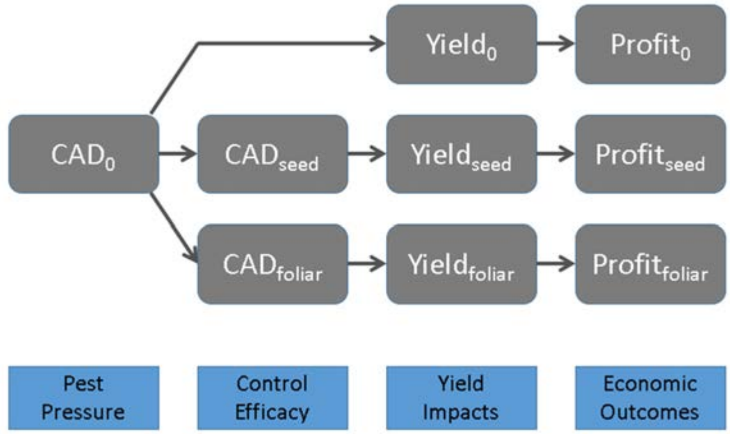


FIGURE 4. Components of the bio-economic model of soybean aphid management

rootworm larval treatments. Previous published research conducted meta-analysis of small plot data to estimate the linkage between reduction in the NIS and yield, and the efficacy of some rootworm insecticide treatments (Dun et al., 2010; Tinsley et al., 2013; 2015). As a result, the meta-analysis assembled small plot data to focus on estimating the efficacy of soil-applied pyrethroids relative to non-pyrethroids.

In total, 89 site years of small plot data were assembled from experiments conducted from 2005 to 2015 across four states, generating 669 observations of the NIS with and without a soil-applied insecticide. The bio-economic model is the same as in Figure 4, except the NIS replaces CAD, and the potential treatments include soil-applied insecticides, both pyrethroids and non-pyrethroids, Bt corn and seed treatment but not foliar treatments. The estimated efficacy results for the different soil-applied insecticide classes were combined with previously published analyses of the efficacy of other treatments and yield benefit models to estimate the yield gains and relative yield advantages of different rootworm treatments.

Soil-applied pyrethroids effectively reduce root injury from corn rootworm larval feeding. The most effective treatment was a pyrethroid-organophosphate premix that reduced the NIS to levels comparable to a single toxin Bt corn (before the development of rootworm resistance). When used alone, pyrethroids were slightly less effective than the premix but provided comparable NIS reduction to organophosphates and significantly better than the other insecticide classes examined (diamides, neonicotinoids and phenylpyrazoles).

Estimated yield gains depend on the average NIS without treatment. Based on the available data, the estimated average yield gain for soil-applied pyrethroids ranges from 9 to 14.5%, but most likely the average yield gain is in the range of 11 to 12%. The estimated average yield advantage of the pyrethroid-organophosphate premix relative to the pyrethroid used alone ranges 0.8 to 1.3%, with 1.0% being the most likely. The estimated yield advantage for a pyrethroid used alone relative to the other insecticide classes examined ranges from 2.8 to 4.5%, with 3.5% the most likely value.

Remaining crops

The meta-analysis of small plot data for the remaining crops did not have sufficient or appropriate data for estimating bio-economic models so the meta-analysis focused on summarizing the small plot data and comparing average efficacy and yield benefits. Small plot studies for the following crops were assembled: alfalfa, citrus, cotton, potato, rice, sorghum, sugar beet, sunflower, sweet corn, tomato and wheat. Data from studies were included if they included yield or some measure of efficacy based on changes in pest abundance, crop damage or crop health for at least one treatment that included a pyrethroid insecticide and an untreated control. Most studies collected data for multiple insecticides, both pyrethroids and non-pyrethroids, as well as tank mixes, premixes or sequences of different insecticides, and these data were included as well. The final data included 335 site-years, generating a total of 2,971 observations for at least one measure of yield or efficacy relative to an untreated control, with data usually from multiple states and several years. The number of observations varied widely among the crops, from a high of 852 for alfalfa to a low of 15 for rice.

Overall, the meta-analysis found that pyrethroid insecticides substantially increase yields, improve crop health and reduce both pest abundance and crop damage. These findings provide empirical support for the long-standing and widespread commercial use of pyrethroid insecticides in these and other crops. Furthermore, the benefits provided by pyrethroid insecticides are at least comparable to those provided by other available insecticide classes, with the magnitude of the benefits tending to follow the same trends across crops.

Notable examples exist in which pyrethroids out-perform other insecticide classes. Most noteworthy is pest abundance, in which the average efficacy of pyrethroid treatments was generally larger than for non-pyrethroid treatments for all pests, with only a few exceptions (Colorado potato beetle in potato, non-lepidopteran cotton pests and pests in wheat). Other notable examples of pyrethroids out-performing other insecticide classes included yield increases for sweet corn, potato and sunflower and for crop damages in cotton, potato, sugar beet, sunflower and tomato. The benefits of pyrethroids are often enhanced when insecticide treatments combine pyrethroids and non-pyrethroids, indicating the benefits from mixing or sequencing pyrethroids with other modes of action. Rotating or mixing modes of action not only increases yield and efficacy in the short-term, but also in the long-term by helping manage insect resistance for multiple modes of action.

5. Uses and value of insect management practices in U.S. alfalfa, corn, cotton, and soybean production

The previous report estimated the value of pest management to farmers based on small plot data. Following a data triangulation approach, this report examines the same question but using a different method and type of data. More specifically, a telephone survey was developed to estimate the value growers assign to pest management and pyrethroids based on non-market valuation techniques. The AgInfomatics team developed a telephone survey script and Market Probe, an international marketing firm specializing in agricultural surveys, administered the survey in states where alfalfa, corn, cotton and soybean are major crops.

A stratified sampling design was created to select states that produced the majority of alfalfa, corn, cotton and soybean. Sampled states for alfalfa comprised 52.4% of national alfalfa acres and 56.4% of national alfalfa production in 2015. The states sampled for corn made up 78.3% of national corn acres, while the states sampled for cotton made up 84.5% of the national cotton acreage in 2015. Soybean sampled states represented 85.4% of national soybean acreage in 2015. The AgInfomatics team prepared a draft survey instrument, and staff in Market Probe, as well as AMVAC Chemical Corporation, BASF Crop Protection, Bayer Crop Science, FMC Agricultural Solutions, Syngenta Crop Protection and Valent (MGK) suggested edits. Market Probe conducted the telephone interviews between February and June of 2016, with a total of 1445 growers of these four crops completing the telephone survey.

Farmers used insecticides to target a number of specific pests. Those growing alfalfa primarily targeted the alfalfa weevil, with aphids and leafhoppers the most common other pests. Corn farmers were most concerned about the corn rootworm and the European corn borer, with roughly one in ten corn farmers also managing for the corn earworm. The targeted pests for cotton producers differed between the period before first bloom of the cotton plant and after first bloom. Before first bloom, the primary pest target was thrips, while plant bugs and aphids were minor targets. After first bloom, the targeted pests became bollworms, stink bugs, and plant bugs. The primary pest for soybean growers is the soybean aphid, but a few growers also reported targeting beetles and stink bugs.

To better understand the factors driving farmer decisions, respondents were asked to rate the importance of 20 different concerns when making their pest management decisions, using a four-part scale from "Not at All Important" to "Very Important". Table 2 summarizes responses by crop for "Very Important".

The percentages for the three most important concerns are indicated in bold type for each crop (alfalfa has four due to a tie for third). For all four crops, "Protecting Yield" and "Family and Worker Safety" are the top two concerns, with the third ranking concern either "Protecting Water Quality" or "Consistent Insect Control." Farmers sees both the risks and benefits of using insecticide, often more immediately and directly than most others. These results are evidence that farmers are not only concerned about yield benefits and monetary issues when making their pest management choices but also very much concerned about human safety and the environmental impacts of the insecticides they use.

Growers were also asked to indicate the dollar value to them of pest management practices they used on their farm, choosing a range from a menu of options (e.g., less than $5 per acre, $5 per acre to less than $10 per acre, …). The report describes the details of the econometric analysis. This summary only reports the estimated average farmer valuations

TABLE 2. Percentage of farmers reporting each concern as "Very Important" when making their pest management decisions (**bold** numerals refer to highest responses for each crop)

Concern	Alfalfa	Corn	Cotton	Soybean
Product & application cost	62%	66%	81%	69%
Protecting yield	**77%**	**89%**	**91%**	**90%**
Crop price	49%	73%	82%	64%
Insect resistance management	53%	65%	75%	64%
Consistent insect control	**73%**	79%	**86%**	78%
Improving plant health	70%	76%	74%	72%
Improving crop stand	67%	79%	79%	65%
Being able to harvest early	48%	39%	31%	41%
Convenience	39%	40%	44%	39%
Simplicity	39%	35%	43%	31%
Flexibility	39%	35%	40%	32%
Saving time and labor	56%	47%	66%	44%
Reducing scouting	30%	25%	36%	25%
Have long lasting insect control	68%	66%	80%	70%
Protecting beneficial insects	57%	57%	73%	59%
Protecting wildlife	47%	54%	59%	53%
Protecting water quality	**73%**	**80%**	80%	**81%**
Family and worker safety	**86%**	**83%**	**89%**	**84%**
Public safety	70%	75%	77%	73%
Crop marketability	53%	70%	76%	73%

for major pest management practices for each crop. For alfalfa farmers using a pyrethroid foliar insecticide, the estimated average value of foliar insecticides was $26.06 per treated acre. For corn farmers, the estimated average value per treated acre was $19.77 for soil-applied pyrethroids and $17.09 for foliar-applied. The estimated average values of foliar pyrethroid treatments for cotton farmers was $36.62 per treated acre prior to first bloom and $50.06 per treated acre after first bloom. For soybean farmers, the estimated average value of foliar pyrethroid treatments was $15.18 per treated acre. The report also statistically examines the association between these averages and farmer characteristics and concerns when making pest management decisions, as well as state and regional differences.

These average values of insecticide and pyrethroid use per treated acre can be aggregated to estimate the total benefit to farmers by multiplying by the total treated acres of each crop in 2015. The estimated total benefit of foliar insecticide use to alfalfa farmers was $180 million in 2015, with $65 million of this total attributable to farmers who used a pyrethroid foliar insecticide on some of their alfalfa acreage. For U.S. corn farmers, the total benefit of soil-applied insecticides was $317 million, with $282 million of this value attributable to farmers who used pyrethroids on some of their corn acres; the estimated total benefit of foliar-applied insecticides was $237 million, with $106 million for farmers who used pyrethroids on some of their corn acres. The estimated total benefit for cotton farmers using pyrethroids in 2015 was $8.5 million before first bloom and $22 million after first bloom. For U.S. soybean farmers, the total benefit of foliar insecticide applications was $282 million, of which $133 million was attributable to those using pyrethroid insecticides.

6. Value of pyrethroid insecticides to urban pest management professionals

A number of insect pests in urban environments threaten human health. Bed bugs (*Cimex lectularius*), German cockroaches (*Blattella germanica*), mosquitoes (*Anopheles* sp.) and several ticks in the family *Ixodidae* are some of the more common arthropods that require pest management strategies. These pests and many others associated with structural, lawn, garden and hospitality industries often require the services of a professional for acceptable management. For this project, the National Pest Management Association (NPMA) and National Association of Landscape Professionals (NALP) cooperated with AgInfomatics team to conduct a survey of their members. These associations represent U.S. pesticide professionals with over 7,000 belonging to the NPMA and over 100,000 served by the NALP. AgInfomatics prepared a draft survey, and staff leadership in both associations added comments and suggestions. The survey asked about the types of pests managed and how these pests were managed. Implications of the counterfactual scenario were addressed by asking how the loss of pyrethroid insecticides would impact their businesses, cost of substitute insecticides and their ability to practice integrated pest management (IPM). Respondents were also asked to describe their businesses in terms of the number of employees, gross sales and types of customers served.

The final survey was sent to Market Probe, an international market research firm, which hosted the survey online. Access information and login passwords were provided to staff in both associations, who determined the best way of contacting and requesting cooperation from their members, although AgInfomatics provided text that could be used in member communication. The goal was to obtain 150 completed surveys from each professional association. After being available for approximately a month, there were 146 complete and usable surveys from NPMA and 149 complete and usable surveys from the NALP.

Answers to several questions were used to categorize the scale of each respondent's business. Gross sales data found that the majority of both NALP and NPMA businesses were large; two-thirds reporting annual gross sales over $1 million, and approximately a third over $5 million. About one quarter of NPMA and NALP respondents said their business grossed a half million or less in the last year. As another indicator of business size, approximately a third (35%) of NPMA and a quarter (27%) of NALP businesses reported more than 100 full-time, year-round employees. Just over a quarter of respondents in both the NPMA (28%) and the NALP (29%) had between one and ten year-round, full-time workers. Also, about half of the businesses in both associations operate in multiple locations and across multiple states.

In terms of the insecticide classes used, pyrethroids had the highest level of use, with 97% of NPMA and 95% of NALP respondents using them in their business. For other classes, 87% of NPMA respondents and 89% of NALP respondents used neonicotinoids, and 45% of NPMA respondents and 57% of NALP respondents used organophosphates. The NPMA respondents were more likely to use fipronil than NALP respondents, 91% versus 58%, respectively. The same applied to the minimum risk insecticides identified under FIFRA 25(b) such as Essentria, Cimexa or Mother Earth. Here 63% of NPMA used these low-risk insecticides, but only 7% of NALP respondents did. This initial pattern of insecticide use is important because under the counterfactual scenario there would have to shift from pyrethroids to other classes of insecticides.

The feasibility of the counterfactual scenario depends on the judgment of these professionals regarding the availability of acceptable alternatives to pyrethroids. There was 12% of NPMA and 17% of NALP respondents who said there are "no acceptable" alternatives to pyrethroids. The largest response category was the 65% of NPMA and 71% of NALP respondents who said that there are "not enough acceptable" alternatives. There are "some acceptable" alternatives was the response given by 22% of NPMA and 13% of NALP respondents. Only one person across both associations said there were many acceptable alternatives. Losing pyrethroids would have a number of impacts on their business as identified by the respondents. More than three-quarters of NPMA and NALP respondents said there would be an increase in the cost of pesticide products. More than two-thirds in both associations said there would an increase in application frequency, and over half would expect a decrease in customer satisfaction and retention. Training and management would increase, while the ability to manage insect resistance would decrease. Also noted was that the ability to control invasive pests would decrease along with their ability to practice IPM.

Regression analysis examined the connection between attributes and responses regarding the effect of the non-pyrethroid scenario. Businesses with sales in excess of $1 million in 2015 were not as concerned about increasing record keeping requirements if they lost pyrethroid insecticides, but they were more concerned about decreasing customer satisfaction and retention as well as their ability to control invasive pests. Medium sized businesses (11 to 50 full-time employees) were significantly more concerned about increased record keeping requirements without pyrethroid insecticides, but were not as worried about customer satisfaction and retention, and their ability to control invasive pests would decrease. Those with more industry experience did not express as much concern that the losing of pyrethroid insecticides would decrease their customer satisfaction and retention, and their ability to manage insect resistance and control invasive pests.

Overall, the professionals associated with the NALP and NPMA provided an unambiguous assessment of the negative impacts that the loss of pyrethroid insecticides would have on their ability to manage pests in the urban landscape. These negative outcomes range from increased insecticide costs and application frequencies to a decreased ability to practice IPM and control invasive pests. Though these businesses operate in residential, commercial and food-handling establishments, and there are parallels between their assessments and those of growers in the agricultural sector.

7. An economic assessment of the benefits of pyrethroid insecticides in the U.S.

This report examines the market-level impacts of the non-pyrethroid counterfactual scenario for 13 crops: alfalfa hay, citrus, corn, cotton, potato, rice, sorghum, soybean, sugar beet, sunflower, sweet corn, tomato and wheat (spring and winter combined). Losing access to pyrethroids changes the cost to produce and/or the yield for each of these crops. Changing costs and/or yields changes the supply side of the market by inducing growers to change the amount of each crop they plant and their production practices. Markets are complex and dynamic processes that integrate across the buying and selling decisions of many consumers and producers. At the market level, the changes in grower behavior due to losing access to pyrethroids imply shifts in the supply curve so that the equilibrium price and quantity shift as well.

The core economic concept embedded in the market-level analysis is surplus, a measure commonly used to measure economic benefits. Consumer surplus is the difference between the price consumers are willing to pay for a good versus what they actually pay for it. Producer surplus is the difference between the price a producer is willing to sell a good for versus the price they actually sell it for. A market is a process by which producer and consumer price behaviors are brought into equilibrium. Changes that shift the supply or demand relationships shift the equilibrium, implying changes in producer and consumer surplus that can be expressed as dollar values. Economists use surplus as a monetary measure of the benefits that aggregates across all consumer and producers, adding up all the producer profits and consumer purchasing power.

For a market-level economic assessment of the benefits of pyrethroid insecticides, the process focuses on how the supply curves for each crop would change if pyrethroids were not available and then estimates how much consumer and producer surplus would change relative to the current baseline. This change in surplus is a monetary estimate of the benefits of pyrethroids to society — the producer profits and consumer purchasing power their use generates for the U.S. economy. The supply curve for each crop was shifted by cost changes and yield changes for the non-pyrethroid scenario. The cost changes for each crop were determined from the analysis of the GfK Kynetec data summarized in the reports 2 and 3. The yield changes for each crop were derived from the results of the small-plot data meta-analysis summarized in the report 4.

Two types of market models were used for the analysis. AGSIM (a multimarket equilibrium model) was used for the commodity crops — alfalfa hay, corn, cotton, rice, sorghum, soybean and wheat. Separate partial equilibrium models are used for the specialty crops — citrus, potato, sugar beet, sunflower, sweet corn and tomato. All models include exports and imports. A multi-market equilibrium model allows interactions among markets as a result of shifts. For example, if loss of pyrethroids makes corn relatively less profitable, farmers would be induced to plant alternative crops such as

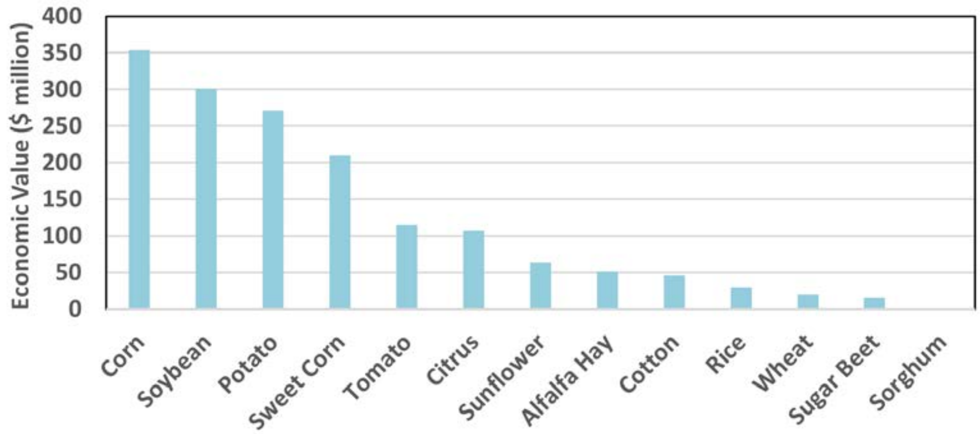
soybean, cotton or wheat. Partial equilibrium models do not allow for such interaction with related markets but are computationally much easier to estimate and use.

The report illustrates and explains how these supply and demand curves would change under the counterfactual scenario. The advantage of the AGSIM model is that it will quantify how shifts in the supply and demand curves for one of the 13 crops will impact the equilibrium prices and quantities for other related crops. The report also notes how international trade is addressed in a multi-market equilibrium model. The AGSIM model was used for modeling the impacts of the loss of pyrethroids for corn, soybean, wheat, cotton, sorghum, alfalfa hay and rice. A partial equilibrium analysis was used for the specialty crops of citrus, potato, sugar beet, sunflower, sweet corn and tomato.

With these fundamentals in place, the report presents results. If pyrethroids were not available, the new equilibrium prices for each crop generally increase, and the new equilibrium quantities decrease, implying an overall decrease in total surplus (the sum of consumer and producer surplus). The decrease in surplus if pyrethroids were not available implies that the use of pyrethroids generates economic value for society. The estimated value of pyrethroids to the U.S. economy is almost $1.6 billion per year, with about half generated by their use on commodity crops and half from their use on specialty crops. Specifically, the net economic benefit is $803 million from their use on commodity crops and $784 million from their use on specialty crops. Consumers capture most of these benefits, as lower costs for food such as meat, dairy and eggs, as well as specialty crops. The results also show that the yield advantages of pyrethroids generate most of these economic benefits, not the cost savings pyrethroids provide to farmers.

Figure 5 illustrates the total benefits from pyrethroid use by crop. The largest total benefits are for corn and soybean, which together generate $655 million of the total benefits. Among specialty crops, the largest impacts are for sweet corn, potato, tomato and citrus, which together generate $703 million in benefits. The other seven crops generate the remaining $229 million in benefits. Though commodity crops and specialty crops each generate about half of the benefits from use of pyrethroids, on a per acre basis, the benefits are much larger since there are far fewer acres of specialty crops. The largest economic benefit on a cropped acre basis is for sweet corn at almost $365/A, followed by $293/A for tomato, almost $248/A for potato and citrus at almost $138/A. Among the commodity crops, rice has the largest economic benefit on a cropped acre basis at more than $11/A. The smallest benefit among the specialty crops is for sugar beet at more than $13/A and sunflower at $38/A, which both exceed the largest values for commodity crops.

FIGURE 5. Projected aggregate economic benefits ($ million per year) of pyrethroids by crop



8. Case studies of pyrethroid use patterns and potential impacts of regulatory changes on production of high-value fruits and vegetables in primary U.S. production states

To help define the internal and external benefits of pyrethroid use, case studies were conducted to determine the value of pyrethroids across the U.S. in the following specialty crop productions systems — citrus fruit, tomato, sweet corn, potato and almond. AgInfomatics arranged interviews with growers, consultants and packing/processing businesses associated with citrus in Florida and California; Florida fresh market sweet corn and fresh market tomato; California almonds; Washington potato and processed sweet corn; and Wisconsin potato and processed sweet corn. AgInfomatics team members visited with representatives of these industries and toured their operations while discussing the value of pyrethroids and probable adjustments to the counterfactual scenario. All conversations were recorded, and Automatic Sync Technologies, LLC. transcribed the tapes.

For specialty crop production, reoccurring themes surfaced from all regions, indicating that pyrethroids provided significant pest management and economic benefits to specialty crop agriculture. Benefits identified in these interviews included:

- Pyrethroids have low product cost that helps to ensure return on investment to growers.
- Pyrethroids have good efficacy against a broad range of existing and emerging pests.
- Pyrethroids provide a low-risk management option for multiple pests within cropping systems and in area-wide operations, and for emerging pests that have few alternative controls.
- Pyrethroids are important in maintaining multiple insecticidal options to use in rotations with selective insecticidal classes to delay the onset of resistance.
- Pyrethroids improve food security by providing pest management in multiple geographic agricultural production locations.

- Pyrethroids offer effective management tools with short pre-harvest intervals (PHIs) that can be used close to harvest and meet the stringent damage-free marketing requirements for specialty crops.
- Pyrethroids have globally established maximum residue levels (MRLs) to provide access to both U.S. based and export markets.
- Pyrethroids are seen as effective tools to use in conjunction with cultural and behavioral controls to enhance their effectiveness.
- Pyrethroids, compared to other insecticides, are viewed as providing improved applicator and farm worker safety.

Many noted that additional restrictions on pyrethroid active ingredients through regulatory action would quickly lead to significant increases in pesticide applications of other materials that would have a higher risk to humans and non-target organisms. Several implications were cited. First, increasing dependence on fewer active ingredients would increase the likelihood of resistance development for those materials, while decreasing their effectiveness. Second, growers expressed concerns that the alternatives would increase the risk to family and farm workers, while also increasing training and safety costs.

Growers pointed out that the decrease in efficacy of pyrethroid alternatives combined with higher pesticide costs would reduce their economic returns. In addition, these changes would also increase the "culls" or rejections due to inability to meet the existing stringent damage-free marketing requirements associated with specialty crops. In general, a common reaction relative to the counterfactual scenario was a likely negative impact on the agricultural economy from local to international scales.

9. A case study of pyrethroid use patterns and potential impacts of regulatory changes on the control of mosquito vectors in Florida

AgInfomatics team members met with and interviewed representatives in Florida associated with control of mosquitoes. These included staff in the Indian River Mosquito Control District; a representative of the American Mosquito Control Association, a representative of the University of Florida Research, Extension and Education organization; a staff member of the USDA/ARS Mosquito and Fly Research Unit; a representative from the Department of Defense's Global Vector Management Liaison with Deployed War-Fighter Protection Program; a member of the Department of Entomology at University of Florida; an entomologist at the University of Florida in the Emerging Pathogens Institute; a staff member of the Navy Entomology Center of Excellence in Jacksonville; and a staff member of the Department of Entomology and Nematology at the University of Florida.

As was the case in agriculture, the interviews initially focused on how insecticides were used in current efforts to control mosquitoes and then shifted to adaptations that would be required under the counterfactual scenario. The interviews were recorded and Automatic Sync Technologies, LLC. transcribed the tapes.

Besides the control of pests in food establishments, another important use of pyrethroids is to control pest vectors of human pathogens. Vector-borne diseases are illnesses that are transmitted by vectors, such as mosquitoes, ticks and fleas. In this case, the emphasis was on mosquitoes, which carry infective pathogens such as viruses, bacteria and protozoa. Worldwide mosquitoes are responsible for infecting humans with malaria, dengue, yellow fever, encephalitis, parasitic roundworms, West Nile virus and most recently Zika virus. This case study was conducted in Florida, where there is an ongoing challenge to manage current endemic disease threats and to combat new virus introductions (such as Zika).

Key findings identified in these interviews included:

- Pyrethroids are essential tools to manage pests that may transmit disease, including mosquitoes and ticks.
- The only alternatives to pyrethroids for adult mosquito control are the organophosphates naled and malathion, which are also undergoing registration review.
- There is a high probability that new mosquito-borne viral threats will be introduced into the continental U.S. from neighboring countries where they are endemic.
- Pyrethroids are essential to mosquito control districts.
- The mosquito vectors of Zika (*Aedes spp*.) require control approaches (in addition to the traditional mosquito control district approaches) that target residences and yards.
- Pyrethroids used as barrier surface treatments are the only active ingredients registered for use in residences and yards.
- The pyrethroid permethrin is the only insecticide registered to treat military clothing and protect deployed personnel from pests.
- Pyrethroids are a key component for control of ticks that may transmit disease (e.g. Lyme disease).
- Pyrethroids are essential as repellents and control agents to control livestock pests.

7.0 Take home messages from the pyrethroid studies

Summarizing the results of hundreds of pages from nine reports on the benefits of pyrethroids is a difficult task. In brief, pyrethroids are a low cost and effective insecticide class that provide control of a broad spectrum of pests in a variety of settings that benefit society.

In agriculture, the use of pyrethroids increases yields and reduces farmer insect manage costs, which generate annual benefits of $1.6 billion for society. About half of these benefits arise from the use of pyrethroids on commodity crops, such as corn and soybean, and about half on specialty crops ,such as potato, sweet corn, tomato and citrus. Consumers capture most of these benefits as lower costs for foods ,such as meat, diary, eggs and specialty crops. The economic analysis showed that pyrethroids are especially valuable for specialty crops but missed key benefits that the case studies highlighted. Appearance is critical for many specialty crops. The short pre-harvest interval for pyrethroids helps growers meet this very stringent, damage-free marketing requirement. Pyrethroids also have globally established maximum residue levels so that U.S. growers can export fruits and vegetables to international markets.

In urban settings, pyrethroids are the most used insecticide class by pest management professionals to manage pests, such as cockroaches, ants, mosquitoes, bed bugs and flies in homes, schools, hospitals, restaurants and other businesses. Urban professional pest managers see few acceptable alternatives to pyrethroids, and the loss of this class would mean increased costs for alternatives that would require more frequent application and reduced ability to manage insect resistance and control of invasive pests. Public health specialists also emphasize that pyrethroids are essential for managing pests, such as mosquitoes and ticks, that transmit several serious pathogens to humans, pets and livestock in the U.S., including new virus introductions such as Zika.

In both urban and agricultural settings, pyrethroids are a critical tool for delaying the development of pest resistance. Pyrethroids offer a low cost, effective and broad-spectrum class to rotate with other most costly and selective classes as part of managing resistance. Data show that several crops rely on pyrethroids and only one, two or three other modes of action, while adult mosquito control for public health only has pyrethroids and organophosphates. Losing one mode would increase reliance on even fewer modes of action and accelerate the development of pest resistance to the remaining modes.

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