The Economic Impact of the IR-4 Project and Programs

March 2022

Steven R. Miller

&

John T. Mann

Michigan State University
Product Center Food-Ag-Bio
Center for Economic Analysis

Supported by: Michigan State University AgBioResearch MICHIGAN STATE UNIVERSITY Extension Department of Agricultural, Food and Resource Economics

Table of Contents

Introduction and Background

All pesticides intended for use in the United States are required to be registered by the Environmental Protection Agency (EPA). Registration entails testing that the intended use of the pesticide will not cause unreasonable risk to life or the environment with respect to the economic, social and environmental effects of the use of that pesticide [1]. As such, the EPA has the potential to limit pesticide options for agricultural producers.

While pesticides are used in home and business environments, their use is most applicable in agriculture. There are several categories of pesticides. Insecticides are used to manage harmful insects, including those that feed on or are otherwise harmful to the health of commercial plants. Miticides and nematicides are similar to insecticides but target mites and nematodes, respectively. Disease-fighting fungicides provide protection against fungal infestations, like molds, mildew and rust, while biocides kill microorganisms. Herbicides manage weeds. Other pesticide categories exist, including rodenticides, repellents, pheromones plant growth regulators and others. All categories of pesticide share a commonality in that they fall under the regulation of the EPA as specified in the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA).

Americans spend less on food today than they did in the 1960s because of advances in agricultural productivity [2]. Much of the productivity gains in agriculture can be linked to pesticide availability and use [3-5]. However, pesticide options are not equal across all crops, and crops that make up the largest share of acreage tend to have greater numbers of pesticide options relative to crops making up smaller shares of acreage. These latter crops are often grouped into a category called “specialty crops” and include most vegetable and fruit crops, as well as horticulture crops, like flowering plants. Specialty crops command fewer acres than row crops and therefore provide smaller markets for pesticide manufacturers than row crops. For manufacturers, these crops make up the largest component of “minor uses” of their pesticides. This report discusses the economic significance of a United States Department of Agriculture (USDA)-sponsored program that assures specialty crop growers have access to sufficient pest management tools.

According to the National Agricultural Statistics Services (NASS) of the USDA, specialty crops make up about 41 percent ($78.5 billion in 2017) of the total value of all crop production ($193.5 billion) in the U.S.

[6]. “Specialty crops” is a USDA classification for crops that occupy low overall acreage relative to total crop acreage in the U.S. Often it is easier to list what is not considered specialty crops than it is to list what crops are included. In that, all oilseed crops (like sunflower, soybean and peanut), grain crops (like corn, wheat and rice), sugar crops, cotton, tobacco and forage crops are not considered specialty crops. Most vegetable crops, tree-nut, fruit, peppers, nuts, herbs, and horticultural crops are considered specialty crops. Another way of thinking about this is to consider that thirty-six different large acreage crops and row crops make up just under 60 percent of the market value of crop production in the U.S., while some 300-plus specialty crops make up about 41 percent of the market value.

As shown in Figure 1, specialty crops make up the largest share of state crop production value in coastal states, while plains states largely specialize in row, or cash crops. Regardless, specialty crops are grown throughout the U.S. and in every state [6]. Like other crops, specialty crops must contend with pest pressures, and access to effective pest management tools is necessary for domestic producers to meet market needs. While specialty crop use is a principal example of a minor use for pesticides, minor uses may also entail row or cash crops. Row crop growers may have minor uses of existing pesticides, or specific off-label needs, where the limited market potential may not be sufficient to incentivize producers to pursue a new registration for that use. Because pesticide registrations for minor uses require similar testing to that of pesticides use on cash or row crops, the costs of registering a pesticide for any one specialty crop can be prohibitively high for the pesticide producer relative to the market value gained. The cost to register a pesticide for use on a crop can exceed hundreds of thousands of dollars and if the number of acres of applicable use is limited, it may not be in the manufacturer’s best financial interest to pursue that registration. Hence, specialty crop growers are at a disadvantage relative to major crop farms in having access to a wide spectrum of pest management tools.

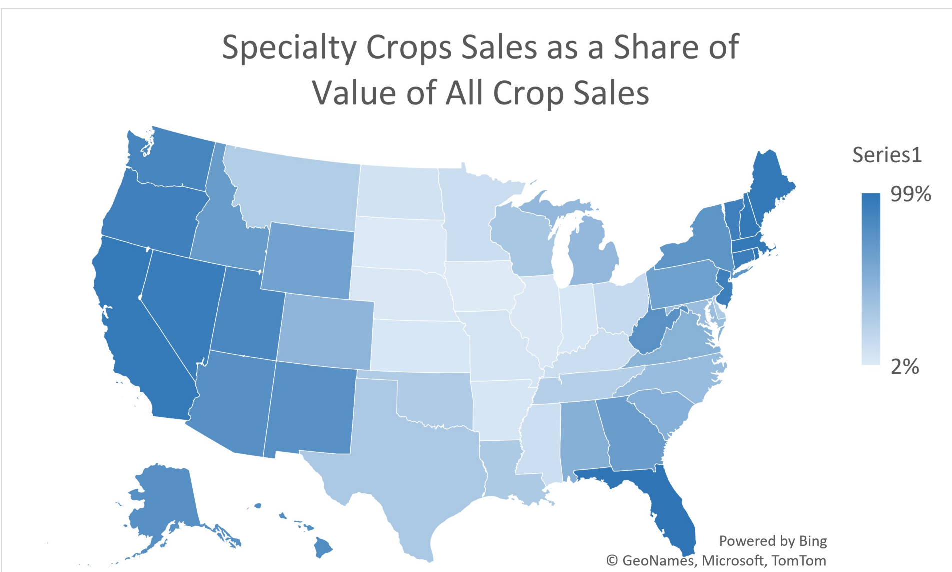


Figure 1: Specialty Crops’ Share of States’ Crop Sales
Source: Authors’ calculation based on 2017 Agricultural Census

Pesticide manufacturers, or registrants, will pursue a registration for use if they believe that registration will net a positive overall financial return, after accounting for the risks inherent in that use. To be profitable for the registrant, the price pesticide producers receive must cover both the average unit cost of registering the pesticide for that use and the variable production and marketing costs. Because the average unit cost for a registered use declines as more of it is sold for that use, registrants will seek uses that promise high sales volume at the expense of minor uses. Because the label lists all uses, it is not possible to price discriminate, like charging a higher price for specialty crop use and a lower price for row crop use. If they did price discriminate based on use, the specialty crop users could simply purchase the same chemical marketed to row crop growers at a lower price. That is, it is not possible to price discriminate to cover the average manufacturing cost differential between row crop use and minor uses (for a more analytic description of this, see Appendix A of this document).

Economic losses to pests may be from reduced yields or degradation of product quality [7]. The value growers place on pesticides largely depends on the value of crop losses the pesticide will avert. As such, the return to investing in pest control is dependent on the value of the commodity being produced. Growers may opt to reduce pest management efforts if the expected returns to crop yields are low. Accordingly, crops commanding higher prices tend to command greater investment in crop protection. Most specialty crops fall into this higher-value crop category, positing a higher risk of loss to growers who do not adhere to effective pest management strategies. Hence, specialty crop growers are particularly reliant on access to reliable pest management options, where crop losses to pests can be excessive.

FIFRA placed responsibility of registering pesticide uses on the EPA. Labels dictate the parameters of pesticide use for which growers are protected against lawsuits for negligent in their use of pesticides. Using pesticides in a manner not authorized under the label may be deemed unlawful and subject the user to both civil and criminal penalties. The EPA sets pesticide residue tolerances on harvested crops. Tolerances represent the highest level of pesticide residue on food and ornamental crops allowed and are often called maximum residue levels (MRLs). These MRLs help establish label use restrictions. EPA approval for pesticide use is preceded by significant investment in research for efficacy, environmental outcomes, and threat to human health. Each intended commodity the pesticide producer targets may require separate trials to generate data on that use, including data on effectiveness and residues left on the crop after harvest. As such, each additional intended use will incur equal research costs as prior registrations to gain EPA approval for that new use. The producer, or registrant, is expected to provide the relevant research data for EPA approval and therefore, is responsible for the research costs. As such, registrants must weigh the expected market returns for each targeted use against the costs of gaining EPA approval for that use.

Pesticide limitations for minor uses was made more pressing with the passage of the Federal Food, Drug and Cosmetic Act (FQPA) of 1996. This act made important changes to the FIFRA and imposed new standards for maintaining existing registrations, while placing higher standards for registering new pesticide uses. With FQPA, the EPA phased out and ruled out future registrations of broad-spectrum pesticides like Methyl Bromide. This had implications on both specialty crop growers and row crops. In the wake of FQPA, pesticide companies leveraged future revenue streams to justify the additional development of pesticides and registration for row-crop use, but specialty crop and minor use growers were largely left with fewer pesticide options.

In summary, pesticide producers face multiple risks when registering pesticide uses. Under high-acreage use, the risks can be distributed across many revenue-generating acres. Specialty crop uses and minor uses for row crops have limited number of acres and therefore provide less market volume to cover market risks. Market risks come in many forms, including risks that sales will not be sufficient to cover development and registration costs, that export markets may not accept the pesticide use, or that the life of a particular registration may be cut short, reducing the time horizon for recovering registration costs. Registrants must also contend with possible litigation due to non-performance, or due to industry or trade standards. In short, the market risk-reward tradeoff often favors those commodities making up the larger share of total crop acreage. This is the crux of what has been called the “minor use problem,” in that, while the demand and, often, the product for effective pest management may exist, the market risk-reward incentives constrain those uses if regulations discourage producer support for such minor uses.

Minor Uses and the IR-4 Project

The minor use problem has plagued specialty crop growers for many years and in 1963, State Agricultural Experiment Stations (SAES) at Land Grant Universities collaboration with the USDA to establish the IR-4 Project. It is a multi-agency funded program for facilitating the registration of more than 75,000 chemicals for minor uses and biopesticides since 1963 [9]. Coordinating with pesticide manufacturers and the EPA, the IR-4 Project assists in the collection of residue and efficacy data necessary for the registration of minor uses of existing pesticides [10]. The Project maintains geographic representation through four regional centers housed in Land Grant Universities across the U.S. In 2021, the IR-4 Project completed the move of its National Coordination Headquarters from Rutgers University, in New Jersey, to North Carolina State University. A detailed history of the program and program areas was published in 2016 [12].

The primary function of the IR-4 Project is to coordinate research and field trials at Land Grant Universities and SAES across the country for developing the efficacy and crop safety data necessary for registering minor uses of existing and new pesticides [13]. As such, the IR-4 Project fills the gap in minor use pesticide options, where registrants do not have sufficient market incentives to pursue registration, and where specialty crop growers have insufficient access to effective pest management resources. As the pesticide producer is responsible for registering their pesticides with the EPA, the IR-4 Project coordinates with agricultural producers, pesticide producers and regulators to address industry priorities for minor uses, collect or generate the necessary data and assists in filing an application for registration with the EPA. Growers and grower organizations establish priorities, while the IR-4 Project works with pesticide producers to identify potential solutions. It then sets out to assemble the data required by the EPA for registering the targeted pesticides for the prioritized minor uses. Research and technical guidance are coordinated with Land Grant Universities and SAES, and this data is then combined with existing producer data to meet EPA requirements for registering the pesticides for minor uses.

Efforts to register minor uses do not always require new trials and new data. In some cases, the data may already exist, and the IR-4 Project will seek to collect all existing data, fill in gaps where they exist and assist in putting together an application package to the EPA for registration. Where possible, the IR-4 Project combines existing data with data the Project either created or sponsored via field trials for completing an application package. Through innovations spearheaded by the IR-4 Project, residue estimates are projected across crop groups where possible, saving the need to conduct residue trials across similar crops. This enables results from one field trial to be applied to multiple crop registrations [12].

Consistent with industry trends, most registrations pursued by the IR-4 Project are pesticides with lower toxicity [14]. While supporting specialty crop growers’ access to pesticides, the IR-4 Project has been instrumental in facilitating the development and market for reduced-risk pesticides. These lower-toxicity pesticides are mostly targeted pesticides with narrow applications as opposed to broad-spectrum pesticides. The alternative broad-spectrum pesticides tend to adversely affect all species within the class of pests. That is, broad spectrum insecticides would control all invertebrates regardless of whether they are harmful or beneficial to the crop.

The IR-4 Project is currently broken out into two broad program areas, Food Crops Program and Environmental (Ornamental) Horticulture Program. A third program area, called the Biopesticides and Organic Support Program, was recently rolled into the Food Crops Program. While part of the Food Crops Program, this new function, now called Biopesticide Regulatory Support, provides services distinct enough from the rest of the Food Crops Program to warrant its own economic contribution estimates. Therefor, and consistent with prior economic contribution estimates of the IR-4 Project, economic contributions of three program areas will be estimated, including:

- Food Crops,
- Environmental Horticulture, and
- Biopesticide Regulatory Support (formerly Biopesticides and Organic Support).

Stakeholders in each of the three program areas set program agendas. Workshops are undertaken to establish priorities and discuss developing issues and threats. Such threats and priorities are driven by grower needs, but solutions are weighted toward those with existing products available. Collectively, the three areas pursue a common goal of generating efficiencies through building collaborative relationships across growers, pesticide producers, research institutions and regulators and combining resources for meeting registration needs.

The IR-4 Project originated with the Food Crop Program, and it remains the most active program area [12]. Its focus is on providing pest management options and education for specialty food crops and has supported nearly 20,000 registrations of conventional and bio-pesticides for use on specialty food crops since 1963 [15]. The Food Crop Program also advocates for the needs of food-crop growers with policy makers and regulators and remains a critical voice in the wake of the FQPA.

As consumer interest in organics continues to rise, the need to provide organic growers pest management options also increases. Biopesticide Regulatory Support provides research and registration support for natural pest management solutions. Such pesticides are drawn from naturally occurring pest repellents and organisms, though their efficacy and safety to growers and consumers must still be determined. Consistent with its efforts to increase use of less toxic agricultural pesticides, the IR-4 Project sought to be an early proponent of biopesticide development. IR-4's Biopesticide Regulatory Support activities are now bundled under the Food Program.

The IR-4 Project established the Environmental Horticulture Program in 1977 in response to the 1972 amendment to FIFRA to address the gap in pesticide tools for nursery and floral crop operations, including greenhouses, short rotation woody crops, forest seedlings, turf grass and Christmas trees. The Environmental Horticulture Program has supported over 56,000 uses in ornamental agriculture [16]. In many cases, the number of acres in horticulture crops are more limited than that allocated to specialty food crops and often posits higher market values relative to other program areas. Therefore, horticulture growers are subject to similar or more dire voids in pest management options. In addition, horticulture includes greenhouse operations, which exhibits unique pest pressures and pesticide safety considerations not relevant for uncovered fields. Unlike the other two crop programs, the Environmental Horticulture Program serves both minor use and row crop interests.

The IR-4 Project does not end with these two programs. Rather, Grower groups and IR-4 stakeholders lobby policy makers and regulators, representing grower and industry needs. In particular, the Project collaborates with regulatory agencies across the globe to harmonize MRLs. International differences in standards for pesticide residues have long been a barrier to trade in agricultural products and hinders the adoption of pest management solutions across borders [17]. For instance, if U.S. producers, abiding by domestic MRLs, attempt to sell to another country with different MRLs, the grower will be required to go through additional and sometimes costly steps to meet the trading country's documentation requirements if they are able to complete the transaction at all. Other countries may not recognize another countries' pest management products and therefore forbid the import of food crops exposed to those products. Harmonized pesticide MRLs across trading partners reduces trade uncertainty, avoids significant transactions costs and levels the playing field for all growers in participating countries. Because the U.S. is a net exporter of agricultural goods, increasing the flow of commodities across borders will disproportionately benefit U.S. growers and the U.S. economy [18]. Another benefit of harmonizing MLRs and testing standards is that regulatory agencies that approve or register pesticide use can also share in research findings across borders. This is particularly exemplified by the sharing of residue trials between the EPA and Health Canada's Pest Management Regulatory Agency (PMRA) [19]. Through these efforts, growers, both domestic and abroad, have greater access to pest management options, and pesticide producers have access to larger markets that improve the market incentives for pursuing registration.

The IR-Project also engages in a number of other crosscutting efforts, including collaborating with industry and agencies for managing invasive species. Controlling invasive species today can reduce future pesticide use, mitigating future economic costs of controlling invasive pests. The IR-4 Project also provides educational content around Integrated Pest Management practices (IPM). Adopting IPM has been shown to reduce pesticide use through scouting for pests and delaying spraying until economically viable thresholds of pest pressure is reached in the fields [20]. That is, rather than applying pesticides based on a pre-determined schedule, those adopting IPM will scout for the pest presence and only use pesticides targeted to the identified pests.

Sources of IR-4 Funding

The IR-4 Project draws funding from multiple sources. Congressional appropriations are the primary source of program funding and are leveraged with other sources of funding, including direct contributions by SAES, the pesticide manufacturing industry and other agencies of the USDA, amongst others. In addition to sources of direct funding, the IR-4 Project benefits greatly through in-kind contributions of key stakeholder groups including SAES, the EPA, pesticide manufacturers and the Canadian counterpart to EPA, the PMRA. These in-kind contributions do not create direct funding but create efficiencies that reduce the costs of running the IR-4 Project or meeting registration requirements. Amongst these, in-kind contributions by the crop protection industry make up the single largest component. The estimated values of in-kind contributions represent costs that the IR-4 Project does not have to expense to carry out targeted research, services and field trials in meeting the program's objectives.

As shown in Table 1, the annual operating budget of the IR-4 Project has been stable over the past four years. Congressional appropriations remain stable at just under $12 million per year, while additional funding sources that leverage congressional funding center around $5.2 million. Collectively, the average annual program funding just tops $17 million per year. In-kind funding represents an overall larger share of value at around $24.6 million per year but does not represent a source of economic impact as new resources at the disposal of the IR-4 Project or collaborators. Land Grant Universities and SAES provide facilities, laboratories and support for undertaking field trials and represent a second significant source of in-kind contributions. The EPA and PMRA Canada provides additional in-kind support through shared information and especially through waiving registration fees.

Bases for Economic Contribution Simulations

The IR-4 Project has multiple bases for generating economic contributions on the national economy. In this section we discuss some of the key channels by which the IR-4 Project contributes to the national economy.

First, the IR-4 Project, and partner organizations, generate expenditures that contribute to the total national economic activity. Such expenditures are made for salaries and wages of employees, the purchase of lab equipment, payments to land used in field trials and others. These expenditures also induce secondary rounds of expenditures. Household earnings, as salaries and wages, will be re-spent in

	2020		2019		2018		2017	
Congressional Appropriations ($000s)		**$11,913**		**$11,900**		**$11,914**		**$11,910**
Regional offices and headquarters	$7,391		$7,491		$7,353		$7,353	
Field trials	$2,531		$2,475		$2,220		$2,300	
Environmental Horticulture Program	$543		$535		$511		$505	
Integrated solutions and legacy biopesticide projects	$371		$317		$387		$390	
IR-4 Laboratories	$234		$234		$228		$228	
Other					$373		$300	
NIFA	$843		$849		$843		$834	
Additional Funding Sources ($000s)		**$4,906**		**$4,711**		**$5,290**		**$5,847**
Multistate Research Funds	$481		$481		$481		$481	
USDA-ARS	$3,170		$3,170		$3,170			
USDA-ARS Environmental Hort. Headquarters	$105		$120		$120		$120	
Industry Contributions	$1,150		$940		$1,090		$1,737	
USDA-FAS					$429		$3,509	
In-Kind Contributions ($000s)		**$24,500**		**$24,750**		**$24,750**		**$24,650**
SAES/land grant universities	$6,000		$6,000		$6,000		$6,000	
EPA Pesticide Registration Improvement Act fee waivers	$6,000		$6,000		$6,000		$6,000	
Crop protection industry	$12,000		$12,000		$12,000		$11,900	
Canada PMRA	$500		$750		$750		$750	
Total Funding (Budget; $000s)		**$16,819**		**$16,612**		**$17,204**		**$17,757**
Total Funding + In-Kind Contributions ($000s)		**$41,319**		**$41,362**		**$41,954**		**$42,407**

Table 1: Annual Budget and Sources of Direct and In-Kind Funding

Source: Annual Report of the IR-4 Project, various years

the economy for goods and services consumed by the household. Expenditures for the purchase of equipment will lead to secondary expenditures to restock products sold, for overhead costs like utilities and rent, and for labor. Other expenditures spur similar secondary rounds of spending, and secondary rounds of expenditures spawn subsequent rounds of expenditures. These subsequent rounds of expenditures will ripple throughout the economy, hindered only by the extent to which recipients use funds to purchase imported goods. We should be careful in how we interpret the economics of such public expenditures. This is because public expenditures through the IR-4 Project necessarily imply that other public expenditures on research or other public functions are not undertaken. A true economic impact assessment would account for public expenditures foregone. This report does not account for alternative uses of public investment in the absence of the IR-4 Project. Rather, the report focuses on economic contributions of direct and associated in-kind expenditures that relate to gross contribution of all moneys spent along with associated commodity and industry effects.

The IR-4 Project's largest contribution to the economy likely arises indirectly from improved grower productivity brought on through better access to pest management tools [21]. Grower efficiencies and lower consumer prices for food go hand in hand. Reduced pest damage is emblematic of reduced costs of production. Assuming price does not change, growers will receive a higher rate of return. Alternatively, because growers compete to find buyers, lower costs of production translate to lower consumer prices. It is likely that efficiencies generate some combination of the two such that, growers share in the gains with consumers and others along the supply chain.

Less obvious, lowering the costs of fruit and vegetables can actually increase total expenditures on them. The IR-4 Project promotes agricultural production of specialty crops through affording growers a wide array of pest management options, and by educating growers of these options. Productivity enhancements will promote intermediate and consumer demands for such specialty crops and can ultimately result in an overall increase in total consumer expenditures for specialty crops [22, 23].[1] However, we caution that if total expenditures for specialty crops increase, the net effect on the economy may not necessarily be positive based on sales value alone. This is because the increased expenditures on specialty crops most likely results in a decrease in expenditures of other food crops. Whether the result is an expansion of economic activity depends on the net effect of this transfer to more specialty crop purchases.

Lower prices can lead to increased exports and therefore economic expansion. With lower costs, prices of domestically produced goods become more competitive in the global marketplace – increasing exports and reducing imports. Increasing net exports retains economic value in the domestic market. However, it is difficult to relate actual changes in net exports to any one cause as trade fluctuations are common.

The IR-4 Project also contributes to the economy in less commercial ways. One directly linkable effect is through improved environmental outcomes. Miller and Mann identified three channels of positive environmental impacts [24]. First, by making more crop options viable for growers, the IR-4 Project promotes crop diversity, over monoculture, or limited rotations. Through diversity of crops, growers have more complete control over soil health and pest pressures. Careful selection of crop rotations can improve non-chemical control of pests [25] and improve soil productivity - reducing the dependence on soil nutrient amendments [26]. Second, most pests develop resistance to repetitive exposure to a single pesticide and as resistance builds, it requires more of that active ingredient in subsequent rounds to have the same level of control. Having a broad range of pesticide options and alternating pesticide use improves growers' ability to manage pests without promoting pest resistance [27]. Third, the IR-4 Project reduces the use of traditional broad-spectrum pesticides. Broad-spectrum pesticides are a product of older pest management strategies that negatively impact all organisms, not just those causing damage to the crops. The IR-4 Project, in agreement with industry direction, pursues minor-use registrations of targeted

[1] That is, consumer demand is elastic to relative price changes across substitutes.

pesticides with lower overall levels of toxicity. Targeted pesticides pose less of a threat to non-targeted organisms and are consistent with IPM operational principles widely adopted in U.S. Agriculture [28].

In promoting health benefits of a varied diet with fruits and vegetables, the USDA MyPlate sets recommended dietary intakes for Americans [29]. This asserts that a balanced food intake across multiple food categories, within moderation, is the key to a healthy diet. As discussed above, by reducing the consumer price of vegetables, pulses, tree nuts, fruits and berries, the IR-4 Project contributes to healthy consumer outcomes. Given the state of America's diets and the relatively high expenditures on healthcare [30], significant potential of improving health outcomes and health-related expenditures exist [31]. Reducing expenditures on healthcare affords equal expenditures on other goods and services. In addition, a healthier workforce has fewer missed work days and greater labor productivity [32]. Such measures of impact are difficult to measure, but small sample analyses show there to be a direct link to economic outcomes [32].

Besides recognizing these important sources of economic contribution, the IR-4 Project also works with multiple regulatory agencies, both domestic and abroad, to create efficiencies in registering pesticides. The IR-4 Project advocates for grower needs to create regulatory innovations that reduce the costs and time necessary for meeting regulatory guidelines. This can allow the costs of conducting field trials to be spread across multiple registration-granting agencies. The project helped to streamline the minor-use registration process for California, where the California Department of Pesticide Regulation (CDPR) regulates pesticide use in this important specialty-crop producing state. The CDPR generally awaits EPA decisions before conducting their own review, which has the potential to double the time it takes new registrations to be available in California. The IR-4 Project facilitated joint reviews between the EPA and the CDPR, where each agency shares in the work of the other. The Project's impacts also cross national boundaries. Consider that registrations jointly pursued in the U.S. and Canada spread the costs of field trials between the IR-4 Project and PMC and avoids duplication of effort [33]. Because a typical field trial costs around $6,000 and that each registration requires multiple field trials, this savings can be significant. In addition, the IR-4 Project contributed to the introduction of electronic data submissions and commodity crop groupings that facilitate shared data across multiple crops for low-risk pesticides and initiated efficiencies in the way crops are categorized that allow extrapolation of residue data across crops within a category. These innovations have not only reduced IR-4 Project costs, but also reduced the time to registration for both EPA, CDPR and PRMA registrations. Such innovations resulted in an estimated $1 million in savings by allowing reduced risk chemistries like azoxystrobin and spinosad data trials be conducted on a crop grouping basis across some 280 minor uses rather than for each specific crop [34].

Finally, the IR-4 Project contributes to the advancement of science and innovations. Innovation is the key to economic growth, and the IR-4 Project advances science and innovation in two broad ways. First, through its relationships with SAES and other research institutions, the IR-4 Project helps to fund the education and research of new scientists. In most SAES labs, undergraduate and graduate students work with research and teaching faculty in field trials and lab analyses. Student labor provides both experience and funding for post-graduate research and degrees, where students go on to have careers in academic research, government and private industry. Advancing new scientists is vitally important in promoting future economic growth. It is difficult to attach a value to student funding and experience gained by working on IR-4 Project funded research, but the Bureau of Labor Statistics reports that median incomes of workers with bachelor's degrees earn 65 percent more income than those with only a high school education, and that those with advanced degrees earn 25 percent more than those with only a bachelor's degree [35]. If earnings reflect contributions to society as most economists claim, then recognition should be made of the IR-4 Project's contribution to promoting students' educational pursuits. Second, and as is highlighted in their annual reports, the IR-4 Project sponsors research publications and presentations, where over the past four years (2017-2020), the Project contributed to some 57 peer-reviewed publications, research reports and newsletters [36]. These represent a key resource toward disseminating information amongst scientists, producers and industry, who take up research outcomes and put them into practice.

Methods

A well-established economic simulation model is applied to estimate overall economic contributions of the IR-4 Project. The model applied is called IMPLAN and is based on a modeling frame called input-output economics. Input-output, or IO models trace the value of transactions through the economy based on historical relationships specified in a social accounting matrix (SAM). The SAM is a double-entry system of social accounting for the transactions underlying an economy and make up the basis of government measures of the size of the national and state economies. As a double-entry system of accounting, the revenues in one sector are exactly offset by expenditures in other sectors. It is intuitive since when one institution makes a purchase, another makes a sale. The SAM tracks transactions across industries as well as between industries and other institutions like households. Businesses buy labor from households and pay a wage. Households take those wages and purchases from businesses. In between those, government imposes multiple forms of taxation and spends such revenues on labor and goods and services from the production sectors. Recognizing that economies are linked via international trade, the SAM also tracks the value of imported and exported goods, where the flow of international funds are necessary to retain the balance of accounts when the value of imports does not equal the value of exports.

The IO model then asks the question, what transactions would be necessary to support some specified level of sales? To answer this, the IO model must look backward to all the transactions that go into the final value of goods or services, plus all the secondary transactions that would follow. Secondary transactions come in two forms. First, when a business sells goods or services, they take part of the revenues earned and make purchases from other businesses to replenish stocks. Another share will go to the purchase of other goods and services necessary to run the business, including payments for utilities, rent and business services. These business-to-business transactions are called indirect transactions. Another portion of a firm's revenues will be spent on labor income, proprietor's income and for business taxes. The institutions receiving these sources of revenues, including households, will spend these earnings in the marketplace for goods and services. These transactions from institutions are called induced transactions. In summary, the original value of transactions is diffused throughout the economy in subsequent rounds of transactions, each of which generates the next round of transactions in response. Subsequent rounds of transactions will continue to ripple throughout the economy, hindered only by the extent to which purchases are made for imported goods. Once dollars leave the economy, they cease to generate additional transactions.

Hence, IO models generate three types of economic contribution estimates, direct, indirect and induced effects (sometimes referred to as multipliers). These effect estimates are additive, such that the total contribution can be determined by simply summing over the three effects. That is, the model estimates can be summarized by the following simple equation:

Total Effect = Direct Effect + Indirect Effect + Induced Effect.

- *Total effect* is the total change in economic activity and can be measured in terms of income, employment, output or gross domestic product.
- *Direct effect* is the measure of the force of change postulated to cause the total change in economic activity. It represents an exogenous infusion to or drain on the economy.
- *Indirect Effect* is the measure of changes in inter-industry transactions resulting from the direct effect.
- *Induced Effect* is the measure of changes in transactions of households and other non-production institutions from changes in income resulting from the direct and induced effects.

The IMPLAN Pro Version 3.0 (IMPLAN) software is used to generate impact estimates based on direct effect estimates described below. IMPLAN uses economic and demographic measures from a host of government statistical reporting agencies including the Bureau of Economic Analysis, Bureau of Labor Statistics, USDA, and the U.S. Census Bureau [37]. The underlying social accounting matrix is based on the Annual Industry Accounts provided by the Bureau of Economic Analysis [38]. This social accounting matrix is specified in terms of output, which is the sum-dollar value of all goods and services exchanged within the economy. The IMPLAN model provides the conversions from output to gross domestic product, employment and wages internally using fixed ratios by sector [37].

Several simplifying assumptions are required in IO simulations. First, IO models are strictly linear in that inputs are additive, and transactions rise in proportion to level of sales modeled. This assumption implicitly assumes no externalities, constant returns to scale, and no capacity constraints. Externalities are both benefits and costs accrued to third parties. One type of externality often discussed with pesticide use is the external costs of pesticide usages that may include public health and environmental quality effects not recognized in the purchase price of the pesticide [39]. The report also abstracts from spillover costs and benefits realized by neighboring fields to those fields that now have pest management options afforded by the IR-4 Project. Given that pests are not confined by field, controlling pests in one field has expected benefits to neighboring fields. Proportionality of purchases also excludes the possibility of economies of scale that may be realized for some inputs, like labor, which becomes more productive with the size of operation. The last potentially restrictive assumption maintains that land, labor, capital, and intermediate inputs are not constrained by availability that would otherwise result in price changes. For relatively small impacts, this assumption is not an issue, but as the source of impact increases relative to the size of the market, accessibility to inputs may be a constraint to further expansion. Other restrictive assumptions of this framework exist but do not necessarily pertain to the analysis at hand. For an introductory treatment of the assumptions of IO modeled impacts, see Coughlin and Mandelbaum [40]. A more complete treatment can be found in Richardson [41, 42]. Finally, this report does not measure the value of foregone uses of public and private funding that goes into the IR-4 Project.

To facilitate estimates, we break impact estimates into five broad areas.

- IR-4 Project Expenditures
- The net value of crop production gains attributable to minor-use registered pesticides
    - Food Crop Program
    - Environmental Horticulture Program
    - Biopesticide Regulatory Support

- Section 18 Exemptions

The first and smallest component is the value of economic activity taken up by the IR-4 Project and its associated partnering universities, businesses and institutions. These activities include direct expenditures for land, labor and inputs necessary to undertake field trials, for compiling registration packets sent to the EPA and for all other efforts directed toward meeting IR-4 Project goals. The second is the net gains in grower sales from the use of pesticides made available by IR-4 Project sponsored registrations. These productivity-induced sources of contributions are limited to farm-level direct effects in terms of added output and revenues attributed to pesticide access. There are three program areas, each with their own estimated economic contributions. The fifth area is the economic value of crop loss aversion due to successful Section 18 Exemptions. Section 18 Exemption requests must be accompanied by a statement of expected economic loss in the absence of the requested off-label use of the pesticides. While those statements of loss are grounded in truth, they are attached to requests for action and therefore may be subject to speculation.

Direct Effects

As discussed above, impact estimates start with estimates of direct effects. Direct effects are broken out into five distinct categories to isolate the effects of IR-4 Project expenditures, the Food Crops Program, Environmental Horticulture Program, Biopesticide Regulatory Support, and the Section 18 Exemption support. In addition to direct expenditures of the IR-4 Project, each program contributes to industry impacts through reductions in crop loses to pests and increases in production value. These industry direct effects are estimated for each IR-4 Project program area and detailed below. The next sections discuss estimates of direct effect and production effects. These direct effects are then used to calculate economy-wide impacts using the IMPLAN economic impact model.

IR-4 Project Expenditure

The expenditures of the IR-4 Project are perhaps the most direct source of economic contribution of the IR-4 Project. However, we caution that these expenditures likely supplant other uses of public and private funds that would accrue in the absence of the IR-4 Project. We base direct effects only on actual transaction values generated by the IR-4 Project and identifiable expenditures by partnering institutions. This ignores in-kind contributions from pesticide manufacturers and other stakeholders. Such in-kind contributions may include existing data or field trial results the pesticide manufacturer created in its initial label packet that may be related to the minor use the IR-4 Project is pursuing. Because such in-kind expenditures would have taken place even in the absence of the IR-4 Project, we do not attribute them to economic contribution estimates, but do recognize that they do exist.

To represent typical annual expenditures of the IR-4 Project, we use the typical expected budgets over four years. The four-year average budget categories used to represent direct expenditure effects are shown in Table 3. Accordingly, the total direct expenditures are estimated at just over $17.1 million per year. About $15.87 million of that is from public sources, like Congressional appropriations and the USDA. It is interesting to note that in 2011, the total annual budget was about $18 million. That is, the operating budget of the IR-4 Project has remained mostly constant or declined in dollar terms since 2011. The actual spending power, however, has declined by 24 percent between 2011 and 2021, once accounting for inflation over that same time frame [43].

	$000s
Congressional Appropriations	**$11,909**
Regional offices, laboratories and headquarters	$7,628
Field trials	$2,382
Environmental Horticulture Program	$523
Integrated solutions and legacy biopesticide projects	$366
Other	$336
NIFA	$842
Additional Funding Sources	**$5,189**
Multistate Research Funds	$481
USDA-ARS	$3,170
USDA-ARS Environmental Hort. Headquarters	$116
Industry Contributions	$1,229
USDA-FAS	$1,969
Total Funding (Budget)	**$17,098**

Table 3: 2016 IR-4 Project Budget
Source: 2016 Annual Report of the IR-4 Project

Though not contributing to the IR-4 Project's economic footprint, we believe it is important to recognize the value of in-kind contributions the Project creates. As shown in Table 4, this includes about $6 million contributed by SAES in research facilities, student research and faculty, as well as about $6 million in registration fee waivers by the EPA. The largest in-kind contribution comes from the pesticide manufacturers themselves. Accordingly, pesticide manufacturers stand to gain if new applications are added to their existing products' labels. These represent cost savings attributed to the IR-4 Project which are created by collaborating with partner institutions when generating operating efficiencies.

	$000s
In-Kind Contributions ($000s)	**$24,663**
SAES/land grant universities	$6,000
EPA Pesticide Registration Improvement Act fee waivers	$6,000
Crop protection industry	$11,975
Canada PMRA	$688

Table 4: 2016 In-Kind Contributions
Source: 2016 Annual Report of the IR-4 Project

Food Crop Program Direct Effects

The Food Crop Program contributes to the economy through its impact on grower productivity. While minor uses of pesticide for food crops spans beyond specialty crops, we focus estimates on specialty crops, as specialty food crops make up the primary focus of this program. An informal survey of minor use registrations indicates that about 60 percent of the minor-use registrations for food crops were advanced by the IR-4 Project [44], and therefore 60 percent of the benefits of pesticide use on specialty crops can be attributed to the Food Crops Program. This is likely an overestimate, as it is conceivable that without the IR-4 Project, other, abet limited, partnerships may be developed in the marketplace to advance high priority specialty crop registrations otherwise advanced by the Project. This may also overstate actual effects in that the counterfactual state is that the same crops are grown without protection. A more likely counterfactual state of production in the absence of Project-advanced pesticide options is that growers would switch much of their acreage away from specialty crops and into row crops, where sufficient pest management options exist. This implies that a much greater share of specialty crops would then be imported to the U.S., which presents a different set of economic, health, and food security concerns. Regardless, assuming the alternative is that the same acreage is set to specialty crops but in the absence of pesticide options is a representative case of the productivity impacts of the IR-4 Project.

Researchers have long studied the contributions of pesticide and other agro-chemical use on farm productivity – providing a rich set of estimates of the contributions of pesticide use to grower yields and net revenues [45]. The literature notes that estimates of the effect of pesticide use on yields and economic return are clouded by different grower practices, inconsistent growing environments across the U.S., variations of pest pressures, and the inability to assign proportional yield loss to various stresses [3, 4, 21, 25]. Such heterogeneity creates varying degrees of impact estimates across the spectrum of applications [46, 47]. For the purposes of this analysis, direct contributions to economic output are measured in terms of the expected contributions to specialty food crop output attributed to pesticide use. This avoids the enumeration of price impacts, where output's impact on prices has the potential to transfer the impacts to other parts of the supply chain, including pesticide manufacturers, landowners, farmers, wholesalers, and consumers to name a few. Generally, such distributional effects only reflect the allocation of the economic effect, not the economic effect itself. Similarly, the assessment assumes no spillover effects to neighboring fields. As noted above, attempts to control pests on one field often has spillover effects on neighboring fields.

For this assessment, most pesticides available for specialty crops are available because of the IR-4 Project. With added review and constraints on pesticide use under FQPA, the dependence on the IR-4 Project for minor use registration is even more relevant. The channel of economic effect is then the food crop loss mitigated by pesticide options afforded by IR-4 Project-supported registrations. In quantifying productivity of pesticide use, Jorgenson and Gollop [5] noted significant declines in agricultural productivity following the recall of DDT. Knutson *et al.*, [4] estimated that a total ban on pesticide use in the U.S., including on row crops, would likely result in a cost of $41 billion per year in higher food costs and lower quality crops and livestock. Fernandez-Cornejo *et al.* [21] provided the most comprehensive review of existing studies, showing a wide range of economic impact estimates associated with pesticide use [24].

There are many approaches used for estimating the effectiveness of pesticides and their net economic effects. Different approaches can produce different estimates [46, 48], though researchers have largely established best practices for estimating the contributions of pesticides to agricultural production and the economy [45]. Because it is difficult to generalize the economic contribution of pesticide use, researchers have turned to meta-analysis approaches to estimating impacts. Meta analyses statistically reviews multiple pesticide- and crop-specific studies to form a generalizable estimate of the average return to pesticide use [49]. Using this approach, Zilberman *et al.* estimated that every dollar spent on pesticide expenditure raises gross agricultural output by three to six dollars [50], while Pimentel *et al.* estimates that aggregate crop losses without pesticides would total about 37 percent of output [25]. In their survey, Fernandez-Cornejo *et al.* found that the return per dollar spent on pesticide applications ranged from $0.11 to $11.90 with a mean of $3.66 [21].

The economic direct effects estimate for the Food Crop Program is, accordingly, based on a $3.66 return to specialty food crop growers for every dollar spent on pesticides. Estimating the total direct effect requires multiplying the total specialty food crop expenditures on pesticide by this simple rate of return to get the average expected benefits of pesticide use facilitated by the IR-4 Project Food Crop Program. There are no government reported statistics that provides an estimate of the amount specialty food crop growers spend on pesticides. So, to estimate total expenditures, we turn to the national social accounting matrix [51]. The national social accounting matrix shows that agrochemical purchases make up about four percent of the value of specialty food crop sales, or about $1.96 billion annually and is comparable with 2017 USDA estimates, which assert that total farm expenditures on all chemicals made up just under five percent of total farm expenditures [6]. Given that the U.S. purchases of pesticides is estimated at $15 billion, this estimate suggests that specialty food crop use of pesticides commands thirteen percent of the total annual sales of pesticides in the U.S. We assume 60 percent of the $1.96 billion in specialty food crop uses of pesticide is attributed to the IR-4 Project. Assuming a $3.66 return to every one dollar spent on pesticides, we anticipate that the total direct economic contribution of pesticide use facilitated by the IR-4 Project to be around $4.31 billion in specialty food crop net output, or just under 10 percent of the farmgate value of specialty food crops in 2017 [6].

Environmental Horticulture Program Direct Effects

Environmental horticulture is the production of plants for ornamental use in constructed environments, both indoors and outdoors. Generally, this is made up of ornamentals and short rotation woody crops. The ornamental crop industry makes up a key component of specialty crop agriculture and like specialty food crops, occupies an important segment of minor uses of existing pesticides. They include floriculture and nursery crops, where floriculture crops include bedding and garden plants, cut flowers, potted flowering plants, indoor foliage plants, and cuttings and other prefinished plants sold to other growers to raise for final sale. They also include food crops grown under protection, vegetable and flower seeds, and aquatic plants. The USDA 2019 Census of Horticulture Specialties [52] estimates total annual sales of commercial horticulture producers to be $13.78 billion. Estimating environmental horticulture sales requires subtracting out food crops, tobacco transplants and several others totaling $2.4 billion, resulting in about $11.38 billion in annual environmental horticulture sales.

Like specialty food crops, the limited number of acres allocated to each horticulture crop limits the market potential for pesticide companies. Accordingly, commercial horticulture producers turn to the IR-4 Project to assist in registering existing and new pesticides for horticulture uses. We make a similar assumption outlined for the Food Crops Program that about 60 percent of current pesticide options would not be available in the absence of the IR-4 Project. This subjects the Environmental Horticulture Program direct effect estimate to the same degree of risk in overstating the true economic contribution of the IR-4 Project. However, like before, given the rigidities set out in the FQPA, this assertion may not be unrealistic. We concede it represents a potential overstatement of overall effects, to the extent that pesticide options exist outside of the ones provided by the Environmental Horticulture Program.

Unlike food crops, there are few studies exploring the economic return to pesticide use for horticulture crops. Therefore, we assume the estimate of the net production return is the same $3.66 return per dollar of pesticide use applied to the Food Crops Program. Additionally, governmental reporting agencies do not report on the total pesticide expenditures of horticulture operations. Hence, we use the social account matrix to trace horticulture transactions for pesticides and infer total agricultural chemical purchases for horticulture. The resulting estimate suggests that horticulture producers expend about 2.0 percent of total receipts on pesticides, or about $230.5 million per year. Hence, about $138.3 million (60%) in horticulture crop expenditures on pesticides can be attributed to the IR-4 Project. Applying the net productivity factor to this suggests that crop losses mitigated by commercial environmental horticulture production total about $506.2 million per year.

Biopesticide Regulatory Support Direct Effects

The biopesticide segment is the fastest growing segment of the pesticide industry. Global sales have reached $4.4 billion and it is expected to reach $10.6 billion by 2027 [53]. The U.S. market is the largest single segment [54] and makes up about $2.1 billion of the global market for biopesticides [55]. A significant proportion of biopesticides are used by fruit and vegetable crop growers, making up about 80 percent of this use [56]. The remaining share is taken up by row crops, where significant growth is projected [57], as well as forestry applications, and in greenhouses and nurseries [58, 59].

Biopesticides are derived from natural sources and fall into two categories, microbial and biochemical. Microbial biopesticides are living organisms that compete or repel targeted pests, while biochemical biopesticides are naturally occurring compounds that repel or kill targeted pests. Biopesticide use is mostly associated with organic crops, but it is also a viable option for conventional crops, as they provide a niche option for those cases where lower toxicity of pesticide application is required. They also provide added flexibility to conventional agrochemical uses in managing resistance. Biopesticides are highly targeted to specific pests and while they can be quite effective, they require more effort and planning on behalf of the grower to reach optimal efficacy. Hence, being effective in one setting may not necessarily imply effectiveness in another.

Because of the wide and targeted applications of biopesticides, there is not a clear consensus on the industry-wide return to the biopesticide industry or use of biopesticides. The limited parameters for which biopesticides are applicable suggests that the overall contribution may be lower than that of chemical pesticides. Alternatively, as biopesticides are most commonly applied to higher value organic crops, the actual economic productivity impacts may be relatively large. Hence, there is limited bases to inferring whether the rate of return to biopesticides exceed or trail that of conventional chemical pesticides. Because of all the additional factors that go into biopesticide uses, we forgo the prior rate of return estimate of $3.66 per dollar in favor of a much more conservative return of $1.50 for every one dollar spent. This lower estimate accounts for the uncertainty and recognizes that there is reason to suspect economic efficacy of biopesticides may be more limited to that of chemical pesticides.

The USDA 2019 Organic Survey estimates that organic crop sales, including food and non-food crops, totaled $5.79 billion in 2019 [60]. While biopesticide use is not limited to organic crop production, this provides a benchmark for our estimates. While U.S. biopesticide purchases total $2.1 billion [55], we should note that not all biopesticides purchased will be for agricultural uses, though we can safely conjecture that at least 50 percent of sales goes to agricultural uses. Taking this conservative option, we model agricultural uses as 50 percent of the total value of biopesticide sales. Hence, of the $2.1 billion in annual sales, we conjecture that $1.05 billion is applied to organic crops. Should the rate of return be a conservative $1.50 for every dollar spent, we can estimate that the net contribution to organic production is approximately $1.58 billion through productivity enhancements and crop damage avoidance.

As pointed out above, there are some caveats with these findings. First, the overall basis for the economic contribution estimates is uncertain and the actual social economic returns may range widely around this point estimate. Also, a true economic impact estimate of Biopesticide Regulatory Support would recognize that growers' decision to place acres in organic crops largely depends on expectations of profitability, and growers would likely grow conventional crops in the absence of profit potential of organic crops. One can argue that the alternative of having no biopesticide option is to go back to conventional crops, but Biopesticide Regulatory Support's share of that decision is not known and outside the scope of this study. On the other hand, if growers do not factor in pesticide management options in their decision to grow organic crops, then the estimates provided here would be an objective assessment of the return to the Biopesticide Regulatory Support function.

Section 18 Direct Effects

The IR-4 Project works with grower organizations and with the EPA and state agencies to get temporary exemptions for minor uses, usually of established pesticides, under emergency conditions. Such exemptions are called Section 18 Emergency Exemptions. Section 18 exemptions can be requested by state or federal agencies under strict guidelines that include a situation that meets the statutory definition of an emergency, and for which a registration is or will be sought for the exempted use. Despite the moniker of emergency exemption, the EPA must be reasonably certain that the use, even under emergency, does not pose a risk to human health, workers or the environment [60]. Therefore, the EPA performs a comprehensive, multi-disciplinary risk assessment of the requested pesticide use that includes dietary risk, occupational risk, and environmental risk before authorizing a Section 18 Emergency Exemption. Though extensive, the review is usually concluded within 50 days of the request [61]. The IR-4 Project assists in the majority of EPA exemptions issued [62], as minor uses make up the majority of such requests. Once issued by the EPA, Section 18 exemptions are valid for a single growing season but may be renewed annually – pending progress toward full registration.

In determining whether an exemption petition meets the statutory definition of an emergency request, the EPA requires a statement of expected economic loss in the absence of the proposed Section 18 exemption. This economic loss statement provides a window into the expected economic contributions of successfully sponsoring a Section 18 exemption and provides a basis for estimating the economic contribution of successfully gaining an emergency exemption. However, caution should be exercised in interpreting the estimated loss mitigations of successful Section 18 filings. Since EPA bases part of their judgment on the potential loss to growers in the absence of the Section 18 exemption, there exists an incentive for applications to inflate the potential loss. However, the EPA will validate the Section 18 package, including the loss avoidance measures [61], providing incentives to curtail inflated loss estimates.

The IR-4 Project maintains a database of successful Section 18 petitions sponsored by the Project. This includes the projected economic losses. Using this database, we calculate an average loss aversion of afforded Section 18 filings sponsored by IR-4 Project (Figure 2). The passage of FQPA was especially disruptive to minor uses, where few options existed and the removal of key pesticides rendered many specialty crop growers without effective control of crucial pest pressures [63]. This is reflected in Figure 2, where the average expected crop loss in the absence of the petitioned Section 18 exemption declined over time as the industry advanced minor use registrations for the most economically significant pesticide needs first and less imperative registrations later. We extrapolate that trend through 2021 and apply it to the number of Section 18 exemptions issued under sponsorship of the IR-4 Project. The EPA reports the number of Section 18 exemptions issued per year [64], while the IR-4 Project indicated the number sponsored by the IR-4 Project [62]. The trend in average loss aversion per IR-4 Project sponsored exemption and the number of IR-4 Project exemptions over the three-year period of 2019 to 2021 are used to estimate the direct effects of $29.7 million per year in crop loss aversion.

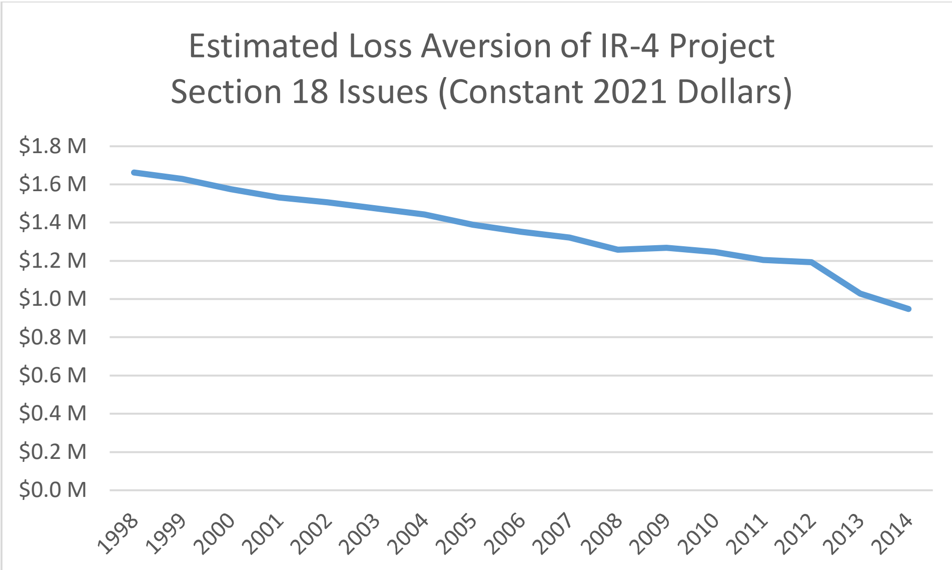


Figure 2: Economic Significance of IR-4 Project Section 18 Filings

The measure of economic direct effects here poses a significant weakness. In this, successful Section 18 petitions are the product of many participants, including the petitioning local regulatory entity petitioning the exemption, industry participants facing economic stress from the said pest pressure, the pesticide manufacturer, the EPA and the IR-4 Project. Others may also play roles. So, when we assert that this economic activity arises because of the IR-4 Project, we must also recognize that without the other partners, these Section 18 impacts would also not be realized. That is, all parties have an equal role in the outcome. Also, we should note that since the passage of FQPA, the number of Section 18 petitions issued by the EPA has declined steadily. We would expect the contribution of future Section 18 support to also decline over time until the next disruptive change in regulation occurs.

Total Effects

As discussed in the Methods section, total effects are modeled based on the direct expenditure or productivity effects detailed in the prior sections. Total effects represent the full scope of economic contributions – entailing all direct, indirect and induced transactions projected by the model. These effects measured in dollar values of sales are also restated in employment and income terms based on fixed ratios of employment and income to industry sales. The resulting estimates are generalizations based on average rates of employment, labor income and contributions to gross domestic product by segment,[2] and conveys a best estimate of such impacts from our estimated direct effects of the IR-4 Project. As productivity impacts implicitly assume that expenditures for all inputs rise in proportion with the value of production, the estimates are objective to the extent that grower expenditures move in proportion with revenues. In most cases, this should be expected.

Modeling results are presented in order of the direct effect estimates in the following sections. As each source of economic contribution is distinct from other sources, the collective economic contribution of the IR-4 Project can be estimated as the simple sum of the component contributions.

[2] The IMPLAN model has 544 segments, representing a significant level of granularity in these estimates.

IR-4 Project Expenditure Total Effects

The direct effects of the IR-4 Project expenditures represent the expenditures that support research and program administration necessary to meet program objectives. Such expenditures include salaries for researchers, student assistants, and other staff as well as the purchase of laboratory and agriculture equipment, seeds and land rents for field trials. It also pays for travel of scientists and representatives to internal and external meetings as well as international representation of U.S. technical issues with trade of agricultural goods, as it relates to common pesticide tolerances and protocols. Such transactions spawn a continuum of secondary transactions that give rise to macroeconomic level of impacts that exceed the direct expenditures as discussed above.

The estimated contributions of the IR-4 Project's expenditures are presented in Table 5, where the direct project expenditures total $17.098 million (Table 3) and supports about one hundred direct jobs. These direct expenditures generate subsequent rounds of expenditures that support another 160 jobs through secondary transactions. The 260 contributed jobs provide about $18.7 million in annual wages and salaries and contribute about $27 million to annual gross domestic product of the U.S.

Impact Type	Employment	Labor Income	Gross Domestic Product
Direct Effect	100	$8.3 Mil	$9.7 Mil
Indirect Effect	60	$4.4 Mil	$6.7 Mil
Induced Effect	100	$6.0 Mil	$10.7 Mil
Total Effect	260	$18.7 Mil	$27.0 Mil

Table 5: Estimated Economic Contribution of IR-4 Project Direct Expenditures

The estimates in Table 5 do not account for other uses of public funds used to support the IR-4 Project. Rather than assert that the estimates represent new expenditures in the economy, we recognize that many of these expenditures would have occurred for other purposes, and that those expenditures would also create a set of secondary transactions, abet amongst a different set of businesses. Rather than conjecture what those expenditures would have gone toward, this assessment follows the gross measures of impact or contributions to the national economy as described above.

Food Crop Program Total Effects

The Food Crop Program estimated direct effects measure the direct change in the productivity of specialty food crops. Expenditures are assigned to each of the specialty food crop commodities in the IMPLAN model based on volume of sales. The model simulation then estimates how those direct effects circulate throughout the economy to generate secondary effects. Estimated economic contributions of productivity enhancements are presented in Table 6. The findings show that the expected increase in specialty food crop sales attributed to IR-4 Project registrations totals $4.31 billion (as calculated in the methods section). This suggests that about 37,700 jobs can be directly attributed to the IR-4 Project Food Crop Program. Once accounting for secondary transactions, food crop productivity enhancements create around 75,300 domestic jobs with $3,593 million in annual contributions to labor income. Collectively, we estimate that the Food Crop Program contributes just over $6.0 billion in annual gross domestic product.

Impact Type	Employment	Labor Income	Gross Domestic Product
Direct Effect	37,700	$1,488.4 Mil	$2,559.9 Mil
Indirect Effect	17,800	$943.9 Mil	$1,418.5 Mil
Induced Effect	19,800	$1,160.4 Mil	$2,057.4 Mil
Total Effect	75,300	$3,592.7 Mil	$6,035.9 Mil

Table 6: Estimated Economic Contribution of IR-4 Project Registrations: Food Crop

Environmental Horticulture Program Total Effects

The IR-4 Project's estimated effects arising from the Environmental Horticulture Program follows a similar logic to that of the Food Crops Program. Improved grower options for pest management and in some cases, having at least one option available to growers is sufficient for creating measurable change in sector output. This has secondary effects as resulting sales are recirculated throughout the economy to generate subsequent transactions. However, given the relatively small size of this segment, overall contributions are smaller than for food crops.

In modeling the economic contributions, industry direct effects are distributed to horticulture commodities based on segment sales. Table 7 shows our estimates based on approximately $506.2 million (Methods section) in industry loss mitigation made available by pesticide uses supported the IR-4 Project. We estimate that horticulture and floriculture producers are able to employ about 4,900 more workers nationwide, because of the increased productivity. Accounting for how the earned dollars recirculate throughout the national economy, we estimate that secondary transactions generate another 4,800 jobs, such that the expected total employment supported by the Environmental Horticulture Program to these sectors is about 9,700. These jobs generate about $456.0 million in annual labor income and contributes about $725.5 million in annual gross domestic product.

Impact Type	Employment	Labor Income	Gross Domestic Product
Direct Effect	4,900	$184.9 Mil	$267.1 Mil
Indirect Effect	2,300	$123.9 Mil	$197.2 Mil
Induced Effect	2,500	$147.2 Mil	$261.2 Mil
Total Effect	9,700	$456.0 Mil	$725.5 Mil

Table 7: Estimated Economic Contribution of IR-4 Project Registrations: Environmental Horticulture

Biopesticide Regulatory Support Total Effects

As noted above, the Biopesticide Regulatory Support effects are not limited to specialty crops, but we use the value of specialty crop use as the basis for estimating the economic contributions of this program. When applied to organic crops, biopesticides make up a system of pest management for both food and ornamental crops. While the total number of acres certified as organic is around 5 percent of the total number of agricultural acres [6, 65], this segment is a high-growth segment and an important focus of the IR-4 Project. In modeling the economic contribution of the Biopesticide Regulatory Support function, we allocate direct effects proportionately over all crop production sectors.

Our estimate suggests that IR-4 Project Biopesticide Regulatory Support supports industry-wide efficiency gains affording additional crop values of about $1.58 billion annually (Methods section). Directly, these efficiency gains generate an estimated 10,300 new jobs (Table 8). Economy-wide contributions, entailing all direct and secondary effects amounts to about 25,700 jobs nationwide with annual income of about

$1.25 billion. Collectively, contributions to this segment can be linked to about a $2.14 billion contribution to annual gross domestic product.

Impact Type	Employment	Labor Income	Gross Domestic Product
Direct Effect	10,300	$393.7 Mil	$710.7 Mil
Indirect Effect	8,600	$452.6 Mil	$716.3 Mil
Induced Effect	6,900	$403.9 Mil	$715.9 Mil
Total Effect	25,700	$1,250.3 Mil	$2,142.9 Mil

Table 8: Estimated Economic Contribution of IR-4 Project Registrations: Biopesticide Regulatory Support

Section 18 Total Effects

Section 18 economic contributions are distinct from other program contributions. The effects are temporary and often precede full EPA registration which provides year over year impacts. Based on typical number of IR-4 Project supported Section 18 issues and projections of the average loss aversion per issue, we estimated that Section 18 support contributes about $31.6 million in crop agricultural impacts (Methods section). Because Section 18 support spans all crop segments, direct contributions are distributed to all crop production segments in proportion to the value of segment sales.

Table 9 shows the estimated economic contribution of Section 18 Emergency Exemptions supported by the IR-4 Project. We anticipate that some two hundred jobs are retained per year with successful Section 18 exemptions. The loss aversion and associated direct jobs retained generates ripples throughout the economy, producing economywide support to about 510 jobs with annual income in the neighborhood of $25 million per year. Aggregating all sources of income, the IR-4 Project support of Section 18 filings is anticipated to contribute about $42.9 million to annual gross domestic product. However, as shown in Figure 2 and reflected in EPA counts of Section 18 filings, there is a tendency for Section 18 support economic contributions to decline over time, and we anticipate those declines to carry into the future until the next major regulatory disruption like that generated by the FQPA.

Impact Type	Employment	Labor Income	Gross Domestic Product
Direct Effect	200	$7.9 Mil	$14.2 Mil
Indirect Effect	170	$9.1 Mil	$14.3 Mil
Induced Effect	140	$8.1 Mil	$14.3 Mil
Total Effect	510	$25.0 Mil	$42.9 Mil

Table 9: Estimated Economic Contribution of IR-4 Project Section 18 Support

Aggregate Estimated Total Effects of the IR-4 Project

Because each of the program areas described above influence industry outcomes in distinct ways, the five contribution estimates can be added to present the overall estimated economic contribution of the IR-4 Project without double counting. Table 10 shows the aggregate economic impacts that sum over the previous impact estimates. Accordingly, the IR-4 Project’s programs are estimated to support about 111,470 jobs with total labor income of $5.34 billion. This includes the collective direct and secondary effects. Based on these estimates, the IR-4 Project collectively adds just under $9.0 billion in annual contributions to gross domestic product.

As discussed above, these estimates leave out some notable sources of economic gains but are representative of the core mission and contributions to the national economy. While notable, additional sources of economic contributions are not included in the estimates. Alternatively, we discussed a few reasons why we may anticipate how the reported estimates may overstate the economic contributions. We conjecture that the risks of overstating economic effects may be equally offset by the risks of understating the effects.

Impact Type	Employment	Labor Income	Gross Domestic Product
Direct Effect	53,210	$2,083.2 Mil	$3,561.6 Mil
Indirect Effect	28,930	$1,533.8 Mil	$2,353.0 Mil
Induced Effect	29,440	$1,725.6 Mil	$3,059.6 Mil
Total Effect	111,470	$5,342.6 Mil	$8,974.2 Mil

Table 10: Estimated Economic Contribution of IR-4 Project

Should we frame these economic contribution estimates as a return on public investment, a simple ratio of the estimated economic contribution to public investment will convey the estimated rate of economic activity realized per dollar of public expenditure. To be sure, the resulting estimate will not be a true benefit cost analysis for several reasons. First, the economic contributions, especially those accruing to industry productivity, is the product of the cumulative effect over many years of industry intervention by the IR-4 Project. Generally, when we think of benefit/cost ratios, we imagine tracing a dollar today, to a given set of outcomes in the future, like the registration of a new pesticide use and the associated year-over-year stream of industry yield gains associated with the use of that new pesticide. Second, we do not discount the expected stream of benefits and costs into the future, which would be required to generate a true rate of return calculation. From this perspective, the current and future stream of costs are not compared with the future expected stream of benefits of those costs. In such, discounting is required to account for differences in timing of the future streams of costs and benefits. However, the current analysis does not trace the value or the timing of expected (or average) industry benefits of a dollar invested in the IR-4 Project today. Rather, the public investment reflects the on-average, or typical public investment per year, against the annual benefits of the accumulative assets for managing pests developed by the IR-4 Project. Finally, the analysis does not provide a true economic impact assessment. A true economic impact assessment measures how much the economy changed because of an institution like the IR-4 Project and would suggest the alternative state of the economy would be without this institution. Because the IR-4 Project is so well established, with a long history and cross-cutting implications, it would be difficult to conjecture the alternative state of the economy in the absence of the IR-4 Project. Rather, this economic contribution analysis measures the extent to which current realized economic activity can be attributed to the past and current existence to the IR-4 Project.

The estimated economics contribution estimates should be interpreted in light of these nuanced constraints. The estimates show that the $15.87 million in direct public support per year is associated with a program that contributes just under $9 billion to annual gross domestic product, or about $565 in gross domestic product per dollar of public investment. Equally, this works out to about seven jobs per $1,000 in public invested. Admittedly, these estimates show what would appear to be unreasonably high estimates of rates of return, but when we recognize economic benefits are cumulated for over 50 years of the IR-4 Project's existence, they do not seem so out of line. That is, registrations supported in the past continue to provide returns today. That is, removing funding from the IR-4 Project today, will not result in the loss of 111,470 jobs (Table 10), as benefits from past activities will continue to be realized in the future.

Summary

This report details the approach and estimated economic contributions of the IR-4 Project through its three program areas and through support for Section 18 Emergency Exemption filings. The Food Crop program is the original impetus of the IR-4 Project, though the Environmental Horticulture Program and Biopesticide Regulatory Support are essential to industry stakeholders. This report explains in economic terms why the IR-4 Project role in developing data to support the registration of safe and effective pest management technology for small market uses is so important. Because of market considerations and regulations, there would be few if any technology approved in these small minor markets. We are careful to note that the EPA function of regulating and restricting the use of pesticides has clear and measurable benefits, but from an economic perspective, pesticide regulations introduce market failures that result in suboptimal economic outcomes. Such shortcomings can be exemplified by cases where specialty crop growers or minor use needs are without viable pest control options, despite the presence of effective pesticides products. The IR-4 Project aims to correct these market-based deficiencies.

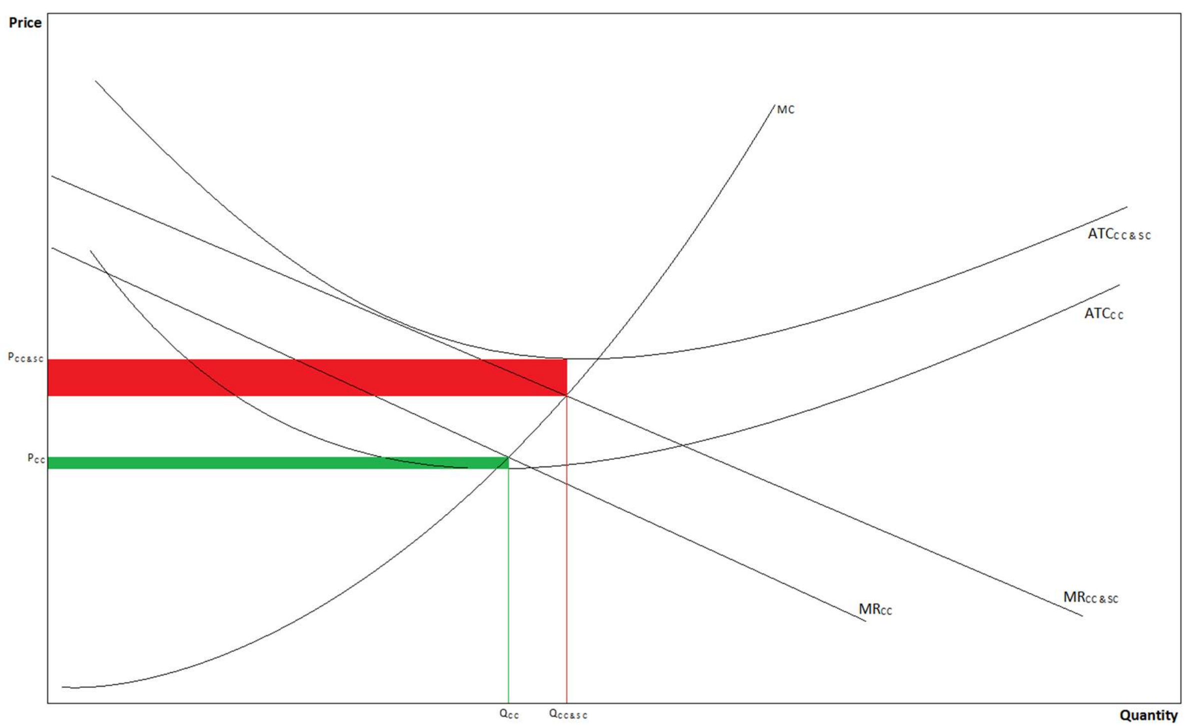
While this report describes and measures the economic contribution of salient services of the IR-4 Project, not all relevant sources of impacts were measured in this assessment. Pesticides are an integral part of the modern food supply and contributes to the general decrease in household expenditure's share on food since the 1960s [66], as well as consumer access to a diverse and healthy diet. Though reducing the cost of consumer access to food frees earnings for other expenditures is sufficient to merit economic value, the resulting food sufficiency and varied diet also improves health and associated economic gains from reduced health-related costs and through a more productive workforce. More directly, the IR-4 Project works in global markets to harmonize data, pesticide registration, MRLs and testing methods to regulating pesticide use, thereby reducing barriers to trade [67]. As the U.S. is a net exporter of agricultural goods, trade liberalization has an asymmetric benefit to U.S. agricultural producers and on the national economy. Other relevant channels to economic impact are explored in the report.

We apply well-established approaches to measuring economic contributions and estimate that the IR-4 Project supports over 111 thousand domestic jobs with total annual payroll of $5.34 billion in 2021 dollars. When accounting for all sources of national income, the IR-4 Project is estimated to contribute $8.97 billion to annual gross domestic product, including direct and secondary effects, which measures how dollars are re-spent throughout the economy. Several channels of economic contribution go into these measures, including direct expenditures of the IR-4 Project, anticipated crop losses mitigated under each of the two IR-4 Programs, through Biopesticide Regulatory Support and through gaining EPA exemptions for pesticide use when few or no other options for pest management exists. Recognizing that benefits realized today come from over 50 years of IR-4 Project efforts, we show that we can attribute about seven jobs today for every $1,000 in annual public investment in the IR-4 Project.

Appendix A§

From an economic perspective, the chemical producer's choice to register for a minor use can be depicted in the accompanying graph. Price is the market-determined selling price, while Quantity is the quantity sold. Under the standard production decision rule, a producer will sell as long as the marginal cost (MC curve) of selling an additional unit is less than or equal to the price they receive. Consumers are willing to buy more at lower prices, as exhibited by the downward sloping marginal revenue curves (MR), derived from downward sloping demand curves. The per-unit profit earned by the producer is determined by the difference between the per-unit costs of production (average total cost (ATC)) and the price received.

Starting with a producer that sells to major crop growers, the decision to register a product for a specialty crop use depends on whether that will enhance total profits. Consider the firm facing a marginal revenue curve from major crop producers, MR_{CC}. This curve meets the upward-sloping marginal cost curve above the average total cost curve providing a profit equal to the shaded green area. Sales can be increased if the registration was expanded for use on a specialty crop. The combined major crop and specialty crop marginal revenue curve is depicted by the line $MR_{CC\,\&\,SC}$. However, because of the limited number of acres allocated to the specialty crop, the potential change in units sold is not significant. Should they choose to pursue this use, the firm will have to undertake field and laboratory tests necessary to meet EPA requirements in determining the health and environmental risks and to assess the pesticide efficacy for the targeted pest. This cost shifts the average total costs up to $ATC_{CC\,\&\,SC}$. Also, increasing production to meet this additional demand, should the registration be granted, will increase the marginal cost of each additional unit along the MC curve. The firm would still produce up to the point that marginal cost is equal to price, indicating a level of output equal to $Q_{CC\,\&\,SC}$. However, at this point, the average total cost per unit exceeds the selling price buyers are willing to pay, and the firm will incur losses. The outcome is that the firm will not pursue the specialty crop registration.



§ Largely derived from Miller, Steven R., and John T. Mann. 2017. The Economic Impact of the IR-4 Project and Programs. East Lansing: Michigan State University.

Appendix B

	Field Crops ($000s)	Specialty Crops ($000s)	Total Crop ($000s)	Percent Specialty Crops (%)
Nation	121,924,722	71,621,978	193,546,699	41%
ALABAMA	717,822	494,507	1,212,329	51%
ALASKA	815	22,799	23,614	77%
ARIZONA	542,690	1,405,905	1,948,594	77%
ARKANSAS	3,458,874	166,054	3,624,928	6%
CALIFORNIA	2,039,870	31,313,964	33,353,833	95%
COLORADO	1,415,700	823,162	2,238,862	46%
CONNECTICUT	44,488	375,555	420,043	91%
DELAWARE	235,713	89,944	325,656	28%
FLORIDA	475,542	5,228,991	5,704,533	98%
GEORGIA	1,536,097	1,735,844	3,271,941	66%
HAWAII	83,475	330,014	413,489	79%
IDAHO	1,510,279	1,699,846	3,210,125	67%
ILLINOIS	13,295,037	548,706	13,843,743	4%
INDIANA	6,783,106	337,954	7,121,060	5%
IOWA	13,597,857	234,717	13,832,573	2%
KANSAS	6,247,135	213,303	6,460,437	5%
KENTUCKY	2,319,067	221,689	2,540,755	13%
LOUISIANA	1,649,986	389,130	2,039,115	29%
MAINE	38,654	370,186	408,839	96%
MARYLAND	598,593	349,534	948,126	39%
MASSACHUSETTS	20,438	339,551	359,988	96%
MICHIGAN	2,755,840	1,888,412	4,644,252	44%
MINNESOTA	9,171,353	1,020,165	10,191,517	13%
MISSISSIPPI	2,064,313	227,577	2,291,889	12%
MISSOURI	5,156,883	319,434	5,476,316	8%
MONTANA	1,336,394	248,443	1,584,837	26%
NEBRASKA	9,036,213	274,795	9,311,008	4%
NEVADA	129,632	145,143	274,775	93%
NEW HAMPSHIRE	12,147	95,656	107,802	96%
NEW JERSEY	106,021	878,509	984,530	91%
NEW MEXICO	228,798	421,937	650,734	76%
NEW YORK	753,159	1,345,706	2,098,864	72%
NORTH CAROLINA	2,324,426	1,410,555	3,734,980	41%
NORTH DAKOTA	6,253,368	427,231	6,680,598	9%
OHIO	4,649,827	776,425	5,426,252	16%
OKLAHOMA	1,189,819	326,933	1,516,751	28%
OREGON	733,945	2,549,410	3,283,355	90%
PENNSYLVANIA	1,197,282	1,584,046	2,781,328	63%
RHODE ISLAND	927	39,983	40,910	99%
SOUTH CAROLINA	616,978	479,266	1,096,244	51%
SOUTH DAKOTA	5,064,462	102,095	5,166,557	3%
TENNESSEE	1,697,067	485,330	2,182,397	26%
TEXAS	5,144,287	1,750,021	6,894,307	30%
UTAH	230,061	330,897	560,957	84%
VERMONT	66,883	120,213	187,095	91%
VIRGINIA	757,198	593,236	1,350,434	49%
WASHINGTON	1,437,440	5,530,167	6,967,607	86%
WEST VIRGINIA	61,677	90,253	151,930	75%
WISCONSIN	2,919,653	1,147,785	4,067,437	32%
WYOMING	213,206	104,306	317,511	62%

Source: USDA, N.A.S.S., *2017 Agricultural Census*. 2019, USDA, National Agricultural Statistics Services: Washington, DC.

Bibliography

1. U.S. Environmental Protection Agency. *About Pesticide Registration*. 2022 February 15, 2022]; Available from: https://www.epa.gov/pesticide-registration/about-pesticide-registration.
2. Zeballos, E. and W. Sinclair. *Budget share for total food dropped by 10 percent in 2020, a new historical low*. 2021 February 8, 2022]; Available from: https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=76967.
3. Pimentel, D., et al., *Benefits and Costs of Pesticide Use in U.S. Food Production.* BioScience, 1978. **28**(12): p. 772-784.
4. Knutson, R.D., et al., *Economic Impacts of Reduced Pesticide Use.* Choices, 1990. **5**(4): p. 25-31.
5. Jorgenson, D.W. and F.M. Gollop, *Productivity growth in US agriculture: a postwar perspective.* American Journal of Agricultural Economics, 1992. **74**(3): p. 745-750.
6. USDA, N.A.S.S., *2017 Agricultural Census*. 2019, USDA, National Agricultural Statistics Services: Washington, DC.
7. Oerke, E.-C., *Crop losses to pests.* The Journal of Agricultural Science, 2006. **144**(1): p. 31-43.
8. Norton, J.A., *A Review of Methyl Bromide Alternatives Evaluated By IR-4*, in *International Conference on Methyl Bromide Alternatives and Emission Reductions*. 2005: San Diego, CA.
9. IR-4 Project, *Pest Management Solutions for Specialty Crops and Specialty Uses*, I.-. Project, Editor. 2022, North Carolina State University: Raleigh, NC.
10. Miller, S. and A. Leschewski, *Economic impacts of the IR-4 project and IR-4 project programs.* East Lansing: Center for Economic Analysis, Michigan State University, 2012.
11. Heiss, J. *The IR-4 Project Completes Transition to NC State University*. 2021 January 24, 2022]; Available from: https://www.ir4project.org/news/ir-4-completes-transition-to-ncstate/#:~:text=The%20IR%2D4%20Project%20has,to%20NC%20State%20in%202019.
12. Baron, J., et al., *The IR-4 Project Over 50 Years of Sustained Success.* Outlooks on Pest Management, 2016. **27**(1): p. 10-25.
13. The IR-4 Project, *Annual Report 2016*. 2017, Rutgers University: New Brunswick, NJ.
14. U.S. Environmental Protection Agency, *Report on Minor Uses of Pesticides*. n.d., Environmental Protection Agency: Washington, DC.
15. IR-4 Project, *Helping Growers Find Solutions: Annual Report of the IR-4 Project*. 2019, North Carolina State University: Raleigh, NC.
16. Project, I.-. *About Environmental Horticulture*. N.D. January 27, 2022]; Available from: https://www.ir4project.org/ehc/.
17. Farm Bureau, *Do Trade Programs Affecting Specialty Crops Need to be Altered?*, in *Farm Bureau 2018 Farm Bill*. 2016, Farm Bureau: Washington, DC.
18. USDA, E.R.S. *U.S. Agricultural trade Data Update*. 2017 September 7, 2017 September 19, 2017]; Available from: https://www.ers.usda.gov/data-products/foreign-agricultural-trade-of-the-united-states-fatus/us-agricultural-trade-data-update/.
19. Miller, S.R. and A. Leschewski, *The Economic Impact of the Minor Use Pesticide Program: Pest Management Centre, Agriculture and Food Canada*. 2011, Michigan State University: Center for Economic Analysis: East Lansing.
20. Fernandez-Cornejo, J., *The microeconomic impact of IPM adoption: theory and application.* Agricultural and resource economics review, 1996. **25**(2): p. 149-160.
21. Fernandez-Cornejo, J., S. Jans, and M. Smith, *Issues in the economics of pesticide use in agriculture: a review of the empirical evidence.* Review of agricultural economics, 1998. **20**(2): p. 462-488.

22. Yen, S.T., et al. *Demand for differentiated vegetables*. in *Selected Paper Prepared for Presentation at the American Agricultural Economics Association Annual Meeting, Denver, Colorado. August*. 2004.
23. You, Z., J.E. Epperson, and C.L. Huang, *A composite system demand analysis for fresh fruits and vegetables in the United States.* Journal of Food Distribution Research, 1996. **27**: p. 11-22.
24. Miller, S.R. and J.T. Mann, *The Economic Impact of the IR-4 Project and Programs*. 2017, Michigan State University: East Lansing.
25. Pimentel, D., et al., *Environmental and economic effects of reducing pesticide use.* BioScience, 1991. **41**(6): p. 402-409.
26. Doran, J.W., *Soil health and global sustainability: translating science into practice.* Agriculture, Ecosystems & Environment, 2002. **88**(2): p. 119-127.
27. Tabashnik, B.E., *Managing resistance with multiple pesticide tactics: theory, evidence, and recommendations.* Journal of Economic Entomology, 1989. **82**(5): p. 1263-1269.
28. Pecenka, J.R., et al., *IPM reduces insecticide applications by 95% while maintaining or enhancing crop yields through wild pollinator conservation.* Proceedings of the National Academy of Sciences, 2021. **118**(44): p. e2108429118.
29. USDA. *MyPlate*. 2017 October 18, 2017]; Available from: https://www.fns.usda.gov/tn/myplate.
30. Retzlaff-Roberts, D., C.F. Chang, and R.M. Rubin, *Technical efficiency in the use of health care resources: a comparison of OECD countries.* Health Policy, 2004. **69**(1): p. 55-72.
31. Gundgaard, J., et al., *Increased intake of fruit and vegetables: estimation of impact in terms of life expectancy and healthcare costs.* Public health nutrition, 2003. **6**(1): p. 25-30.
32. Boles, M., B. Pelletier, and W. Lynch, *The Relationship Between Health Risks and Work Productivity.* Journal of Occupational and Environmental Medicine, 2004. **46**(7): p. 737-745.
33. IR-4 Project, *IR-4 Project: 2020 Annual Report*. 2021, North Carolina State University: Raleigh, NC.
34. Holm, R.E., *The IR-4 Program: Meeting the U.S. minor crop pest control challenge.* Phytoparasitica, 2003. **31**(3): p. 213-216.
35. Bureau of Labor Statistics. *Median weekly earnings by educational attainment in 2014*. TED: The Economics Daily 2015 October 10, 2017]; Available from: https://www.bls.gov/opub/ted/2015/median-weekly-earnings-by-education-gender-race-and-ethnicity-in-2014.htm.
36. IR-4 Project, *Annual Report*. various, Rutgers University: New Brunswick, NJ.
37. Minnesota IMPLAN Group, I., *User's Guide: IMPLAN Pro. Version 2.0*. 2004, Stillwater, MN: Minnesota IMPLAN Group, Inc.
38. Bureau of Economic Analysis. *Input-Output Accounts Data*. 2017 October 3, 2017]; Available from: https://www.bea.gov/industry/io_annual.htm.
39. Headley, J.C., *The Economics of Pest Management*, in *Introduction to Insect PestManagement*, R.L. Metcalf, Editor. 1975, John Wiley & Sons: New York, NY. p. 75-99.
40. Coughlin, C.C. and T.B. Mandelbaum, *A consumer's guide to regional economic multipliers.* Federal Reserve Bank of St. Louis Review, 1991. **73**(January/February 1991).
41. Richardson, H.W., *Input-Output and Regional Economics*. 1972, New York: Halsted Press.
42. Richardson, H.W., *Input-Output and Economic Base Multipliers: Looking Backward and Forward.* Journal of Regional science, 1985. **25**(4): p. 607-661.
43. Bureau of Labor Statistics, *Consumer Price Index*, United States Department of Labor, Editor. 2021: Washington, DC.
44. Chojnacki, K., *Personal Communication*, S.R. Miller, Editor. 2022.
45. Frisvold, G.B., *How low can you go? Estimating impacts of reduced pesticide use.* Pest management science, 2019. **75**(5): p. 1223-1233.

46. Carpentier, A. and R.D. Weaver, *Intertemporal and interfirm heterogeneity: implications for pesticide productivity.* Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie, 1996. **44**(3): p. 219-236.
47. Norwood, F.B. and M.C. Marra, *Pesticide productivity: Of bugs and biases.* Journal of Agricultural and Resource Economics, 2003: p. 596-610.
48. Saha, A., C.R. Shumway, and A. Havenner, *The economics and econometrics of damage control.* American Journal of Agricultural Economics, 1997. **79**(3): p. 773-785.
49. Alston, J.M., et al., *A meta-analysis of rates of return to agricultural R&D: Ex pede Herculem?* Vol. 113. 2000: International Food Policy Research Institute.
50. Zilberman, D., et al., *The economics of pesticide use and regulation.* Science(Washington), 1991. **253**(5019): p. 518-522.
51. IMPLAN Group LLC. *Introducing the Social Accounting Matrix (SAM)*. 2015 October 3, 2017]; Available from: http://support.implan.com/index.php?option=com_content&view=article&id=290:290&catid=228:228.
52. USDA, N.A.S.S., *2019 Census of Horticultural Specialties*. 2021, USDA: Washington, DC.
53. Fortune Business Insights. *Agricultural Biologicals/Biopesticides Market*. Market Research Report 2020 February 8, 2022]; Available from: https://www.fortunebusinessinsights.com/industry-reports/biopesticides-market-100073.
54. Samada, L.H. and U.S.F. Tambunan, *Biopesticides as promising alternatives to chemical pesticides: A review of their current and future status.* OnLine Journal of Biological Sciences, 2020. **20**: p. 66-76.
55. Market Data Forecast. *North America BioPesticide Market*. 2021 February 8, 2022]; Available from: https://www.marketdataforecast.com/market-reports/north-america-bio-pesticide-market.
56. Alexander, L., *Biopesticides by the Numbers*, in *Biopesticides Primed for Growth*, Certis USA, Editor. 2014, Certis: Columbia, MD.
57. Pucci, J., *Biopesticides Move into Row Crop Territory: Suppliers see Big Opportunities Beyond the Specialty Crop Markets*, in *Biopesticides Primed for Growth*, Certis USA, Editor. 2014, Certis: Columbia, MD.
58. Baron, J., *Personal Communications*. 2017.
59. Hodges, A.W., et al., *Production and marketing practices and trade flows in the United States green industry in 2013.* Journal of Environmental Horticulture, 2015. **33**(3): p. 125-136.
60. U.S. Environmental Protection Agency. *Pesticide Emergency Exemptions*. 2022 February 9, 2022]; Available from: https://www.epa.gov/pesticide-registration/pesticide-emergency-exemptions.
61. U.S. Environmental Protection Agency. *FIFRA Section 18: Pesticide Emergency Exemptions* 2006 August 18th April 25, 2007]; Available from: http://www.epa.gov/opprd001/section18/.
62. Baron, J., *Personal Communication*. 2022.
63. Whalon, M.E., et al., *Agricultural Impact of The Sudden Elimination of Key Pesticides Under the Food Quality Protection Act*, in *Issues Paper*. 1999, Council For Agricultural Science and Technology.
64. U.S. Environmental Protection Agency. *Emergency Exemption Database*. 2021 January 12, 2022]; Available from: https://ordspub.epa.gov/ords/pesticides/f?p=section18.
65. USDA, N.A.S.S., *2019 Organic Survey*. 2020, USDA: Washington, DC.
66. Damalas, C.A., *Understanding benefits and risks of pesticide use.* Scientific Research and Essays, 2009. **4**(10): p. 945-949.

67. Gomes, H.d.O., et al., *A socio-environmental perspective on pesticide use and food production.* Ecotoxicology and Environmental Safety, 2020. **197**: p. 110627.