Pesticide Use and IPM Adoption: Does IPM Reduce Pesticide Use in the United States?

Authors

Jason Maupin
Virginia Tech
Department of Agricultural and Applied Economics
jdmaupin@vt.edu

George Norton
Virginia Tech
Department of Agricultural and Applied Economics
gnorton@vt.edu

Selected Paper prepared for presentation at the Agricultural & Applied Economics Association 2010 AAEA, CAES, & WAEA Joint Annual Meeting, Denver, Colorado, July 25-27, 2010

Pesticide Use and IPM Adoption: Does IPM Reduce Pesticide Use in the United States?

Abstract

In 2001, the United States General Accounting Office issued a report entitled "Management Improvements Needed to Further Promote Integrated Pest Management." This report documents that overall agricultural pesticide usage increased from 1992 to 2000 while the use of the most toxic levels of pesticides have decreased. The USDA suggests that these changes in pesticide use could have been caused by integrated pest management (IPM) adoption. However, the GAO maintains that there is not enough evidence to support this claim. This paper contributes to this debate by estimating the relationship between pesticide use and IPM practices adopted for number of commodities across the nation from 1996 to 2005. The paper exploits an aggregated data set that combines surveys from different crops and different years, but it also examines specific surveys conducted on cotton and corn crops to better control for other factors that could affect pesticide use. The paper applies multiple definitions of IPM and uses different spatial variables to control for environmental effects that affect pesticide use. Although some specific strategies such as GM adoption decreased the amount of active ingredients sprayed on cotton and corn, the results suggest that on average the adoption of IPM strategies lead to slightly increased pesticide spending and pounds of active ingredient sprayed per acre. This result is confirmed in both the analysis on the aggregated data as well as the analysis of the cotton and corn data. The results also suggest that fixed environmental factors explain a significant amount of chemical spending and pesticide use in the United States. The significance of these factors demonstrates the importance of research and programs that aid farmers in making intelligent pesticide use decisions at the local level.

Keywords: Pesticide Use, Integrated Pest Management, Corn Production, Cotton Production

Acknowledgements

We gratefully acknowledge funding support from USDA/CSREES through the Southern Region IPM program without implicating them in any errors or omissions.

We thank Bob Dubman at ERS, Brad Summa at NASS, Dave Mueller and Herman Ellison and the Virginia Field Office of NASS for assistance in obtaining access to the ARMS data.

We also thank Jeff Alwang, Dan Taylor, Chris Parmeter, Jaren Pope and seminar participants at the Sixth Annual IPM Symposium for helpful comments. All remaining errors and omissions remain our own.

Introduction

Since the 1970s, government officials, university researchers, and extension specialists have worked together under the umbrella of integrated pest management (IPM) to establish and implement improved pest management practices. These practices are designed to provide economic benefits and reduce environmental and health risks. The national impacts of IPM on environmental and health risks have been called into question by federal officials. The United States General Accounting Office (GAO) (2001) used data from the Environmental Protection Agency (EPA) and the Center for Food and Agricultural Policy data to demonstrate that overall agricultural pesticide use (measured by pounds of active ingredient) increased between 1992 and 2000. The report found that the use risky pesticides as defined by EPA's risk classifications in agriculture decreased, but it concluded that the evidence is insufficient to support the USDA's claim that this reduction is due to IPM. The report cited EPA officials who suggest that changes in pesticide use could be due to EPA's ban on some of the most toxic pesticides, discontinuation of certain pesticides due to liability concerns, and lack of efficacy of some risky pesticides due to pest resistance. This suggestion is supported by a survey of United States IPM coordinators, the majority of whom felt that the decline in risky pesticide use was due primarily to EPA regulatory action and business decisions by pesticide companies to withdraw risky and ineffective pesticides from the market (Ratcliffe and Gray, 2004). The EPA also suggested that the introduction of GM crops has reduced the reliance on the most toxic pesticides, although the report does not recognize that the adoption of GM crops can be a component of an IPM strategy (Kogan, 1998).

Pesticide use depends on a multitude of factors that change yearly and a simple comparison across years may not accurately reflect true trends in pesticide use. For example, USDA Agriculture Chemical Use Survey data on total pesticide use per acre in bell peppers from 1992 to 2006 and plotted in Figure 1. The graph demonstrates that there has been no distinguishable trend in pesticide use in bell peppers over that period. Pesticide use on peppers in 1992 was higher than it was in 2006, but in 2002 and 2004 pesticide use was higher than it was in 1992. No inference can be made about a long-term trend in pesticide use on bell peppers. This example is not unique to peppers but applies to aggregate pesticide use as well (Figure 2) (Osteen and Livingston, 2006).

It is difficult to draw inferences about pesticide use from a simple comparison of overall usage in two time periods. Pesticide use depends on a number of factors and fluctuates heavily over time due to factors such as weather and pest pressures, and to management practices such as the adoption of new technologies (Norton and Mullen, 1994).

National IPM leaders responded to the GAO report by developing a National Roadmap for IPM. The Roadmap calls for documenting how pesticide use has changed over time and for connecting these changes to IPM adoption. This paper responds to that call by assessing the effects of IPM practices on farmer pesticide use for a number of crops in the United States. It also examines the decline in risky pesticide use was due to pesticide bans, pesticide company decisions to withdraw certain pesticides, and the adoption of GM crops.

Motivation

Pesticides have helped the world meet growing food demand by increasing agricultural productivity and reducing the effects of pest outbreaks. Unfortunately, chemical pesticides also cause adverse environmental and health impacts. Starting with Rachel Carson's *Silent Spring* in 1962 that alerted the public to pesticides' damaging effect on birds through more recent studies that suggest the link between pesticides and human maladies such as asthma and autism, pesticide risks have been scientifically demonstrated and brought to the public's attention (Kogan, 1998; Delaplane, Roberts, et al., 2007; Zilberman, et al., 1991). Several researchers have calculated the costs of banning or partially banning the use of some or all pesticides, and found that the burden in terms of increased food costs and other welfare measures would be substantial (Fernandez-Cornejo, et al., 1998; Zilberman, et al., 1991; Burton Jr and Martin, 1987) . The positive and negative aspects of pesticide use create a tradeoff that all pesticide users and pesticide regulators face when they make decisions about pesticides.

In recognition of this tradeoff, researchers since the 1970s have developed IPM programs that specifically address this economic-environmental dilemma (Kogan, 1998; Fitzner, 2002). IPM programs seek to account for economic benefits and environmental costs by combining biological, cultural, and chemical pest control techniques to reduce pest infestation to economically acceptable levels (Gianessi and Puffer, 1992). These programs aim to improve both the economic well-being of adopters while also reducing environmental and health risks. IPM was founded on the premise that many pesticide users overspray chemical pesticides to the detriment of both the environment and their own incomes (Fitzner, 2002). This dangerous overuse of pesticides has been commonly found in agriculture, and other areas as well. It has led researchers to create IPM programs for numerous commodities, locations, and target populations. For example, recently-developed IPM programs have focused on low-income urban households who face cock-roach infestations that lead to asthma attacks and school buildings where it was found that overuse of pesticides could put children at risk (Spengler, et al., 2005). Unfortunately, the impacts of these recent programs are difficult to quantify due to their relative newness and the lack of non-agricultural pesticide use data. For these reasons, this study focuses on agricultural pesticide use.

IPM Definitions

Despite the proliferation of IPM programs over the past thirty years, IPM continues to be difficult to define very precisely (Royer, et al., 1999; Fitzner, 2002). IPM programs typically involve multiple practices and can be adopted to varying degrees. One way to describe IPM is as a "way of thinking." Theodore Alter describes IPM this way: "IPM is a holistic way of thinking that improves our ability to mitigate the negative impacts of pests in agricultural production, horticulture, buildings and other situations, while at the same time reducing costs and improving environmental quality." (Burlingame, 2002) (pg. 2) This description highlights the fact IPM involves an economic-environmental tradeoff in managing pest problems. It also demonstrates that IPM is a broad concept that is not easily quantifiable.

Researchers use broad categories of individual practices to help conceptualize IPM. For example, some common groups of practices used in IPM programs are prevention, avoidance, monitoring, and suppression practices (PAMS). Prevention practices include water management practices and cleaning farm tools after fieldwork. Avoidance practices include adjusting planting and harvest dates and adopting pest-resistant crop varieties (including GM varieties) to minimize the likelihood of a pest infestation. Monitoring practices include scouting for pests and keeping written records to track pest populations. Suppression practices include using biological pesticides, alternating pesticides with different mode of actions (MOA), and using other non-chemical methods such as introducing beneficial insects. Another classification separates IPM practices into biological, cultural, and pesticide efficiency practices (Fernandez-Cornejo and Ferraioli, 1999). In this classification system, biological practices include using natural enemies, resistant varieties and biological pesticides, cultural practices include pruning and tillage methods, and pesticide-efficiency practices include scouting pest populations and using economic thresholds. The exact practices recommended by specific IPM programs depend on each practices' effectiveness which differs between crops and locations. These broad categories help better define IPM, but they do not solve all the problems related to measuring IPM adoption. The research presented in this paper uses multiple definitions of IPM in an effort to circumvent some of these problems.

Previous Literature

Many national and state resources have been used to develop IPM programs and support IPM adoption, but as the GAO report documents, national effects of IPM on the environment, human health, and income remain uncertain. However, many localized impact assessments of IPM have reported positive environmental and health benefits. Norton and Mullen (1994) review 61 economic evaluations of IPM programs in the United States and found that IPM adoption leads to "generally lower pesticide use, production cost, and risk, and higher net returns to producers" (Norton and Mullen, 1994). Fernandez-Cornejo and Rakshit (2007) examine more recent IPM impact studies, both national and international, and reach similar conclusions. The GAO report itself discusses the success of a West Coast apple and pear IPM program and a Wisconsin potato IPM program at reducing risky pesticide use, but concludes these studies do not provide sufficient evidence to suggest that IPM has made a significant impact at the national level. Some individual IPM studies have documented no change or a slight increase in pesticide use, but the majority of studies document a positive effect of IPM on the environment through reduced pesticide use. The challenge is to aggregate these studies to determine the national level impacts of IPM on the environment, health, and economic wellbeing.

There is circumstantial evidence that IPM has been successful at meeting these goals. The widespread growth in IPM adoption, both domestically and internationally over the last thirty years, suggests that IPM has been successful at the very least in convincing adopters and policymakers that it is beneficial to the environment and to adopters. One recent report reviews pesticide reduction alternatives and recommends to the Natural Resources Conservation Service (NRCS) that IPM programs be further developed and given additional resources (Hamerschlag, 2007). The report concludes "Integrated pest management, or IPM, can provide effective crop protection while minimizing risk to health and the environment. These smarter, prevention-based pest control practices can avoid resistance problems that occur with traditional pesticides and may reduce overall costs by lowering chemical inputs, reducing liability and worker injuries, and improving public relations (Hamerschlag, 2007)." The GAO report also mentions that several food processors encourage their growers to use IPM practices because it reduces processing costs. The anecdotal nature of most of the evidence supporting IPM does not satisfy the demand by the GAO or national IPM leaders for national impact assessments on how IPM has affected pesticide use in the United States. As Norton and Mullen (1994) state, “These (aggregate) assessments are needed for informed choices on policies and public investments affecting IPM.”

There have been attempts to assess the aggregate benefits of IPM. Resosudarmo (2001) uses a general equilibrium model to determine the economic impacts of IPM in Indonesia. He concludes that IPM has created significant and widespread increases in incomes and has improved health for Indonesians. Others have used general equilibrium models to determine the impacts of other technologies such as GM rice nationally and internationally (Hareau, et al., 2006). General equilibrium models can be useful for national impact assessments, but their data requirements and strong assumptions make them difficult to implement in an economy as large and interdependent as the United States (Resosudarmo, 2001). These models also do not address pesticide usage directly, but instead present monetary benefits, making it difficult to address the specific issue of actual pesticide use.

Fernandez-Cornejo (1996) uses another technique to examine the impact of IPM on pesticide use and farm profits. He develops and applies a model that accounts for the self-selectivity involved in the IPM adoption decision, and the simultaneity between IPM adoption and the farmers’ profit maximization problem when deciding on the amount of pesticides to use on the farm. Fernandez-Cornejo (1996; 1998) and Fernandez-Cornejo and Ferraioli (1999) applies this technique to different crops across the United States to determine the impact of IPM on pesticide use in specific crops. These studies separately examine fresh tomatoes, grapes, and peaches, and account for farmers across the United

States. They estimate of the national impacts of the crop specific IPM programs in the United States. The major limitation of these studies is that they only analyze the impacts for one growing season and one commodity. This limitation is due mostly to data constraints they faced at the time they were conducting their studies (Fernandez-Cornejo and Ferraioli, 1999). As mentioned earlier, it is problematic to draw inferences about pesticide use without considering multiple years and multiple crops. Results from Fernandez-Cornejo (1996; 1998) and Fernandez-Cornejo and Ferraioli (1999) suggest that IPM practices have mixed effects on the environment and are dependent on the specific crop being analyzed. For example Fernandez-Cornejo (1996) concludes that IPM adoption reduces insecticide and fungicide use in fresh tomatoes, but increases overall pesticide use and the toxicity of pesticides used in peach production. These results are only for a single growing season, and further study is needed to determine if these results hold over time. Fernandez-Cornejo's model also allowed them to estimate the effect of IPM adoption on profits, but their results were mixed as profits were slightly higher for grape and tomato growers but there was no significant effect on peach growers. In conclusion, studies that have measured the effectiveness of IPM and specific IPM groupings at reducing pesticide use have yielded mixed results.

The major limitation that prevented Fernandez-Cornejo (1996; 1998) and Fernandez-Cornejo and Ferraoli (1999) from doing time series analysis was the lack of a sufficient data set. These studies use NASS agricultural chemical usage surveys, but these surveys sample different crops and different states in different years making it difficult to get an accurate and consistent time series of pesticide use in United States agriculture. The agricultural chemical usage surveys are part of the USDA Pesticide Data

Program, but the main focus is on pesticide residues. Its goal is to "enhance the quality of information on pesticide residues in food" and not to determine the effect of IPM or other farmer practices have on pesticide use (2007). Other agencies like Natural Resource Conservation Services (NRCS) and United States Geological Survey (USGS) collect or compile pesticide data, but most of these data focus on pesticide use as it relates to the specific topics the agencies are researching and do not consider farm practices. These data also begin later than the NASS surveys, and therefore do not have as many observations. Thelin and Gianessi (2000) document the difficulties in compiling pesticide use data for the USGS project. Unfortunately, many sources of data on pesticide use fail to collect data on IPM practices, making it impossible to determine the effects of IPM on pesticide use.

The Agricultural Resource Management (ARMS) surveys do collect both IPM practice and pesticide use data. The ARMS surveys began in 1996 for the purpose of conducting a national accounting of farmers' resource usage across the country. The ARMS survey also collects information on farmers' finances, production practices, use of chemicals, and other resources. ARMS surveys have collected information on more than 15 crops.[1] ARMS surveys do not reach every agricultural pesticide user, but they sample agricultural pesticide users in a manner that is representative of the whole population. An ARMS survey is conducted in three phases. The first screening phase (Phase 1) surveys potential respondents on the crops grown and types of livestock present on the farm. The second phase (Phase II) elicits information on production practices and enterprise

[1] ARMS surveys also collect information on some livestock, but these livestock surveys are not included in this analysis even though some IPM practices and pesticides are used on livestock.

management practices. The third phase (Phase III) collects financial information from the farm.

It is important to note that the ARMS surveys are designed and written specifically for the crop and year that is being surveyed. In other words, individual ARMS surveys do differ between crops and years. ARMS surveys have sampled corn, soybeans, cotton, winter, spring, and durum wheat, fall potatoes, rice, sorghum, flue-cured tobacco, sugarbeets, peanuts, sunflowers, oats, and barley in different years. These surveys have been used in other studies to examine a number of different topics. For example Daberkow et al. (2003) studied the adoption of precision agriculture.   Falck-Zepeda and Traxler (2000) estimated the rents generated by Bt cotton and herbicide resistant soybeans. Marra et al. (2002) used the data set to analyze whether GM crops do lead to lower pesticide use.

These studies concentrated on particular crops or a single year and did not use the complete set of ARMS surveys that are currently available. This study examines pesticide use at a more aggregated level. Therefore most of the data used in the first part of the study of this study are taken from the Crop Production Practices Report (CPP) of ARMS. This data set does not include the financial information collected in Phase III but combines all of the practice data for all of the crops surveyed into a single data set. The CPP makes it possible to compare practices of farmers across surveys without directly addressing the differences between surveys across years and crops. By not including Phase III information, some specific farmer characteristics cannot be included in the analysis conducted in this report. Also the CPP does not include data on actual pesticide usage due to the overwhelming number of different pesticides used on different crops combined with the changes in pesticide brands and active ingredients over the years. Because of this situation, pesticide cost per acre was used in this study as a proxy for pesticide use. Admittedly, this proxy might not be perfectly correlated with risky pesticide use, as some less risky pesticides (as defined by the EPA) might be more expensive, but it does provide a fair picture of the overall chemical pesticide use by farmers. The measure should correlate with general pesticide use, and be useful in determining if IPM and other factors affect pesticide use.

To explicitly recognize some of the limitations imposed by only using the CPP data, a more complete analysis using specific cotton data from 1997 and 2003 was also conducted. This analysis included information from both Phase II and Phase III of the ARMS surveys and provides more direct comparisons to previous single crop studies. Also by examining cotton, the analysis can separate the effects of IPM and the adoption of genetically modified crops on pesticide use. This issue has been examined in previous studies making our results directly comparable to these studies.

Corn data were also analyzed to enable the examination of the effects of specific IPM practices, essentially an unbundling of IPM. Corn was chosen here, because the data offered more IPM practices to analyze.

Model

Equation 1

$$\mathbf{PestExpend} = \boldsymbol{\alpha} + \boldsymbol{\beta}(\mathbf{IPM}) + \boldsymbol{\gamma}(\mathbf{Spatial, Pest\ Pressure, and\ Time\ Dummies}) + \boldsymbol{\epsilon}$$

The basic model used in this study is represented in equation 1. PestExpend represents pesticide expenditures per acre, α is an intercept term, IPM represents the adoption of IPM strategies, β represents the impacts that IPM strategies have on chemical spending, and γ are the effects of Spatial, Pest Pressure and Time Dummies. The following paragraphs and tables report the results of applying this model using different definitions of IPM and using different IPM practices. The basic model does not include any farmer-specific characteristics because the CPP data that were used lacked the Phase III ARMS data. It should be noted that some proxies for farmer characteristics such as total acres on the farm, whether or not the farmer adopted conservation practices, and irrigation use, were also used in preliminary regressions. These variables were rarely statistically significant, but also reduced the number of observations and crops surveyed due to the fact that the same questions were not used for every crop in every year. The reduction in crops inhibited achievement of the study's primary goal of conducting an aggregate assessment of IPM's effect on pesticide use. Therefore these variables were not included in the final regressions. Results by crop reported later in the study explicitly account for some of the relevant Phase III data.

CPP Results

The percentage of farmers in the ARMS sample who adopted a single practice in a P,A,M,S strategy, and the percentage who had attended a pest management training class within the last year are reported in Table 1. For example, any farmer who answered that they "scouted," no matter what they scouted for, was considered to adopt monitoring strategies. This concept of one practice being equal to IPM adoption is used throughout the paper unless another definition is noted. All practices were not reported in the survey for every crop and wording of questions has changed as the ARMS survey and program has progressed. This lack of consistency makes comparing specific practices or developing a more concrete definition of IPM adoption difficult with CPP. The adoption of a single practice equaling the adoption of IPM represents a broad definition of IPM adoption, and later specifications will narrow that definition by combining and redefining strategies. The table does suggest that the adoption of prevention and monitoring strategies are prevalent on most American farms.

A preliminary regression that did not control for any fixed environmental factors except for the crop and whether the crop was grown after 2000 grown led to some unexpected results. Choosing the year 2000 roughly split the data in half and was an arbitrary first step to include time in the analysis. Practices that were found to significantly increased chemical spending per acre were monitoring ($2.59), suppression ($6.55), and pest management training ($2.20). This regression demonstrated the importance of controlling for crops and time. Most of the crops resulted in different chemical spending than corn, and farmers spent less on chemicals (-$2.03) after 2000. These results suggest that better controls for issues such as pest pressures could significantly change the results.

A second set of regression results are reported in Table 2. These results separately control for the crop grown, the state where the crop was grown, and the specific year that the crop was grown. Prevention and avoidance strategies were found to have a non-significant effect on chemical spending. Monitoring and suppression practices significantly increased chemical spending, as did participating in a pest management training program in the last year. Crop, state, and time specific effects were also significant. Half of the crops differed significantly from corn, half of the states differed significantly than Iowa, and in six years farmers spent significantly less than in

1996. Even with the larger number of control variables, monitoring ($2.48) and suppression ($5.45) practices had a significant positive effect on chemical spending.

A third model controlled for environmental factors by creating a variable (pest pressure) that separated each state by crop and year. For example, a variable was created that represented Iowa corn farmers in 1996, Ohio soybean farmers in 1998, another variable for Iowa corn farmers in 2000, and another variable for Ohio soybean farmers in 2001. These variables combined all of the information collected in the second model, but allowed for a more focused analysis on the effect of a single location in a given year on chemical spending. This pest pressure variable was intended to identify localized pest pressure situations that could cause a spike in pesticide use in a given year. This variable is not perfect, because some states, especially larger states, face different pressures within the state. The variable should also help control for some farm characteristic, because it is expected that farmers of the same crop in the same state (especially geographically smaller states) have similar characteristics, especially with respect to prices received and expected for their crop and other input costs.

The results from this specification are presented in Table 3. The effects of monitoring ($1.67) and suppression ($4.86) decreased, but the strategies still increased chemical spending overall. Also, over fifty percent (129 out of 238) of the pest pressure variables were significant at the 5% level. This result indicates that pesticide use is not strictly determined by use practices but also by environmental factors.

A fourth model was created that separated individual practices into those that should clearly reduce chemical use (non-chemical) and those practices that had an unknown effect on chemical usage. This specification was designed to separate some of the ambiguous effects that IPM practices such as scouting have on pesticide use. Scouting can lead to either an increase or a decrease in pesticide use depending on the pests and pest numbers identified by the scouting. This fourth model retained the pest pressure variables of the third model, and the results are reported in Table 4. These results also yielded unexpected results as even those farmers who adopted practices that should clearly reduce chemical use spent more on chemicals than those who did not.

A fifth model analyzed the effect of adopting all of the P,A,M,S strategies. This definition represents a narrow definition of IPM adoption as it requires the farmer to adopt at least one IPM practice in each of the separate P,A,M,S strategies, but the effect ($4.12) of adopting all strategies also increased chemical spending and was statistically significant. Other models that included combinations of P,A,M,S strategies led to similar results. The general conclusion from all of these specifications was that IPM adoption and pest management training lead to slightly greater chemical spending on average.[2] Table 5 summarizes the different effects that P,A,M,S strategies have on chemical spending across the different specifications controlling for different spatial variables. The implications of these conclusions will be discussed later.

These results suggest that IPM might actually increase spending on pesticides.

Chemical Use on Cotton

As discussed before, most previous studies have focused on a single crop during a single year. The benefit of this type of analysis is that it allows the researcher to control for more farm and farmer-specific characteristics. For example, Fernandez-Cornejo (1996) controlled for a number of farmer-specific variables such as farm size, farmer

---

[2] These results were robust to the removal of outliers.

experience, education level of the farmer, where farmers received their pest information, and the price of inputs. In a similar way, an analysis was completed that combines the ARMS Phase II and Phase III data to more directly examine the impacts of IPM on chemical use in cotton in 1997 and 2003. Also by examining cotton production, the effects on pesticide use attributed to IPM can be separated from the effects of adoption of genetically modified herbicide (HR) and insecticide resistant (IR) cotton varieties. This separation permits a comparison with other studies that have specifically examined the relationship between IR and HR adoption and pesticide use in cotton production in the United States.

Equation 2.2

$$\mathbf{AI} = \boldsymbol{\alpha} + \boldsymbol{\beta}(\mathbf{IPM}) + \boldsymbol{\varphi}(\mathbf{IR, HR\ Dummy}) + \boldsymbol{\delta}(\mathbf{Farmer\ Characteristics}) + \boldsymbol{\omega}(\mathbf{Farm\ Specific\ Charateristics}) + \boldsymbol{\epsilon}$$

By focusing on cotton, the analysis was also able to create a dependent variable of pounds of herbicide and insecticide active ingredient (AI) used per acre which is preferable to using pesticide expenditures. Although A.I. does not explicitly consider riskiness of pesticides, it is more applicable to the GAO report and addresses some of the previously discussed concerns with using chemical spending per acre as a proxy for pesticide use. Similar to the previous models, multiple definitions of IPM were used. One definition (Any IPM)) defined IPM adoption as adopting any single IPM practice. A more restrictive definition (Intensive IPM) ensured that an adopter practiced scouting and at least one other IPM practice. In different models, other IPM practices were separated from IR or HR adoption. In these models, HR or IR did not count towards IPM adoption. The farm and farmer characteristics chosen to be independent variables were the same as those used in Fernandez-Cornejo (1996) and included farm size, years of farming experience, farm income, price received for cotton, farm tenure, type of cotton grown, cost of pesticides, origin of pesticide information, and if the farmer had received IPM training in the last two years. The issue of selection bias where the IPM adopters are systematically different than non-adopters and can bias results is also explicitly considered by Fernadez-Cornejo (1996) (1998), but statistical tests conducted on this data determined that selection bias was not significant in any of the following estimated pesticide demand equations, and therefore only the reduced form results are reported.

This analysis also employs different spatial variables. The models used regional dummies as defined by ERS, state dummies, and zip code dummies. These spatial variables, the analysis helped control for specific pest pressures that affect certain farms as well as other unobserved variables that are associated with location.

Previous studies that have examined pesticide use in cotton have yielded somewhat contradictory results. Marra et al. (2002) found some evidence that the introduction of Bt cotton might have reduced pesticide use. Benbrook (2002) suggested that the benefits of GM cotton in terms of reduced pesticide usage might have been overstated, and suggested that further study and technologies were needed to ensure that pesticide use is actually reduced. A recent study suggested that chemical use in cotton is somewhat sporadic and might have increased over the past few years (Fernandez-Cornejo, et al., 2009).

The effects that IPM and HR and IR have on herbicide and insecticide use are reported in Table 6-9. For the 1997 regressions, there were 688 observations, and for the 2003 regressions there were 1230 observations. In most models, the farm and farmer characteristics had the expected signs based on economic theory and previous empirical studies, but the statistical significance of these variables varied depending on the year, spatial variables, and IPM definition used. IPM training rarely had a significant effect on pesticide use. Also those farmers who received their pesticide information from extension professionals tended to use more chemicals in some models, but in most models, this effect was not statistically significant. The adjusted R-squared of the models varied from 0.10 to 0.40. The models that included state variables tended to have slightly better fit statistics than those models that included zip code variables. As with the CPP regressions, many of the spatial dummies were significant and suggested that pesticide use differed between locations.

These cotton results confirm the aggregate results in the sense that IPM seems to be associated with increased pesticide use. But these results also question whether some IPM practices, in this particular case, the adoption of GM technologies might actually decrease pesticide use. In 1997, the adoption of HR varieties significantly reduced the herbicide pounds of active ingredient sprayed on cotton, and in 2003 in the models where region and states were controlled for, adopting IR significantly reduced insecticide pounds of active ingredient sprayed on cotton. Neither HR nor IR adopters sprayed less pesticides in both years, but neither demonstrated the statistically significant positive signs associated with the IPM adoption definitions either. By focusing on measures of IPM adoption that bundle multiple practices might be generating results that do not properly assess the importance of some specific practices that actually decrease pesticide use. Also the broad definitions of IPM increased pesticide use more than the restrictive definitions. The next section addresses these issues by examining specific practices in corn production.

Chemical Use on Corn

The aggregate analysis of factors affecting pesticide use separates IPM into broad categories that do not allow for the possibility that specific practices may have different effects on pesticide use. As in the case of cotton, aggregate analyses that uses broad IPM categories also might lead to the bundled factors canceling out the effects of each other, as specific practices in the bundles increase pesticide use while others decrease pesticide use. The result might be an under-estimation of the significance of certain IPM practices that do reduce pesticide use. For example, the relatively small magnitude of the significant coefficients and the lack of significance of prevention and avoidance activities in the CPP regressions could be explained by some practices within the profile increasing pesticide use and other practices reducing pesticide use. For example in the cotton estimates, when HR is bundled together with other IPM practices, the pesticide decreasing nature of HR cannot be seen.

Equation 2.3

$$\mathbf{AI} = \boldsymbol{\alpha} + \boldsymbol{\beta}(\mathbf{IPM}) + \boldsymbol{\omega}(\mathbf{Farm\ Specific\ Charateristics}) + \boldsymbol{\gamma}(\mathbf{State}) + \boldsymbol{\epsilon}$$

To better address this bundling issue, other models using only corn data were run. These models allowed for specific practices (IPM) to be examined, and controlled for the state where the corn was grown. Also, some farm specific characteristics such as irrigation practices and the farm's conservation practices were added to the model. Like with cotton, by focusing only on 1996 corn data, the analysis was able to create another dependent variable of pounds of herbicide and insecticide active ingredient (AI) used per acre.

The results suggested that some practices increased chemical spending and pounds of active ingredient applied while other practices decreased chemical spending and pounds of active ingredient applied. The farmer characteristics were not statistically significant in explaining the pesticide use. The significant results are presented in Table 10. Some practices, even monitoring practices such as scouting for rootworms and prevention practices such as adjusting planting dates and row spacing, reduced pesticide use. These results highlight that combining practices might not be telling the full story of the effects that IPM related practices are having on pesticide use.

A similar type of analysis was done with the ARMS corn data from 2001, except chemical spending per acre was used as the dependent variable. The results from 1996 corn production differed from the results from 2001 corn production. For example, in 2001 systematic scouting decreased chemical spending while in 1996 it had an increasing effect. This contrast reinforced the importance of time and environmental factors on pesticide use and reiterated the dangers in just comparing two years worth of pesticide use data.

Examining specific practices illuminated the complexity entailed in evaluating an IPM program's effect on pesticide use. Farmers face numerous choices concerning how to use pesticides. Some of these choices are controllable such as IPM practices, but other factors are uncontrollable such as weather and pest infestations in a given year. Aggregate analysis allows us to get an unfocused picture of how IPM affects pesticide use, but it does not give insights into how to improve IPM programs or other ways to reduce pesticide use. By examining specific practices, IPM practitioners can get a better idea of what IPM practices actually decrease pesticide use and which practices increase pesticide use.

Limitations of this study

The methods of this study have a number of limitations. First, multiple definitions of IPM were used in this study. Second, individual IPM programs make specific recommendations while the ARMS surveys were created to take a national sample of producers. The ARMS surveys were not specifically designed to study the impacts of IPM, and therefore, do not have the detail of localized IPM impact practices. As the analysis of corn and cotton suggests, the significance of a particular practice in a specific location can lead to significant reductions. By examining aggregate relationships and using the broad IPM definitions necessary to estimate these relationships, it is difficult to determine the specific practices that are important in determining IPM's effect on pesticide use. The underlying difficulty in an aggregate analysis is that IPM programs are unique, and it is hard to control for this uniqueness in an aggregated study.

It also must be mentioned that analyzing national "all-inclusive" surveys is a time consuming process that involves a number of constraints. The surveys offer a wealth of data, but some of these data are not relevant to IPM impact assessment. As with all empirical studies, there are questions about which data to include or exclude, and which data best approximate the suggested theoretical variables. With data as comprehensive as the ARMS data, these questions and the number of different possible variables can become almost overwhelming.

Also, the definitions used in this analysis cannot account for large IPM related programs such as the boll weevil eradication program (BWEP) and soybean rust monitoring program. Participants in these programs could not be separated in order to determine the effect that these programs have on pesticide use. Research suggests these programs could have a large economic and environmental impact (McCorkle, et al., 2008; Roberts, et al., 2006). These large-scale programs have benefits for IPM adopters and non-IPM adopters that are not being directly accounted for in this analysis. Also the BWEP goal of eradication might initially lead to increased pesticide use, but over the long-term, the program could lead to significant reductions in pesticide use as the boll weevil is eradicated.

The ARMS data used in this paper do not include fruit and vegetable pesticide use. Although these fruit and vegetable crops account for less than 25% of agricultural pesticide use in the United States, they are important crops for which IPM has made inroads in reducing pesticide use (Fernandez-Cornejo, et al., 2009). By not including these crops, some of IPM's ability to reduce pesticide use might be understated.

Conclusions

This paper does not directly consider all the benefits of IPM, but IPM has multiple objectives and is not limited to reduced pesticide use (Kogan, 1998). The only environmental factor examined in this paper is pesticide use. IPM programs have been instrumental in educating farmers about proper pesticide use, and the benefits from pesticide applicators having a greater awareness of the dangers inherent in pesticide use has probably helped reduce pesticide application accidents that can cause health complications and death. Studying IPM's effect on the awareness of pesticide risks and other environmental measures such as environmental indices could be examined in future research.

The results presented in this paper suggest that adoption of some IPM strategies lead to increased pesticide use on average. This result is robust to a number of different IPM definitions and specifications. Some individual practices for particular crops certainly decrease pesticide use, but using national data and multiple definitions for IPM adoption, the models presented in this paper suggests that IPM adoption actually increases chemical spending and pounds of active ingredient sprayed on U.S. farms. These results suggest that IPM practices may have been more directed at increasing farmer profits than not reducing pesticide use. Identifying the practices that increase profits but do not actually decrease pesticide use, and directing research to practices focused on reducing pesticide use should be part of the future of IPM research. This paper provides a first step in understanding the long-term relationship between IPM practices and pesticide use.

IPM coordinators have expressed doubt in IPM's ability to decrease pesticide use, and a number of individual studies have reported that IPM has mixed effects on pesticide use. This being said, there is other evidence that suggests that individual IPM programs have reduced pesticide use in the United States at the local level. The GAO report mentions some of these, but there are numerous other examples in the literature. The more aggregated results reported in this paper may be an example of Simpson's Paradox where aggregate trends overwhelm important local trends. In other words, this analysis might be underselling important IPM programs that do decrease pesticide use. Agricultural pesticide use in U.S. farming is dependent on a number of farmer-specific practices and a number of environmental constraints. Individual farmers face different pest pressures, climates, and other uncontrollable environmental factors. The results of this research suggest that these uncontrollable factors explain a significant portion of pesticide use. They may explain a greater proportion of pesticide use than do farmer practices. Pesticide use in the United States is dependent on issues not completely controlled by the farmer. Increased pest pressure and other environmental factors can lead to greater pesticide use, and IPM practices designed to meet the local needs of farmers can certainly help to mitigate both the economic and environmental damage done by this increased pressure.

Figures

Figure 1 Bell Pepper Pesticide Use in the United States from 1992 to 2006

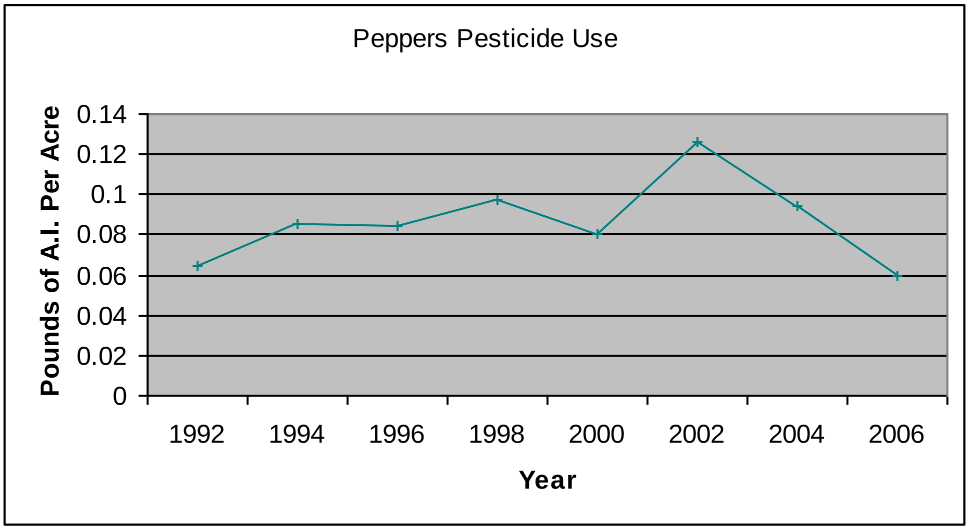
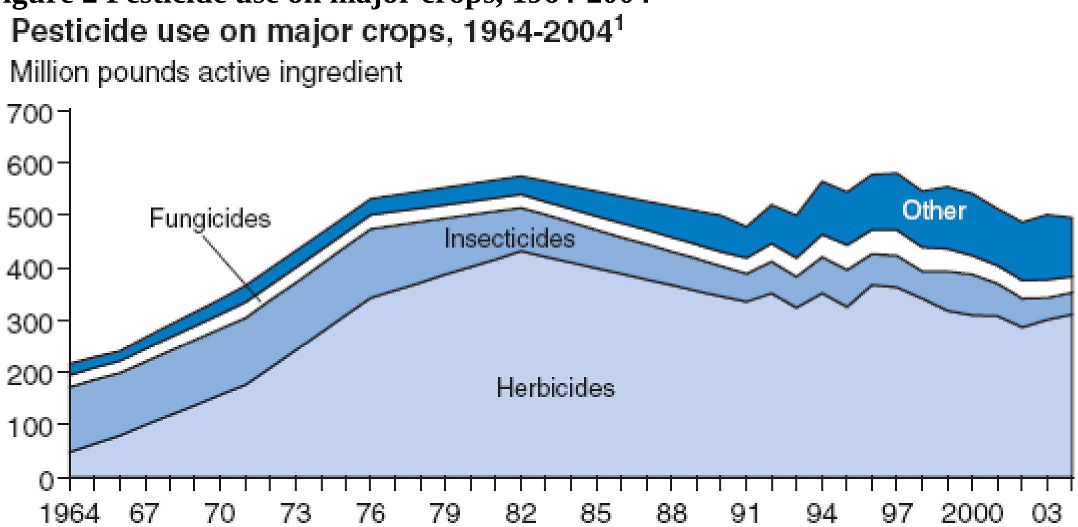


Figure 2 Pesticide use on major crops, 1964-2004



[1]Linear interpolation of use estimates between survey years from 1964 to 1990.

Source: Padgitt et al., 2000, U.S. Census Bureau and unpublished ERS data.

Table 1: Percentages of Strategy Adoption over Whole Sample

Practice Groupings	Overall Percentage of Adoption or Training
Prevention	82%
Avoidance	41%
Monitoring	81%
Suppression	25%
IPM Training	32%

Table 2: Effect of P,A,M,S Practices on Chemical Spending Only Controlling for Crops and Years

Practice Groupings	Effect	Standard Error	t Value
Prevention	-$0.50	0.47	-1.06
Avoidance	$0.48	0.47	1.26
Monitoring	$2.48	0.42	5.29
Suppression	$5.45	0.38	13.11
Pest Management Training	$2.01	0.39	5.22

Table 3: Effect of P,A,M,S Practices on Chemical Spending Controlling for Pest Pressures

Practice Groupings	Effect	Standard Error	t Value
Prevention	$0.18	0.46	0.39
Avoidance	$0.11	0.37	0.30
Monitoring	$1.67	0.45	3.68
Suppression	$4.86	0.4	12.00
Pest Management Training	$2.26	0.38	6.03

Table 4: Effects of Non-chemical and Unknown Effect Practices on Chemical Spending Controlling for Pest Pressures

Practice Groupings	Effect	Standard Error	t Value
Non-Chemical	$1.66	0.48	3.43
Unknown Effect	$2.95	0.48	6.11

Table 5: Summary of P,A,M,S Effects Using Different Spatial Variables

Practice Groupings	No Spatial	State	Pest Pressures
Prevention	-$0.26	-$0.50	$0.18
Avoidance	$0.31	$0.48	$0.11
Monitoring	$2.59***	$2.48***	$1.67
Suppression	$6.55***	$5.45***	$4.86
Pest Management Training	$2.20***	$2.01***	$2.26***

*** represents statistical significance at the 1% level

Table 6: Effects of IPM and HR on Pounds of AI of Herbicides Sprayed in 1997 Cotton Production

Variable	Region	State	Zip
Any IPM Weeds (including GM)	0.17	0.16	0.18
Any IPM Weeds (not including GM)	0.24*	0.25*	0.37**
Intensive IPM Weeds (including GM)	0.26**	0.25**	0.28**
Intensive IPM Weeds (not including GM)	0.24**	0.24**	0.27*
HR (Any IPM Weeds)	-0.38**	-0.48**	-0.37*
HR (Intensive IPM Weeds)	-0.37**	-0.47**	-0.37*

*represents statistical significance at the 10% level
** represents statistical significance at the 5% level
*** represents statistical significance at the 1% level

Table 7: Effects of IPM and IR on Pounds of AI of Insecticides Sprayed in 1997 Cotton Production

Variable	Region	State	Zip
Any IPM Insects (including GM)	0.43***	0.28***	0.24**
Any IPM Insects (not including GM)	0.34***	0.30***	0.29***
Intensive IPM insects (including GM)	0.27***	0.23***	0.17*
Intensive IPM Insects (not including GM)	0.24***	0.24***	0.17*
IR (Any IPM Insects)	0.23**	0.22**	0.00
IR (Intensive IPM Insects)	0.38***	0.23**	0.01

*represents statistical significance at the 10% level
** represents statistical significance at the 5% level
*** represents statistical significance at the 1% level

Table 8: Effects of IPM and HR on Pounds of AI of Herbicides Sprayed in 2003 Cotton Production

Variable	Region	State	Zip
Any IPM Weeds (including GM)	-0.13	-0.16	-0.40
Any IPM Weeds (not including GM)	0.45	0.45	.31
Intensive IPM Weeds (including GM)	0.29***	0.22***	0.19**
Intensive IPM Weeds (not including GM)	0.29***	0.22***	0.19**
HR (Any IPM Weeds)	-0.01	-0.03	0.06
HR (Intensive IPM Weeds)	-0.02	-0.03	0.05

*represents statistical significance at the 10% level
** represents statistical significance at the 5% level
*** represents statistical significance at the 1% level

Table 9: Effects of IPM and IR on Pounds of AI of Insecticides Sprayed in 2003 Cotton Production

Variable	Region	State	Zip
Any IPM Insects (including GM)	-0.04	-0.01	0.03
Any IPM Insects (not including GM)	0.00	0.02	0.04
Intensive IPM insects (including GM)	0.17**	0.21***	0.10
Intensive IPM Insects (not including GM)	0.17**	0.21***	0.11
IR (Any IPM Insects)	-0.14**	-0.12*	-0.10
IR (Intensive IPM Insects)	-0.15**	-0.13*	-0.10

*represents statistical significance at the 10% level
** represents statistical significance at the 5% level
*** represents statistical significance at the 1% level

Table 10: Effects of Specific Practices in 1996 Corn Production on Pounds of Insecticide Active Ingredient in 1996 Corn Production

Practice	Effect	Standard Error	t Value
Scouting For Rootworms	-0.12	0.04	-2.73
Adjust Planting Dates for Pest Control	-0.15	0.05	-2.94
Adjust Row Spacing for Pest Control	-0.08	-0.05	-1.86
Scouting Records for Borers	0.15	0.05	2.72
Considered Beneficial Organisms	0.22	0.04	5.33
Alternate Pesticides	0.14	0.03	5.68

References

Benbrook, C.M. "Impacts of Genetically Engineered Crops on Pesticide Use in the United States: The First Eight Years" BioTech InfoNet, Technical Paper Number 6. November (2006).

Burlingame, S. J. "Integrated Pest Management: Teaching teachers is key." *Penn State Outreach*, Spring 4, no. 2(2002). Accessed April 19 2010. http://www.outreach.psu.edu/news/magazine/Vol_4.2/ipm.html

Burton Jr, R. O., and M. A. Martin. "Restrictions on Herbicide Use: An Analysis of the Economic Impacts on US Agriculture." *North Central Journal of Agricultural Economics* 9, no. 2(1987): 181-194.

Carson, R. *Silent Spring*. Boston: Houghton Mifflin 1962.

Daberkow, S.G. and W.D. McBride. "Farm and Operator Characteristics Affecting the Awareness and Adoption of Precision Agriculture Technologies in the US." *Precision Agriculture* 4, no. 2 (2003), 163-177.

Delaplane, K. S. "Pesticide Usage in the United States: History, Benefits, Risks, and Trends." Athens, GA: Cooperative Extension Service, The University of Georgia College of Agriculture and Environmental Sciences, 2002.

Falck-Zepeda, J.B., G. Traxler, and R.G. Nelson. "Rent Creation and Distribution from Biotechnology Innovations: The Case of Bt Cotton and Herbicide-Tolerant Soybeans in 1997." *Agribusiness* 16, no. 1(2000), 21-32.

Fernandez-Cornejo, J., and J. Ferraioli. "The Environmental Effects of Adopting IPM Techniques: The Case of Peach Producers." *Journal of Agricultural and Applied Economics* 31, no. 3(1999): 551-64.

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* 20, no. 2(1998): 462-88.

Fernandez-Cornejo, J., et al. "Assessing Recent Trends in Pesticide Use in U.S. Agriculture". Selected Paper presented at AAEA & ACCI 2009 Joint Annual Meeting, Milwaukee, WI. 2009.

Fitzner, M. S. "Three Decades of Federal Integrated Pest Management Policy." in *Pesticides in Agriculture and the Environment*, edited by W. B. Wheeler. Boca Raton, FL: CRC Press 2002, 1-24.

Gianessi, L.P. , and C.A. Puffer. "Reregistration of Minor Pesticides: Some Observations and Implications." Inputs Situation and Outlook Report. U.S. Department of Agriculture, Economic Research Service. (1992) February:52-60.

Hamerschlag, K. "More Integrated Pest Management Please." New York, NY: National Resources Defense Council Issue Paper, 2007.

Hareau, G. G., B. F. Mills, and G. W. Norton. "The potential benefits of herbicide-resistant transgenic rice in Uruguay: Lessons for small developing countries." *Food Policy* 31, no. 2(2006): 162-179.

Kogan, M. "INTEGRATED PEST MANAGEMENT:Historical Perspectives and Contemporary Developments." *Annual Review of Entomology* 43, no. 1(1998): 243-270.

Marra M.C., P.G. Pardey, J.M. Alston. "The Payoffs to Trangenic Field Crops: An Assessment of the Evidence" *AgBioForum* 5 no. 2 (2002) 43-50.

McCorkle, D., et al. "The Economic Impact of Boll Weevil Eradication in Texas," Paper presented at Southern Agricultural Economics Association 2008 Annual Meeting, Dallas, TX. 2008.

Norton, G. W., and J. Mullen. "Economic Evaluation of Integrated Pest Management Programs: A Literature Review." Blacksburg, VA: Virginia Cooperative Extension. 1994.

Osteen, C., and M. Livingston. "Pest Management Practices." in *Agricultural Resources and Environmental Indicators*, edited by K Wiebe and N. Gollehon. New York, NY: Nova Science Publishers. 2006. 107-116.

Ratcliffe, S. T., and M. E. Gray. "Will the USDA IPM centers and the national IPM roadmap increase IPM accountability?-Responses to the 2001 General Accounting Office report." *American Entomologist* 50, no. 1(2004): 6-9.

Resosudarmo, B. P. "Impact of the integrated pest management program on the Indonesian economy." The Australian National University, Economics and Environment Network (2001).

Roberts, E. M., et al. "Maternal Residence Near Agricultural Pesticide Applications and Autism Spectrum Disorders Among Children in the California Central Valley," Washington DC: U.S. Department of Human Services, National Institutes of Health, Environmental Health Perspectives. 2007.

Roberts, M. J., et al. "The Value of Plant Disease Early-Warning Systems: A Case Study of USDA's Soybean Rust Coordinated Framework," Washington DC: U.S. Department of Agriculture, Economic Research Service, Economic Research Report 18. 2006.

Royer, T. A., P. G. Mulder, and G. W. Cuperus. "Postmarked: Extension, U. S. A. Renaming (Redefining) Integrated Pest Management: Fumble, Pass, or Play." *American Entomologist* 45, no. 3(1999): 136-139.

Spengler, J. D., et al. "Final Report to HUD: The Healthy Public Housing Initiative." U.S. Department of Housing and Urban Development. 2005

Thelin, G.P., L.P. Giannessi. "Method for Estimating Pesticide Use for Coutny Areas of the Continuous United States." Sacramento, CA: U.S. Geological Survey, Pesticide National Synthesis Project (2000).

U.S. General Accounting Office. *Agricultural Pesticides: Management Improvements Need to Further Promote Integrated Pest Management*, Report GAO-01-815. Washington DC: U.S. General Accounting Office, 2001

U.S. Department of Agriculture. *Agricultural Resource Management Survey: Soybean Production Practices and Costs Report*, Washington DC: U.S. Department of Agriculture, Economic Research Service, 2006

U.S. Department of Agriculture. *Pesticide Data Program--Progress Report,* Washington DC: U.S. Department of Agriculture, 2007

Zilberman, D., et al. "The Economics of Pesticide Use and Regulation." *Science* 253, no. 5019(1991): 518-522.