Journal of Agricultural and Applied Economics, 29,2(December 1997):243–253

Economic Analysis of Environmental Benefits of Integrated Pest Management

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ABSTRACT

Public support for integrated pest management (IPM) is derived in part from concerns over food safety and the environment, yet few studies have assessed the economic value of health and environmental benefits of IPM. An approach is suggested for such an assessment and applied to the Virginia peanut IPM program. Effects of IPM on environmental risks posed by pesticides are assessed and society's willingness to pay to reduce those risks is estimated. The annual environmental benefits of the peanut IPM program are estimated at $844,000. The estimates of pesticide risks and willingness to pay can be applied elsewhere in economic assessments of IPM.

Key Words: environmental benefits, integrated pest management, willingness to pay.

Effective pest management is essential to the economic vitality of U.S. agriculture. Since the 1950s, crop damage from pests has been managed in a relatively effective and inexpensive manner by synthetic pesticides. However, growing concerns about potential environmental and health risks associated with pesticide use, increased problems of pest resistance to pesticides, loss of established pesticides due to regulatory decisions, and increased costs of new pesticides have stimulated the search for new pest management strategies. Consequently, integrated pest management (IPM) strategies are being developed and implemented that combine biological, cultural, physical, and chemical control tactics to minimize economic, environmental, and health risks.

Many IPM strategies are being developed and implemented with the assistance of public research and extension. Much public support for IPM research and extension has resulted from concerns over food and farm worker safety, over groundwater contamination, and from increased environmental awareness. Despite these concerns, most economic evaluations of IPM programs have concentrated on farm-level profitability or risk, or on aggregate economic benefits resulting from IPM-induced cost reductions or yield changes (e.g., Ferguson and Yee; White and Thompson; Hatcher, Wetzstein, and Douce; Rajotte et al.). A few have assessed the economic impacts of acute human health effects associated with pesticide exposure (Antle and Pingali; Rola and Pingali) or the relative environmental risks associated with specific pesticides (Kovach et al.; Higley and Wintersteen), but none have provided an economic assessment of the environmental and health impacts of an IPM program.

The purpose of this study is to provide an

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This study was funded in part by the U.S. Department of Agriculture under Grant No. 92-EPMP-1-0027. It has not been subjected to the department's peer and administrative review, and therefore does not necessarily reflect the views of the USDA; no official endorsement should be inferred. The authors would like to thank Ames Herbert for helpful comments.

approach for such an assessment and to apply it to the peanut IPM program in Virginia. The approach contains two primary components. The first is to estimate the effects of IPM on the risks posed by pesticides to the environment and human health (hereafter referred to simply as the environment). The second is to determine society's willingness to pay to reduce those risks. Implementing these two components requires five basic steps: (*a*) identifying risks posed by individual pesticide active ingredients to the environment, (*b*) defining the degree of IPM adoption, (*c*) assessing the effects of IPM adoption on pesticide use, (*d*) estimating society's willingness to pay to reduce pesticide risks, and (*e*) combining the willingness-to-pay and pesticide risk-reduction estimates to calculate the economic value of the environmental benefits of the IPM program.

Results for the peanut IPM program evaluation in Virginia show substantial environmental benefits to the Early Leaf Spot Advisory program. Some of the risk levels calculated for specific pesticide active ingredients and all of the willingness-to-pay estimates (based on a national survey) can be applied in IPM evaluations in other states, thereby facilitating replication of the approach.

Identifying Pesticide Risks to the Environment

Identifying pesticide risks is essential for valuing the environmental benefits of IPM programs. Pesticide risk to the environment is related to the amount of active ingredients (a.i.) applied. However, total pounds of a.i. applied per year is not the best indicator of risk, because pesticides differ with respect to their toxicity, mobility, and persistence. A given pesticide also may pose different levels of risk to different components of the environment. Substitution of one pesticide for another may reduce the risk to one environmental component, but raise it for others. To address this issue in the current study, the environment is divided into eight broad categories: groundwater, surface water, acute human health, chronic human health, aquatic species, birds, mammals, and arthropods. Further, three levels of pesticide risk are identified: high, moderate, and low.[1]

Active ingredients are assigned one risk level ($j = 1$ to 3) for each environmental category ($i = 1$ to 8), resulting in 24 risk/environmental classes for pesticides. Rather than measuring the change in total pounds of all a.i., the change in pounds of a.i. in each ij pesticide class attributable to IPM adoption is measured. Separate criteria are used for each environmental category to classify the risk posed by each a.i. A brief summary of those criteria is presented below (with additional details available from the authors).

The criteria presented below make use of the current state of knowledge with respect to data that indicate pesticide risk to individual environmental categories. A more complete model of pesticide hazards to these categories would trace vector and timing of exposure from the application of pounds of a.i. in a particular form, at specific points in time, under specific environmental conditions (e.g., soil pH, moisture level, the length of time before it rains), and other factors (e.g., method of application, potential toxic synergies from mixing chemicals) to human exposure and environmental contamination, and then to health and other environmental impacts. These impacts would depend on the age distribution of the population, types of aquatic species, mammals, insects present, etc. Recognizing the limitations of available data and information, the criteria and hazard categories below make the ceteris paribus assumption that highly toxic, persistent chemicals pose a greater risk to human health and other categories of the environment than pesticides that are inherently less toxic and deteriorate quickly.

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[1] The environmental categories are the same as those used by Higley and Wintersteen, and similar to those used by Kovach et al., thereby facilitating comparison of results even if the methods differ. The criteria do involve some overlap, particularly between groundwater and chronic human health, and between surface water and aquatic species.

Groundwater Criteria

The assignment of groundwater risk to an active ingredient is based on the Pesticide Leaching Matrix developed by the U.S. Department of Agriculture's Soil Conservation Service (SCS) (Becker et al.). This matrix accounts for both soil and pesticide properties and classifies pesticides as having high, moderate, or low risk to groundwater based on the soil leaching rating (high, intermediate, nominal) where the pesticide is applied and on the leaching rating for the pesticide (large, medium, small). Not all pesticides have a pesticide leaching rating. When leaching ratings are not available, Gustafson's Groundwater Ubiquity Score (GUS) is used to assign the groundwater risk level to the pesticide. The GUS is defined in terms of the soil half-life of the pesticide, $t_{½}^{soil}$, and the pesticide's soil adsorption index, K_{OC}. Measures of $t_{½}^{soil}$ and K_{OC} are obtained from Wauchope et al.:

$$(1) \qquad GUS = \log_{10}(t_{½}^{soil}) \times [4 - \log_{10}(K_{OC})].$$

Gustafson classifies pesticides as leachers (GUS > 2.8), nonleachers (GUS < 1.8), and transition ($1.8 <$ GUS < 2.8), which translate to high, low, and moderate groundwater risk, respectively.

Surface Water Criteria

The assignment of surface water risk to an active ingredient is based on the Surface Runoff Matrix developed by the SCS (Becker et al.). This matrix accounts for both soil and pesticide properties and classifies pesticides as having high, moderate, or low risk to surface water based on the soil surface loss rating where the pesticide is applied and on the surface loss rating for the pesticide. Not all pesticides have been assigned a surface loss rating. When runoff ratings are not available, three pesticide characteristics are evaluated: (*a*) water solubility, (*b*) soil K_{OC}, and (*c*) soil half-life. The U.S. Environmental Protection Agency (EPA) has defined "red flag" values for each characteristic (water solubility > 30 ppm, soil $K_{OC} < 300$, and soil half-life > 21 days) (Becker et al.). For this study, if two or more of the red flag values are exceeded, the pesticide is considered a high risk to surface water; if one red flag value is exceeded, it is considered a moderate risk; and if no red flags are exceeded, it is considered a low risk.

Acute and Chronic Human Health Criteria

The assignment of acute human health risk levels is based on the signal words assigned by the EPA to the formulated product (Becker et al.). Because the EPA requires all pesticides to be labeled with "Danger," "Warning," or "Caution" based on toxicity [LD_{50}s for oral, dermal, and inhalation exposure, and for eye and skin effects (table 1)], every pesticide has a corresponding signal word which can correlate with a high, moderate, or low rating.[2]

Criteria for assigning chronic health risk levels are based on the results of tests evaluating the teratogenicity, mutagenicity, and carcinogenicity of each pesticide. The classifications and their definitions are: (*a*) "negative"—conclusive evidence that the pesticide is not a teratogenic, mutagenic, or carcinogenic agent; (*b*) "no evidence"—to date, there is no evidence indicating the pesticide is a teratogenic, mutagenic, or carcinogenic agent; (*c*) "inconclusive"—contradictory results have been observed; (*d*) "data gap"—reliable studies have not been conducted; (*e*) "possible"—while there is no conclusive information to date, the pesticide has certain physical properties that warrant further testing; (*f*) "probable"—the same as "possible," except the physical properties of "probable" pesticides lend themselves more readily to teratogenic, mutagenic, or carcinogenic effects than do pesticides classified "possible"; and (*g*) "positive"—conclusive evidence is available demonstrating the pesticide is a teratogenic, mutagenic, or carcinogenic agent. A pesticide is assigned a high chronic health risk if it has one or more "positive" classifications, a moderate risk if it has one or more "data gap," "possible," or

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[2] LD_{50} is the pesticide dose that kills 50% of the test population.

Table 1. EPA Signal Words and Assignment of Relative Risk Levels

Signal Word	Relative Risk	Relative Toxicity Ranking	Oral LD_{50} (mg/kg)	Dermal LD_{50} (mg/kg)	Inhalation LD_{50} (µg/l)	Eye Effect	Skin Effect
"Danger" or "Danger/Poison"	High	Highly toxic	0–50	0–200	0–200	Corrosive	Corrosive
"Warning"	Moderate	Moderately toxic	50–500	200–2,000	200–2,000	Irritation for 7 days	Severe irritation
"Caution"	Low	Slightly toxic	>500	>2,000	>2,000	Irritation for <7 days	Moderate irritation

"probable" classifications, and a low risk if results of all three tests are classified either "negative," "no evidence," or "inconclusive."

Aquatic Species Criteria

A given pesticide does not affect all aquatic species to the same degree. In this study, the highest level of risk a pesticide poses to any aquatic species is the risk level assigned to that pesticide. Because a pesticide poses little risk to aquatic species if it does not reach surface water, the aquatic species risk level is weighted by the surface water risk level. A high or moderate surface water risk will not alter the aquatic species risk. A low surface water risk, however, will drop a high aquatic species risk to a moderate risk, and a moderate aquatic species risk to a low risk (table 2).

Avian and Mammalian Criteria

Assignment of risk to a pesticide with respect to the avian and mammalian categories is based on the highest level of risk the pesticide poses to any species within the category: high if LD_{50} is $<$ 50 ppm, moderate if LD_{50} is between 50 and 500 ppm, and low if LD_{50} is $>$ 500 ppm. Risk levels are not weighted by a mobility factor due to the ability of these species to enter the target area. There are some pesticides for which toxibiological tests have not been conducted. A pesticide is assumed to pose a moderate level of risk to any category where "data gaps" exist.

Nontarget Arthropod Criteria

In most cases, the toxicity of pesticidal compounds to arthropods has not been formally assessed. To assign an arthropod risk level to an active ingredient, a variety of references are consulted: EXTOXNET; Smith; Higley and Wintersteen; Kovach et al.; Worthington; Hartley and Kidd; and U.S. EPA re-registration reports. If *any* of these references report an active ingredient as "highly toxic" or "extremely toxic" to *any* beneficial arthropod species, a high level of risk is assigned to that

Table 2. Risk Assignment Criteria for Aquatic Species

High Risk	Moderate Risk	Low Risk
$LC_{50} < 1$ ppm *and* High or Moderate Surface Water Risk	1 ppm $< LC_{50} <$ 10 ppm *and* High or Moderate Surface Water Risk *or* $LC_{50} < 10$ ppm *and* Low Surface Water Risk	$LC_{50} > 10$ ppm *or* 1 ppm $< LC_{50} <$ 10 ppm *and* Low Surface Water Risk

Note: All LC_{50} notations in this table are 96-hour LC_{50}s; this term is defined as the concentration of active ingredient that kills half the test population within 96 hours.

pesticide. If none of the references report the active ingredient as "highly toxic" to arthropods *and any* reference reports the a.i. as "moderately toxic" to *any* arthropod, a moderate level of risk is assigned. A low level of risk is assigned to pesticides if none of the references identify the pesticide as posing a high or moderate level of risk to arthropods.

Defining Levels of IPM Adoption

Integrated pest management involves a variety of practices that are specific to individual crops and locations. In some cases, an IPM program may be limited to a single practice, but typically, multiple practices are involved. Therefore, IPM adoption is usually a matter of degree. Adoption can be defined by level (i.e., high, medium, low, none) for each specific crop and location, with the levels based on groupings of particular sets of practices (see, for example, Rajotte et al.) or on the assignment of points to individual practices so that adoption along a scale is identified (Hollingsworth et al.). Alternatively, one could base adoption on the degree of adoption of IPM practices by utilizing an algorithm that transcends crops and locations but takes into account the proportion of available practices employed by producers and the importance of each class of pests.

Regardless of approach, the degree of adoption must be assessed based on information provided both by scientists and by producers. Often it is necessary to involve other stakeholders as well (e.g., consumers or representatives of environmental groups) if different weights are placed on particular IPM practices in defining the degree of adoption.

Assessing Effects of IPM on Pesticide Use

To estimate the reductions in external costs attributable to an IPM program, an estimate is needed of the proportional change in pesticide use induced by adoption of IPM on the study crop. Estimating this change entails comparing the current level of pesticide use under IPM to an estimate of what use would be in the absence of the IPM program.

Using the environmental/risk criteria developed above, pesticide active ingredients applied within the study area can be classified with respect to their environmental category, i, and risk level, j. The total pounds of an active ingredient class applied per year to the entire study area is denoted Use_{ij}. For example, the pounds of a.i. applied that represent a high risk to aquatic species or a medium risk to acute human health, etc. are calculated. Use_{ij} is composed of two elements, use on the study crop (Use_{ijs}) and use on other crops in the study area (Use_{ija}), so that

$$(2) \qquad Use_{ij} = \sum_{a=1}^{n-1} (Use_{ija}) + Use_{ijs},$$

where n = number of crops grown in the study area.

An IPM program for the study crop affects Use_{ij}, and hence the external cost in the study area, through Use_{ijs}. Use of pesticide active ingredients represents an input demand derived, at least in part, from profit-maximizing behavior. Hence, one might expect Use_{ijs} to be a function of output and input prices, acreage, pest pressure, and producer characteristics, in addition to IPM adoption (a substitute input). In a study area, prices received and paid by farmers are relatively uniform, and hence the general form of the relationship between IPM adoption and Use_{ijs} can be represented by

$$(3) \quad Use_{ijs} = F(IPM\ Adoption,\ Acreage\ of\ the\ Study\ Crop,\ Pest\ Severity,\ Farmer\ Characteristics).$$

Regression analysis can be used to examine the relationship between Use_{ijs} and various levels of adoption of IPM. For example, four levels of IPM adoption can be included as dummy variables, and variables such as farm size, farmer age, farmer education, and an index of pest infestation severity can be included. If the IPM program involves only a single practice, and farm size and pest severity are relatively homogeneous across farms, it may be possible to assess adoption based on a simple survey. If pest severity is relatively homogeneous across years, it may be possible to assess adoption by surveying the same farmers over time. Otherwise, a relatively detailed survey and a regression analysis are needed to control for variation in acreage, pest severity, and farmer characteristics.

A proportional reduction in Use_{ij} resulting from IPM adoption can be expressed as follows:

$$(4) \quad Reduction_{ij} = 1 - \frac{E(Use_{ij}\ with\ IPM)}{E(Use_{ij}\ without\ IPM)},$$

where E denotes expected, and $E(Use_{ij}\ with\ IPM)$ is derived as follows:

$$(5) \quad E(Use_{ij}\ with\ IPM) = \sum_{a=1}^{n-1} E(Use_{ija}) + \sum_{k=1}^{4} E(Use_{ijsk}).$$

The subscript k refers to IPM adoption levels, where $k \in$ {none, low, medium, high}. In other words, $E(Use_{ijsk})$ is the expected use of active ingredients with risk level j for environmental category i on the study crop by producers with a k level of IPM adoption. $E(Use_{ij}\ without\ IPM)$ is the same as in equation (5) when k = "none" for all producers.[3,4]

Willingness to Pay to Reduce Pesticide Risks

Estimates are needed of society's willingness to pay to avoid pesticide risks to the eight environmental categories. Willingness to pay is related theoretically to risk perceptions and may be influenced by factors such as gender, age, income, household size, where people live, and other socioeconomic characteristics.[5] Unfortunately, there are few market proxies for the willingness to pay to avoid risk to any of the eight categories, and none that would serve for all of them. Therefore, a contingent valuation survey (CVS) was administered to a random sample of U.S. residents.[6]

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[3] The derivation of Use_{ijsk} *with IPM* is made by estimating equation (3) for a particular set of variables (farmer characteristics, etc.) and then calculating $E(Use_{ijsk})$ for each k by substituting the mean values of those variables for that k back into the estimated equation. For example, if farmer age, farmer education, pest severity, and farm size were the variables, then $E(Use_{ijsk}) = \hat{a}_0 + \hat{a}_k IPM_k + \hat{a}_2(Education) + \hat{a}_3(Severity) + \hat{a}_4(Acreage_k)$ would be calculated using the mean values of the variables for each k in estimating Use_{ij} *with IPM*. In estimating Use_{ij} *without IPM* (if k = "none" for all producers), the mean values of the variables for the entire sample would be substituted into this equation (without the IPM intercept dummies).

[4] Potential reductions in Use_{ij} also can be estimated that would represent potential reductions in the use of active ingredients in class ij that would result if *all* the study crop areas adopted a given level of IPM: $Potential_{ijk} = 1 - E(Use_{ij}\ with\ all\ IPM_k)/E(Use_{ij}\ without\ IPM)$.

[5] Questions related to socioeconomic characteristics were included in the survey mentioned below. The survey questionnaire is available from the authors upon request.

[6] Contingent valuation remains a controversial technique due to many potential biases (Portney). However, it is one of a limited set of procedures available for valuing nonmarket goods, some of the biases

The survey contained an introduction with a brief overview of the value of pesticides as an agricultural input and of the potential for pesticides to damage the environment and human health. The purpose of this introduction was to inform the survey respondent about the nature of the risks posed by pesticides. The questionnaire began by asking the amount of the respondent's average monthly grocery bill. This question was relatively easy to answer and served to get the respondent involved in the survey. It also provided a baseline for a subsequent question on willingness to pay.

The willingness-to-pay (WTP) questions began with a brief definition of "high risks to the environment and human health from pesticide use." Respondents were asked their willingness to pay to avoid high risks via an increase in their monthly grocery bill. This payment vehicle was chosen because grocery prices might increase if the use of an entire class of pesticides was restricted.[7] After answering the WTP questions, the respondents were asked to rate (on a scale of 0 to 6) how important it is to avoid high risks to each of the eight environmental and human health categories considered in the study. The same format—risk definition, willingness-to-pay questions, and assignment of importance levels—was repeated for moderate and low risks.

The survey was mailed to 3,000 individuals drawn randomly from motor vehicle registration records and local telephone directories throughout the United States. A second mailing was sent 25 days later to 833 addresses, selected at random from those that had not returned the survey. Several surveys (384) were returned as undeliverable, and 454 responses were received.

To minimize the length of the questionnaire, the CVS respondents were asked to reveal their willingness to pay to avoid a given level of risk to the environment as a whole (WTP_j), rather than their willingness to pay for each category (WTP_{ij}). The importance rankings by category from the survey were then used to infer the respondent's WTP_{ij} from their WTP_j:

$$(6) \qquad WTP_{ij} = \frac{Importance_i}{\sum_{i=1}^{8} Importance_i} \times WTP_j.$$

The results of the contingent valuation survey, with 46 outliers deleted, are presented in table 3. Following previous studies (Desvousges et al.; Mitchell and Carson), responses are considered outliers if the WTP_j exceeds 5% of the respondent's annual income.

Application of the Model to Virginia Peanuts

The environmental risk, IPM adoption, pesticide use, and willingness-to-pay analyses were combined in an analysis of the environmental benefits of the Virginia IPM program on peanuts.[8,9] Eight southeastern Virginia counties were chosen as the peanut study area. Pesti-

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can be minimized in the survey process, and evidence suggests it can, in some cases, provide reasonable estimates of willingness to pay (Arrow et al.; Hanemann).

[7] A second vehicle, an increase in yearly federal income tax liability, also was used, but the results were excluded from the analysis after tests revealed payment vehicle bias. This bias likely is due to aversion to taxes. Information is available from the authors on nonparametric tests used to determine that vehicle bias exists.

[8] Analysis also was completed of the Virginia Apple IPM program, with results available from the authors.

[9] Although this study was concerned with the peanut IPM program in Virginia, the contingent valuation survey was administered to a sample of the entire United States population so that the data can be used to evaluate IPM programs in other states. To ensure that the countrywide estimates are valid for each state, individually, the sample mean for each state should be compared to the sample mean of every other state. The minimum number of observations needed to ensure the statistical validity of a comparison of sample means has not been conclusively defined in the statistics literature, but a sample size of 15 generally is agreed to be sufficient. With this in mind, the sample means for each state with more than 15 usable responses (11 states including Virginia) were compared using the Kruskal-Wallis nonparametric F-test. The null hypothesis is that the mean willingness to pay to avoid a given level of risk to a given environmental category is the same for each comparison state. In all 24 tests, the null hypothesis is sustained. Tables of the results of these tests are available from the authors.

Table 3. Contingent Valuation Survey Results: Willingness to Pay to Reduce Environmental Risk ($/month)

	High Risk (N = 397)		Moderate Risk (N = 392)		Low Risk (N = 388)	
Environmental Category	Mean	Std. Error	Mean	Std. Error	Mean	Std. Error
Acute Human	4.28	.23	2.89	.17	1.74	.14
Chronic Human	4.59	.24	3.14	.19	1.89	.15
Groundwater	4.56	.24	3.08	.18	1.86	.15
Surface Water	4.40	.23	2.93	.17	1.76	.14
Aquatic Species	4.37	.23	2.88	.17	1.75	.14
Avian Species	4.15	.23	2.72	.16	1.63	.14
Mammalian Species	4.13	.22	2.71	.16	1.65	.14
Arthropods	3.76	.22	2.49	.16	1.50	.13

Note: Based on 1992 dollars.

cides used on all the crops in the peanut study area were classified with respect to environmental risk levels (tables are available from the authors), using the methods described above. It was necessary to classify all pesticides and not just the ones used on peanuts, because any risk reduction on peanuts must be considered as a proportion of the total risk associated with pesticide use in the area.

The Virginia IPM program in peanuts focused on developing a disease forecasting system to reduce fungicide use. In 1979, the Early Leaf Spot Advisory (ELSA) system was implemented in Virginia to identify environmental conditions favorable to early leaf spot infection. Prior to ELSA, the conventional method for combating early leaf spot in Virginia peanuts was to apply chlorothalonil to peanut fields at 14-day intervals. By accurately predicting periods of early leaf spot infection, the ELSA forecasts and fungicide recommendations have allowed farmers to apply chlorothalonil in a more judicious manner.

In a four-year study from 1987 through 1990, it was found that farmers following ELSA recommendations made, on average, 33% fewer applications of chlorothalonil than farmers using the 14-day spray regime (Phipps). Yields from the ELSA farms were not significantly different than yields from the 14-day spray farms, nor was there a significant difference in the value of those yields. By 1990, 94% of Virginia's peanut producers were applying chlorothalonil based on ELSA recommendations (Phipps).

Recall that Use_{ij} is comprised of two components, the total amount of active ingredient class *ij* applied to all crops in the study area other than the study crop ($\Sigma\ Use_{ija}$), and the total amount of active ingredient class *ij* applied to the study crop (Use_{ijs}). The calculation of Use_{ija} is represented by

$$(7)\qquad Use_{ija} = \sum_{p=1}^{m} (Acres_a \times Treat_{ap} \times Rate_{ap}),$$

where m = number of active ingredients of class *ij* applied to crop *a*, $Acres_a$ = number of acres of crop *a* harvested in the study area, $Treat_{ap}$ = proportion of study area acres of crop *a* treated with active ingredient *p*, and $Rate_{ap}$ = pounds of active ingredient *p* applied per acre per year to crop *a*.

Similarly, $Use_{ijs,w/ELSA}$, the amount of active ingredient of class *ij* actually applied to peanuts in the study area in 1992, is calculated by

$$(8)\qquad Use_{ijs,w/ELSA} = \sum_{p=1}^{m} (Acres_s \times Treat_{sp} \times Rate_{sp}),$$

where m = number of active ingredients of class *ij* applied to peanuts, $Acres_s$ = number of harvested acres of peanuts in the study area, $Treat_{sp}$ = proportion of study area peanut acres treated with active ingredient *p*, and $Rate_{sp}$ =

Table 4. Contingent Valuation Survey Results: Estimates of Chlorothalonil Use With and Without ELSA, and Savings in External Costs (environmental benefits)

Active Ingredient Class	$Use_{ij,w/ELSA}$ (1,000 lbs.)	$Use_{ij,w/oELSA}$ (1,000 lbs.)	Reduction in Use_{ij} Due to ELSA (%)	Savings in External Costs ($1,000s)[a]
Low Risk to Groundwater	747	844	11.56	142
High Risk to Surface Water	1,937	2,035	4.80	139
High Risk to Aquatic Species	1,857	1,954	4.99	144
High Risk to Acute Human Health	1,745	1,842	5.30	149
Moderate Risk to Chronic Human Health	2,268	2,366	4.13	85
Low Risk to Avian Species	2,241	2,338	4.17	45
Low Risk to Mammalian Species	965	1,063	9.18	100
Low Risk to Nontarget Arthropods	2,325	2,423	4.03	40
Total Savings				844

[a] Amounts are in 1992 dollars.

pounds of active ingredient p applied per acre per year to peanuts.

The total amount of active ingredient class ij applied to the *entire* study area in 1992 is given by the following:

$$(9) \qquad Use_{ij,w/ELSA} = \sum_{a=1}^{n-1} (Use_{ija}) + Use_{ijs,w/ELSA},$$

where n = number of crops grown in the study area. It was not necessary to use equation (3) in assessing the effect of IPM adoption on pesticide use because only one practice was involved, and the survey had determined that 94% of the producers were adopters and that chlorothalonil use was reduced 33% for adopters.

Assuming that producers following ELSA recommendations applied 33% less chlorothalonil in 1992 than producers using a calendar spray schedule, *and* that 94% of Virginia's peanut producers used ELSA while 6% used calendar sprays, one can solve for the amount of chlorothalonil that would have been applied in the absence of ELSA using the following: $X = 1.5 \times Y$, and $Z = Acres_s \times (.94 \times Y \times .06 \times X)$, where X = pounds of chlorothalonil applied per acre per year to farms using a 14-day spray schedule, Y = pounds of chlorothalonil applied per acre per year to farms following ELSA recommendations, $Acres_s$ = number of peanut acres harvested in the study area in 1992, and Z = total pounds of chlorothalonil applied to peanuts in the study area in 1992.

Equation (10) is used to estimate the amount of a.i. class ij that would have been applied to the study area without ELSA, $Use_{ij,w/oELSA}$:

$$(10) \qquad Use_{ij,w/oELSA} = \sum_{a=1}^{n-1} (Use_{ija}) + \sum_{p=1}^{m-1} (Use_{ijsp}) + X \times Acres_s,$$

where n = number of crops grown in the study area, $m - 1$ = number of active ingredients of class ij other than chlorothalonil applied to peanuts in the study area, and $X \times Acres_s$ = total pounds of chlorothalonil that would have been applied to the study area in the absence of ELSA.

The estimates of $Use_{ij,w/ELSA}$ and $Use_{ij,w/oELSA}$ for the relevant active ingredient classes are presented in table 4. The savings in the external costs for each of the risk/environmental categories is represented by $Savings_{ij} = WTP_{ij} \times POP \times Reduction_{ij}$, where POP = number of households in the study area, and $Reduction_{ij}$ = the realized proportionate reduction in Use_{ij} as defined in equation (4).[10] The total

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[10] Respondents to the survey were asked how much they would be willing to pay to avoid a risk, but the reduction in pesticide use resulted in only a fraction of the risk being eliminated. The formula for calculating

savings in external costs (environmental benefits) attributable to the ELSA program is simply the sum of the savings for each of the eight relevant *ij* categories (table 4).

The total savings in external costs are approximately $844,000 per year (in 1992 dollars). Each of the nearly 59,000 households in the peanut study area would have been willing to pay an extra $14 per year for groceries to realize the reduction in pesticide use that ELSA provides. Annual public expenditures on the ELSA program are approximately $10,000 per year including personnel, equipment, and operating costs. In addition, farmers experience substantial direct cost savings associated with reduced pesticide use. The return to the ELSA program is clearly very high.

Conclusions and Implications

A method for assessing the environmental benefits of IPM has been presented. Application of the method to the peanut IPM program proved straightforward and demonstrated a high environmental return. One of the major accomplishments of this study is the estimation of societal willingness to pay for pesticide hazard reduction for eight environmental categories. These willingness-to-pay estimates can be applied in other studies without the need to repeat the CVS. Procedures also were developed for assessing risk levels to eight environmental categories, and risk levels were assigned to more than 130 pesticidal active ingredients in Virginia. Tables with these risk levels (available from the authors) can reduce the time and effort required in future studies. These risk assignments also may be used by farmers to guide their selection of pesticides.

Integrated pest management was conceived as a means of easing producers' reliance on chemical pesticides while maintaining agricultural production and preserving profitability. Certainly, many IPM programs have attained these goals, but evaluations are needed to quantify the degree of success. Analyses of the social/environmental benefits of reduced pesticide use must examine the toxicity, mobility, and persistence characteristics of the pesticides being used. When farmers reduce the total pounds of pesticidal active ingredient applied, but simultaneously substitute highly toxic, mobile, and persistent chemicals for relatively benign ones, it is difficult to argue that society has gained.

The results of the CVS administered for this study indicate that society values the nontarget resources that are adversely affected by pesticide use. Applying those results to the ELSA peanut program has illustrated the magnitude of environmental benefits that an IPM program can generate. In these times of tight budgets, integrated pest management programs will be subject to the same scrutiny as other publicly funded activities. If public funding for IPM research and extension is to continue, IPM must demonstrate net social benefits, particularly of an environmental nature. If such benefits exist, this study illustrates how they can be assessed.

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