Economic Evaluation of Integrated Pest Management Programs

A Literature Review

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ECONOMIC EVALUATION OF INTEGRATED PEST MANAGEMENT PROGRAMS:

A Literature Review

George W. Norton and Jeffrey Mullen*

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*Professor and Graduate Research Assistant respectively, Department of Agricultural and Applied Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061. This study was supported in part by USDA-Extension Project No. 92-EPMP-1-0027. Information provided in this report does not necessarily reflect the views of USDA-Extension.

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Executive Summary

Integrated Pest Management (IPM) is an approach to making pest control decisions with increased information and the use of multiple tactics to manage pest populations in an economically efficient and ecologically sound manner. The IPM concept emphasizes the integration of pest suppression technologies such as biological control, e.g., using beneficial organisms against pest organisms; cultural control, e.g., using rotations and cultivations to reduce pest problems; legal control , e.g., abiding by state and federal regulations that prevent the spread of pest organisms; and chemical control, e.g., judiciously using pesticides and other chemicals in a responsible manner.

The economic effects of IPM are realized both by individual farmers, ranchers, and homeowners, and by society at large. IPM programs can influence pest control costs, the level and variability of producer income, and the health of pesticide applicators. The programs also can affect food safety and water quality for human and wildlife and the long-run sustainability of agricultural systems.

Economic evaluations of IPM programs have been undertaken for roughly 20 years. Over this time period, the methods of analysis and issues addressed have broadened from a heavy emphasis on field and farm level budgeting of IPM alternatives, to assessment of risk, to more sophisticated modeling of pest-practice dynamics, and to aggregate evaluations of social impacts of IPM programs on consumers and producers including environmental benefits. One reason for the early emphasis on farm and field level budgeting of IPM alternatives was the desire to demonstrate IPM profitability to encourage its adoption by farmers. As public concern has intensified over both the environmental effects of pesticide use and the return on public investments in general, economic evaluations have expanded in scope to include environmental and social benefits of IPM.

The purpose of this report is to review briefly the current state of knowledge on the economic evaluation of IPM programs. Information is provided on the economic benefits of IPM, the effects of IPM on pesticide use, and methods for evaluating IPM practices and programs. An annotated bibliography of IPM evaluation studies is included.

Farm-level Evaluations of IPM

Most IPM programs are targeted at particular commodities. Consequently, studies of the farm-level economic benefits of IPM have focused on the costs and benefits of IPM by commodity. The primary evaluation tools have been enterprise or partial budgeting. In some but not all cases, procedures have been used to assess if the differences in yields, costs, and profitability of alternative pest management practices are statistically significant. In a few cases, the monetary risk associated with alternative practices has been evaluated. The primary tool used for risk analysis has been a technique called stochastic dominance.

The results of 61 economic evaluations of IPM programs in cotton, soybeans, vegetables, fruits, peanuts, tobacco, corn, and alfalfa are presented in summary form in table 1. These evaluations indicated that pesticide use, on average, decreased for seven out of eight commodities or commodity groups. Several individual studies within the commodity groups, however, did find increases in pesticide use and therefore the averages presented in table 1 mask substantial variation. Cost of production decreased or was unchanged in four out of the five commodities for which production cost changes were reported. Yield increased for six out of seven and net returns increased in all seven commodities for which the changes were measured. Monetary risk to farmers decreased in all three cases for which it was evaluated.

The picture that emerges from the farm-level evaluation of IPM benefits and costs is one of generally lower pesticide use, production cost, and risk, and higher net returns to producers. Because pesticide costs are a relatively small proportion of total production cost, what appears to be relatively small changes in total costs and yields due to IPM can result in substantial changes in net returns.

Table 1. Summary of Results of Farm-level Economic Evaluations of IPM Programs

Commodity	States	Number of Studies	Average Percent Change in Pesticide Use[a]	Percent Change in Production Cost with IPM[a]	Percent Yield Change with IPM[a]	Percent Change in Net Returns Per Acre[a]	Level of Risk with IPM
Cotton	TX, GA, MS, NC, SC, LA, MO, TN, AZ, NM, CA, AR	18	-15	-7	+29	+79	decreased
Soybeans	NC, VA, MD, GA, IN	7	-35	-5	+6	+45	decreased
Corn	IN, IL, and 10 other states	3	+20	+3	+7	+54	--
Vegetables and Flowers	CT, CA, MA, TX, FL, OH, NY, HI	15	-43	Quality increased in 4 studies and remained the same in others			
Fruits	NY, MA, WA, NJ, CA, CT	8	-20	0	+12	+19	--
Peanuts	GA, TX, OK, NC	5	-5	-5	+13	+100	--
Tobacco	NC	2	-19	--	0	+1	--
Alfalfa	OK, WI, Northwest	3	-2	--	+13	+37	decreased
Unweighted Average[b]			-14.9	-2.8	+11.4	+47.8	decreased

[a] For those producers that adopted the specified IPM practices compared to those that did not.

[b] Weighting is not possible without an accurate accounting of the acreage affected for each commodity in each state.

The studies summarized evaluated a variety of IPM practices, but particularly the use of scouting and economic thresholds. It should be pointed out that 13, or 21 percent, of the 61 studies found increased use of pesticides with IPM. As environmental concerns have intensified, the emphasis in IPM programs has increasingly shifted toward increased use of beneficials, cultural controls, and generally more bio-intensive IPM tactics that require fewer pesticides.

Evaluation of Aggregate Economic and Environmental Effects of IPM

The impacts of IPM programs extend well beyond the immediate economic effects on the farms where IPM practices are applied. When IPM is adopted by a large number of producers, resulting cost reductions and changes in supply can influence commodity prices. Thus, in the aggregate there are potential distributional effects on producers and consumers. IPM can also generate benefits by reducing pesticide use with its attendant negative environmental externalities. The effects of IPM on water quality, food safety for humans and wildlife, pesticide applicator safety, and the long-run sustainability of pest management systems all generate benefits that can potentially be measured in economic terms.

Most of the studies that have addressed these aggregate and other economic effects have presented theoretical models and discussions with few empirical examples. However, a few empirical studies do exist. Napit (1986) found a 300 percent rate of return for the cotton IPM program in Mississippi and a 425 percent rate of return for cotton in Texas. A report on the 1983 Beltwide Cotton Production Research Conference (Lambert 1983) listed aggregate economic benefits for cotton IPM programs is several states. Total acres considered to be produced under IPM programs was 6,865,460 in 15 states. The grower cost for IPM beltwide was $14,343,072. Returns to IPM, based on data obtained from 11 states, amounted to $133,598,000 annually. A national study of IPM programs for the three-year period ending in 1985 reported a total economic benefit of $578 million per year in nine commodities (Rajotte et. al.).

A study by Pimental et al (1980) provided rough estimates of environmental and social costs associated with pesticide use in the United States. The implications for IPM benefits are that if pesticide use is reduced by IPM programs, then the benefits may be realized in proportion to the pesticide reductions. For example, they estimated the environmental and social costs for pesticides in the United States at $839 million. This total was based on costs for human exposure of $184 million, livestock poisoning and product contamination of $12 million, reduced natural enemies and increased pesticide resistance of $287 million, honey bee poisonings and reduced pollination of $135 million, losses of crops and trees due to pesticide drift of $70 million, fishery and wildlife losses of $11 million, and cost of government pollution controls of $140 million. Unfortunately these numbers were arrived at by pulling estimates from a wide variety of individual studies and then extrapolating to the whole country based on a set of heroic assumptions.

A study by Higley and Wintersteen (1992) in the north central states estimated the environmental cost by insecticide per application per hectare for each of 32 insecticides. These costs ranged from $2.25 to $11.52. To the extent that reductions in pesticide use are documented for IPM programs, their results can be used to estimate environmental benefits from particular insect IPM programs. They obtained their estimates using a method called contingent evaluation (CV). The CV method is a survey-based technique that asks respondents how much they would be willing to spend to avoid particular risks from pesticide applications.

Relatively little empirical work has been completed that attempts to estimate the aggregate and environmental benefits of IPM programs. One reason for this is the location specificity of each IPM program. Another reason is the difficulty in assessing environmental effects of pesticide use and in estimating the value of benefits that are not priced in the market place. For example, it is very difficult to place an agreed-upon value on a human life or wildlife. Nevertheless, it is also clear from the methodological work that has been completed, not just in the IPM area but in other types of economic and environmental evaluations, that additional and more rigorous evaluations of IPM programs can be made. These assessments are needed for informed choices on policies and public investments affecting IPM.

ECONOMIC EVALUATION OF INTEGRATED PEST MANAGEMENT PROGRAMS

Integrated Pest Management (IPM) emphasizes making pest control decisions with increased information and the integration of biological, cultural, and chemical control methods. The economic effects of IPM programs are realized both by individual farmers, ranchers, and homeowners and by society at large. IPM programs can influence pest control costs, the level and variability of producer income, and the health of pesticide applicators. The programs also can affect food safety and water quality for humans and wildlife and the long-run sustainability of agricultural systems. This diversity of potential impacts implies that economic evaluations of IPM can focus on a variety of issues and serve multiple purposes.

Evaluating the effects of IPM on profitability, production and income risk, pesticide applicator safety, and other potential private benefits and costs can provide information to individuals that may help them decide if they should adopt particular IPM practices. However, if net benefits to society at large exceed private benefits, there may be insufficient provision and adoption of IPM programs. Hence, economic evaluation of IPM can be helpful to policymakers trying to decide if additional funding is needed for public IPM programs and if subsidies, taxes, regulations, or other institutional changes are required to encourage IPM adoption. To evaluate social benefits, assessments are needed of consumer benefits and of many non-priced environmental benefits in addition to effects on producer profit and risk.

Economic evaluations of IPM programs have been undertaken for roughly 20 years. Over this time period, the methods of analysis and issues addressed have broadened from field and farm level budgeting of IPM alternatives, to assessments of risk, to more sophisticated modeling of pest-practice dynamics, and to aggregate evaluations of social impacts of IPM programs on consumers and producers including environmental benefits. However, the vast majority of the studies found in the literature still present relatively simple budgeting of IPM alternatives.

The purpose of this document is to summarize the current state of knowledge on the economic evaluation of IPM programs. It is divided into three parts. The first part summarizes the results of economic evaluations of IPM undertaken over the past 20 years. The second part summarizes methods used to generate these results. The third and final part is an annotated bibliography that guides the reader to the individual studies that have provided economic evaluations of IPM programs. The rationale for this particular ordering is that most readers will be interested in the estimated benefits and costs of IPM, a smaller number of readers will be interested in the methods section, and a yet smaller number will use the detailed references to the literature. The audience for the first part is both public policy makers and scientists from a variety of disciplines. The second or third parts will primarily be of interest to the scientists.

In preparing this paper we have benefitted from previous literature reviews by McCarl (1981) and Osteen, Bradley, and Moffitt (1981). Since publication of those reviews, increased attention has been devoted by economists to issues related to risk, pest-crop-control dynamics, and to environmental assessment. Therefore, the methods section pays particular attention to these topics.

RESULTS OF ECONOMIC EVALUATIONS OF IPM

Most IPM programs are targeted at particular commodities. Consequently this section is structured around IPM programs on cotton, fruits and nuts, vegetables, soybeans, tobacco, peanuts, corn, small grains, and alfalfa. The programs evaluated involved insect, disease, weed, and nematode IPM. Most of the studies focused on costs and returns at the producer level and the results are summarized in a set of tables below. A few studies examined consumer or aggregate level benefits and a limited number considered environmental effects. These results are summarized as well.

Cotton

IPM methods have received their greatest application in reducing insect pests in cotton. Cotton is grown from Virginia to California and pest problems differ by region. Cotton bollworms have been the most severe pest in all regions (Suguiyama and Carlson 1985a). Bollweevils have also been a serious problem, especially in the southeast, although successful IPM programs have sharply reduced Bollweevil losses in recent years. Fleahoppers, aphids, spider mites, lygus bugs, pink bollworms, and other insects have also been problems. Diseases and a variety of weeds have affected cotton production as well.

Scouting programs with economic thresholds, genetic resistance of cotton varieties to certain insects and diseases, pheromone traps, cultural practices, release of sterile insects, biological control with predators and parasites, and bioinsecticides and biofungicides are some of the IPM tactics applied.

Summarizing the economic effects of IPM programs in cotton is difficult because of differences in locations, time periods, and practices considered. Some of the results are based on statistically valid samples while others are not. While a majority of the cotton IPM research results are published in well-known journals, many are found in relatively obscure state publications and often provide few details on methods. Nevertheless, several of the estimated per acre changes in pesticide use, costs, yields, and net returns are listed in Table 1. Four of the studies also considered economic risk associated with IPM practices.

The majority of the cotton IPM evaluations focus on IPM programs in Texas. Many studies were completed in the 1970s and used per acre budgeting to evaluate cultural practices, scouting, use of beneficials, resistant and short-season varieties, and parasite release. With five exceptions, pesticide use decreased as a result of IPM. Production costs generally, but not always, decreased while net returns generally increased. In three cases yields decreased. Risk was found to decrease in those studies that considered risk. Large variations in these factors were observed across programs. The study by Hall (1977) which appeared to be relatively careful with its statistical analysis, found substantial decreases (37 to 64 percent) in pesticide use but relatively little change in yield or net returns. A review of several economic analyses of cotton IPM programs is found in Lacewell and Masud (1989).

Soybeans

Soybeans are grown in three primary regions: the Southeast, the Mississippi Valley, and the north central states and the relative importance of various pests differ across the regions and over time. Major soybean insect pests have been velvet bean caterpillars, Mexican bean beetles, stink bugs, fall armyworms, bollworms, cabbage loppers, and two-spotted spider mites, among others. However, weeds are perhaps the most serious pests in soybeans while disease and nematodes are also problems.

Cultural controls are the most important non-chemical IPM practices for weeds while host plant genetic resistance is a primary pest management tactic for diseases and nematodes. Cultural controls including such practices as trap-cropping, narrow-row spacing, and altered planting dates are important for certain insects. Other IPM practices include scouting, parasite releases, and resistant varieties.

The results of several economic evaluations of soybean IPM programs are presented in Table 2. These studies consistently found decreased pesticide use with IPM and increased net returns per acre. Greene et al (1985a,b) found reduced levels of risk as well.

Vegetables and Flowers

IPM programs on vegetables have expanded significantly in the past 15 years. Vegetables are grown throughout the United States, but California is by far the largest producer followed by Florida. Because vegetable production encompasses a wide variety of commodities, a large number of insects, disease, and weeds are vegetable pests. The hot humid conditions in the Southeast mean that pesticide use is especially heavy in that region. Potatoes and tomatoes are the vegetable crops with the highest total value with more than $3 billion of production. These crops are especially susceptible to diseases and insects. Tomatoes, for example, represent less than 10 percent of total U.S. vegetable acreage but account for more than 20 percent of the pesticide acre-treatments (Green and Cuperus, 1991).

Scouting and monitoring techniques to assess if pests exceed economic thresholds is the most prevalent IPM practice (Table 3). Other practices include biological controls (parasites, predators, and pathogens to lower pest populations), cultural controls, pest-resistant varieties, and biopesticides. IPM specialists have reported that IPM programs were developed for more than 30 vegetable crops during the 1980s.

Table 1. Results of Economic Evaluations of Cotton IPM Programs

Author(s)	State	Type of IPM Practice	Percent Change in Pesticide Use	Percent Change in Production Cost with IPM	Percent Yield Change with IPM	Percent Change in Net Returns Per Acre	Level of Risk with IPM
Adkisson et al (1981)	TX	Scouting, Cultural	Decreased	-11 to -36	+25 to +53	+76 to +306	-----
Frisbie et al (1976)	TX	Scouting, Beneficial	Decreased	+5 to -11	+3 to +21	+10 to +112	-----
Hatcher el al (1984)	GA	Scouting	Increased	Increased	Increased	No Impact	-----
Hall (1977)	CA	Scouting	-37 to -64	-----	-8 to +2	+4 to -6	Decreased
Lacewell et al (1976)	TX	Cultural	-22 to +34	0 to +17	+25 to +53	+11 to +43	-----
Larson et al (1975)	TX	Cultural	-34 to -61	-9 to -10	-----	+22 to +50	-----
Liapis and Moffitt (1983)	AR	Parasites	-----	-----	-----	-----	Decreased
Masud et al (1981)	TX	Cultural, Genetic, Scouting, Beneficial	-35 to -49	+12 to +50	+25 to +94	+11 to +28	-----
Sprott et al (1976)	TX	Scouting	Decreased	-29 to -44	+25	Increased	-----
Condra et al (1977)	TX	No insecticides	-100	-32 to -34	-1 to -30	+192 to +387	-----

(Table 1. continued)

Author(s)	State	Type of IPM Practice	Percent Change in Pesticide Use	Percent Change in Production Cost with IPM	Percent Yield Change with IPM	Percent Change in Net Returns Per Acre	Level of Risk with IPM
Clarke et al (1980)	TX	Cultural, Genetic	Decreased	______	+104	+174	______
Collins et al (1979)	TX	Cultural	-36 to -98	______	______	-58 to +33	Decreased
Napit (1986) and Rajotte et al (1987)	TX	Scouting	+41 to +42	+5	+30 to +31	+100[a]	______
Napit (1986) and Rajotte et al (1987)	MS	Scouting	+29	+11	+20	+100[a]	______
Teague and Shulstad (1981)	AR	Scouting	-14	-19	______	______	______
Casey et al (1975)	TX	Scouting, Cultural	-50	-4 to +1	+47 to +50	+47	______
Carruth and Moore (1973)	AZ	Scouting	-92	______	-5	______	______
Ferguson and Yee (1993)	AL, GA, NC, SC	Scouting	+6	______	+12	______	______
	AR, LA, MO MS, TN	Scouting	+39	______	+23	______	______
	OK, TX, NM	Scouting	+92	______	+57	______	______
	AZ, CA	Scouting	+34	______	+7	______	______
Ferguson, et al (1993)	MS	Scouting	Increased	Increased	+49	Increased	Lower

a Returns were negative without IPM

Table 2. Results of Economic Evaluations of Soybean IPM Programs

Author(s)	Type of IPM Practice	State	Percent Change in Pesticide Use	Percent Change in Production Cost with IPM	Percent Yield Change with IPM	Percent Change in Net Returns Per Acre	Level of Risk with IPM
Carlson (1981)	Scouting	NC	-21	-16	-26	+54	______
Greene et al (1985a)	Scouting, Trap Crops, Parasites	VA	-85 to -97	-4 to -7	______	+27 to +42	Decreased
Weathers (1981)	Scouting	NC	-40	-15	+28	+56	______
Reichelderfer (1979)	Parasite, Scouting	MD	-100	-1 to +1	______	+3 to +13	______
Hatcher et al (1984)	Scouting	GA	______	Decreased	Increased	Increased	______
Napit (1986) and Rajotte et al (1987)	Scouting	VA	+70 to +83	+10 to +12	+11 to +20	+42 to +100[a]	______
Thomas et al (1988)	Scouting	IN	0	______	______	______	______

a Returns were negative without IPM in the Napit Study

Table 3. Results of Economic Evaluations of Vegetable and Flower IPM Programs.

Author	State	Commodity	IPM Technique	Comparison Method	IPM Group	Control pre-IPM	Reduction in IPM Users' Pesticide Cost		IPM Costs	Quality or yield change
					Number of sprays		Dollars	Percent	Dollars per acre	
Adams (1989)	CT	Sweet corn	Integrated insect control	IPM growers/ non-IPM growers	--	--	2,913	-78	--	Increase
Antle and Park (1984)	CA	Processing tomatoes	Economic thresholds for 2 insects	IPM growers/ control group	--	--	0	-22	0.58	Increase
Coli (1985-1987)	MA	Potatoes	Economic thresholds for 2 insects	IPM growers/ control group	4.4	7.5	96,536	--	4.00	Increase
					5.7	7.5	for all	--	4.00	Increase
					4.9	7.5	3 years	--	4.00	Same
Coli (1987)	MA	Sweet corn	Economic thresholds for 3 insects	IPM growers/ control group	---	--	2,000	--	--	--
Frisbie (1987-1988)	TX	Processing carrots	Economic thresholds for one insect	Previous contract required 6 sprays	2.0	6.0	21,600	-66	--	Same
Frisbie (1987-1988)	TX	Cabbage	Economic thresholds for one insect	Growers with IPM/ non-IPM fields	8.0	14.0	--	-43	--	--
Pohronezny (1984-1985)	FL	Tomatoes	Economic thresholds insects & disease	Survey respondents using/not using commercial scouts	--	--	121/ac	-25	--	Increase
		Peppers					95/ac	-50	--	Increase
		Snap beans					95/ac	-10	--	Increase
Toscano and others (1980-1981)	CA	Fresh tomatoes	Economic thresholds: Fruitworm	IPM growers/ control group	5.5	6.5	--	--	--	Same
			Pinkworm		1.0	1.3	--	--	--	Same
			Beet army worm		3.7	6.7	--	--	--	Same
Welty (1989)	OH	Processing cabbage	Economic thresholds for three insects	Growers with IPM/non-IPM fields	--	--	--	-25 to -50	--	--
Wright and others (1984-1985)	NY	Fresh potatoes	Economic thresholds for several insects	IPM growers/ control group	6.2	9.3	58/ac	--	8.00	Same
					6.9	8.8	31/ac	--	8.00	Same
					4.8	7.0	38/ac	--	8.00	Same
					7.8	6.9	31/ac	--	8.00	Same

(Table 3. continued)

Author	State	Commodity	IPM Technique	Comparison Method	IPM Group	Control pre-IPM	Reduction in IPM Users' Pesticide Cost		IPM Costs	Quality or yield change
					Number of sprays		Dollars	Percent	Dollars per acre	
Adams (1992)	CT	Strawberries	Scouting, monitoring, beneficials, others	IPM growers/ non-IPM growers	--	--	67/ac	-27		Increase
Adams (1992)	CT	Sweet corn	Scouting, monitoring, beneficials, others	IPM growers/ non-IPM growers	--	--	19/ac	-35		Increase
Adams (1992)	CT	Cole Crops	Scouting, monitoring, beneficials, others	IPM growers/ non-IPM growers	--	--	135/ac	-81		--
Adams, Bowler, and Gauthier (1990)	CT	Sweet corn	Scouting, monitoring, beneficials, others	IPM growers/ non-IPM growers	9.8	16	26/ac	-33		Increase
Hara et al (1990)	HI	Cut Flowers	Scouting	IPM growers/ non-IPM growers	--	--	566/ac to 87 quarter/acre	-69 to +31		--

-- = Not available.   Source: Greene and Cuperus (1991) (revised)

Fruits and Nuts

Fruit and nut IPM programs have focused primarily on tree fruits and have included scouting, a variety of cultural practices, biological controls, semiochemicals, and host plant resistance among other techniques (Table 4). Insects, diseases, weeds, and rodents are all serious problems and include an immense number of individual pests. Many of the insects and diseases are economic problems not only because of their influence on yields but because they affect fruit quality. Damaged fruit usually ends up in the processed rather than the fresh market and receives a substantially lower price. In part because of this quality factor, fruits receive greater amounts of pesticides than most other crops. A summary of pest problems on fruits is provided in Suguiyama and Carlson (1985b).

Economic evaluation of IPM in fruit crops has focused to a significant extent on apples. Most studies report reduced pesticide costs and higher returns with IPM. However, one study on apples in New York (Napit, 1986) and one on pears in Washington state (King and O'Rourke, 1977) did find greater pesticide use with scouting programs.

Peanuts, Tobacco, Corn, and Alfalfa

Peanut production in the United States is heavily concentrated in the Southeast with additional acreage in Texas, Oklahoma, and New Mexico. A variety of insects, weeds, disease, and nematode pests are serious problems in peanut production. To a substantial degree, peanut growers in the United States have practiced IPM out of necessity for more than 20 years. Economic evaluations have not always found reductions in pesticide use as a result of these programs, but the increases in yields and net returns have generally been substantial (Table 5).

Tobacco production is highly concentrated in the Southeast as well. Nematodes, diseases, insects, and weeds are all severe problems in tobacco with the result that tobacco is the field crop with the second largest number of pesticide applications after cotton. However, substantial progress has been made in tobacco IPM programs including scouting and resistant varieties (Cast, 1982). Some reductions in pesticide use and increases in net returns have been reported as a result of IPM in tobacco (Table 5).

Weeds and insects are the more serious pest problems on corn. Corn rootworms are the number one insect problem throughout the United States whenever corn is grown continuously, while the importance of other pests varies regionally. The relative importance of IPM compared to chemical pest control is small, but cultural control of weeds and scouting of insect pests have had some success in increasing net returns (Table 5).

Alfalfa is grown for hay and silage on about 90 million acres in the United States with the highest concentration in the north central and northeastern states (Cast, 1982). The alfalfa weevil and potato leaf hopper remain the most serious pests. Scouting programs have proven successful in reducing pesticide use and increasing net returns (Table 5).

Aggregate and Other Economic Effects of IPM

Aggregate IPM analyses assess the impacts of IPM programs upon those not directly involved in their use as well as upon the agricultural community. To the extent that IPM has been adopted by a large number of agricultural producers, resulting cost reductions and changes in supply can influence commodity prices. Thus, in the aggregate there are potential distributional effects on producers and consumers.

Economic value can also be placed on reduced negative environmental externalities including effects on water quality and food safety for humans and wildlife. Effects on the long-run sustainability of pest management systems may also generate an economic value.

Most of the studies that have addressed these aggregate and other economic effects have presented theoretical models and discussions with few empirical examples. However, a few empirical studies do exist. Napit (1986) found a 300 percent rate of return for the cotton IPM program in Mississippi and a 425 percent rate of return for cotton IPM in Texas. Napit (1986) and Taylor and Lacewell (1977) found that consumers receive most of the aggregate benefits of cotton IPM programs through increased quantities of cotton lint at lower prices. However, neither of their models considered the influence of international trade. Trade tends to moderate price effects that result from changes in domestic production. Hence

Table 4. Results of Economic Evaluations of IPM Programs in Fruits and Nuts

Author(s)	State	Commodity	Type of IPM Practice	Percent Change In Pesticide Cost	Percent Change In Production Cost with IPM	Percent Change in Yield	Percent Change in Net Returns Per Acre	Level of Risk with IPM
Napit (1986) and Rajotte et al (1987)	NY	Apples	Scouting and Monitoring	-15 to +14	+8 to +15	+3 to +21	+36 to +30[a]	____
Napit (1986) and Rajotte et al (1987)	MA	Apples	Scouting	-29	-5	+12	+5 to +6[b]	____
King and O'Rourke (1977)	WA	Apples	Scouting	-43	-10	____	____	____
		Pears	Scouting	+7	+20	____	____	____
Rossi et al (1983)	NJ	Apples	Monitoring and Cultural	-12	-1	____	____	____
White and Thompson (1982)	NY	Apples	Scouting	-24	-14	____	____	____
Barnett et al (1978)	CA	Pears	Scouting	Decrease	____	____	____	____
Hendley and Hoy (1987)	CA	Almonds	Predators and Scouting	-41	-5 to -10	0	____	____
Adams and Los (1990)	CT	Apples	Scouting, Monitoring, Beneficials	-18	____	____	____	____

[a] Price was also higher due to quality change

[b] Price was lower due to quality change

Table 5. Results of Economic Evaluation of IPM Programs in Peanuts, Tobacco, Corn and Alfalfa

Author(s)	State	Commodity	Type of IPM Practice	Percent Change in Pesticide Cost	Percent Change in Production Cost with IPM	Percent Yield Change with IPM	Percent Change in Net Returns Per Acre	Level of Risk with IPM
Napit (1986) and Rajotte et al (1987)	GA	Peanuts	Scouting	-11 to +10	+3 to +4	+10 to +11	+224 to +500	_____
Von Rumker et al (1975)	TX	Peanuts	Scouting	-50	-1.5	0 to +29	+3 to +133	_____
	OK	Peanuts	Scouting	-81 to +177	-43 to +48	_____	-18 to +144	_____
Hatcher et al (1984)	GA	Peanuts	Scouting	decreased	increased	increased	increased	_____
Carlson (1981)	NC	Peanuts	Scouting	-17	-10	_____	+11	_____
Napit (1986) and Rajotte et al (1987)	IN	Corn	Scouting	+15 to +47	+3	+3 to +10	+47 to +62	_____
Hanthorn and Duffy (1983)	10 States	Corn	Insect Scouting	+67	_____	+7	_____	_____
Pike and Gray (1992)	IL	Corn	Scouting Cultural	-24 to -50	_____	_____	_____	_____
McGuckin	WI	Alfalfa	Cultural	decreased	decreased	_____	increased	decreased
Napit (1986) and Rajotte et al (1987)	Northwest US	Alfalfa Seed	Scouting	-1 to -4	0 to +1	+9 to +17	+35 to +39	_____
Ward et al (1990)	OK	Alfalfa	Varietal Resistance Cultural	_____	decreased	_____	increased	_____
Van Rumker et al (1975)	NC	Tobacco	Scouting	-22.5 to -43.5	decreased	_____	increased	_____
Napit (1986) and Rajotte et al (1987)	NC	Tobacco	Scouting	-5 to 0	0	0 to +1	0 to +1	_____

they probably overestimated the benefits to consumers relative to producers.

A report on the 1983 Beltwide Cotton Production Research Conference (Lambert 1983) listed aggregate economic benefits for cotton IPM programs in several states. Total acres considered to be produced under IPM programs was 6,865,460 in 15 states. The grower cost for IPM beltwide was $14,343,072. Returns to IPM, based on data obtained from 11 states, amounted to $133,598,000 annually.

Few studies exist on integrated pest management in livestock. However, a study in Canada by Klein et al (1990) estimated net economic benefits of integrated cattle grub control of $20-25 million for the province of Alberta.

A study by Pimental et al (1980) provided estimates of environmental and social costs associated with pesticide use in the United States. The implications for calculating IPM benefits are that if pesticide use is reduced by IPM programs, then the benefits may be realized in proportion to the pesticide reductions. For example, they estimated the environmental and social costs for pesticides in the United States at $839 million. This total was based on costs for human exposure of $184 million, livestock poisoning and product contamination of $12 million, reduced natural enemies and increased pesticide resistance of $287 million, honey bee poisonings and reduced pollination of $135 million, losses of crops and trees due to pesticide drift of $70 million, fishery and wildlife losses of $11 million, and cost of government pollution controls of $140 million. Unfortunately these numbers were arrived at by pulling estimates from a wide variety of individual studies and then extrapolating to the whole country based on a set of heroic assumptions. Little discussion of methods was provided.

A study by Higley and Wintersteen (1992) in the north central states estimated the environmental cost by insecticide per application per hectare for each of 32 insecticides. These costs ranged from $2.25 to $11.52. To the extent that reductions in pesticide use are documented for IPM programs, their results can be used to estimate environmental benefits from particular insect IPM programs. They obtained their estimates using a method called contingent valuation (CV). The CV method is a survey-based technique that asks respondents how much they would be willing to spend to avoid particular risks from pesticide applications.

It is clear from reviewing the literature that very little empirical work has been completed that attempts to estimate the aggregate and environmental benefits of IPM programs. One reason for this is the location specificity of each IPM program. Another reason is the difficulty in assessing environmental effects of pesticide use and in estimating the value of benefits that are not priced in the market place. For example, it is very difficult to place an agreed-upon value on a human life or wildlife. Nevertheless, it is also clear from the methodological work that has been completed, not just in the IPM area but in other types of economic and environmental evaluations, that additional and more rigorous evaluations of IPM programs can be made.

METHODS FOR ECONOMIC EVALUATION OF IPM

A wide variety of methods have been used for economic evaluations of IPM techniques and programs. Seldom are the methods direct substitutes for each other. Because the issues addressed, data availability, time available for the analysis, and skills of the analysts differ from study to study, so too does the appropriate method. Methods are also complementary in many uses. For example, budgeting is often a necessary precursor for mathematical programming or economic surplus analysis.

Many studies in economics journals contain methods that have been applied once or infrequently. One reason is that most economics journals encourage the presentation of new methods or extensions of previous methods more than the presentation of empirical results derived with well-known methods. This methods bias arises, in part, because the economic issues addressed require improvements in existing methods. However, it also means that many of the empirical results of IPM evaluations using standard methods such as budgeting and analysis of variance are found in less accessible outlets.

The most common methods used for economic analyses of IPM programs are reviewed below. For ease of exposition, the methods are grouped into those used primarily to assist with farm-level decision-making and those used for more aggregate evaluations of economic benefits and costs, although some of the methods fit into both groups. The intent of this review is to (a) provide a quick guide to scientists, including non-economists, as to which method may be most useful for answering particular questions, (b) indicate briefly the nature of each method, and (c) give a reference to the literature for each method that illustrates its application.

Farm-level analysis of IPM Programs

Economic analyses of IPM programs at the farm level focus primarily on choice among alternative means of pest control and on the optimal use of pest management practices. Most of the analyses consider increased net returns to be the major objective of farmers. Other studies also consider the objective of reduced risk.

Choice of alternative pest control strategies

The most widely used method for evaluating alternative pest control strategies has been **budgeting** analysis, particularly *enterprise* budgeting and *partial* budgeting. An enterprise budget is a listing of all estimated income and expenses associated with a particular enterprise to provide an estimate of its profitability. Use of enterprise budgets for IPM evaluation involves developing per-acre crop budgets or per-head livestock budgets, including input quantities and costs, output quantities and prices, and net returns for non-IPM production practices and IPM production practices. Input costs are broken down into variable and fixed costs. Variable costs can be broken down into pest management and non-pest management costs. An example from Napit (1986) that compares three levels of IPM adoption is presented in Table 6. This example does not list the non-IPM costs in detail as they were assumed not to change.

One pitfall with enterprise budgets is that differences in management priorities and other factors may not be adequately captured in a sample of producers divided into users and non-users of IPM. As a result, misleading conclusions may be drawn about differences in net returns or pesticide use between the two groups. Also, it can be difficult to classify producers into users and non-users, as IPM may be adopted in varying degrees.

Partial budgeting differs from enterprise budgets in that several enterprises may be involved in the change in practices. Also, only the benefit and cost items expected to change significantly with the new production systems are considered. A blank form that can be used to complete the partial budget is presented in Table 7. If no changes in crop acreage are expected, partial budgeting can provide a quick analysis of the effects of IPM on per acre or per head profitability.

When budgeting is used to compare yields, costs, or profitability of alternative pest management practices, calculation of **t-statistics** or an **analysis of variance** should be used to assess if the difference between practices are statistically significant. For example, the t-statistic used to test for significant differences between two means is given by

$$t=\frac{(\bar{x}_1-\bar{x}_2)}{\left[s^2\left(\frac{1}{n_1}+\frac{1}{n_2}\right)\right]^{1/2}}$$

where s^2 is the pooled variance

$$s^2=\frac{\left[(n_1-1)s_1^2+(n_2-1)s_2^2\right]}{(n_1+n_2-2)}$$

and where s^2_1 and s^2_2 are the sample variances of the two groups. The F-statistic used to test the null hypothesis that variances are equal is given by $F' =$ (larger of s^2_1, s^2_2)/(smaller of s^2_1, s^2_2).

F' is a folded form of the F statistic and a test of F' is a two-tailed test since it is not specified which s^2 is expected to be larger. Under the assumption of unequal variances, the appropriate t-statistic is computed as

$$t=\frac{(\bar{x}_1-\bar{x}_2)}{\left[\frac{s_1^2}{n_1}+\frac{s_2^2}{n_2}\right]^{1/2}}$$

Napit (1986) provides an example of using these t-statistics to test for significant differences between IPM adopters and non-adopters.

Likewise an analysis of variance could be used to test for differences among a set of IPM practices. For example, let y_1, y_2, and y_3 be the average yields of a crop grown under each of 3 levels of IPM usage I_1, I_2, and I_3. To test the hypothesis, Ho, that $y_1 = y_2 = y_3$, an independent random sample of the same size is drawn from I_1, I_2, and I_3. Assume that the crop given under each IPM practice has the same variance, $\sigma^2_1 = \sigma^2_2 = \sigma^2_3 = \sigma^2$ where σ^2_1, σ^2_2, σ^3_3 represent the variances of the 3 populations, I_1, I_2, I_3. For a one-way classification, the following analysis of variance model can be used:

$$x_{ij} = y + a_i + e_{ij} \quad (i = 1, 2, 3)$$

where: x_{ij} = the j^{th} observation in the i^{th} sample

y = the overall mean of x_{ij} values for all populations in the analysis, which is an unknown constant

a_i = the extent to which x_{ij} values reflect consistent deviation (a treatment effect) from the overall mean

e_{ij} = a random element from a normally-distributed population with mean zero and standard deviation zero.

Using the above model, testing the null hypothesis that $y_1 = y_2 = y_3$ is equivalent to testing the null hypothesis that $a_1 = a_2 = a_3 = 0$.

When samples are derived from populations of IPM adopters and non-adopters (or adopters of different levels), **regression analysis** can be used to hold constant many of the non-IPM variables when testing for significant differences due to IPM. For example, a yield response equation can be estimated in which dummy variables are included to account for different levels of IPM adoption. T-statistics are then calculated for the coefficients on the dummy variables to test for significant differences. Masud et al (1984) provides an example for delayed planting dates to control bollweevils in the Texas Rolling Plains.

In economic analysis of IPM programs, there is a need for greater emphasis on statistical techniques with carefully designed samples of adopters and non-adopters. Many of the results reported earlier in this bulletin were not presented in the original studies with statistical tests of significance. Hence, their scientific credibility is difficult to assess.

Risk can also be a concern to producers when they choose an IPM practice. This risk may arise due to biological, technical, or economic factors. For example, pest density can vary from season to season depending on a variety of factors, pest managment practices may be applied improperly, and crop prices can change rapidly. A **pay-off matrix** can be developed that lists projected net returns for different pest management practices and severity of pests. (see Figure 1).

Pest Severity	Conventional	IPM
Light	+200	+350
Severe	+50	-50

Figure 1. A monetary payoff matrix for insect control per hectare for a hypothetical crop.

The decision to adopt a particular practice must be made before information is available on pest severity. Therefore the decision will depend on the producer's ability to absorb risk and assessment of the probabilities of light or severe pest attacks. If historical information is available to help in calculating the probabilities, expected monetary outcomes could be calculated for each pest management practice. In addition, the cells in the matrix could be subdivided to account for risks associated with crop prices and other factors.

Pest forecasting can be used to provide information on the probability of a severe pest attack. This forecast can be based on factors such as weather, spore counts, etc. Perfect forecasting is unlikely and hence the profitability of a forecasting scheme depends on the probability of a correct forecast and the probabilities of light and severe attacks. Producer surveys can be used to estimate how accurate the forecast must be before producers will adopt it.

Producers have different degrees of risk aversion but generally are willing to trade off some monetary gains for reduced risk of loss, particularly a severe loss. Other benefits such as reduced pollution costs can also be included in the evaluation.

Table 6. Georgia peanut budgets for average, non-, low, and high users of IPM.

			Average Grower			Non-user			Low user			High user	
	Unit	Price	Quantity	Value	Price	Quantity	Value	Price	Quantity	Value	Price	Quantity	Value
GROSS RECEIPTS	lbs.	0.25	3453.55	873.33	0.26	3222.00	822.36	0.26	3333.33	853.52	0.25	3541.66	899.74
VARIABLE COSTS													
Preharvest (Non-Pest Management)				325.53			325.53			325.53			325.53
Preharvest (Pest Management)													
Insecticide				9.74			8.38			15.13			7.34
Herbicide				33.78			24.94			40.32			33.80
Nematicide				2.59			3.81			2.08			2.47
Fungicide				37.75			37.48			36.53			38.18
Scouting				0.57			0.22			0.50			0.68
Labor and machinery				36.90			28.66			42.21			38.70
Total Pest Mngt.				121.33			103.50			136.77			122.26
Total Preharvest				446.86			429.02			462.30			447.79
Total Harvest Cost				96.35			96.35			96.35			96.35
Interest on pest mgmt. variable costs*		0.12	60.67	7.28	0.12	51.75	6.21	0.12	68.38	8.21	0.12	61.13	7.34
Total Variable Costs				550.49			531.59			566.86			551.48
TOTAL FIXED COSTS (including Machinery, Irrigation, Land Charge, and Overhead)				281.60			281.60			281.60			281.60
TOTAL COSTS				832.09			813.19			848.46			833.08
Return to Management				41.24			9.18			5.07			57.66

*Note: Interest calculated on one-half of pest management variable costs due to the typical 6-month debt carrying period.
Source: Napit (1986)

TABLE 7. Partial Budget Form

Proposed change: ______________________________

____

Assumptions:

1. ______________________________

2. ______________________________

3. ______________________________

ITEMS THAT ADD TO NET INCOME		ITEMS THAT REDUCE NET INCOME	
Added Returns:		**Reduced Returns:**	
____________________	$________	____________________	$________
____________________	$________	____________________	$________
____________________	$________	____________________	$________
____________________	$________	____________________	$________
____________________	$________	____________________	$________
Total	$______	Total	$______
Reduced Costs:		**Added Costs:**	
____________________	$________	____________________	$________
____________________	$________	____________________	$________
____________________	$________	____________________	$________
____________________	$________	____________________	$________
____________________	$________	____________________	$________
Total	$______	Total	$______
TOTAL ADDED RETURNS AND REDUCED COSTS(A)	$______	TOTAL REDUCED RETURNS AND ADDED COSTS(B)	$______

A minus B equals change in net farm income: $________

Pest scouting can be used to provide current information on pest levels and hence further reduce uncertainty in pest control decisions. Because scouting costs money when scouts are hired or involves an opportunity cost of the producer's time spent scouting rather than doing other activities, scouting costs must be netted out of the projected payoff in the matrix.

Additional discussion of payoff matrices is found in Reichelderfer, Carlson, and Norton (1984). An example of the use of economic analysis in a decision theory approach to crop disease forecasting and control is provided by Carlson (1970).

The attractiveness of alternative pest management practices under risk can also be evaluated using a technique called **stochastic dominance** (SD). Stochastic dominance allows for comparisons of probability distributions to determine the most preferred choice for different classes of decisionmakers. There are three basic types of SD. First-degree SD ranks distributions for all decisionmakers. Second-degree SD ranks distributions for risk averters. Unfortunately, many distributions are left unranked with first and second degree SD. The third type of SD, called generalized SD, can be used to determine whether or not all producers in more narrow sets of risk preferences will prefer one cumulative distribution of net income associated with a management strategy or another, or have no preference. Pairs of alternative management strategies may be examined for various sets of producers. These sets of producers can be defined by their levels of risk aversion.

An example of the use of generalized SD in the economic evaluation and comparison of IPM strategies with conventional strategies for soybeans is found in Greene et al (1985a,b). Studies using first and second degree SD include Musser et al (1981), Moffit et al (1983), and McGucklin (1983).

Optimal Use of Pest Management Practices

Farm-level economic evaluations of IPM programs are often concerned not only with the choice of practices, but with the optimal level of pest control by a particular practice or set of practices. Assuming profit maximization as the goal, optimal use of an IPM practice occurs when the marginal increase in net returns from applying another unit of the practice equals the marginal cost of its application. Headley (1972) related the concept of economic optimization to earlier work on **economic thresholds** by Stern (1959) and others. Headley defined the economic threshold as the "pest population that produces incremental damage equal to the cost of preventing that damage" (p.105).

Several alternative definitions of the economic threshold have been developed. Stern (1973) defines the economic threshold as the pest density at which control measures should be used to prevent an increasing pest population from reaching economic injury level. Headley (1972), Reichelderfer et al (1984), and others have pointed out that the minimum pest density that economically justifies treatment is likely to be larger than the lowest one causing some minimal crop loss. Hence a more useful definition of an economic threshold is the pest population that produces incremental damage equal to the cost of preventing that damage (Headley, 1972). This threshold is thus the maximum and minimum threshold level that justifies treatment. If pest density is below this level, no treatment is justified. If it is above this level, treatment should occur to reduce pests to this level. IPM programs often involve monitoring or scouting to provide information to producers on pest densities in relation to the threshold.

The determination of what the economic threshold level should be is difficult because it is influenced by a large number of factors. **Damage functions** are needed that relate pest levels to crop losses. Pesticide costs, output prices, effects of pesticide use on the development of pest resistance, and effects on predators are other important factors that influence the threshold. And, if risk aversion on the part of producers and off-site costs of pesticide pollution are considered, economic thresholds might differ substantially from ones that only consider direct effects on net returns to producers. Higley and Wintersteen (1992) suggest modifying the components of the formula used to calculate economic injury levels to account for environmental costs. They used **contingent valuation** to calculate the economic value of environmental costs associated with pesticide use. The use of contingent valuation is discussed below in the section on valuing environmental benefits of IPM.

Most of the studies by economists on optimal use of pest management practices have used **mathematical programming** techniques such as **linear programming, non-linear programming,** and **dynamic programming**. Linear programming maximizes an objective function (e.g. net return from a set of cropping activities) subject to resource contraints (e.g. land, labor, capital, water, etc.). Cropping activities can be included that incorporate various types of IPM practices. Enterprise budgets are incorporated in the model and the sensitivity of the solution to changes in prices and resource availability is easily examined. Linear programming assumes all activities and constraints can be cast in linear form. Martin et al (1991) provide an example for an analysis of alternative tillage systems, crop rotations, and herbicide use on East-Central corn belt farms. Non-linear programming is an extension of linear programming that allows for non-linear relationships. An application of non-linear programming to a pest management problem that includes pesticide resistance is found in Gutierrez et. al (1979). Despite their relative simplicity, the time involved in constructing and specifying mathematical programming models means that they are little used for farm-level decisionmaking.

Dynamic optimization models have been prevalent in the pest management literature since the early 1970s. Shoemaker (1973) and Hueth and Regev (1974) were among the early studies that utilized dynamic programming or control theory to design optimal pest management actions given a set of state variables such as potential plant product, pest population density, and the stock of pest susceptibility to pesticides. Most of these studies have focused on optimal pesticide use (often without IPM) and have not incorporated empirical data. An exception is a study by Zacharias and Grube (1983) who used dynamic programming to examine optimal management strategies for control of corn rootworm and soybean cyst nematode in Illinois. The inherent complexity of these models has constrained their widespread empirical application. More discussion of these models is presented below in the section on methods for designing optimal pest management policies.

Analysis of Aggregate Economic and Environmental Impacts

Many of the methods for economic analysis of IPM programs are for evaluation of aggregate social and environmental impacts that extend beyond the farm gate. The purpose of the analysis may be to estimate regional or national benefits of IPM or to design optimal pest management policies.

Evaluating IPM Effects on Aggregate Income

When widespread adoption of IPM occurs across large areas, changes in crop prices, cropping patterns, producer profits, and social welfare can occur. These differences arise because of changes in costs and because greater supplies affect prices to producers and consumers. These changes are illustrated in Figure 2. The demand curve for the commodity is represented by D while the supply curve is represented by S_0 before the adoption of IPM. Adoption of IPM lowers the cost of production per unit of output, shifting the supply curve from S_0 to S_1. The original price (P_0) and quantity (Q_0) changes to the new price (P_1) and quantity (Q_1). Consumers have more of the commodity available at a lower price while producers supply more at a lower cost of production but at a lower price. Consumers are said to gain a **consumer surplus** that can be represented by the area P_0 a b P_1 in Figure 1. Producers have a change in **producer surplus** represented by I_0 cbI_1 - P_0acP_1. In net, producers may gain or lose depending on the slopes of the demand and supply curves. Examples of studies that have evaluated these income benefits to producers and consumers are found in Taylor and Lacewell (1977) and Napit et al (1988).

Masud and Taylor (1985) point out that calculations of consumer and producer surplus often find losses to producers as a result of adopting new technologies (including IPM practices). The reason for the losses are the price declines due to additional supplies. Alston, Norton, and Pardey (1994), however, disagree with this generalization. They note that while producers lose when the demand curve is assumed to be inelastic (very steep) with no international trade and when the supply curve is assumed to shift in a pivotal (rather than a parallel fashion is shown in Figure 2), these are very special assumptions. The prices of most agricultural commodities are influenced by world market prices and hence increases in supply do not result in as sharp a price decline as illustrated in Figure 2. Reductions in cost of production due to IPM increase international competitiveness and help offset cost increases that can result from increased restrictions on pesticide use. Also, the supply curve is as likely to shift out in a parallel fashion as it is in a pivotal fashion. Formulas for calculating consumer and producer surplus gains and losses are presented in Alston, Norton, and Pardey for a variety of market situations, including those influenced by government policies.

The most difficult component of an economic surplus analysis is the calculation or prediction of the proportionate shift in supply following IPM adoption. Cost differences as well as adoption rates must be calculated or projected. Adoption rates are particularly difficult to estimate because they include changes in acreage as well as the proportion of producers adopting. Individual producers also may partially adopt IPM practices. Producer surveys can help in estimating past adoption. Several studies have estimated econometric relationships that assess factors influencing past adoption. These models can then be used to help predict future adoption. Napit et al (1988), Harper et al (1990), and Fernandez-Cornejo et al (1992) provide examples in which **logit models** were used to estimate the relative importance of several socio-economic and other variables in influencing IPM adoption.

Once changes in economic surplus are calculated or projected over time, benefit/cost analysis can be completed in which **net present values**, **internal rates of return**, or **benefit/cost ratios** are calculated. The benefit side is the total economic surplus calculated year by year and the costs are the public expenditures on IPM programs. Benefit cost analysis takes into account the fact that the sooner the benefits occur the more they are worth.

Changes in economic surplus can also be imbedded in mathematical programming models to predict interregional changes in production following the introduction of a widespread IPM program or to predict the impacts of IPM following policy changes that encourage and discourage IPM use. The interregional analysis can use **quadratic programming** while policy models are likely to use dynamic programming (see, for example, Archibald, 1984) or **dynamic simulation** (see, for example, Kazmierczak, 1991). These dynamic models do not have standard algorithms and hence are more difficult to solve than the static (linear or quadratic) programming models. However, because the impact of IPM programs is inherently dynamic due to factors such as pest resistance to pesticides, the results of dynamic models can be more realistic than static models if sufficient complexity is incorporated in the models. The advantage of dynamic simulations overs dynamic programming is the ability to add more complexity to an empirically tractable model.

Valuing Environmental Benefits

Increased attention has focused in recent years on the actual or potential environmental benefits of IPM. Measurement of these benefits is difficult for two primary reasons. First, assessing the physical or biological effects of alternative levels of pesticide use under different IPM practices is challenging. Second, the economic value associated with environmental effects is generally not priced in the market. The first problem was recently addressed in studies by Kovach et al (1992) and Higley and Wintersteen (1992). Kovach et al divided the environmental effects into farmer, worker, consumer, and ecological components and used a variety of databases on toxicity of pesticides in different settings to classify and weight the environmental impacts of pesticides based on dermal toxicity, chronic toxicity, systemicity, fish toxicity, leashing potential, surface loss potential, bird half-life, soil half-life, bee toxicity, beneficial arthropod toxicity, and plant surface half-life. This weighting allowed them to arrive at an **environmental impact quotient** by pesticide. They then multiplied this quotient by the percent active ingredient and application rates to obtain an environmental rating for the pesticide in field use. They compared the environmental impacts of traditional and IPM strategies. Kovach et al did not attempt to place an economic value on these differences in environmental impacts.

Higley and Wintersteen assessed the environmental risks of pesticides on three broad areas of environmental risk (water quality, non-target organism, and human health) that were then subdivided into eight specific categories (surface water, groundwater, aquatic organisms, birds,

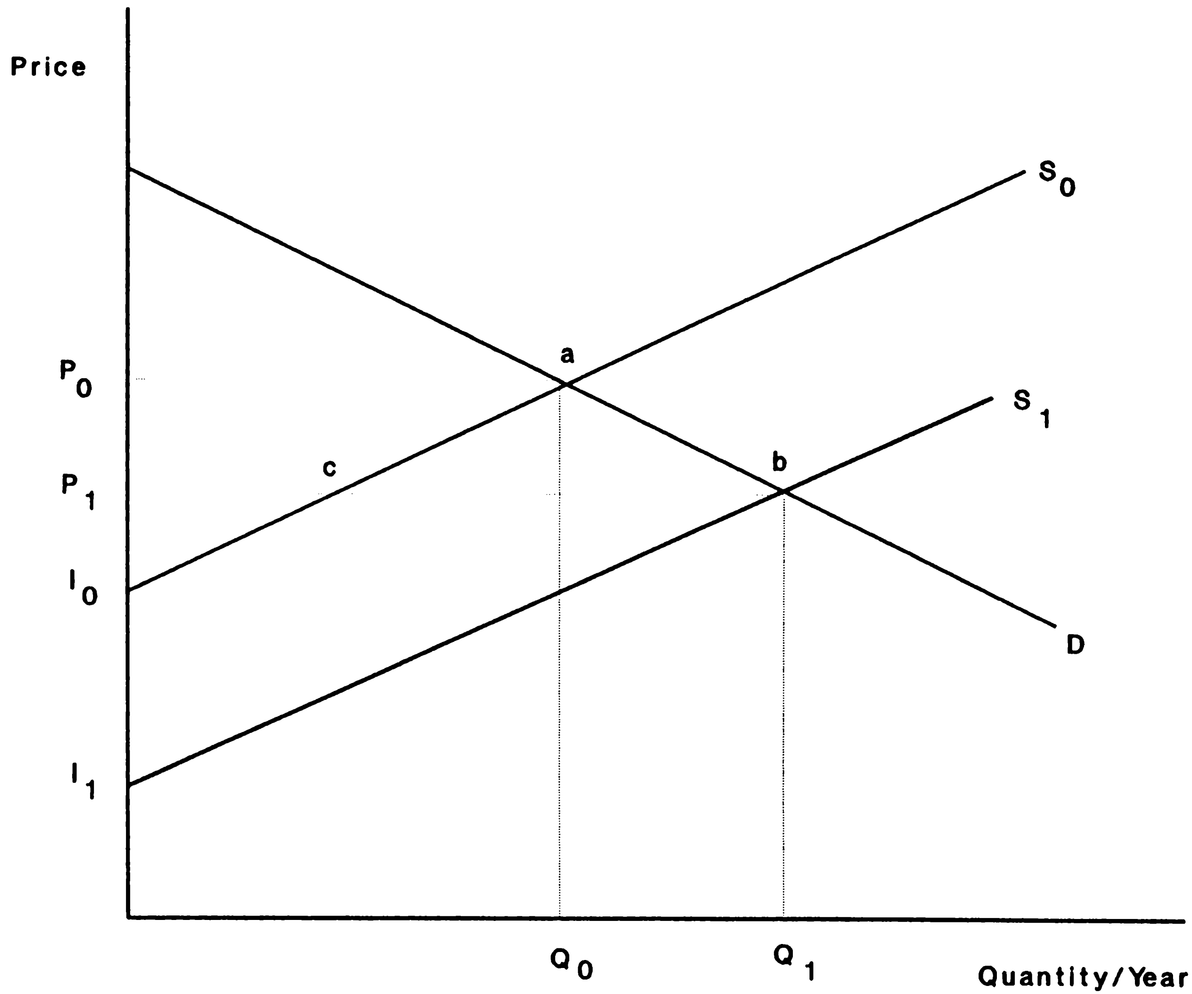

Figure 2. Aggregate Economic Benefits from IPM

mammals, beneficial insects, humans (acute toxicity), and humans (chronic toxicity). They then classified each pesticide into high risk, medium risk, low risk, or no risk for each environmental category based on a set of criterion from several different studies. Unlike Kovach et al, however, they then tackled the issue of placing a value on benefits not priced in the market. They used **contingent valuation** (CV) to assess the relative importance that individuals place on the environmental risk categories and the amount they would be willing to pay to avoid high, moderate, and low levels of risk from a pesticide for a single application on a per-acre basis. A total of 8000 producers were surveyed in four midwestern states. They used the results to estimate the environmental costs per pesticide. Therefore if the amount of change in pesticide use as a result of IPM adoption is calculated, the environmental cost or savings can be calculated.

Contingent valuation is one of the few procedures available for estimating environmental costs associated with pesticide use (or environmental benefits of IPM if pesticide use declines). The procedure has been used for roughly 20 years (and particularly in the last 5 years) in other settings to estimate non-market costs or benefits. Typically, CV studies provide respondents with information about a hypothetical action that would reduce the likelihood of a future environmental problem such as pesticide exposure to fish. Respondents are given some specific information about the nature of the damages. They are then confronted with a question or questions about the maximum amount they would be willing to pay to reduce the problem.

The CV technique has been controversial. Some have argued that respondents give answers that are irrational, that they do not understand what they are being asked to value, that they do not take the questions seriously because they are hypothetical, and have raised other objections as well (Arrow et al, 1993). Others have argued that these problems can be minimized with carefully designed and administered surveys. Arrow et al provide a detailed discussion of these issues.

The CV technique is one of the few procedures currently available for estimating the aggregate environmental benefits of IPM programs. However other methods could be used for specific types of environmental effects. For example, hospital records on the costs associated with acute pesticide poisonings, insurance costs for farm workers exposed to pesticides, costs of restoring polluted wildlife habitats, and other partial market-based techniques can be used in some situations. To date, however, very little attention has been devoted to this difficult area of measuring the environmental benefits of IPM.

CONCLUSION

Most of the economic analyses of pest management programs have provided simple per acre budget analyses of IPM and non-IPM (or low-IPM) programs. Few have evaluated the aggregate effects of IPM on either income or the environment. Many of the more sophisticated studies have developed theoretical models with little empirical content.

Clearly, economic analyses are needed for farm-level decisions on choice of pest management practices and their optimal use. Budgeting and calculation of economic thresholds are the minimum analyses required. Stochastic dominance can help in assessing risk effects of IPM. Improvement is needed in the procedures used to calculate environmental costs before these effects can readily be incorporated into economic thresholds.

Using farm level budgets and adoption analyses as a base, consumer and producer surplus analysis can be used to estimate aggregate income benefits of IPM for society. Benefit cost procedures that incorporate economic surplus measures can then be used to access net social benefits. An environmental component can be added if additional work is devoted to refining procedures for environmental benefits from reduced pesticide use.

Dynamic models, particularly those that are empirically tractable such as dynamic simulation, can be useful for accessing the implications of alternative governmental policies in encouraging adoption of IPM and reducing problems with pesticide resistance. However, these models require joint modeling of biological processes and economic effects to be most useful.

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Annotated Bibliography of Economic Analyses of IPM

Introduction

This bibliography is a compilation of the economic literature related to integrated pest management (IPM). It is, essentially, an extension of the annotated bibliography written by Osteen, Bradley, and Moffitt (1980) on the economics of pest control. While no document could include everything written on the subject, we have attempted to assemble relevant theoretical writings and empirical studies to date.

The writings assembled here have been gathered from English-language journals, extension reports, research reports, and books. This document follows the format laid out by Osteen, Bradley and Moffitt, but our annotations are generally more detailed, particularly with respect to empirical results. In some instances the abstract written by the author(s) is included rather than a separate annotation. Where this is done, it is clearly noted. Quotations that appear in the annotations are taken directly from the cited work.

The works are arranged alphabetically by senior author. Empirical studies are organized under the following headings:

Topic (T): Subject or problem addressed.

Data (D): Type of data used.

Model (M): Model or approach used to investigate the problem.

Estimation technique (E): Technique employed for statistical estimation.

Results (R): Empirical results and conclusions.

Annotations which do not fit neatly into the above format are described in paragraph form.

For easy reference, subject and author indices are compiled in the back of the bibliography. Each annotation is numbered. The number corresponding to an annotation is listed in the indices, rather than the page number on which the annotation appears.

We hope this bibliography will be a useful reference to anyone interested in the many economic facets of integrated pest management.

1. Adams, Roger G. State of Connecticut Integrated Pest Management Program 1992 Annual Report to the Connecticut Legislature. University of Connecticut Cooperative Extension Service and Department of Plant Science, 1992.

The accomplishments, from 1984 through 1992, of the Integrated Pest Management (IPM) programs undertaken by the University of Connecticut Cooperative Extension Service are summarized in this report. Programs were developed for the following commodities: tree fruits, strawberries, sweet corn, field corn, cole crops, and turf grass. Over the nine-year period, the IPM programs reduced total pesticide costs for these commodities $423,820. The reduction in pesticide costs was realized from a reduction in the amount of pesticides applied, including active ingredient (AI), by the program participants. In general, the quality and the yield of participants' crops were either maintained or increased. Below are some results reported for the 1992 programs.

Item	Tree Fruits	Straw-berries	Sweet Corn	Field Corn	Cole Crops	Turf-Grass	Totals & Averages
# Trained	9	3	8	21	1	13	56
# IPM Acres	342	46	508	5,683	5	540	7,124
Pesticide reduction							
Lbs. AI	3,137	199	427	9,372	68	149	13,352
% AI	28	27	35	36	81	11	33
Pesticide $ Saved							
Total $	32,638	3,074	9,683	69,562	677	3,783	119,417
$/acre	95.43	66.82	19.00	12.24	135.00	7.00	16.76

2. Adams, Roger G., T. Jude Boucher, and Norman Gauthier. Impacts of the University of Connecticut Integrated Pest Management Program for Sweet Corn 1984-1987. Cooperative Extension Service, The University of Connecticut, College of Agriculture and Natural Resources, 90-26.

T: Presentation of results from a full-season IPM training program for Connecticut sweet corn producers conducted from 1984 through 1987. In addition, an IPM mini-program for sweet corn producers in Connecticut, conducted in 1987 only, is evaluated.

D: "Program evaluation and impact data were gathered each year by questionnaires, review of pesticide records and personal interviews with growers."

M: "Dollar savings reported in this study were based only on the costs of pesticides used. Costs for fuel and labor needed for pesticide applications or crop scouting were not included in this study."

R: Summary results are presented, separately, for the full-season and mini-programs. The questionnaires used to evaluate the programs are presented along with the percentage of responses in each answer category. In addition, a table summarizes "Total Impacts of the Sweet Corn IPM Training Program with Full-Season and Mini-Program Results Combined, 1984 Through 1987." This table appears on the following page.

Category	Total Impacts
# Growers Trained	31
# IPM Acres Impacted	2,783
Total Lbs. Pesticide Formulation Saved	10,004
Lbs. Formulation Saved/Grower	323
Lbs. Formulation Saved/Acre	3.60
Total Lbs. Active Ingredient (AI) Saved	3,144
Lbs. AI Saved/Grower	101
Lbs. AI Saved/Acre	1.13
Total $ Saved	57,923
$ Saved/Grower	1,869
$ Saved/Acre	20.81

3. Adams, Roger G., and Lorraine M. Los. Impacts of the University of Connecticut Integrated Pest Management Program for Apples 1984-1987. Cooperative Extension Service, The University of Connecticut, College of Agriculture and Natural Resources, 90-22.

T: Presentation of results from a full-season IPM training program for Connecticut apple producers conducted from 1984 through 1987. In addition, an IPM mini-program for apple producers in Connecticut conducted in 1987 only, is evaluated.

D: "Program evaluation and impact data were gathered each year by questionnaires, review of pesticide records and personal interviews with growers."

M: "Dollar savings reported in this study were based only on the costs of pesticides used. Costs for fuel and labor needed for pesticide applications or crop scouting were not included in this study."

R: Summary results are presented, separately, for the full-season and mini-programs. The questionnaires used to evaluate the programs are presented along with the percentage of responses in each answer category. In addition, a table summarizes "Total Impacts of the Apple IPM Training Program with Full-Season and Mini-Program Results Combined, 1984 Through 1987." This table appears below.

Category	Total Impacts
# Growers Trained	24
# IPM Acres Impacted	1,334
Total Lbs. Pesticide Formulation Saved	22,931
Lbs. Formulation Saved/Grower	956
Lbs. Formulation Saved/Acre	17.2
Total Lbs. Active Ingredient (AI) Saved	11,015
Lbs. AI Saved/Grower	459
Lbs. AI Saved/Acre	8.3
Total $ Saved	90,811
$ Saved/Grower	3,784
$ Saved/Acre	68.07

4. Adkisson, Perry L., R. E. Frisbie, J. G. Thomas, and G. M. McWhorter. "Impact of IPM on Several Major Crops of the United States," printed in Integrated Pest Management on Major Agricultural Systems, edited by Raymond E. Frisbie and Perry L. Adkisson, Texas A & M University, Texas Agricultural Experiment Station MP-1616. From a symposium sponsored by the Consortium for Integrated Pest Management and USDA/CSRS held October 8-10, 1985.

The various positive impacts of the research conducted under the Consortium for Integrated Pest Management (CIPM) are described. During the tenure of the CIPM, more than 1,100 scientific articles were published reporting new advances in crop management and protection. "Very large percentages of apples, alfalfa, cotton, and soybeans grown in the United States are produced under some form of IPM." IPM's impact on insecticide use is also addressed. "The increased usage [of insecticides] on corn and soybeans, in terms of millions of pounds applied, might be accounted for by the increased acreage planted to the crop rather than to changes in use pattern dictated by control practices." However, "a significant part of the decrease [in insecticides applied to cotton, sorghum and peanuts] can be attributed to the IPM systems that have been implemented on the vast majority of the acreages planted to these crops."

5. Adkisson, P.L., R.E. Frisbie, J.G. Thomas, and G.M. McWhorter. "Organization and Implementation of an Integrated Pest Management System," *The Southwestern Entomologist*, Vol. 6, No. 4, December, 1981.

T: Description and evaluation of a cotton IPM program in the Lower Rio Grande Valley, Trans-Pecos, Central Blacklands, and South Texas regions of Texas.

D: IPM pilot programs were conducted under the leadership of the Texas Association of Cotton Producer Organizations.

M: The program used 3 cropping techniques: conventional cotton planted in 40" rows (IPM cc40), shortseason cotton planted in 40" rows (IPM ss40), and shortseason cotton planted in 26" rows (IPM ss26). These techniques were evaluated against a typical non-participant planting conventional cotton in 40" rows (Non-IPM cc40).

R:

	Non-IPM cc40	IPM cc40	IPM ss40	IPM ss26
Pesticides (lbs):	9.6	16.9	6.6	6.6
Costs (cents/lb):	47.60	42.56	33.84	26.90
Yield (lb/ac):	500	625	649	765
Net Returns ($/ac):	62	109	170	252

6. Allen, W.A., and J.E. Roberts, Sr. "Economic Feasibility of Scouting Soybean Insects in Late Summer in Virginia," *Journal of Economic Entomology*, Vol. 67, No. 5, October, 1974.

T: The economic feasibility of scouting soybean insects.

D: In 1972, 36 fields averaging 23.9 acres were scouted for 4 weeks in Middlesex County at a cost of 7.2 cents/acre/week. In 1973, 32 fields averaging 27.0 acres were scouted for 6 weeks in Virginia Beach at a cost of 5.5 cents/acre/week.

M: The Boyer and Dumas survey method was used, and insect control decisions were made using Virginia Polytechnic Institute and State University Extension Insect Control Recommendations.

R: Scouting soybeans in Virginia is economically feasible with existing labor and insect treatment practices, and at work efficiencies obtained in 2 years of study. The percentage of insect control costs spent before insect populations reached levels at which Virginia Polytechnic Institute and State University recommends control was 87.2% in Middlesex County and 89.7% in Virginia Beach. Elimination of unnecessary control costs would have yielded net savings per dollar of outlay equal to $4.54 in 1972 and $3.13 in 1973.

7. Andres, L.A. "The Economics of the Biological Control of Weeds," *Aquatic Botany*, Vol. 3, 1977, pp. 111-123.

The article is a discussion of the costs involved in the research, development and implementation of weed control programs based on biological methods. The costs of such programs is divided into three categories: 1) project development costs; 2) project implementation costs; and 3) hidden costs (i.e. costs of undesired side effects of the program). These costs are to be expressed in scientist years, i.e. the technical and administrative costs involved in supporting one scientist for one year. The development and implementation costs for a "classical" biological program are estimated to be between 11.5 and 12.5 scientist years, based on studies with host specific weed-feeding insects. The author notes, however, that this figure may vary widely from project to project. The hidden costs from biological control are "unknown or difficult to obtain." The cost/benefit estimates of several biological control programs are favorable enough to warrant further support and research for programs of this sort.

8. Antle, John M., and Seong K. Park. "Economic Benefits and Costs of an Integrated Pest Management Program for Processing Tomato Production," *California Tomato Grower*, May 1986, pp. 4-5.

T: Economic benefits and costs of a 1984 tomato IPM program in California.

D: Cost, yield, and revenue data were collected from 21 IPM-participant fields and 35 non-participant fields.

R: IPM-participant fields had 39.5% lower average worm damage than non-participant fields; IPM-participant fields had less variation in worm damage than non-participant fields; IPM-participant fields used an average of 22% less insecticide than non-participant fields (12% less on mid-season fields, and >40% less on late-season fields); IPM-participants can expect revenue increases of $7.70/acre with an increase in labor costs of $0.58/acre, and no reduction in insecticide cost.

9. Araji, A.A. "The Economic Impact of Investment in Integrated Pest Management," *Research Bulletin 115*, University of Idaho, Moscow, ID, January 1981.

T: Ex-ante evaluation of the impact of present and future investment in IPM.

R: B/C ratios vary with commodity (high of 191, low of -20); significant returns to investment require Extension involvement; IPM leads to a dramatic aggregate reduction in pesticide use; and IPM technology is transferable, but the degree of transferability varies across crops and pests.

10. Barnett, William W., Clarence S. Davis, and Gordon A. Rowe. "Minimizing Pear Pest Control Costs Through Integrated Pest Management," *California Agriculture,* Vol. 32, No. 2, February 1978, pp. 12-13.

The article provides some background information on the USDA's 1973 IPM program for pear production in California. Some pest control costs for IPM participants and non-IPM producers are compared.

11. Baum, K.H. and R.W. Tillman. "The Economics Behind Integrated Pest Management," Cooperative Extension Service, V.P.I. and S.U., Virginia Agricultural Economics, Number 297, December 1978.

This article is a brief graphical demonstration of how changes in output price affect the profit maximizing level of pest control inputs. As output price increases the optimal level of control inputs increases as well, *ceteris paribus*. Likewise, as the cost of control inputs rises the optimal level of their employment decreases, *ceteris paribus*.

12. Benedict, J. H., K. M. El-Zik, L. R. Oliver, P. A. Roberts, and L. T. Wilson. "Economic Injury Levels and Thresholds for Pests of Cotton," Chapter 6 in Integrated Pest Management Systems and Cotton Production, edited by Raymond E. Frisbie, Kamal M. El-Zik, and Ted L. Wilson, 1989, pp. 121-153.

The chapter begins with a conceptual overview of the economic injury level (EIL) and its components, and the relationship between the EIL and the economic threshold (ET). The following subjects are then discussed: 1) EIL's and ET's for plant pathogens; 2) EIL's and ET's for weeds; 3) methods EIL's and ET's for nematodes; 4) EIL's and ET's for spider mites; and 5) EIL's and ET's for insects. The determination of injury-damage functions and estimation of losses for each of the pest categories above are also addressed.

13. Boggess, William G., Gerald A. Carlson, Luis R. Zaveleta, and Kenneth W. Paxton. "Economics of Improved Soybean Production Systems," printed in Integrated Pest Management on Major Agricultural Systems, edited by Raymond E. Frisbie and Perry L. Adkisson, Texas A & M University, Texas Agricultural Experiment Station MP-1616. From a symposium sponsored by the Consortium for Integrated Pest Management and USDA/CSRS held October 8-10, 1985.

The abstract accompanying this paper reads as follows: "Soybean economic research accomplished under the Consortium for Integrated Pest Management (CIPM) Project is reviewed. The research focused on weed, insect and nematode pests. Profit, risk and environmental objectives were considered. Both cropping system and control strategy alternatives were analyzed. In addition, considerable effort focused on improving the level and quality of scouting information.

"Some of the studies analyzed specific cropping systems or management practices. These included analyses of double-cropping, optimal rotations, use of a trap crop, use of pest management consultants, and alternative tillage practices and management inputs. Other studies resulted in fundamental theoretical and methodological developments. These included the use of a Kalman filter to improve information quality, the initial economic research on economic thresholds for weeds in soybeans, and the development of a methodology for determining dynamic, multiple-pest economic thresholds."

14. Boggess, William G., Dino J. Cardelli, and C. S. Barfield. "A Bioeconomic Simulation Approach to Multi-Species Insect Management," *Southern Journal of Agricultural Economics*, Vol. 17, No. 2, December 1985, pp. 43-55.

T: "The objective is to develop and implement a methodology with which to evaluate multi-species, non-stochastic, managerial decision variables subject to stochastic elements of weather and the plant-insect system." Soybean pest management was used for demonstration.

D: Weather data (daily radiation, precipitation, and maximum and minimum temperature) from 1954-1963 were used. G. G. Wilkerson et al.'s report "SICM Florida Soybean Integrated Crop Management Model: Model Description User's Guide." Agr. Eng. Dep. Rpt. AGE 83-1, University of Florida, November 1983, provided light trap data for velvetbean caterpillar influx intensity and Julian dates of influx timing.

M: The Florida Soybean Integrated Crop Management (SICM) Model was used. First degree and second degree stochastic dominance rules are applied to evaluate pest management strategies with respect to "risk efficiency" and profit sensitivity. "Forty strategies were developed to account for five threshold levels of total worms (0, 5, 10, 15, and 20 per 3 row feet), four scouting intervals (3, 5, 7, and 10 days) and two chemical combinations." The SICM model has four components: 1) a crop growth model (SOYGRO); 2) an insect model composed of insect development, mortality, and consumption; 3) a tactics model (e.g. pesticides and irrigation); and 4) an economics model.

R: The expected net returns for each strategy are reported. The strategy consisting of a 3-day scouting interval, 5 worms per 3 row feet threshold, and methomyl for early applications and methyl-parathion for late-season applications had the greatest expected net returns. "There is considerable variation in mean net returns over the 40 strategies, ranging from a low of $-15.82 per acre to a maximum of $83.92 per acre." As the threshold level increases (holding the scouting interval and pesticide type constant), mean net returns decrease and the standard deviation of net returns increases. Marginal value product and several marginal cost curves for pest control based on a 3-day scouting interval and methomyl, methyl-parathion pesticide combinations are also generated. The curves all intersect at threshold levels between 5 and 10 worms.

15. Boutwell, John L., and Ronald H. Smith. "A New Concept in Evaluating Integrated Pest Management Programs," *Entomological Society of America Bulletin*, Vol. 27, No. 2, pp. 117-118.

A technique is developed to measure the level of IPM practices employed by cotton producers in Alabama. As IPM programs are adopted, the traditional evaluation technique of separating producers into IPM participants and non-participants becomes obsolete. Factors and practices that influence IPM for particular crops are weighted according to their relative importance. Maximum IPM utilization would be indicated by a score of 100. As IPM programs evolve, the weights would be revised.

16. Burrows, Thomas M. "Pesticide Demand and Integrated Pest Management: A Limited Dependent Variable Analysis," *American Journal of Agricultural Economics*, Vol. 65, No. 4, November 1983, pp. 806-810.

T: Examination of the issue of simultaneity between pesticide use and IPM adoption is undertaken when the latter is represented as a binary choice.

D: Presents the effects of IPM on yield, pesticide and other input use, cost and revenue for 47 cotton growers in the San Joaquin Valley, CA, over a five year period (1970-1974).

M: Estimation of simultaneous and single equation models.

R: Simultaneous equation model found IPM adoption and non-adoption to be substitutes; single-equation model found them to be complements; IPM led to a reduction in pesticide use. Conclusion: IPM reduces negative externalities while preserving yield and profit.

17. Cammell, M.E., and M.J. Way. "Economics of Forecasting for Chemical Control of the Black Bean Aphid, Aphis Fabae, on the Field Bean, Vicia Faba," Annals of Applied Biology, Vol. 85, No. 3, April 1977, pp. 333-343.

T: Economic performance of forecasting for chemical control of the black bean aphid on field beans.

D: Counts of over-wintering eggs and active stages of the aphid were made on sample spindle bushes in the spring.

M: Forecasts were made regarding the probability of exceeding the economic threshold of infestation. The alternatives to forecasting were no treatment, preventive treatment or eradicative treatment.

The value of the forecasting strategy, calculated using gross margins, was compared with the value of routine treatment. Both developmental and operational costs were considered.

R: Forecasting failed to recommend treatment which would have been profitable 1% of the time and recommended unprofitable treatment 18% of the time. Risk associated with incorrect timing of pesticide application was reduced. With forecasting, 1% of the fields would have suffered losses due to no treatment while 8% would have suffered losses due to unnecessary treatment. The costs associated with forecasting rose over the study period, but were offset by savings from avoiding unnecessary chemical applications. The overall cost:benefit ratio for the study region was calculated to be 1:27.

18. Carlson, Gerald A. "Externalities and Research Priorities in Agricultural Pest Control," *American Journal of Agricultural Economics,* Vol. 71, No. 2, May 1989, pp. 453-457.

The article identifies the positive and negative externalities associated with pesticides, IPM, and biotechnology products. The difficulty of measuring and the lack of accurate information regarding these externalities are addressed. Government's attempt to force the pesticide industry to internalize (via FIFRA regulations) some of the externalities of pesticides is discussed. The author articulates the need for pesticide demand models that "incorporate changes in information about externalities, IPM, resistant crop varieties, and other factors." Area-wide pest management programs may offer the best opportunity to assess the value of information with respect to IPM, and the benefits of IPM research.

19. Carlson, Gerald A. "Pest-Resistant Varieties, Pesticides, and Crop Yield Variability: A Review," Variability in Grain Yields: Implications for Agricultural Research and Policy in Developing Countries. Baltimore: Johns Hopkins University Press for the International Food Policy Research Institute, 1989, pp. 242-50.

"This chapter discusses the role of pest-resistant crop varieties in changing cereal (especially rice) production variability. The genetic approach to pest control in most countries is part of the spread of modern varieties. Pest resistance is one of the important traits upon which cereal varieties are selected. However, it is not possible to examine the effects of resistant crop varieties without also considering irrigation, fertilizer, labor, farm size, and background (unknown) sources of production variability that are linked to weather and pest development."

20. Carlson, Gerald A. "Economics of Apple IPM Implementation," printed in Integrated Pest Management on Major Agricultural Systems, edited by Raymond E. Frisbie and Perry L. Adkisson, Texas A & M University, Texas Agricultural Experiment Station MP-1616. From a symposium sponsored by the Consortium for Integrated Pest Management and USDA/CSRS held October 8-10, 1985.

The abstract accompanying this paper follows. "Profitable apple production in humid areas is difficult because of high disease levels and long periods of exposure of fruit to insects. Studies in North Carolina and New York show that use of IPM consultants can increase profits slightly. Farmers do appear to monitor tree and fruit status in making pesticide use decisions. Protecting trees against early death can be valuable. Farmers seem to overestimate insect and disease levels and this leads to high pesticide use. Risk aversion can also explain why farmers are reluctant to move away from calendar spray programs."

21. Carlson, Gerald A. "IPM Experience in North Carolina Crops," *Tar Heel Economist*, North Carolina State University, Raleigh, NC, September 1981.

The article presents a comparison between a non-IPM control group and an IPM group using standardized product prices and input costs. Corn, soybeans and peanuts were evaluated with respect to yield, pesticide expenditure, total variable cost, non-adjusted net returns and yield-adjusted net returns. There is also a brief look at boll weevil eradication in terms of Benefit/Cost. IPM vs. non-IPM data are presented on 45 apple orchard blocks in Henderson County, North Carolina.

22. Carlson, G. A. "Economic and Biological Variables Affecting Demand for Publicly and Privately Provided Pest Information," *American Journal of Agricultural Economics*, Vol. 62, No. 5, 1980, pp. 1001-1006.

A brief review of the history of economic studies addressing IPM consulting and scouting is presented. Analysis of the spatial aspects of IPM services, the effect of extension activities on the profitability of similar private IPM practices, and a model to evaluate future changes in state licensing of consultants and proposed regional training centers are all needed. The production and dissemination of IPM advice is divided into three components: 1) transportation-communication; 2) monitoring activities; and 3) diagnosis and recommendations. Each of these components is further divided into the inputs that influence their supply. The three components are then reunited to form a supply function for IPM advice, under the assumption that IPM consulting firms are profit maximizers. A demand function for IPM consultants is also developed. The author then derives a grower demand function for IPM advice. The model reveals that "more extension effort in monitoring and recommendations will lower the supply price of consultants time and increase the supply of consultants in a region for a given consultant advice demand. On the other hand, lowering the price of extension specialist information can lead to its substitution and reduced consultant demand." Finally, USDA pesticide use surveys are briefly discussed.

23. Carlson, G.A. "Economic Aspects of Crop Loss Control at the Farm Level," Crop Loss Assessment Methods, edited by L. Chiarappa, Food and Agriculture Organization, Rome. pt. 2, 1973. pp. 2.3/1-2.3/6.

The paper addresses three areas where economists can assist in farm level crop protection: 1) the determination and utilization of economic thresholds; 2) estimation of long-range factors influencing crop protection decisions; and 3) evaluation of the potential of group crop protection programs. A diagrammatic scheme for combining biological and economic factors to establish economic thresholds is presented. The economic threshold is defined as the "pest density at which the incremental control costs and additions to crop income are equal." Long-range economic factors focus on the future. Because pest populations in one season often are functions of the survival rate of the pest from the previous season, growers must consider the future as well as the present productivity of pest management resources in order to maximize returns to those resources. A diagrammatic scheme illustrating the complexities of group pest management is also presented.

24. Carlson, Gerald A. "A Decision Theoretic Approach to Crop Disease Prediction and Control," *American Journal of Agricultural Economics*, Vol. 52, No. 2, May 1970, pp. 216-223.

The abstract accompanying this articles reads: "The pesticide application practices of California peach growers in controlling peach brown rot are used to demonstrate how Bayesian decision theory procedures can be used to arrive at optimal crop disease control practices. Subjective probabilities of disease loss intensity are measured and used on the decision model. Information from an analyst (this researcher) is combined with farmers' subjective probabilities of disease loss by means of Bayes' theorem. Optimal pesticide use actions are computed for three different objective functions -- maximum subjective expected returns, mean-standard deviation of returns, and maximum expected returns with a minimum income side condition."

25. Carlson, Gerald A., and Emery N. Castle. "Economics of Pest Control," in Pest Control Strategies for the Future. Washington, D.C.: National Academy of Sciences, 1972, pp. 79-99.

"In this paper we attempt to present (1) some indicators of benefits and hazards of pest control, (2) a discussion of depletion of and investment in pest control research, (3) economic alternatives in pest control, and (4) a social strategy for pest control."

Four types of externalities associated with pesticide use are discussed: (1) chemicals finding their way onto neighbors' land; (2) residues ingested by consumers; (3) exposure to chemicals by laborers, applicators and people on or near the site; (4) environmental degradation as a result of pesticides leaching, drifting or running off the target site. The authors propose viewing the "current stock of pesticide material and use recommendations as *biological capital*." As such, they would be subject to appreciation and depreciation. Pesticide supply and demand factors are discussed briefly.

Both the decrease in agricultural labor force and the relatively small increase in agricultural land from 1952-1968 may be partially attributed to the use of pesticides and fertilizers. The authors are unsure of the costs of reallocating these resources. Several substitution possibilities for pesticides, including crop insurance, are also explored. The need for consumer adjustments with respect to cosmetic changes in food is addressed. Finally, mechanisms for public intervention are discussed as a means for correcting market failures with respect to pesticides. Interventions mentioned include: Socialization, Administrative Regulation, Modification of the Incentive Framework, Tax on Externalities, Subsidies, Redefinition of Property Rights by Government Action, and Market Allocation of a Restricted Input.

26. Carlson, G.A., and C.E. Main. "Economics of Disease-Loss Management," *Annual Review of Phytopathology*, Vol. 14, 1976, pp. 381-408.

The article presents a general overview of the literature and concepts pertaining to economic evaluation of disease-loss management, including a review of the economic threshold and pest-control simulation models. The authors stress that "the important economic aspect of disease control is cost relative to income." Monitoring is recognized as a large cost in disease control. The value of forecasting is discussed, elaborating on the difficulty of assigning benefits to particular practices. The mathematics of estimating expected value are presented. A review of the fundamentals of risk analysis is included with an illustrative example from peach brown rot control. Long-term adjustments (resistant varieties, certified seed investments, rotations) are also reviewed, including Griliches' logistic adoption transformation of hybrid-corn. Headley's formula for present value of income streams from a pesticide that includes resistance is presented. Hueth and Regev's model of insecticide resistance is discussed along with economic analyses of plant breeding and managing crop disease spread.

27. Carruth, Laurence A., and Leon Moore. "Cotton Scouting and Pesticide Use in Eastern Arizona," *Journal of Economic Entomology*, Vol. 66, No. 1, February 1973, pp. 187-190.

T: The effect of scouting on pesticide use in cotton production in Eastern Arizona.

D: Data was provided by a cooperative, grower-sponsored, cotton-scouting program conducted during the summers of 1969, 1970 and 1971 in the Safford, AZ, area, and for the summer of 1968 when a timed insecticide treatment program (no scouting) was conducted in the same area.

M: Pest control costs and yields were compared for the two pest control techniques.

R: A summary of the costs and yields reported appears below.

Factor	1968	1969	1970	1971
Program Acres	13,263	12,750	9,655	11,051
Scouting Program:				
cost/program acre		$1.67	$1.63	$1.65
Pesticide Applications:				
% program acres sprayed	100%	16%	18%	29%
avg. # applications/ sprayed acre	6	1.6	1.7	3.8
total acre-applications	79,578	3,264	2,955	12,122
Total spray costs	$220,000	$11,750	$10,687	$43,069
Avg./Acre Yields of Cotton Lint (500 lb. bales):				
long staple	1.13	1.36	0.85	1.03
short staple	1.61	1.67	1.37	1.55

28. Casey, James E., Ronald D. Lacewell, and Winfield Sterling. "An Example of Economically Feasible Opportunities for Reducing Pesticide Use in Commercial Agriculture," *Journal of Environmental Quality*, Vol. 4, No. 1, 1975, pp. 60-64.

T: A comparison of pest control strategies for cotton production in Texas.

D: Yearly yield, pesticide, and other input data were collected from the Texas Department of Corrections (TDC) cotton farms in the Trinity River and Bravos River Regions for 1968 through 1972. 1968-1970 production utilized the traditional pest management strategy of spraying pesticides every 5-6 days. 1970-1972 production used a new strategy, the focus of which was "(i) to control boll weevil with a fall diapause program, (ii) control fleahopper with low dosages of insecticides applied as early as feasible and (iii) to terminate fleahopper, *Pseudatomoscelis seriatus* (Reuter), treatments quickly to allow beneficial insects to build and control bollworm and budworm."

M: An enterprise budget generator was used to develop per hectare cotton budgets for each pest control strategy examined. The results of the experiment were extrapolated onto the entire study region, and region-wide changes in costs, returns, yields, and pesticide use were estimated.

R: Selected results from the study appear below.

	Unit	1968-1970	1970-1972
TDC Farms			
Trinity River			
Insecticide Use	kg/ha	12.28	6.22
Cotton Yield	kg/ha	390	572
Net Returns	$/ha	40.34	211.94
Brazos River			
Insecticide Use	kg/ha	14.51	7.19
Cotton Yield	kg/ha	257	387
Net Returns	$/ha	-22.69	89.06
Entire Study Area			
Trinity & Bravos River Regions			
Insecticide Use	kg	1,211,364	603,738
Cotton Yield	bales	111,067	165,795
Net Returns	$	-589,401	10,404,685

29. Casey, James E., Ronald D. Lacewell, and Winfield Sterling. Economic and Environmental Implications of Cotton Production Under a New Pest Management System, Texas Agricultural Experiment Station, Texas A & M University, June,1974.

T: Examination of pesticide use and yield associated with a new pest management strategy for cotton production on Texas Department of Corrections (TDC) farms. The new management strategy consisted of: 1) a fall diapause program for boll weevil control; 2) low dosage insecticide applications in the early cotton fruiting phase to control the cotton leafhopper; 3) early termination of leafhopper insecticide treatments to bolster populations of beneficials; 4) increase the infestation level at which bollworm-budworm treatments are initiated; and 5) early harvest and destruction of crop residues.

D: TDC farm records provided data on yields, and pesticide and other input use. The TDC farms were divided into two regions, Trinity River Area and Brazos River Area. "The data for the traditional or systematic method of pest control applies to 1968-1970 operations while the new pest management system was initiated in the fall of 1970 and applies to 1970-1972 data."

M: Enterprise budgets of inputs, costs, and returns were developed for both regions under both the "traditional" and the new pest management strategy.

R: Selected results from the study appear below.

Item	Trinity River Area Traditional	 New	Brazos River Area Traditional	 New
Total Pesticides (lbs./acre)	10.96	5.55	12.94	6.42
Cotton Yield (lbs./acre)	348	510	229	345
Net Returns ($/acre)	16.53	85.77	-9.18	36.04

30. Cashman, Christopher M., Marshall A. Martin, and Bruce A. McCarl. "Indiana Farm-Level Impacts of Possible Environmental Protection Agency Bans on Selected Soybean Insecticides," *Southern Journal of Agricultural Economics*, Vol. 12, No. 2, December 1980, pp. 147-152.

T: The effects of carbaryl (Sevin^{TM} 80S and Sevin^{TM} 4 oil), malathion, and methomyl on yields on a 600-acre Indiana corn-soybean farm.

D: Yield data was supplied from test plots in five Indiana counties (1975-1977).

M: A math programming model was designed to maximize net income for the farm. Land, labor, machinery and field time constraints were imposed on the model.

R: "On the basis of the empirical results of [the] study, if carbaryl (Sevin^{TM} 80S) -- which is currently on the RPAR review list -- were banned, both malathion and methomyl could serve as technically and economically acceptable substitutes." The authors emphasize that the cost-benefit analysis in the study is reflective of private costs, not social costs. Selected results appear below:

	Untreated Soybeans	Carbaryl Sevin 80S	Malathion	Methomyl
Return to management/ fixed resources	59,654	62,424	62,939	62,371
Net Revenues/acre	67	76	78	77
Income/$ of insecticide	NA	2.0	2.2	2.7

31. Cochran, Mark J. "Economic Methods and Implications of IPM Strategies for Cotton," printed in Integrated Pest Management on Major Agricultural Systems, edited by Raymond E. Frisbie and Perry L. Adkisson, Texas A & M University, Texas Agricultural Experiment Station MP-1616. From a symposium sponsored by the Consortium for Integrated Pest Management and USDA/CSRS held October 8-10, 1985.

A number of cotton IPM studies are reviewed. In Mississippi, a dynamic threshold strategy was compared via simulation to a control program using a constant economic threshold for cotton pests. The dynamic threshold reduced insecticide treatments and increased per acre profit. Studies regarding Arkansas bollworm management communities indicate the communities lead to increased yields and net returns, and reductions in control costs and insecticide use. Results from the Texas Coastal Bend study conducted by Masud et al., 1984, and annotated in this bibliography below, are included in this paper. A Boll Weevil Eradication program in northeastern North Carolina and Virginia revealed benefits to IPM adoption as well. "Additional work is needed in several areas. Aggregate analysis is needed to check what impact the increases in profits and yields and the decreases in production costs may have on national supply and, hence, cotton prices. It is possible that a result of successful IPM programs may be a lower price of cotton, leaving the economic benefits to consumers and early adopters. Second, more attention needs to be focused on the risk aspects of IPM and the implications that risk efficiency may have on adoption. Finally, more attention should be placed on IPM systems designed to combat non-insect pests such as weeds and/or the interactions of these programs with the insect control."

32. Coffelt, Mark A., and Peter B. Schultz. "Development of an Aesthetic Injury Level to Decrease Pesticide Use Against Orangestriped Oakworm (Lepidoptera: Saturniidae) in an Urban Pest Management Project," *Journal of Economic Entomology*, Vol. 83, No. 5, October 1990, pp. 2044-2049.

The abstract accompanying this article reads as follows: "The orangestriped oakworm, *Anisota senatoria* (J. E. Smith), has become a major pest of urban oak plantings along city streets in Norfolk, Va., since 1981. Insecticidal sprays were applied by city employees at citizen request to control this pest, resulting in needless pesticide use; >50% of citizen requests for pesticide application in 1987 and 1988 were for trees with <5% defoliation. Justification for an urban pest management program for *A. senatoria* was based on the economic value of urban oak trees ([x bar] = $5,131 per tree) and the large pesticide volume sprayed for control (55,172 liters in 1986) Monitoring and establishing an aesthetic injury level of 25% defoliation in 1988 resulted in a decrease in pesticide volume of 80% and a real cost savings on 55% over the previous year."

33. Collins, Glenn S., Ronald D. Lacewell, and John Norman. "Economic Implications of Alternative Cotton Production Practices: Texas Lower Rio Grande Valley," *Southern Journal of Agricultural Economics*, Vol. 11, No. 1, July 1979, pp. 79-82.

T: Economic comparison of short-season and conventional cotton production on irrigated and dryland fields.

D: 1973-1975 yield and production data were provided by the Texas Agricultural Extension Service in the Lower Rio Grande Valley. The data came from 115 irrigated and 88 dryland fields of light to medium textured soils. The analysis is not applicable to other soil types. Tamcot SP-37, Stoneville 256, and Deltapine 16 were the major varieties planted in the study area.

M: Partial budgeting was used to develop per-acre budgets for the four production scenarios examined. Breakeven analysis was used to determine the sensitivity of each production scenario to yield and cotton price changes.

R: The following mean yield and net return were calculated for dryland and irrigated cotton for the period 1973-1975 (the article presents calculations for each year as well):

	Irrigated	Dryland
Lint Yield (lbs.)	550.5	496.3
Coefficient of Variation (%)	34.0	31.9
Net Returns ($/ac)	25.07	108.65

The 1973-1975 period is disaggregated into conventional (Conv.) and short-season (S-S) techniques, although calculations are not given for individual years.

	Irrigated		Dryland	
	S-S	Conv.	S-S	Conv.
Lint Yield (lbs.)	457.0	580.6	474.9	512.7
Coefficient of Variation (%)	25.1	33.8	30.1	33.0
Insecticide Applications (#)	11.0	13.2	.44	5.79
Insecticide Use (lbs.)	14.1	22.1	.15	12.32
Net Returns ($/ac)	9.52	31.49	126.31	94.98

34. Davidson, Alexander, and Richard B. Norgaard. "Economic Aspects of Pest Control". For presentation at the Conference on Plant Protection Economy sponsored by the Europe and Mediterranean Plant Protection Organization, May 15, 1978, Brussels, Belgium.

The article suggests a need for a National Research Program to be aimed at developing IPM strategies. "The objective of this paper is to introduce plant protection scientists to economic principles and problems related to the design and implementation of optimal management strategies." Farmer objectives are presented first. A basic explanation of profit maximizing behavior is given. Injury, damage, compensation and loss are defined from an economic perspective. The concept of the economic threshold is articulated. The authors propose "damage threshold" be used for the level of a pest population which begins to inflict damage. Farmer risk aversion is discussed. That pest management practices on a particular farm will affect pest levels on other farms in the region is noted. Because of this phenomenon, a regional pest management institution could ensure pest control methods lead to regional profit maximization.

35. Davidson, B.R. "Economic Aspects of Weed Control." Proceedings, Weed Society of New South Wales, 1974, 6:34-43.

The article begins with a discussion of the nature of costs, defining fixed and variable costs. An explanation of how the optimum level of herbicide is determined follows. One of the major difficulties of agricultural economic analysis is data collection. The author notes the general disparity between experimental data and farm data, and the difficulty of isolating a particular input factor for analysis. The role of regression analysis in overcoming some of the inherent data problems is discussed. Partial budget analysis is also presented as a technique to evaluate a change in weed control methods when production functions cannot be estimated. This technique compares the costs avoided by the new method plus the revenues gained versus the new costs incurred plus the revenues lost. The article concludes with a short discussion of the differences between extensive Australian agriculture and intensive European agriculture.

36. Deen, William, Alfons Weersink, Calum G. Turvey, and Susan Weaver. "Weed Control Decision Rules Under Uncertainty," *Review of Agricultural Economics*, Vol. 15, No. 1, January 1993, pp. 39-50.

"A model of weed control, which took into account the stochastic nature of crop price, yield, and weed density, was developed to assist farmers in determining weed densities that justify herbicide application and the optimal rate of application. In an application of cockelbur control in soybeans, it was found that the value of following the 'if-then-else' treatment strategy versus a fixed application rate regardless of weed density was approximately $25 per acre at low weed numbers. Profits of the marginal treatment strategy are higher than the 'if-then-else' strategy, but may not be sufficient to cover the additional informational costs. Under both strategies, the total amount of herbicide applied decreases with increases in uncertainty under the assumption of risk neutrality. The result is due to the convex relationship between weed density and yield loss. Under the assumption of maximizing expected utility, there are instances in which herbicide use increases with risk aversion as per conventional wisdom."

37. Dively, Galen P., and William Mellors. *An Evaluation of the 1980-1981 Mexican Beetle Biocontrol Demonstration Project*, University of Maryland, 1982.

T: Demonstration and evaluation of the effectiveness of the parasite, Pebiobius foveolatus, as a biocontrol agent of the Mexican bean beetle in the states of Delaware, Maryland, New Jersey and Virginia. Issues addressed in the report include: optimum release ratios or strategies at different host levels; whether nurse plot characteristics host population and parasite production; average relative consumption indices, defoliation levels, and yield losses with and without parasites in 1980 and 1981.

D: 553 and 471 nurse plots established in 1980 and 1981, respectively. Weekly average levels of live stages (adults thru pupae including mummies), height of plants, percentage plant cover, and percentage defoliation in the nurse plots presented by state and planting date. Trigger and peak host population levels, parasite releases, and parasite production in the nurse plots, by state and planting date.

R: Yield losses with and without parasites, selected from tables in the report appear below.

State	Site No.	%Yield Loss 1980 With	%Yield Loss 1980 Without	%Yield Loss 1981 With	%Yield Loss 1981 Without
DE	1	1.26	1.26	1.29	1.29
	2	1.26	1.26	1.27	1.27
	3	1.25	1.25	1.25	1.25
MD	1	2.65	2.85	2.52	2.62
	2	2.27	2.70	2.27	2.48
	3	1.93	1.97	2.32	2.35
NJ	1	1.40	1.41	1.44	1.45
	2	1.44	1.51	1.45	1.54
	3	1.89	1.94	1.77	1.82
VA	1	2.1	2.50	2.30	2.54
	2	2.12	2.30	2.15	2.26
	3	1.63	1.63	1.71	1.71

38. Epperson, James E., and John R. Allison. "Multiple Cropping and Pest Control Intensity -- Preliminary Economic Results," Submitted for Consideration as a Selected Paper for the 1980 Meeting of American Agricultural Economics Association at the University of Illinois.

T: Four pest control intensities (PCI's) are compared for the following cropping system: turnip greens for processing, planted in February 20; field corn, planted in April 15; and southern peas for processing, planted in August 15.

D: Yield data by crop for each PCI and year, and cost and return data for each PCI and year are presented from the Coastal Plain Experiment Station in Tifton, Georgia, (1975-1979).

M: The levels and variances of net returns are calculated for PCI's.

R: For all five years, PCI 4, the one with the lowest intensity level, generated the largest net return. "PCI 4 involves less than virtual control of weeds. Only 1 herbicide is used to reduce weed competition. Insecticides are applied on the basis of scouting reports. However, chemicals are less toxic than those used on other levels. A soil fumigant, hand weeding, and a nematicide are not used. A foliage fungicide though is used for prevention." PCI 4 also had the lowest costs. On the other hand, PCI 1, with the highest intensity level, had the lowest calculated risk value. The risk associated with the other PCI's was not statistically significant.

39. Ervin, R. Terry, Francis M. Epplin, and Donald R. Barnard. *Identification of Economic Threshold Levels for Ticks on Preweaner Calves: An Application of Pest Management to Livestock Production*. Professional Paper PP-1818 of the Oklahoma Agricultural Experiment Station, Stillwater, OK, 1985.

T: Identifying both the economic threshold levels (ETL) for Lone Star ticks (*Amblyomma amercanum*) on preweaner calves under range conditions, and the most economical control measure.

D: The experiment involved two groups of cow-calf pairs randomly assigned to either a tick-free environment or a tick-infested environment. A 60 acre pasture in the Ozark Mountain region was used. The experiment was replicated over a two year period.

M: The rate of gain (lbs.) per animal per day was regressed on the number of Lone Star ticks attached, seasonal dummy variables, and the interaction between ticks and season.

E: The Prais-Winsten Two Step method was used to identify autocorrelation estimates.

R: "The regression coefficient on the tick number variable is -0.0039. This indicates that, for example, an average of 50 Lone Star ticks attached over the 100 day period can reduce weight gain by 19.5 pounds per calf...The application of ten acaracide treatments per head spread over the tick season is cost efficient if the tick population is greater than an average constant attachment of 26-38 ticks. For most situations found in the Ozark Region this low ETL indicates that a tick control program during the tick season would be cost effective...Given the data, a cost efficiency ranking places Toxaphene-Lindane, Dioxathion, and Stirofos in descending order."

40. Ervin, R.T., L.J. Moffitt, and D.E. Meyerdirk. "Comstock Mealybug (Homoptera: Pseudococcidea): Cost Analysis of a Biological Control Program in California," *Journal of Economic Entomology*, Vol. 76, No. 3, June 1983, pp. 605-609.

T: Analyzes the hypothetical losses associated with a failure to utilize biological eradication methods when the Comstock mealybug was detected in California in 1970.

D: A range of potential crop loss is identified based on mealybug infestation experience outside of California.

M: Benefit/Cost (B/C) analysis was performed by computing present values of B/C streams using appropriate discount rates. A mealybug migration model was developed; the value of crops in the projected infestation area was estimated via previous California crop production data.

R: Overall program costs were compared to expected crop losses and a B/C ratio of 22/1 was obtained.

C: Biological control of the Comstock mealybug was highly cost effective and worthy of future investment.

41. Feder, Gershon. "Pesticides, Information, and Pest Management under Uncertainty," *American Journal of Agricultural Economics*, Vol. 61, No. 1, February 1979, pp.97-103.

The post-pesticide-crop model is developed to examine how farmers, as risk-averse utility maximizing producers, make decisions concerning pesticide use. A static decision framework is adopted to reflect the mobility of most pests. Farmers' decisions to apply pesticides are treated as being based on infestation levels in a particular period, not as a means to prevent infestation in the future (over which they have limited control due to pest mobility). A profit function is derived which incorporates profits in the absence of pests, damage level per pest, number of pests surviving after pesticide application, and the total cost of pesticide application. Risk-averse farmers face a concave utility function which is expressed as a function of profits. Optimal levels of pesticides for the farmer can be derived from the farmers expected utility function. The authors then examine the implications of their model by considering how changes in the random variables affect pesticide application.

42. Ferguson, Walter, Jet Yee, and David Parvin. Cotton Yield and Yield Risk of Mississippi Farmers Using Professional Scouting Services, Published by the Office of Agricultural Communications, Division of Agriculture, Forestry, and Veterinary Medicine, Mississippi State University. Mississippi Agricultural and Forestry Experiment Station Bulletin 1002, August 1993.

T: Comparison of cotton production characteristics of producers employing professional scouting services (PROS) versus those using "on-farm" employees as scouts (NON-PROS). Producers in Mississippi are compared, as well as producers across the Delta states of Arkansas, Louisiana, Mississippi, Missouri and Tennessee. The characteristics examined are yield, yield-risk, pesticide use, and nonchemical pest management practices.

D: Data from a 1989 USDA survey of cotton producers were used. While the survey included 1500 cotton producers covering 14 states, only data on producers in the Delta states were used in this study.

M: Yield and pesticide treatments were compared using a Z-test. "Differences in use of nonchemical control practices, irrigation, enrollment in the Acreage Reserve Program (ARP) and Federal Crop Insurance (FCI), and farmer characteristics (education, age, tenure)" were compared using a chi-squared test. Coefficients of variation were used to compare yield risk.

R: The mean values (AV) and standard deviations (STD) of the categories that were significantly different at the 0.05 confidence level are presented in the following table.

	Delta States				Mississippi			
	PROS		NON-PROS		PROS		NON-PROS	
Variable	AV	STD	AV	STD	AV	STD	AV	STD
Yield (bales/A)	1.38	.54	1.12	.78	1.43	.62	.94	.91
Chemical Pest Controls (# Treatments/A)								
Herbicide	3.45	1.44	2.97	1.35	3.42	1.19	2.74	.96
Insecticide	6.36	3.69	3.93	3.61	not significantly different			
Fungicide	2.50	2.49	1.17	1.97	3.40	2.47	1.61	1.97
Defoliant	1.18	.67	.74	.76	1.38	.06	.61	.72
Growth Retardant	1.65	1.87	.78	.96	2.52	2.26	1.17	1.47

Variable	Delta States PROS AV	STD	NON-PROS AV	STD	Mississippi PROS AV	STD	NON-PROS AV	STD
Nonchemical Pest Controls (Proportion Using Control)								
Stalk Destruction	.90	.30	.72	.45	not significantly different			
Pheromone Traps	.48	.50	.17	.38	.58	.50	.22	.42
Socioeconomic Characteristics (Proportion)								
College Degree	.38	.49	.16	.37	.52	.50	.13	.34
Owner-manager	.60	.49	.40	.49	not significantly different			
Other Characteristics (Proportion)								
Irrigation	.34	.48	.14	.35	.33	.47	0	0

The yield-risk calculated for the Delta states PROS was 0.39 and 0.70 for NON-PROS, whereas the Mississippi PROS had a yield-risk of 0.43 and 0.97 for the NON-PROS. The per acre value of professional cotton scouting in Mississippi under 1989 conditions was estimated to be $134.73.

43. Ferris, H. "Nematode Economic Thresholds: Derivation, Requirements, and Theoretical Considerations," *Journal of Nematology*, Vol. 10, No. 4, October 1978, pp. 341-350.

The abstract accompanying this article reads as follows. "Determination and use of economic thresholds is considered essential in nematode pest management programs. The economic efficiency of control measures is maximized when the difference between the crop value and the cost of pest control is greatest. Since the cost of reducing the nematode population varies with the magnitude of the reduction attempted, an economic (optimizing) threshold can be determined graphically or mathematically if the nature of the relationships between degree of control and cost, and nematode densities and crop value are known. Economic thresholds then vary according to the nematode control practices used, environmental influences on the nematode damage function, and expected crop yields and values. A prerequisite of the approach is reliability of nematode population assessment techniques."

44. Fitzner, Michael S. "Can Integrated Pest Management Survive Sustainable Agriculture?" 1992 Eighteenth Annual Illinois Crop Protection Workshop Proceedings, Cooperative Extension Service, Illinois Natural History Survey, University of Illinois at Urbana-Champaign, March 1992.

The article addresses the potential implications of "sustainable agriculture" on the future of IPM. The "Sustainable Agriculture Research and Education" (SARE) legislation contained in the 1990 Farm Bill is outlined. While IPM and sustainable agriculture may appear to be competing terms, they are compatible concepts. **"In fact, IPM is a basic building block of sustainable agriculture."** The author urges the IPM community to assume a leadership role in the development of sustainable agriculture.

45. Fohner, G.R., G.B. White, and S. J. Schwager. The Value of Economic Thresholds for Managing Agricultural Pests, Agricultural Economic Research 82-46, Department of Agricultural Economics, Cornell University, Ithaca, NY, 1982.

"The objectives of this study were to describe the characteristics of pest problems that most affect the value of economic thresholds, indicate the types of pest problems for which the thresholds are potentially most valuable, and determine the quality of information needed to fulfill that potential.

"A mathematical model and Monte Carlo simulation were used to compare the costs of pesticide and crop loss using economic thresholds, routine application of pesticide, and no applications. This comparison was made for a range of alternative assumptions about five factors: 1. the magnitude and variability of pest density among fields and growing seasons, 2. the function relating pest density and expected crop loss, 3. the variability in the effect of pest density on crop loss, 4. the effectiveness with which pesticide prevents crop loss, and 5. the accuracy of the decision maker's information about pest density and the relationship between pest density and crop loss.

"The performance of the economic threshold depended primarily on the magnitude and variability of pest density. Economic thresholds were most valuable when pest densities both well above and well below the threshold were likely to occur. While this variability in pest density favored the use of economic thresholds, variability in crop losses for particular pest densities was unfavorable because it reduced the predictability of crop loss based on estimated density. The value of increasing the accuracy of the estimated threshold depended on the magnitude and variability of pest density and the slope of the function relating pest density and expected crop loss. Thresholds based on estimates of crop loss within 20 percent of the true average loss generally performed nearly as well as the true economic threshold. When sample counts were assumed to be errorless, and the spatial distribution of the pest in the field was negative binomial, the value of using the economic threshold was not increased substantially by sampling 60 instead of 30 plants.

"The concepts, methods, and results of this study may contribute to pest management programs in three ways: 1) as a conceptual framework illustrating the interdependencies among decision rules, sampling procedures, quality of information, and characteristics of pests and crops in determining the value of economic thresholds; 2) for classifying pest problems according to suitability for economic thresholds; and 3) for selecting decision rules, sampling procedures, and setting research priorities."

46. Fohner, G.R., G.B. White, and W.E. Fry. A Stress-Test Evaluation of Disease Forecasting for Managing Potato Late Blight, Department of Agricultural Economics, Cornell University Agricultural Experiment Station, Ithaca, NY, A.E. Res 82-38, November, 1982, 28 pages.

"In this study, disease forecasting based on Blitecast was compared to regular, prescheduled sprays in a stress-test experiment using computer simulation. The objective was to perform the comparison using methods of analysis that were consistent with the characteristics of stress-test experiments, and with the difficulty of estimating the cost of disease."

"In addition to comparing forecasting and prescheduled intervals at equal severities of disease, decision rules were compared using severity of disease in the simulation experiment to estimate relative effectiveness, then translating relative effectiveness into differences in cost using information about the cost of late blight on farms. Relative effectiveness was measured using frequency of high levels of disease and annual ratios of disease for the rules being compared."

"The nearness of the forecasts to the prescheduled response curve...indicates that neither prescheduled spraying nor forecasting was clearly dominant in terms of controlling late blight in the simulation experiment. Since forecasting requires information and management not required for prescheduled sprays, the results of this experiment imply that replacing prescheduled sprays with forecasting is unjustified."

"The prescheduled and forecast rules were also compared using two other measures: one that estimates percent loss of harvested tubers (James et al. 1972, MacKenzie and Petruzzo), and another that estimates percent loss of tubers of marketable size (James et al. 1973)...Neither forecasting nor prescheduled intervals were clearly superior to the other."

47. Folwell, Raymond J., Daniel L. Fagerlie, George Tamaki, Alex G. Ogg, Richard Comes, and John L. Baritelle. Economic Evaluation of Selected Cultural Methods for Suppressing the Green Peach Aphid as a Vector of Virus Diseases of Potatoes and Sugarbeets, Bulletin 0900, College of Agriculture Research Center, Washington State University, 1981.

T: Estimation of costs and benefits from modification or elimination of overwintering sites of the green peach aphid (*Myzus persicae*), a major potato and beet pest.

D: Using 1980 input prices, annual peach production budgets were developed with the help of those involved in commercial peach production in the Pacific Northwest, including growers, input suppliers, cooperative extension personnel, and research specialists. Washington Cooperative Extension provided production budgets for fall potatoes and sugarbeets, while USDA provided cost data for the control of hoary cress.

M: Costs and benefits associated with three practices for green peach aphid management were compared: 1) standard practice of early April disking and pre-harvest disking; 2) the standard diskings plus a timed disking in the middle of the growing season; and 3) establishment of grass strips between peach tree rows and suppression of weeds with herbicides.

R: Total cost for standard management practice was $5,470 per acre. The per acre cost for standard practice plus a mid-season disking was $1.05 less than the standard practice alone. This savings was realized because the extra disking eliminated the need for one of the orchard mowings. (Disadvantages of this technique include the precise timing of the disking, and a potential increase on soil erosion and other ecological concerns.)The use of grass strips adds $33.80 or $24.91 per acre, depending on the type of fertilizer, to the cost of standard production. While grass strips are more costly to maintain, they are most effective at controlling the green peach aphid, increase sprinkler infiltration rates and organic matter levels, lower surface soil bulk density, may reduce dust problems during harvest, and may help control mites. If grass strips were established in all peach orchards, the cost of fall potato production would drop an estimated $40.61 per acre. "The net benefits from suppressing the [green peach aphid] are estimated to be $21 million in reduced production costs for potatoes and sugarbeets in the [Pacific Northwest]." The environmental benefits from less pesticide use were noted but not quantified in this study.

48. Foster, R.E., J.J. Tollefson, J.P. Nyrop, and G.L. Hein. "Value of Adult Corn Rootworm (Coleoptera: Chrysomelidae) Population Estimates in Pest Management Decision Making," *FORUM: Journal of Economic Entomology*, Vol. 79, No. 2, pp. 303-310.

The abstract accompanying this article follows: "Corn rootworm adult densities were monitored in 31, 43, and 44 Iowa corn-fields in 1979, 1980, and 1981, respectively. The season after monitoring, plots with no soil insecticide were left in most fields. Rootworm larval damage was measured in untreated areas, and yield was estimated in both treated and untreated areas of each field. Linear regressions indicate significant relationships between adult densities and larval damage and yield loss, but much of the variation in damage or yield loss was not explained by the model. Current economic thresholds did not accurately predict economic damage or appreciable yield loss > 50% of the time. Addition of edaphic and agronomic variables improved the model, but 60% of the variation in yield loss was still unexplained. Value of adult sampling information was determined by Bayesian analysis to be zero. A 6-fold increase in ability to predict when economic loss would not occur would be necessary for sampling to be worthwhile. The optimal strategy for managing corn rootworms in Iowa in our study was not to sample for adults and always treat corn following corn with a soil insecticide at planting time."

49. Foster, Henry S., Jr., and Michael Duffy. An Economic Evaluation of Alternative Policies to Combat the Spread of the Gypsy Moth: A Stochastic Simulation. Economic Research Service, U.S.Department of Agriculture, Washington, D.C., February, 1983.

T: Prediction of infestation patterns, and estimation of cost and damage levels associated with different policy options for controlling the gypsy moth.

D: Standard metropolitan statistical areas (SMSA's), outside the generally infested area (GIA) of the Northeast, were selected to serve as proxies for local regions of the U.S. A dummy variable value of 0, 1, or 2 was assigned to each SMSA to represent the type of region in which it was located: 0 for regions where an isolated infestation was not likely to survive, 1 where it would survive and grow slowly, and 2 where it would survive and grow quickly.

M: Simulation model: The probability of an isolated infestation occurring in each SMSA was estimated assuming the probability is directly proportional to the population of the SMSA and inversely proportional to the distance of the SMSA from the GIA. A probability density function and its corresponding cumulative distribution function (c.d.f.) were then generated. However, a new c.d.f. must be established for each time period because the GIA continues to expand. The SMSA's which receive isolated infestations are chosen at random. Three policy scenarios were examined and allowed to run the full course of the program, i.e. until the GIA covered the U.S.; discounted costs and losses were then calculated.

R: A detailed explanation of the selection of the model's parameters is included in the article. Table 1, "Summary of Policy Alternatives Simulated," is presented below.

Policy	% Decrease in # of infestations	Damage	Cost	Total
		----------------Million dollars---------------		
No Program	---	380	----	380
Inspection of campers and commercial products	5-10	339	31	370
Inspection of household goods	24	308	9	317

50. Frisbie, Ray. *Implementation and Economic Returns From the Systems Approach to Pest Management in Cotton*. XV International Congress of Entomologists, August, 1976.

"A historical perspective of United States cotton insect management systems centered around the boll weevil is presented. The importance of using past technology and incorporating new technology into a total system approach is stressed. Methods are presented on the implementation of pilot pest management programs systems leading to large-scale expansion based on economic and environmental advantages."

51. Frisbie, R.E., J.M. Sprott, R.D. Lacewell, R.D. Parker, W.E. Buxkemper, W.E. Bagley, and J.W. Norman. "A Practical Method of Economically Evaluating an Operational Cotton Pest Management Program in Texas," *Journal of Economic Entomology*, Vol. 69, No. 2, April 1976, pp. 211-214.

The authors recognized that the difficulty in evaluating pest management strategies results from the extreme number of variables between producers. This experiment reduced the biological variables by restricting the control and experimental groups to specific regions and plant varieties. Human input variables were contrasted by comparing farms of equal "management capability." The evaluation of management capability was based on a farm's historical average annual net income and yield per acre. Two types of data were collected: insecticide cost per acre, and dollar amount received per acre yield. An "enterprise budget generator" was used to evaluate the data. Results: Net returns were higher for all program groups in every region and every time period.

52. Gholson, Larry E. "Economic Evaluation of Integrated Pest Management (IPM)," *Tar Heel Economist*, North Carolina State University, Raleigh, NC, September 1981.

A very brief sketch of IPM and the difficulties associated with evaluating IPM programs.

53. Goodell, Grace. "Challenges to International Pest Management Research and Extension in the Third World: Do We Really Want IPM to Work?" *Bulletin of the Entomological Society of America*, Vol. 30, No. 3, Fall 1984, pp. 18-26.

IPM represents a divergence from traditional small-scale farming practices in developing countries. As such, there are two main costs which the public sector must absorb to facilitate the adoption of IPM: research and extension. Often times these two represent substitutes rather than complements, with respect to agriculture. The author argues that there is a general bias toward research, as opposed to outreach, in developing countries. She calls on researchers to further "distill" the inherent complexities of IPM to facilitate the extension and adoption of its techniques. There is a need for additional research and development of easy monitoring methods to curtail proliferation of fraudulent chemicals and seed varieties. Early warning surveillance and field-level scouting techniques also have room for improvement. The author suggests a need for real and perceived crop loss assessment in IPM planning and extension within developing countries. Another problem is that the economics of IPM adoption are rarely considered with respect to small-scale farmers in developing countries. The author asserts the importance of IPM researchers to familiarize themselves with the farmers they wish to assist and the cultural and institutional environment in which the techniques they wish to replace have emerged. There is a need for "old-fashion," hands-on, field-level extension rather than the high gloss media barrage associated with many IPM extension programs. The author acknowledges the valuable role the media can play, but asserts it will be most effective after the fundamental lessons have been learned in the field. In addition, the author cautions against the premature pooling of ideas throughout large regions. This has a tendency to suppress individual initiatives and lead to regional uniformity -- a result that can carry significant ecological consequences. Each IPM program is urged to "walk through" the initial stages alone.

54. Greene, Catherine R., and Gerrit W. Cuperus. *Integrated Pest Management (IPM) in the Vegetable Industry During the 1980's*. U.S. Department of Agriculture, Economic Research Service, Washington, D.C., February 1991.

The authors examine the funding and adoption of IPM programs for vegetable crops during the 1980's. Historical data representing the increase in pesticide use is presented. A table summary of recent economic comparisons between IPM and conventional pest control systems reveals "most growers using IPM reduce their use of pesticides, while maintaining crop yield and quality, and that many growers have reduced production costs and increased revenues as well." Reduction in IPM users' pesticide costs ranged from 78% to 0%. There has been a dramatic increase in State, Federal and industry IPM funding ($64,213 in 1978 to $2.8 million in 1989) with the biggest increase coming from industry (grower payments for IPM services). The total vegetable acreage under IPM has risen from 742,000 in 1984 to 1,923,340 in 1989. This increase is disaggregated by state and commodity in the report. Also shown is the rather constant number of IPM scouts trained and the steady rise in the number of producers trained in IPM.

55. Greene, Catherine R., Randall A. Kramer, George W. Norton, Edwin G. Rajotte, and Robert M. McPherson. "An Economic Analysis of Soybean Integrated Pest Management," *American Journal of Agricultural Economics*, Vol. 67, No. 3, August 1985, pp. 567-572.

T: The importance of the degree of risk aversion on soybean pest management strategy choice was examined.

D: "Information on the use of insecticides by producers using IPM was obtained from 8 years of scouting records kept in 4 contiguous counties in eastern Virginia..the variable cost of production excluding pest management costs, was a fixed value in the simulation program based on 1983 Extension Service budgets for the area." Extension agents helped calculate scouting, parasite, and trap-crop costs on a per acre basis.

M: A net revenue simulation model was run utilizing 5 stochastic components: soybean yield, soybean price, wheat yield, wheat price, and insecticide treatment. Six distributions of net revenues were generated to correspond with alternative cropping systems and pest management strategies(conventional pest management, scouting used alone, scouting used with trap-crops, and scouting used with parasites under full-season and double-cropped soybean cropping systems). These distributions were then compared using the generalized stochastic dominance criteria of Meyer.

R: All of the IPM strategies were found to dominate conventional pest management. "For the fourth risk-preferring group and all risk averse groups, the preferences ranked from highest to lowest are: (1) scouting with the double-cropped system, (2) scouting plus parasites with the full-season system, (3) scouting with the full-season system, (4) scouting plus trap-cropping with the full-season system, (5) conventional management with the double-cropped system, and (6) conventional management with the full-season system."

56. Greene, Catherine R., Edwin G. Rajotte, George W. Norton, Randall A. Kramer, and Robert M. McPherson. "Revenue and Risk Analysis of Soybean Pest Management Options in Virginia," *Journal of Economic Entomology*, Vol. 78, No. 1, February 1985, pp. 10-18.

IPM economic effect is the major impetus behind farmer adoption. This study compares soybean pest management strategies with respect to average net revenues and risk using generalized stochastic dominance. Full-season soybeans and double-cropped soybean systems were examined with respect to "conventional" and IPM practices. The IPM practices were: 1) scouting alone; 2) scouting with trap-crops; 3) scouting with parasite releases. "In this analysis, we used 2813 scouting reports from 696 soybean fields from 1974-1982. The fields were located in Richmond, Westmoreland, Lancaster, and Northumberland counties." Action thresholds for the major soybean pests (Mexican bean beetle, corn earworm, brown and green stinkbug) were compared to pest population densities from the scouting data to determine the probability of insecticide treatment. A detailed description of the model is included. Eight levels of producer attitude toward risk, four risk-preferring and four risk-averse, were analyzed using stochastic dominance. "For the fourth risk-preferring group and all risk averse groups...the preferences ranked from highest to lowest are: (1) scouting with the double-cropped system, (2) scouting plus parasites with the full-season system, (3) scouting with the full-season system, (4) scouting plus trap-cropping with the full-season system, (5) conventional management with the double-cropped system, and (6) conventional management with the full-season system." Among the data presented in the report are per acre net revenues associated with the two cropping systems and the different pest management strategies: $21.75 for Full-Season Conventional; $30.20 for Full-Season Scouting; $30.60 for Full-Season Scouting with Trap-Cropping; $31.07 for Full-Season Scouting with Parasite Release; $30.21 for Double-Cropped Conventional, $38.49 for Double-Cropped Scouting.

57. Hagstrum, David W., and Paul W. Flinn. "Integrated Pest Management of Stored-Grain Insects," Chapter 14 in Storage of Cereal Grains and Their Products, D. B. Sauer (ed.), St. Paul, MN: American Association of Cereal Chemists, Inc., 1992.

"Simulation models are used to illustrate the effects of various environmental conditions and pest management practices on insect population growth...The importance of sampling is emphasized for determining whether insect populations have reached the economic threshold. Guidelines are provided for developing a sampling program. The prospect of automation of insect monitoring using acoustical sensors is also discussed."

58. Hall, Darwin C. "Profitability and Risk of Integrated Pest Management," *California Agriculture,* Vol. 32, No. 2, February 1978, p. 10.

A brief discussion of how IPM, in general, performed over the years 1970-1974 with respect to yield, producer costs, net profit and risk. Cotton and citrus production are mentioned.

59. Hall, Darwin C. "The Profitability of Integrated Pest Management: Case Studies for Cotton and Citrus in the San Joaquin Valley," *ESA Bulletin*, Vol. 23, No. 4, 1977, pp. 267-274.

T: Supervised control (SC), or IPM, is compared to conventional control (CC) on cotton and citrus in the San Joaquin Valley, CA. The author discusses the limits of the empirical analysis, risk as a factor influencing IPM adoption, and policy implications of IPM.

D: Yield and pesticide data were gathered by interviewing 100 cotton and citrus growers in 1972 and reinterviewing 75 of them in 1975.

M: Estimation of the differences in yield, expenditures for pesticide materials, and net revenues between users of SC and users of CC on cotton and citrus under two separate sets of assumptions.

E: Analysis of variance.

R: The study fails to reject, at .05 significance level, the hypothesis that there is no difference in yield between SC and CC practices on the two crops; the hypothesis that pesticide use is not reduced by employing SC is rejected at the .01 significance level for each crop.

60. Hall, Darwin C. *An Economic and Institutional Evaluation of Integrated Pest Management with an empirical investigation of two California crops*. Paper for EPA No. 68-01-2982, November 1977.

The abstract attached to this report reads as follows: "Criteria for evaluating national and state regulatory programs are developed and applied to current programs. Alternative programs, especially those which emphasize integrated pest management (IPM), are compared with current national and state programs. It is concluded that regulatory programs emphasizing IPM are the most effective and least expensive for mitigating public health and environmental consequences from pesticide use.

"The economic consequences and pesticide reduction from IPM are estimated in an empirical investigation of two California crops during the five-year period from 1970 through 1974. A large sample of data was collected from both growers using and not using IPM as commercially practiced. Alternative theoretical and empirical estimation procedures resulted in the conclusions that IPM reduces pesticide use by approximately 50 percent and reduces risk to growers while maintaining current yields and profit.

"Production functions, pesticide demand, and pesticide expenditure functions are estimated to separate those factors which influence yield and pesticide use from the factor of primary interest herein--IPM. Variables affecting yield in the production function include 6 measures of soil quality, 5 weather variables, the level of pest infestation, 3 characteristics of fields and orchards, labor, capital, irrigation, other expenses, size of farm, 13 measures of managerial ability,fertilizer, herbicides, insecticides and miticides, IPM, and 2 additional information technologies. Explanatory variables in the pesticide demand and expenditure analysis include pesticide price, expected yield, farm size, managerial ability, the number of years under an IPM program, 5 weather variables, irrigation, 2 characteristics of orchards, and the pest infestation level.

"A theory of pesticide demand is developed. Methodologies for measuring managerial ability are presented. Details of sample design and questionnaire design are provided."

61. Hall, Darwin C., and Gregory M. Duncan. *Econometric Evaluation of New Technology with an Application to Integrated Pest Management.* University of California, Giannini Foundation Paper No. 714.

"The purposes of this paper are to present an intuitive discussion of self selection and choice based sampling biases, propose a solution, and apply our solution to evaluate IPM. [The authors] proceed as follows. First, [they] state the problem of evaluating IPM given endogenous stratification of panel data...Second, [they] present a straightforward solution to the problem of self selection bias and show when it is permissible to use ordinary least squares (OLS) in the presence of self selection. Third, [they] present a simple correction for simultaneous self selection bias and choice based sampling bias using instrumental variables, based upon what [they] call the isonomy assumption. [They] call [their] estimators the isonomic instrumental variable estimators (IIV). Last, [they] discuss some empirical results."

62. Hanthorn, Michael, and Michael Duffy. "Returns to Corn Pest Management Practices," *Agricultural Economic Report Number 501*, United States Department of Agriculture, Washington, D.C., June 1983.

T: The productivity of pesticides applied to corn in 1980.

D: The study area included the following states: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Nebraska, Ohio, South Dakota, Wisconsin. Data were collected on four major variables: pesticide use and severity of pest infestations, other farm production practices and inputs, weather, and farm location.

M: A farm-level production function was estimated incorporating the four major variables listed above. Nonchemical pest management practices (tillage systems, mechanical cultivation and field scouting) were analyzed using Duncan's multiple range test.

R: Some of the major findings presented at the beginning of the article include:

* "Marginal product of a pound (a.i.) of herbicides was 1.24 bushels of corn per acre. With an average herbicide material cost of $3.81 per pound (a.i.), farmers' breakeven price for corn with respect to their herbicide use was $3.07 per bushel. The estimated return to $1 spent for herbicides was $1.05."

* "Farmers who applied insecticides harvested an additional 2.44 bushels of corn per acre compared to farmers who did not apply insecticides. The return to $1 spent for insecticides was $1.03."

* "Farmers who either used insect scouting or who received integrated pest management information applied a significantly greater amount of insecticides at a higher per acre cost than did the other farmers."

63. Hara, Arnold H., Wayne T. Nishijima, James D. Hansen, Brian C. Bushe, and Trent Y. Hata. "Reduced Pesticide Use in an IPM Program for Anthuriums," *Journal of Economic Entomology*, Vol. 83, No. 4, August 1990, pp. 1531-1534.

T: An economic comparison of conventional pest management and a proposed IPM program for Anthurium cultivation.

D: Three farms in east Hawaii County, Hawaii, were divided into a conventional and IPM section. "Data were collected from all three farms from fall 1985 to summer 1986, but only from Farm 2 and Farm 3 from fall 1986 to summer 1987. Farm 1 implemented the IPM concept on their anthurium production after the first year's trial."

M: Economic injury levels were used to determine when to spray the IPM plots; the conventional plots received calendar pesticide applications.

R: IPM program had fewer pesticide applications, but applied twice the volume of pesticides per hectare than the calendar spray regime. IPM generally reduced producer pest control costs, however the difference was not statistically significant when compared across all farms for the two growing seasons examined.

64. Harper, Carolyn R., and David Zilberman. "Pest Externalities from Agricultural Inputs," *American Journal of Agricultural Economics*, Vol. 71, No. 3, August 1989, pp. 692-702.

The abstract accompanying this article reads: "Agricultural inputs such as water, pesticide, and even time may have the unintended effect of stimulating some pest populations, leading to crop losses. A conceptual model is developed to contrast optimal use of pesticide and nonpesticide inputs with myopic use patterns which ignore pest externalities. Under most conditions, optimal management is found to entail reduced input levels. These issues are illustrated for Imperial Valley cotton using biological simulation. Correct calculation of the relative profitability of conventional and integrated pest management techniques, such as shortened growing season, is found to depend crucially on whether pest externalities are taken into account."

65. Harper, Jayson K., M. Edward Rister, James W. Mjelde, Bastiaan M. Drees, and Michael O. Way. "Factors Influencing the Adoption of Insect Management Technology," *American Journal of Agricultural Economics,* Vol. 72, No. 4, November 1990, pp. 997-1005.

T: Identification of factors influencing the adoption of insect sweep nets and treatment thresholds, and those influencing insecticide application decisions for control of the rice stink bug in the Texas Rice Belt.

D: 117 Texas rice producers provided data on sampling and control practices, 1986 season production information, socio-economic factors, and attendance at field days and extension demonstrations. The data was collected by a mail survey in the fall of 1986 with a follow-up survey in the spring of 1987.

M: A logit model was developed to analyze the probability of Texas rice producers adopting sweep nets and treatment thresholds (SWEEP). A separate logit model was developed to analyze the probability of farmers spraying insecticides to control the rice stink bug (SPRAY).

E: Maximum Likelihood with a 20% significance level.

R: Six factors are statistically significant in the SWEEP model (the sign following the factor indicates how the factor was related to the probability): (1) farmer education level (-); (2) proportion of neighboring land in pasture (-); (3) proportion of rice acreage planted to semidwarf rice varieties (+); (4) geographic location; (5) attendance at the Eagle Lake field day (+); (6) attendance at the Beaumont field day (+).

Thirteen factors are statistically significant in the SPRAY model. "The probability of spraying increases as age, field size, and nitrogen application per acre increase. The probability of spraying also increases (by 11.3%) when sweep nets and treatment thresholds are adopted, the producer has more than a high school education, neighboring land is in pasture or grain sorghum, the field is located west of Houston, and the farmer attends the Eagle Lake, Beaumont summer, and/or commercially offered field days. The probability of spraying...is significantly decreased if the farmer of the field attends either county extension demonstrations or the Beaumont fall field day."

66. Harris, P. "Costs of Biological Control of Weeds by Insects in Canada," *Weed Science*, Vol. 27, No. 2, 1977, pp. 242-250.

The abstract accompanying the article reads as follows. "The purpose of the paper is to permit the calculation of prospective costs before starting the biological control of a weed. The costs of the Canadian program from its start in 1950 to the end in 1976 was tabulated in scientist-years by target weed, agent, and the type of study done. This information and international data on the number of agents required to control a weed were used to calculate expected costs. A complete biological control program is likely to cost 18.8-23.7 scientist-years or currently $1.2 to $1.5 million and thus is only economical for use against major weeds. However, it is often possible to capitalize on studies done elsewhere, and under these circumstances biological control may be economical for solving more minor weed problems."

67. Hatcher, Jerry E., Michael E. Wetzstein, and G. Keith Douce. "An Economic Evaluation of Integrated Pest Management for Cotton, Peanuts, and Soybeans in Georgia," *Research Bulletin 318*, College of Agriculture Experiment Station, University of Georgia, November 1984.

T: Economic evaluation of a multicrop IPM program for peanuts, cotton, and soybeans implemented by the Georgia Cooperative Extension Service for the 1981 and 1982 growing seasons.

D: Production data was supplied by 50 Georgia IPM producers, 10 of whom grew two of the above crops, and 40 of whom grew one. This data was used to calculate: (1) total machinery expenditures; (2) total irrigation expenditures; (3) adjusted net returns; (4) total costs; (5) total variable costs; and (6) insecticide costs.

M: Factor analysis was employed to construct IPM indices measuring the degree of producer IPM participation. Seemingly unrelated regression was used to estimate equations for yield, adjusted net return, insecticide cost, and total variable cost.

R: IPM increased net returns for producers of peanuts and soybeans, but had no significant effect on net returns to cotton production. Yields increased as the degree of IPM participation increased. IPM participation was not found to decrease pesticide use.

68. Headley, Joseph C. "Economic Analysis of Navel Orangeworm Control in Almonds," *California Agriculture*, Vol. 37, May-June 1983, pp. 26-29.

T: Net revenue effects of navel orangeworm control programs in almond production.

D: Fixed and variable costs were assumed, as well as the efficacy of the practices examined in reducing navel orangeworm damage. The control programs examined were: (1) treatment I, benchmark, no specific treatment for navel orangeworm; (2) treatment II, a May guthion spray application; (3) treatment III, sanitation through winter cleanup of mummies with no poling after shakers; (4) treatment IV, a combination of treatment III and early harvest; (5) treatment V, treatment IV combined with poling after shakers.

M: Partial enterprise budgets were developed for a hypothetical 320-acre almond stand. The budgets were computed for each management program under varying almond meat prices and varying navel orangeworm damage levels.

R: The optimal navel orangeworm control program varies with the level of infestation. At an untreated damage level of 20% net revenues for all treatment alternatives exceeded those of the benchmark at each almond price examined. The difference between the benchmark and the alternatives was as little as $83/acre and as much as $243/acre. At an untreated damage level of 10% all treatment alternatives yielded higher net revenues than the benchmark for each almond price examined, except treatment II at an almond price of $0.70/lb. At an untreated damage level of 5%, only treatment III yielded higher net returns than the benchmark at every almond price examined.

69. Headley, J.C. "Pest Control as a Production Constraint for Grain Crops and Soybeans in the United States to 1990," *Research Bulletin 1038*, University of Missouri-Columbia Agricultural Experiment Station, February 1981, 94 p.

T: The report is divided into five sections covering the following topics: "(1) the current state of pesticide use practices for grain crops and soybeans in the U.S., (2) an analysis of the impact of pesticides on grain crop and soybean production, location of production, cropping systems, produce prices and return to land, (3) a review of the outlook for the development of pesticide technology and practices over the coming decade [1980's], (4) possible environmental consequences of the continued use of pesticides, and (5) some suggested policy strategies to reduce the reliance on chemicals."

D: "Four scenarios are identified and defined as follows: Scenario 1 - No chemical pesticides used on grain crops or soybeans using yield reduction coefficients based on a survey of agricultural experts. Scenario 2 - No chemical pesticides used on grain crops, soybeans or cotton using yield reduction coefficients based on a survey of agricultural experts with cotton yield reduction coefficients supplied by C. R. Taylor of Texas A & M resulting from boll weevil control research. Scenario 3 - No chemical pesticides used on grain crops, soybeans or cotton using yield coefficients supplied by C. R. Taylor for all crops. Scenario 4 - No tillage for grain crops or soybeans using coefficients for expected adoption, yield, pesticide use and other resource needs based on a survey of agricultural experts."

M: Pest control options that appeared to be feasible were incorporated into a national linear programming-spatial equilibrium model. The objective function of the model was to maximize consumer plus producer surplus. "Four different pest control scenarios were examined and a solution for the model was obtained for each and compared to the 1975 benchmark solution. The benchmark solution was obtained by solving the model to obtain acreages, production and prices with no restrictions on pesticide use."

R: The results of the model simulations under the various scenarios are presented in an extensive set of tables, and explained within the text. The appendix provides a review of consumer and producer surplus. Selected data from the tables are presented below. The values are for the entire U.S.

Item Scenario:	1	2	3	4
Change in Consumers' Surplus ($\$10^6$)	-38,413	-43,815	-12,595	-358
Change in Producers' Surplus ($\$10^6$)	27,747	28,652	6,733	150
Change in Sum of Consumers' and Producers' Surplus ($\$10^6$)	-10,666	-15,163	-5,862	-208
Irrigated Land Rent ($\$10^6$)	1,736	2,474	1,393	396
Total Land Rent ($\$10^6$)	32,120	32,286	11,449	5,862

70. Headley, J.C. "The Economics of Pest Management Decisions by Individual Growers," *Iowa State Journal of Research*, Vol. 49, No. 4, pt. 2, May 1975, pp. 623-628.

This paper illustrates pest management decisions criterion for agricultural producers in three situations: 1) using economic thresholds under certainty in a static framework; 2) using economic-injury levels under uncertainty in a static framework; and 3) pest control decisions under uncertainty in a dynamic framework. In the first situation, a simple added cost-added return principle is appropriate, i.e. pest control should be undertaken only if the benefit-cost ration exceeds one. To make profitable pest control decisions in the second situation, information on the behavior of pest populations and the factors influencing their development is needed. In a dynamic setting, "economic-injury levels are valuable for deciding if a control method is feasible, [however] they do not constitute the set of necessary and sufficient conditions for an optimum strategy for decisions longer than one period."

71. Headley, J.C. "The Economics of Pest Management," in Introduction to Insect Pest Management, R.L. Metcalf, New York: Wiley Publishers, 1975.

"Pest control through the various management techniques currently available or to be developed can only be justified in terms of its net contribution to human values, that is, the difference between positive and negative values." Simple Benefit-Cost (B-C) analysis from a micro perspective and a social perspective are discussed. Micro level, B-C maximization is presented and the abstractions from reality this analysis employs are identified. Risk and uncertainty are also discussed in the micro framework. Finally, a dynamic element is added to the analysis. Macro level pest management, market failure and public policy aspects are addressed, in addition to pest-management technology and the fallacy of composition (i.e. that the action of individuals is independent of the result for the industry).

72. Headley, J.C. "Defining the Economic Threshold," *Pest Control Strategies for the Future*. Washington, D.C.: National Academy of Sciences, 1972.

The author develops a model to identify the economic threshold of pest populations. The article is a straightforward derivation of this model. The conclusions the author reaches are: "1. The economic threshold is responsive to and determined by prices of the product protected and the prices of control inputs. 2. It is entirely possible that the population level justifying control activities is larger than the population level where yield damage first occurs. 3. The economic threshold, when given this particular *economic* definition also becomes the optimal (net return-maximizing) level of pest population. No smaller or larger population will provide greater net returns above control costs. 4. Unless the incremental costs are less than the incremental value of damages prevented for the entire range of population levels, there is no economic justification for eradication policies under the assumption of time-independence built into this definition. The exception to this would be a guaranteed, once-and-for-all eradication, with a cost of maintaining zero level populations less than the costs of maintaining populations at greater than zero levels."

73. Headley, J.C. "Economics of Agricultural Pest Control," *Annual Review of Entomology*, Vol. 17, 1972, pp.273-286.

A basic, static certainty model is presented to illustrate producer decisions as to whether or not to adopt a particular pest control method. Two points are emphasized: 1) "The economically efficient level of output is the level of output that maximizes the difference between total benefits and total costs."; 2) "Unless optimal control methods are 100 percent effective...there will always be some loss due to pests."

The average value of cotton, apples, peanuts, potatoes, corn, alfalfa, soybeans and wheat per pound of pesticides applied, in 1966, are presented in a table and disaggregated by type of pesticide (i.e. insecticides, herbicides and fungicides). A review of Cost/Benefit estimation is included. The author believes capital budgeting should be utilized and control of secondary pests should be assessed as a cost of the initial control method. Examples are given to demonstrate the mathematical mechanics of estimation which incorporate these two aspects.

The following conclusions are reached: "1. Estimates of benefits and costs of pest control for the agricultural industry cannot be based on 'with' and 'without' experiments because they ignore the distinction between private and social values and may overlook the resource-saving aspect of pest control technology. Such estimates are of value only to individual producers; 2. ...Any estimate of the benefits of pest control at a point in time is subject to the error of labeling as benefits, costs which belong to a previous time period...This is particularly true in the case of chemical insect control."

74. Headley, J.C. *The Economics of Pest Management Decisions*. University of Missouri-Columbia, Agricultural Economics Paper Number 1977-58.

This paper examines producer decisions with respect to pest management via "(1) use of economic injury levels under certainty in a static framework, (2) use of economic injury levels under risk in a static framework, and (3) use of dynamic injury levels under certainty in a dynamic framework." Under static certainty the use of "added cost-added return" principle is appropriate for pest management decisions. Under static uncertainty decisions are made without knowledge of pest population levels and damage/population ratios. The population and damage per pest may be viewed as a discrete probability situation to calculate expected damage. From the expected damage a decision on the level of pest management to employ may be made.

Decision making under dynamic certainty "involves decomposing the two period problem into two one period problems by finding the optimal decision for the second period as a function of the population at the beginning of that period. This is the essence of the dynamic programming technique for sequential decisions...The important point from this analysis is that while economic injury levels are valuable for deciding if a control method is feasible, they do not constitute the set of necessary and sufficient conditions for an optimum strategy for decision horizons longer than one period."

75. Headley, J.C., and Marjorie A. Hoy. "Benefit/Cost Analysis of an Integrated Mite Management Program for Almonds," *FORUM: Journal of Economic Entomology*, Vol. 80, No. 3, June 1987, pp. 555-559.

T: Cost comparison of three mite control programs for California almond production: (1) conventional control using label rates of propargite (Omite), cyhexatin (Plictran), or fenbutatin-oxide (Vendex); (2) integrated control using lower-than-label rates of the above pesticides and biological spider mite control by native strains of *M. occidentalis*; and (3) integrated control using lower-than-label rates of the above pesticides and biological spider mite control by carbaryl/organophosphorus/sulfur resistant strains of *M. occidentalis*. In addition, the return to investment in the integrated programs is estimated under 25% adoption in year 1, 50% adoption in year 2, and 75% adoption in year 3.

D: Seventy-one almond growers provided production cost data in interviews and surveys. Present value costs of IPM research were developed from the salaries and benefits of the researchers compounded at 12% annual interest up to 1985.

R: Returns to investment in integrated mite management (IMM) were positive under all three adoption rates (Total cost reduction due to IMM adoption below). Production costs were lower for both IMM programs than for conventional control. Because IMM is not expected to increase or reduce almond yields compared to conventional control, almond prices are assumed unaffected, and all savings from IMM adoption are realized by producers. Some of the numerical estimates from the study appear below.

Item	25% adoption Year 1	50% adoption Year 2	75% adoption Year 3
Total conventional treatment cost	$23,700,000	24,885,000	26,129,250
Total cost for IMM adoption	$20,540,000	18,249,000	15,677,550
Total cost reduction due to IMM adoption	$ 3,160,000	6,636,000	10,451,700

Control Program	Present Value Grower Cost Savings Over 5 years at 12% annual interest
IMM with no release of resistant *M. occidentalis*	$396.55 per hectare ($158.62 per acre)
IMM with release of resistant *M. occidentalis*	$351.90 per hectare ($140.76 per acre)

76. Heaton, C.R., J.M. Ogawa, G. Nyland. "Evaluating Economic Losses Caused by Pathogens of Fruit and Nut Crops," *Plant Disease*, Vol. 65, No. 11, November 1981, pp. 886-888.

A block of 200 peach trees were planted where 4% were infected with Prunus ringspot prior to planting. The block was observed over a 14 year period (1961-1974). Data are presented for these years which include the spread of the disease, yield for diseased and healthy trees, yield loss, harvest cost reduction, gross revenue loss, and net revenue loss.

The economic losses were calculated to account for the effects the disease has on the quantity and quality of the fruit produced and the intertemporal dependence of costs and yields. The formula used to calculate economic loss incorporated the following factors: a discount factor for interest rate adjustment, expected unit price of the crop, actual unit price of the crop, expected yield without the pathogen, actual yield with the pathogen, expected cost, and actual cost.

77. Hebblethwaite, M.J. "The Application of Economics to Pre- and Post-Harvest Pest Control Programmes in Developing Countries," *Tropical Science,* Vol. 25, No. 3, 1985, pp. 215-230.

The abstract accompanying the article reads, "Pest control is an inter-disciplinary subject, to which economics should contribute. The volume and scope of work in pest control economics and constraints to increased efforts are reviewed. It is contended that the economic threshold concept and the valuation of pest-induced losses should not form the principal focal points for pest control economics in developing countries. Rather, a wide potential economics contribution is seen, in programmes ranging from the identification of R & D projects to the evaluation of pest control practices after their adoption. The exploitation of concepts and methodologies from outside the conventional emphases in pest control economics is advocated, especially those developed in a developing country situation.

78. Higley, Leon G., and Wendy K. Wintersteen. "A Novel Approach to Environmental Risk Assessment of Pesticides as a Basis for Incorporating Environmental Costs into Economic Injury Levels," *American Entomologist*, Vol. 38, No.1, September 1992, pp. 34-39. (Also appears in 1992 Eighteenth Annual Illinois Crop Protection Workshop Proceedings, Cooperative Extension Service, Illinois Natural History Survey, University of Illinois at Urbana-Champaign, March 1992.)

The abstract accompanying the article reads, "A novel approach has been developed to assess environmental risks associated with the single use of a pesticide. Levels of environmental risk for specific pesticides are determined by objective criteria, and the relative importance and monetary value of avoiding different risks are estimated through contingent valuation surveys. These data provide the basis for calculating environmental economic injury levels, which include both economic and environmental criteria for making management decisions regarding pests. The model was tested by establishing environmental costs and economic injury levels (EILs) for field crop insecticides, based on a contingent valuation survey of field crop producers in four north central states. Results indicate that use of environmental EILs could reduce pesticide use dramatically and improve pesticide selection. The model answers a long-standing need for pest management programs to address environmental safety directly and also provides a formal method for assessing environmental risks from pesticides at the level of individual users, as well as at the regional or national level."

Among the data presented are the level of environmental risk and calculated environmental costs for 32 insecticides evaluated across 8 environmental categories (surface water, ground water, aquatic environment, birds, mammals, beneficial insects, humans -- acute toxicity, and humans -- chronic toxicity).

79. Hueth, D., and U. Regev. "Optimal Agricultural Pest Management with Increasing Pest Resistance," *American Journal of Agricultural Economics*, Vol. 56, No. 3, August 1974, pp. 543-552.

The abstract accompanying this article follows. "The effect of increasing pest resistance to insecticides on the optimal control of a pest population is investigated by constructing a single-pest, single-crop management model and analyzing the resulting optimality conditions. Use of insecticides under these conditions results in both monetary costs and user costs. It is suggested that growers do not generally consider these user costs and therefore do not obtain maximum profits. The dynamic formulation of the model results in an extension of the literature dealing with the 'economic-threshold,' which under reasonable conditions is shown to be increasing during the course of the season."

80. Hussey, N.W. "Some Economic Considerations in the Future Development of Biological Control". S.C.I. Monograph No. 36, Glasshouse Crops Research Institute, Littlehampton, Sussex, England..

Biological control is an effective means of controlling pest infestations. The annual release of sterilized male screw worms at a cost of $10 million has yielded $100 million in annual benefits. However, biological control is generally developed within public research institutions which do not conduct many step by step financial assessments or profitability studies. In 1963 the economic threshold of red spider mites, *tetranychus urticae*, on cucumbers was established. Subsequently, a biological control program employing *phytoseiulus persimilis* was developed. Effective biological control of the red spider mite and the white fly requires uniform pest infestation. Both the pest and the predator may need to be introduced to the crop to ensure effective control and predictable damage levels. The cost of introducing *phytoseiulus persimilis* was estimated at £ 30/acre, while the white fly and its parasite, *Encarsia*, were estimated at £ 10/acre. *Aphis gossypii* control via *Aphelinus flavipes* requires the introduction of the predator into the aphid population prior to distribution, at an estimated cost of £ 30/acre. In Lea

Valley, chemical control of these pests is estimated at £ 200-400/acre per season. Biological control via the methods articulated in the article costs approximately £ 70/acre. Research in Addington has shown the use of *phytoseiulus persimilis* decreases labor hours while increasing yields as much as 20 percent. To have a viable industry, however, there is a need for year-round predator demand. The authors discuss the possibility of the chrysanthemum industry providing that demand during the part of the year when the cucumber industry does not. The complementarity and potential problems of such an arrangement are discussed. Of particular concern is the use of quinomethionate for mildew control which eliminates biological control possibilities. Simple techniques that may be easily adapted by producers are emphasized. The constraint uncertainty places on private investment in the industry presents a possible role for government to play.

81. Hutchins, Scott H., Leon G. Higley, and Larry P. Pedigo. "Injury Equivalency as a Basis for Developing Multiple-Species Economic Injury Levels," *Forum: Journal of Economic Entomology*, Vol. 81, No. 1, February 1988, pp. 1-8.

The abstract accompanying this article reads as follows. "A technique for developing and using multiple-species economic injury levels (EILs) is proposed, discussed, and evaluated. Grouping insects into injury guilds, based on the plant's physiological response to the injury, forms the theoretical basis for the multiple-species approach. In addition, a method for estimating crop injury, using an injury equivalency system, is proposed as a technique for refining the accuracy of EIL-based decision making. A detailed discussion concerning the theory and assumptions behind multiple-species EILs and injury equivalency is presented. As an example of the usefulness of the proposed system, we present data on a leaf-mass consuming insect guild on determinate soybeans. The paradigm includes an extensive review of defoliation-yield loss relationships for soybean and the calculation of EILs at four crop growth stages. Consumption data for five common soybean defoliators were also reviewed. These data were converted to equivalency coefficients based on the relative consumption potential of each species. With this system, each species within a guild can be related to every other species on the basis of its ability to contribute to overall injury. Finally, we present actual data for a leaf-mass soybean consuming guild and relate sampling information to the EIL. The result is a refined estimate of injury when species and size class consumption differences are incorporated in the estimate. Perhaps more significant, however, is the usefulness of the technique in assessing host injury, in economic terms, from multiple insect pests."

82. Keerthisinghe, C. I. "Fiducial Inference in Economic Thresholds," *Protection Ecology*, Vol. 6, No. 1, 1984, pp. 85-90.

Because economic thresholds vary depending on weather conditions and other factors, serious difficulties arise when one attempts to apply experimentally developed thresholds in large-scale management programs extending over wide areas and time periods. "The fiducial interval and the lower fiducial limit can be useful tools in establishing a threshold, beyond which the true or parametric injury level lies with a known probability. The fiducial interval also expresses locational and temporal variability, and thus eliminates the difficult task of monitoring such variability....A prerequisite for using the lower fiducial limit would be the use of the optimal sample size, in order to minimize the effects of sampling error."

83. Key, James P., Eddy Finley, and Darryl Mortensen. Impact of the Oklahoma State University Extension Integrated Pest Management Program in a Four-County Area of Oklahoma, A paper prepared for presentation at the Western Region Agricultural Education Research Meeting, Boise, Idaho, April 1985.

T: Changes in wheat producers' awareness, attitudes, practices, and sources of information concerning production and stored grain IPM.

D: A telephone survey of 1,556 Oklahoma wheat growers from four counties was conducted in 1980. 1,194 responded to the survey. In 1984 a follow-up survey was conducted of those originally contacted. The 1984 survey had 858 respondents (81% of those still eligible to complete the survey).

R: The report presents the survey results in paragraph form, as well as presenting the questionnaires and the responses to each question. Chi-square tests are performed and reported for each question. Below is a compilation of the major conclusions of the surveys.

ITEM	1980	1984
% who had heard of IPM	30%	55%
% who thought IPM was profitable	74%	86%
scouting of wheat fields	51%	92%
% Extension personnel to scout	19%	75%
% encountering climatic problems	51%	26%
% encountering weed problems	27%	51%

84. Khan, Mahmood Hasan. "Economic Aspects of Crop Losses and Disease Control," *Economic Nematology*. John M. Worster, editor, New York: Academic Press, 1972.

The article presents a general discussion of the economics of crop losses and disease control. Data regarding crop losses are extremely hard to come by. "Losses" are difficult to assess and records are difficult to maintain -- in most countries such records are not kept at all. The data presented in the article, "Annual world crop losses (in million tons)" and "Annual world crop losses (in million U.S. dollars)," come from Cramer's 1967 study.

85. Klein, K. K., C. S. Fleming, Douglas D. Colwell, and Philip J. Scholl. "Economic Analysis of an Integrated Approach to Cattle Grub (*Hypoderma* spp.) Control," *Canadian Journal of Agricultural Economics*, Vol. 38, No. 1, 1990, pp. 159-173.

T: Evaluation of the costs and benefits of an integrated cattle grub control program undertaken jointly by Canada and the United States. The Canada-U.S. program utilized insecticide treatments and sterile male releases. The costs and benefits of this program are compared to cattle grub control relying solely on chemical treatments.

M: Two chemical only areas were established, one in Montana, U.S., and one in Alberta, Canada. The integrated area straddled the Canada-U.S. border and was divided into two sections: 1) eastern half used sterile *Hypoderma lineatum*; and 2) western half used sterile *Hypoderma bovis*. Costs and benefits over a ten year period are estimated when eradication of the cattle grub occurs within five years, and when eradication does not occur within the ten year period. Real discount rates of 5% and 10% are used. All benefits and costs are converted into 1985 Canadian dollars.

R: Using only chemical control, the mean intensity of cattle grubs was reduced from 13.3 grubs per animal to 2.2 in the U.S. and 2.7 in Canada. In the eastern half of the integrated program area virtual eradication of *Hypoderma lineatum* was observed, while *Hypoderma bovis* remained at levels comparable to those observed with chemical control only. In the western half of the integrated program area *Hypoderma bovis* was virtually eliminated, while *Hypoderma lineatum* remained at levels comparable to those attained in the chemical control only area. Estimated costs and benefits from the programs appear below.

Year:	1	2	3	4	5	6	...	10
Chemical control alone			($1000 Canadian 1985)					
Benefits	5,186	5,186	5,186	5,186	5,186	5,186	...	5,186
Costs	(1,931)	(1,931)	(1,931)	(1,931)	(1,931)	(1,931)	...	(1,931)
Net	3,255	3,255	3,255	3,255	3,255	3,255	...	3,255
Integrated control (no eradication)								
Benefits	5,544	5,544	5,544	5,544	5,544	5,544	...	5,544
Costs	(6,486)	(4,893)	(2,000)	(2,000)	(2,000)	(2,000)	...	(2,000)
Net	(942)	651	3,544	3,544	3,544	3,544	...	3,544
Integrated control (eradication)								
Benefits	5,544	5,544	5,544	5,544	5,544	5,544	...	5,544
Costs	(7,005)	(5,412)	(2,519)	(2,519)	(2,519)	(519)	...	(519)
Net	(1,461)	132	3,025	3,025	3,025	5,025	...	5,025

86. King, Norman B., and A. Desmond O'Rourke. "The Economic Impact of Changes in Pesticide Use in Yakima Valley Orchards," *Bulletin 841*. Washington State University, College of Agriculture Research Center, Pullman, WA, March 1977.

T: "This study attempted to (a) collect cost data on current (1972) practices, (b) explain how costs respond to different types of orchard operation, and (c) show how costs for IPM programs would differ from current costs."

D: Fifty-two orchardists in lower Yakima Valley, Washington, were surveyed. Their primary products were pears and apples, with the remainder of their land going to cherry, peach, and other fruit production. Survey data include: number and size of the orchards; average gross and net farm and off-farm income dissaggregated by farm size; cost data on spray equipment, labor and miscellaneous costs; average yield, price per ton, and gross returns per acre for apples, pears, cherries, and peaches disaggregated by orchard size.

R: IPM is economically beneficial for apple production (lowering costs, applications and dosages of chemical pesticides), but not for pear production. The survey revealed that commercial pesticide fieldmen are the major source of information on pest management for farmers. Because fieldmen generate their living based on the amount of pesticides sold, there is a concern about possible conflicts of interest between their advisory role and that of salesmen.

"[O]ne must be cautious in interpreting any estimate of total pest management cost for the typical Yakima Valley fruit orchardist. Our data apply only to the 1972 season. Pest conditions in other seasons could differ markedly. In addition, many costs have risen sharply since 1972 (appendix table 3)." Selected data from a table, "Summary of all average costs per acre of spraying with integrated pest management and standard pest control programs on apples and pears in sample area," is presented below.

Item	Apples Standard pest control	 IPM	Pears Standard pest control	 IPM
	--------------------dollars	----------	----------	----------
Insecticides & Fungicides	36.20	15.20	60.09	64.21
Growth regulators, thinners, nutrients herbicides	12.18	12.18	2.09	2.09
Labor	8.20	6.56	13.00	13.00
Total Equipment	8.15	8.15	15.19	15.19
Other	10.14	8.81	15.84	15.84
IPM costs	___	16.75	___	16.75
Total Costs	74.87	67.65	106.21	127.08

87. Knight, Alan L., and George W. Norton. "Economics of Agricultural Pesticide Resistance in Arthropods," *Annual Review of Entomology,* 34:293-313, 1989.

The article examines the economic impacts of increased pesticide resistance at both the field/farm level and "beyond the farm gate." IPM reduces the amount of pesticides in the production of many crops while maintaining the efficacy of many pesticides. Chemical intensive farming is promoted, in part, by the agrochemical industry in an effort to capture the large costs associated with the development of new pesticides. Such practices often speed up the rate of resistance development among the target species. Subsidization of agrochemicals is another catalyst to resistance.

The authors review the economic techniques which are used to evaluate the following: the effects of pest resistance on pesticide productivity; the optimal use of pesticides over time; and alternative pest control strategies. Pest mobility, the environmental effects of pesticide use, and the level and distribution of economic benefits resulting from increased resistance are addressed, as well as the implications of resistance on public policy and private sector pest management. The article concludes with recommendations for future research.

88. Koopmans, Tom TH. "An Application of an Agro-economic Model to Environmental Issues in the EC: A Case Study," *European Review of Agricultural Economics*, Vol. 14, No. 2, 1987, pp. 147-59.

The summary attached to the article follows: "This paper provides an application of IIASA's Basic Linked System (BLS) to environmental issues in EC agriculture. In order to find out whether such an integrative exercise can be done without exceeding the limits of the model, a nutrient balance of EC agriculture was constructed, which reflects the differences between nutrient extraction and delivery of nutrients to the soil; this balance was then run together with selected model scenarios. One of the conclusions is that the BLS can indeed be considered a suitable instrument for policy analysis, because it provides insights into the possible economic and environmental consequences of certain EC policies for the medium and long term. A second important conclusion drawn is that policy measures to protect and improve the environment do not need to be at variance with agricultural income objectives. The results provide a basis for further research, which may become possible with a more detailed EC model of the same type, developed at the Centre for World Food Studies, which specifies the EC countries separately and distinguishes a larger number of agricultural commodities."

89. Kovach, J., C. Petzoldt, J. Degni, and J. Tette. "A Method to Measure the Environmental Impact of Pesticides," *New York's Food and Life Sciences Bulletin*, Number 139, Cornell University, New York State Experiment Station, Geneva, New York, 1992.

The authors develop a method to calculate the environmental impact of most common fruit and vegetable pesticides. A rating system for pesticides is developed that includes mode of action, toxicity to fish, birds, bees, beneficials, long term health effects, plant surface residue half life, soil residue half life, ground water and runoff potential, and acute dermal LD50 for rabbits/rats. The ratings are the basis of an environmental impact quotient (EIQ) the authors develop. The ratings and EIQs are presented in comprehensive tables for fungicides and nematicides, insecticides and miticides, and herbicides. A Field Use Rating is also calculated with the EIQ data. Examples of pest management strategies are compared on the basis of their environmental impacts.

90. Kovach, J., and J. P. Tette. "A Survey of the Use of IPM by New York Apple Producers," *Agricultural Ecosystems and Environment*, Vol. 20, No. 2, 1988, pp. 101-108.

T: Three topics are addressed in the article: (1) comparison of background and behavioral characteristics of IPM apple producers and non-IPM apple producers in New York; (2) identification of the major source of pest management information used by New York apple producers; and (3) economic consequences of using IPM.

D: 218 New York apple producers were surveyed by telephone regarding background and behavioral characteristics. The respondents were classified as non-users, low users or high users depending on their responses.

R: 19.3% of surveyed growers were classified non-users, 73.4% as low users, and 7.3% as high users of IPM. "A majority (63%) of high users of apple IPM indicated a greater willingness to accept some risk of a decrease in profit in order to use all the scientific knowledge available to protect their crop. At the same time, 56% of the non-users and 47% of the low users preferred to spray on an insurance or calendar-type basis." The preferred source of pest management information was dealers and sales persons for non-users, extension newsletters for low users, and the extension handbook for high users. From 1976-1986 the average costs incurred by IPM users were $237.24/hectare, and $333.04/hectare for non-IPM users. IPM users applied 6.2 kg/ha less pesticides than non-IPM users, on average, during this period.

91. Lacewell, R. D., and S. M. Masud. "Economic Analysis of Cotton IPM Programs," Chapter 12 in Integrated Pest Management Systems and Cotton Production, edited by Raymond E. Frisbie, Kamal M. El-Zik, and Ted L. Wilson, 1989, pp. 361-388.

The authors examine the economic implications of cotton IPM programs from the farm level, regional level, and national level. At the farm level, studies conducted in Mississippi (1972-1973), Alabama (1972-1973), Arkansas (1974), North Carolina (1974), and Texas (Wintergarden short-season cotton 1974, Lower Rio Grande Valley short-season cotton 1973-1978, and Texas Trans-Pecos 1972-1973) are reviewed. Selected results from these studies appear below.

Mississippi: IPM participants averaged 2.8 fewer pesticide applications per acre than non-participants, leading to a $3.50 per acre savings in pest control costs. No significant difference in cotton yield was found between IPM participants and non-participants.

Alabama: Fields that used pest scouting applied an average of 5.76 insecticide treatments per season, whereas fields on fixed spray schedules averaged 12 insecticide treatments per season.

Texas Wintergarden: Compared to traditional production techniques, IPM increased yield 149 lb/acre, reduced pesticide use 2.4 lb/acre, increased production costs $4/acre, reduced production costs 13.8 cents/lb lint, reduced energy use 33 gallons/acre (1,179,075 kcal/acre; 3,481 kcal/lb lint), and increased profit $97.57/acre.

Texas Lower Rio Grande Valley: IPM participants averaged 7.4 lb/acre of insecticide in 7.5 applications, as opposed to 19.9 lb/acre in 11.2 applications for non-participants. Across all study years yield variation was 7% lower for IPM participants than non-participants.

Texas Trans-Pecos: Two IPM programs were evaluated: full-season, and short-season cotton. "Implications of [the full-season] program were (1) the average yield for participants was 35 lb per acre higher than the average for nonparticipants, and (2) insect control costs were reduced by $200,000 for the area...net returns per acre were $30.59 higher for participants than for nonparticipants. The participants in the program applied insecticides 6.1 times versus 10.4 times for nonparticipants. The total quantity of insecticide used per acre was 10.4 lb for participants and 10.2 lb for nonparticipants." A summary of the short-season program appears in the table below.

		Production Technique	
Item	Unit	Traditional	IPM
Yield	lb/acre	700	630
Pesticide Use	applications	7	2
Nitrogen	lb/acre	250	60
Irrigation	inches/acre	40	30
Profit	$/acre	-105	81.50

At the regional level, studies of the Texas Coastal Bend Short-Season Cotton Production program, Texas Rolling Plains Uniform Planting Date Cotton Production program, Arkansas Bollworm Management Community Program, and North Carolina Boll Weevil Eradication Program are reviewed. The section on national implications reviews the USDA's 1974 cost/benefit study of three alternative federally sponsored boll weevil control programs. Potential shifts in cotton acreage, changes in land rents, and social benefits are also examined.

92. Lacewell, Ronald D., and Sharif M. Masud. "Economic and Environmental Implications of IPM," printed in Integrated Pest Management on Major Agricultural Systems, edited by Raymond E. Frisbie and Perry L. Adkisson, Texas A & M University, Texas Agricultural Experiment Station MP-1616. From a symposium sponsored by the Consortium for Integrated Pest Management and USDA/CSRS held October 8-10, 1985.

"The purpose of this report is to overview some of the economic and environmental implications of IPM programs for cotton, alfalfa, apples and soybeans. The important mechanics and biology of the programs are not discussed in this paper...Overall, [cotton] IPM has been shown to be effective in benefiting targeted producers or regions and in all cases of benefiting consumers." Alfalfa IPM strategies for controlling alfalfa weevil resulted in a $25 per acre increase in returns and a 45% reduction in insecticide use for producers in the North Central Region of the U.S. Likewise, profits increased $28 per acre and insecticide use decreased 75% for producers in Southern climates. Coordinated IPM control of scab, mite and coddling moth in apple production increased net revenues 16% to 46% over calendar based control programs. With respect to soybean production, "for maximum income/minimum risk, two of 18 systems evaluated were clearly superior: (1) low pesticide management levels and conventional tillage and (2) medium pesticide management level and reduced tillage, both in a corn/soybean rotation."

93. Lacewell, Ronald D., J.M. Sprott, G.A. Niles, J.K. Walker, and J.R. Gannaway. "Cotton Grown with an Integrated Production System," *Transactions of the ASAE,* Vol. 19, No. 5, 1976, pp. 815-818.

T: Cotton production techniques in Frio County, Texas, 1974. The techniques vary from a typical winter garden system of 101.6 cm (40 in) row of long-season cotton (typical) to a 66.04 cm (26 in) row of short-season cotton under a production management system (66.04 ss).

D: "[A]ll input data were converted to kilocalories to evaluate the energy efficiency of each production technique." Four tables present data on each production technique. One table shows per hectare production characteristics expressed in traditional measurements (kg, hrs, applications, etc.). A second table shows production characteristics expressed in energy equivalents (kilo-calories). A third table shows per hectare and per kilogram energy consumption, energy savings, costs and cost reductions. A fourth table shows kilograms of active ingredients of insecticide and herbicide use per hectare.

M: Analysis of the techniques is conducted using cotton enterprise budgets. "[A]ll input data were converted to kilocalories to evaluate the energy efficiency of each production technique.

R: Selected results from the tables are presented below.

	Typical	66.04 ss
Yield/ha	560 kg	857 kg
Irrigation	5,080 M^3/ha 1,810,749 Kcal	3,048 M^3/ha 650,565 Kcal
Labor	36.65 hrs 19,958 Kcal	37.49 hrs 20,415 Kcal
Insecticides/ha (active ingredients)	8.975 kg	3.366 kg
Desiccant/ha (active ingredients)	0	6.724 kg
Total energy/ha	8,956,024 Kcal	6,042,531 Kcal
Energy consumption (per kg lint)	15,984 Kcal	7,049 Kcal
Cost/kg lint	$1.05	$0.593

94. Lacewell, Ronald D., and C. Robert Taylor. "Benefit-Cost Analysis of Integrated Pest Management Programs," Chapter 22 in Pest and Pesticide Management in the Carribean, E. G. B. Gooding (ed.), Proc. of Seminar, CICP, Bridgetown, Barbados, Vol. II, 1980.

T: Benefits and Costs of switching to short season cotton varieties in the Texas High Plains, Lower Rio Grande Valley and the Texas Coastal Bend.

D: Data is taken from various sources. Tables in the article present information on, among other things, "Lint Yields, Insecticide Applications and Use, and Net Returns of Short-Season and Conventional Production Techniques with and without Irrigation, Lower Rio Grande Valley of Texas, 1973-75," "Estimated Impact of the Texas High Plains' Reproductive Diapause Boll Weevil Control Program" initiated in 1964 and evaluated in 1974 by Lacewell et al., and "Typical Per Acre costs and returns ($) for Cotton by Selected Years and Regions."

R: While gross revenues nearly doubled for cotton producers in the Texas High Plains, Lower Rio Grande Valley and Texas Coastal Bend from 1967-1979, total costs out-paced them in the High Plains and Lower Rio Grande Valley. The Coastal Bend experienced a 265% increase in net returns; the High Plains and Lower Rio Grande Valley experienced a decrease of 65% and 140%, respectively.

One table presents "Implications of a Short-Season IPM Cotton Production System for South Texas." Selected results appear below.

Item	Traditional	IPM
Yield (lb/acre)	500	649
Pesticide Use (lb/acre)	9	6.6
Production Costs ($/acre)	278	282
Energy Use (Kcal/lb lint)	7249	3768
Profit ($/acre)	12.4	104.97

Short-season cotton has lower yields than conventional cotton under both irrigated and dryland cultivation. Insecticide use is considerably lower for short-season cotton both with and without irrigation. Profits are lower for short-season cotton than conventional cotton under irrigation, but higher under dryland cultivation.

"Implications of a Short-season IPM Cotton Production System for West Texas" and "Implications of the Texas Agricultural Extension Service IPM Programs for Cotton" are presented. "In this IPM program, yield is reduced. However, the dramatic reduction in costs of production more than offsets the revenue loss associated with the yield reduction. Per acre costs of production are reduced 46 percent. With the reduced level of inputs, energy use per acre is reduced 57 gallons in fossil fuel equivalents. Profit is increased from a negative $105 to a positive $81.50 per acre. Yields were up 66 lb/acre in 1973 and 36 lb/acre in 1974. "The social benefits of the program as measured by the benefit cost ratio was $7.33 return in 1973 and $4.60 return in 1974 for each dollar of program cost, including program cost allocated to the farmer."

Using a macro model, the authors estimate a decrease in aggregate farm income by $43.9 million/year, resulting from the increase in yields and subsequent decline in price. Net social benefits are estimated to be $1,255 million. Advantages and drawbacks using partial budgeting, mathematical programming and econometric simulation for macro economic analysis are also discussed.

95. Lambert, William R. A Decade of Extension Cotton Integrated Pest Management, From the 1983 Proceedings of the Beltwide Cotton Production Research Conferences, San Antonio, TX, January 2-6, 1983. Printed by The University of Georgia, Cooperative Extension Service, Tifton, GA.

The symposium included the following papers highlighting cotton IPM from 1972-1982: (1) "Cotton Pest Management: The National Viewpoint"; (2) "Educational Techniques Used to Implement IPM"; (3) Impact of IPM on Acreage Scouted and Insecticide Use"; (4) "The Economic Impact of IPM"; (5) "Impact of IPM on the Private Sector"; (6) "The Future of IPM." Two conclusions from the papers are: (1) IPM contributed to the decline in insecticide use over these years by enabling growers to adjust to and capitalize on changes in the types of pest control materials, geographical distribution of acreage, and insect pressure; (2) "returns to IPM, based on data obtained from 11 states, amounted to $133,598,000 annually."

96. Larson, James L., Ronald D. Lacewell, James E. Casey, Marvin D. Heilman, L. Neal Namken, and Roy D. Parker. "Economic, Environmental and Energy Use Implications of Short-Season Cotton Production: Texas Lower Rio Grande Valley," *Southern Journal of Agricultural Economics,* Vol. 7, No. 1, July 1975, pp. 171-177.

T: Short-season narrow spaced cotton is compared to conventional cotton production methods in the Lower Rio Grande Valley with respect to economic, environmental and energy use characteristics.

D: Texas Agricultural Extension Service enterprise budgets were used for baseline data. Tables compare the two methods' production characteristics for irrigated cotton; and insecticide use, costs and returns for irrigated and nonirrigated cotton.

M: Oklahoma State University Crop and Livestock Budget Generator.

R: "One feature of short-season cotton is that no yields are sacrificed." Under irrigation, short-season cotton reduces diesel fuel use by approximately 0.26 gallons per acre. This translates into a 47,892 gallon savings for the Lower Rio Grande Valley. Without irrigation the difference in fuel use between the two varieties is minimal. Some selected data is presented below.

	Irrigated Cotton		Nonirrigated Cotton	
	Conventional	Short-Season	Conventional	Short-Season
Total Insecticides (1,000 lbs)	2,234.3	1,480.9	554.2	216.1
Total Costs ($1,000)	49,057.9	45,650.2	14,839.6	13,917.1
Net Returns ($1,000)	6,865.2	10,272.9	4,152.7	5,075.2

97. Lazarus, William F., and Earl R. Swanson. "Insecticide Use and Crop Rotation under Risk: Rootworm Control in Corn," *American Journal of Agricultural Economics,* Vol. 65, No. 4, November 1983, pp.738-747.

The abstract from the article reads as follows: "The economic threshold concept is extended to a combination of two pest controls, insecticide and crop rotation, in a corn-soybean farm model. Effect of risk attitudes on the optimal combination of controls is explored, using a stochastic simulation with random crop prices, yields, and rootworm damage. Crop insurance may cause a risk-averse farmer to adopt a riskier cropping program. Reduced risk aversion causes the farmer to specialize in the more profitable corn crop. The insecticide and rotation thresholds both increase with reduced risk aversion. Depending on pest densities on individual fields, insecticide use may increase or decrease."

98. Le Baron, Allen. "Pesticide Use or Non-Use -- Economics as a Basis for Policy Decisions," *Utah Science*, 32(2), June 1971, pp. 69-72.

The article discusses pesticide pollution in terms of market failure. An understanding of demand and supply relationships for agricultural commodities is required to evaluate the social benefits and costs related to pesticide use. A basic demonstration is given of how supply shifts in response to pesticide introduction, and the role acreage restricting policy can play in maximizing net social benefit in the presence of price supports. The same situation is demonstrated in the presence of transfer payments or subsidies rather than price supports. Ideas regarding how to bring non-market objectives into cost/benefit calculations are also presented.

99. Leslie, Anne R., and Gerrit W. Cuperus. "Integrated Wheat Management," Chapter 3 in <u>Successful Implementation of Integrated Pest Management for Agricultural Crops</u>, Lewis Publishers: Boca Raton, Ann Arbor, London, Tokyo, 1993.

This chapter "is intended to present management concepts and the role these play in developing and delivering crop management programs to agribusiness and producers." The chapter is divided into the following sections: the economic threshold/sufficiency concept, fertility inputs, secondary and micronutrient, liming, accomplishments in fertility management, cropping systems, rotations and tillage, pest management, pest management program implementation, program impacts on pest management, overall impact on profitability, and wheat storage. The authors summarize the chapter as follows: "Information delivery mode and timing is crucial when program management strategies are controversial or represent a change from traditional operating procedures. Many IPM programs must be dynamic and have access to near-real time nutrient, pest, crop, and weather information to make short-term rapid decisions. The success of IPM programs often depends upon the reaction of clientele to consistent, effective information delivery methods. Many sources of IPM information are available including: the CES [Cooperative Extension Service], independent crop consultants, trade associations, and other media outlets. It is important that these sources interact frequently and deliver consistent, effective management information to clientele...Issues of profitability, sustainability, and food safety must be addressed from a systems approach...Wheat field and storage IPM programs have had significant emphasis the past 10 years and have shown substantial improvement of producer management skills that have resulted in a more competitive, profitable, and environmentally sustainable agricultural system."

100. Liapis, Peter S., and L. Joe Moffitt. "Economic Analysis of Cotton Integrated Pest Management Strategies," *Southern Journal of Agricultural Economics*, Vol. 15, No. 1, July 1983, pp. 97-102.

"The purpose of this paper is to report on an evaluation of strategies, including biology-based control, under risk, utilizing the exponential-utility, moment-generating function approach to stochastic efficiency recently developed by Yassour, Zilberman, and Rausser.

The data for this study are derived from a 1981 test undertaken to determine the feasibility of releasing the wasp *Trichogramma prediosum*, an egg parasite, to control the *Heliothis* complex ... on cotton.

...Although caution should be exercised in drawing final conclusions, present results indicate that biological control of the *Heliothis* complex through release of a parasitic wasp, *Trichogramma*, is preferred to the other IPM strategies considered when risk aversion is an important characteristic of grower behavior."

101. Lincoln, Charles. "Use of Economic Thresholds and Scouting on the Basis for Using Predators and Parasites in Integrated Control Programs," Proceedings, Summer Institute on Biological Control of Plant, Insects and Diseases, 1974, pp. 182-189.

Economic thresholds (ET's) are not fixed values, rather they are dependent on the crop and its end use, weather variables, growth stage of the crop and pest, potential yield, status of biocontrol agents, and other factors as well. The author urges treatment thresholds to be set at the highest tolerable levels to avoid unnecessary pesticide applications and to give biological and cultural control a chance to work. Issues related to ET's for the following cotton pests are discussed: 1) thrips; 2) cutworms; 3) fleahoppers and plant bugs; 4) boll weevil; and 5) bollworm-tobacco budworm.

102. Linder, David K., Michael E. Wetzstein, Wesley N. Musser, and G. Keith Douce. An Economic Evaluation of the Georgia Extension Service Integrated Pest Management Programs for Cotton. Research Bulletin of the University of Georgia Agricultural Experiment Stations, Athens, GA: The Stations, May 1983 (293) 32 p.

T: Economic analysis of the Georgia Extension Service's cotton IPM programs.

D: A set of "subjective" and "objective" characteristics are identified. Surveys were conducted to collect data on the subjective characteristics (number of times the producer was in contact with county agents and others regarding IPM). Application records were used for data collection on objective characteristics (reflecting the degree to which the producer utilized IPM practices).

M: The Georgia Cooperative Extension Service's IPM program is evaluated using indices generated by the principal components method. A regression model is developed using the indices as independent variables in conjunction with land, labor, and capital variables. Principal Component analysis condenses a large number of production characteristics into a small number of pairwise uncorrelated indices. Principal Components analysis reduced the character variables to two objective and two subjective indices, accounting for 75% and 69% of total variation, respectively.

E: OLS was applied separately for yield, net returns, total pesticide, and total variable costs as the dependent variables.

R: An indication that "the 'proper' application of pesticides does significantly increase yield," that Georgia cotton growers have a tendency to over capitalize, and that IPM has no influence on pesticide expenditure.

103. Lindquist, D.A. "Social and Economic Aspects of Alternative Insect Control Methods," *Pesticide Science,* Vol. 8, No. 4, August 1977, pp. 389-393.

The author discusses impediments to the development and adoption of alternative pest control strategies (e.g. insect pheromones, hormones, microbial agents, cultural control). Four broad categories are identified: social, legal, organizational, and economic. Social arrangements are hypothesized to be the primary problem. The author contends that until legal action is taken, in the form of legislation which holds individuals accountable for the movement of noxious insects from their property to another's, and strong farmers organizations are created, the social impediments will remain. The case is made for area-wide control strategies.

104. Madsen, Harold F. "The Status of Integrated Control on Deciduous Tree Fruits," *Environmental Letters,* Vol. 1, No. 3, 1971, pp. 205-216.

The development of IPM practices for tree fruit production is related, along with some of the practical problems researchers have encountered due to the complexity of the tree fruit ecosystem. Challenges associated with establishing economic thresholds for tree fruits are also discussed.

105. Main, C.E. "Crop Destruction -- The Raison d'Etre of Plant Pathology," *Plant Disease,* Vol. 1, 1977, pp. 55-78.

This work discusses, among other topics, quantitative models for disease assessment (critical-point models, multiple-point models, area under the curve models, response-surface models) and the economics of disease loss (the economic threshold concept, short-run vs. long-term adjustments).

106. Martin, Marshall A., Marvin M. Schreiber, Jean Rosscup Riepe and J. Robert Bahr. "The Economics of Alternative Tillage Systems, Crop Rotations, and Herbicide Use on Three Representative East-Central Corn Belt Farms," *Weed Science,* Vol. 39, No. 2, April-June 1991, pp. 299-307.

T: Short-term economic consequences of alternative tillage systems on Drummer type soils found in the East-Central Corn Belt.

D: "Yield data were obtained from an integrated pest management project conducted at the Purdue University Agronomy Farm, which has highly productive, well-drained, Drummer silty clay loam soil, during the 1981 through 1988 crop years."

Three tillage systems were compared: (1) moldboard plowing prior to planting in the fall and spring (T1); (2) Chisel plowing prior to planting in the fall and spring (T2); (3) No-till (T3). Seven crop rotations were planted using each tillage system, for a total of 21 main plots. The rotations (where C = corn, S = soybeans, W = wheat) were: C-C, C-S, C-S-W, S-S, S-C, S-W-C, W-C-S. Each main plot was divided into three sections one of which received the minimum herbicide application (W1), another received moderate herbicide application (W2), and the third received maximum herbicide application (W3). The main plots were replicated 4 times in every year of the experiment.

M: A linear programming model was designed to examine the crop rotation, tillage system, and level of herbicide application to maximize net farm income. The model was run for three farm sizes: (1) 120 ha.; (2) 240 ha.; (3) 480 ha.

R: Optimal crop rotation and herbicide application varied from year to year. These results are reported for each year in the article. Z-tests were used to compare the three tillage systems with respect to average gross margin (gross revenue minus variable costs), and net farm income. "At the 95% confidence level, average gross margins for T1 and T2 were not significantly different, while both were found to be significantly larger than the average gross margin for T3. These findings also held true at the 99% confidence level. At the 95% confidence level, average net incomes for T1 and T2 were not significantly different, while both were found to be significantly larger than average net income for T3. Only T1 was found to be significantly greater than T3 at the 99% confidence level."

107. Martindale, Deborah Jean. *Cost/Benefit of Using Sticky Red Spheres for Monitoring the Apple Maggot, Rhagoletis Pomonella Walsh.* Project and Report submitted to the Graduate Faculty of the Virginia Polytechnic Institute and State University, Blacksburg, VA, December 1980.

T: Comparison of costs required for apple production, per acre income, and fruit quality associated with a standard versus a reduced spray program for controlling the apple maggot.

D: Four farms in Columbia County, New York, were examined during the 1980 growing season. On each farm, one planting block received the standard spray program, and another was monitored three times weekly for number of apple maggots trapped, the sex of each, and presence or absence of eggs on trapped females. Per acre costs of the standard and reduced spray programs were recorded throughout the season.

R: The average number of pesticide applications during the season were 9.25 and 8.25 for the standard and reduced spray programs, respectively. The reduced spray program had slightly lower spray material costs, but higher total production costs than the standard spray program. Total profits were lower under the reduced spray program in the production of both McIntosh and Red Delicious apples.

108. Masud, Sharif M., and Ronald D. Lacewell. Economic Implications of Alternative Cotton IPM Strategies in the United States. The Texas Agricultural Experiment Station, Information Report No. 85-5, College Station, TX, July 1985.

This report provides a review of the economic evaluation techniques applicable to IPM, with explanations of why they are appropriate, and the basic aspects of each technique. The techniques discussed include budgeting analysis, partial budgeting, breakeven analysis, analysis of variance, regression analysis, linear programming, mathematical programming, econometric simulation, and import analysis. Results of farm level, regional, and national economic evaluations of cotton IPM programs are also presented. Many of the results appear elsewhere in this annotated bibliography.

109. Masud, Sharif M., Ronald D. Lacewell, C. Robert Taylor, John H. Benedict, and Lawrence A. Lippke. "Economic Impact of Integrated Pest Management Strategies for Cotton Production in the Coastal Bend Region of Texas," *Southern Journal of Agricultural Economics,* Vol. 13, No. 2, December 1981, pp. 47-52.

T: An examination of the value and economic impact of the short-season cotton production system under IPM strategies as it relates to yield and producer returns in the Coastal Bend Region of Texas.

D: Tamcot SP-37 and CAMD-E varieties are examined in Jim Wells, Nueces, and San Patricio counties. Enterprise budgets were developed for each, reflecting per acre dryland costs and returns. As grain sorghum is also important to the region, an enterprise budget was developed for this crop as well. Separate budgets for IPM and "Typical" production techniques were generated for each cotton variety. "The use of scouting and lesser amounts of insecticide and participation in a pest management program were defined for a short-season cotton production system under 'IPM' techniques, while the converse practices were defined for short-season cotton under 'Typical' production techniques."

Selected data from tables presenting expected price, yield and production cost of grain sorghum and different cotton varieties, and a per acre comparison of insecticide use and costs for alternative cotton production systems for the study area are below.

	IPM Strategies		Non-IPM Strategies	
	CAMD-E	SP-37	CAMD-E	SP-37
Lint Yield (cwt/acre)	6.80	6.21	5.43	4.73
Seed Yield (cwt/acre)	10.88	9.94	8.69	7.60
Returns to Land, Management, Overhead and Risk ($/acre)	174.34	158.58	106.93	83.53
Total Insecticide Cost ($/acre)	3.88	3.88	8.80	8.80
Total Costs (Insecticide, Application, Scouting) ($/acre)	10.68	10.68	16.40	16.40

M: A linear programming model was developed for the region, the objective function of which was "to maximize producer net returns, subject to the amount of acreage of each soil type."

R: "The baseline solution in which all of the six cropping activities were included indicated that out of the total 1,285,206 acres of land for the 82 soil types, 903,959 acres would be devoted to IPM CAMD-E cotton, 139,690 acres to grain sorghum production, and the remaining 241,557 acres of land to some use other than crop production to maximize net returns throughout the three counties." One table shows the state and regional impact of combinations of the crops with the two production techniques. Selected data from this table appear below.

	Average Regional Impact (Million Dollars)	
	Coastal Bend	State (Texas)
IPM CAMD-E and Grain Sorghum	$729.40	$1,101.65
IPM SP-37 and Grain Sorghum	679.19	1,026.46
Typical CAMD-E and Grain Sorghum	440.05	688.93

110. McCarl, Bruce A. Economics of Integrated Pest Management: An Interpretive Review of the Literature. Agricultural Experiment Station, International Plant Protection Center, and Department of Agricultural and Resource Economics, Oregon State University, Special Report 636, August 1981.

This report is divided into seven sections. As Mr. McCarl explains in the preface, "The ordering of sections somewhat reflects the author's inquiry process as he pursued the literature. The first sections are general, offering definitions involved, background to development of integrated pest management (IPM), and an overview of issues involved. A literature review follows, concentrating on economic aspects of IPM. The final sections appraise the literature and suggest future research."

111. McGuckin, Tom. "Alfalfa Management Strategies for a Wisconsin Dairy Farm -- An Application of Stochastic Dominance," *North Central Journal of Agricultural Economics,* Vol. 5, No. 1, January 1983, pp. 43-49.

The abstract for this article reads: "Alternative management practices are evaluated by stochastic dominance for a representative dairy farm in Wisconsin. Analysis of harvesting schedules, integrated pest management, and harvesting technology indicates that a mid-bud cutting schedule using silage technology achieves maximum income at minimum risk. An additional benefit is reduced pesticide applications."

112. McNamara, Kevin T., Michael E. Wetzstein, and G. Kieth Douce. "Factors Affecting Peanut Producer Adoption of Integrated Pest Management," *Review of Agricultural Economics*, Vol. 13, No. 1, January 1991, pp. 129-139.

T: An examination of producer characteristics, management practices, farm structure, and institutional characteristics to determine their association with IPM adoption by peanut producers in Georgia.

D: 376 randomly selected Georgia peanut producers were surveyed by telephone in 1985. Data collected in the survey include: whether the farmer thinks IPM reduces health hazards; farmer's age (age); farmer's educational attainment (education); years of farm experience; total income; percent farm income; per acre peanut yield (yield); if practice IPM on other crops; if nematode test was conducted; percentage of agricultural literature received that is read; number of requests of extension (extension requests); if participate in federal crop insurance program; if use forward contracting (forward contracting); if animals are produced on the farm; percentage of peanuts that are quota peanuts; percentage of irrigated peanut acreage; total farm acres; percentage of total acreage in peanuts; total farm assets; total farm debt; and if farmer received IPM information from extension agents (extension IPM).

M: A logit probability model is used to model peanut producers' decisions with respect to IPM adoption.

E: Maximum Likelihood Estimation.

R: Age, percent farm income, yield, and forward contracting were found to have a significant association with IPM adoption at a 10% significance level. Extension IPM, extension requests, and education were significant at the 5% level. The logit regression coefficients of these significant characteristics are presented below.

Explanatory Variable	Coefficient	Standard Error
Age	0.045	0.025
Education	0.377	0.163
Percent Farm Income	0.671	0.359
Yield	0.001	0.001
Extension Requests	0.376	0.180
Forward Contracting	0.758	0.401
Extension IPM	0.752	0.353

113. Miranowski, John A. "Estimating the Relationship between Pest Management and Energy prices, and the Implications for Environmental Damage," *American Journal of Agricultural Economics*. Vol. 62, No. 5, December 1980, pp. 995-100.

T: Derivation of demand equations for insecticide and herbicide treatment in corn production, and how rising energy prices influence the supply and demand of pest management systems and the implied use of insecticides.

D: The insecticide and herbicide treatment demand was derived by pooling 1966, 1971, and 1976 cross-sectional data from the USDA's ten agricultural regions.

M: A log-log function was estimated where share of corn acres treated with herbicides or insecticides (ST_i) is the dependent variable and price of insecticides or herbicides (P_i), price of fuel (P_f), value of corn output per acre (Y), share of corn acres in cropland acres (SCA), lagged production-oriented research and extension expenditures (RE), and the farm wage rate (P_L) are all independent variables.

E: Weighted least squares.

R: The demand equation was regressed three times: once with insecticide treatments and without farm wage rate; once with herbicide treatments and without farm wage rate; and once with herbicide treatment and with farm wage rate. The estimated coefficients appear below. (Each regression had 30 observations.)

Exogenous Variables	Insecticide Treatment $\ln ST_I$	Herbicide Treatment $\ln ST_H$	$\ln ST_H$
Constant	-47.50	-9.14	-7.69
$\ln P_i$	-0.78	-0.75	-0.03
$\ln P_f$	15.17	4.42	3.99
$\ln P_L$			1.89
ln Y	2.97	0.69	0.27
ln SCA	0.19	0.22	0.22
ln RE	-1.43	-0.44	-0.34
R^2	0.36	0.67	0.77

A model depicting the per-acre cost of pest monitoring was also estimated. That model indicated that "fuel costs do not significantly affect the costs of supplying monitoring services to corn producers." The cost of supplying monitoring services was then incorporated into a corn production profit function to evaluate how fuel costs impacted the choice of corn root worm management strategies. (The empirical data employed in the profit model are from unpublished sources, while the enterprise-budget data come from Iowa State Univ. Extension Service circulars and a 1976 USDA report.) Assuming constant relative prices for corn and soybeans, the profit model shows that as fuel prices rise, monitoring becomes more profitable than prophylactic soil insecticide treatment. As fuel prices continue to rise, corn-soybean rotations become more profitable than continuous corn. (The assumptions under which this model was designed are noted by the author.)

114. Miranowski, John A. *Integrated Pest Management in Corn Rootworm Control: A Preliminary Economic Assessment.* Natural Resource and Environment Session Annual Meetings, American Agricultural Economics Association, Washington State University, July 29-August 1, 1979.

T: Description of the "optimal CRW [corn root worm] management strategy for a single Iowa corn producer, who is concerned with both net returns and risk."

M: Nine management strategies were compared using a decision-theoretic framework. Expected yield loss, variance of yield loss, and production costs for each strategy, and prices were translated into expected net returns using enterprise budgets for each strategy. A logarithmic utility function was then employed to translate these results into expected utility and variance for each strategy. The strategies examined were: CC-N; CC-I; CC-A; CS-N; CCS-N; CCS-I; CCS-A; CCOMM-N; CCOMM-I (where CC is continuous corn; CS is corn-soybean rotation; CCS is corn-corn-soybean rotation; CCOMM is corn-corn-oats-meadow-meadow rotation; N is no control regardless of need; I is CRW insecticide applied regardless of need; A is adult CRW control program only as needed based on economic threshold levels).

R: CS-N management leads to both maximum utility and maximum net returns. CCS-I and CCS-A follow closely with respect to utility, but generate only about 60% of the net returns of CS-N.

115. Moffitt, L. Joe, Darwin C. Hall, and Craig D. Osteen. "Economic Thresholds Under Uncertainty with Application to Corn Nematode Management," *Southern Journal of Agricultural Economics*, Vol. 16, No. 2, December 1984, pp. 151-157.

The economic threshold concept has been of limited practical use to agricultural producers due to its inherent complexities. These complexities arise from the concept's focus on optimization and profit maximization. To use the economic threshold, the producer must understand the pest-crop system in such a way as to compute optimal treatment dosages when encountered with a pest management decision. In contrast, the action threshold is easier to use, but falls short of profit maximizing decision rules. In the context of nematode control in corn production, this paper develops a decision rule which combines the action threshold with the economic threshold. The result, the mixture or M-threshold, is a decision rule that is as simple to use as the action threshold, but more profitable.

116. Moffitt, L.J., L.K. Tanigosh, and J.L. Baritelle. "Incorporating Risk in Comparisons of Alternative Pest Control Methods," *Forum: Environmental Entomology,* Vol 12, No. 4, August 1983, pp. 1003-1011.

"This paper considers techniques for comparing pest control methods that give variable results. The techniques described are equally valid for the technical and economic evaluation of control methods. The concepts and rules for stochastic dominance which provide a means of comparing random results are explained first. Then information required to conduct such a comparison is specified. Finally, an economic analysis of citrus pest control methods is provided to illustrate the approach."

117. Mumford, J.D., and G.A. Norton. "Economics of Decision Making in Pest Management," *Annual Review of Entomology,* Vol. 29, 1984, pp. 157-174.

A review of several economic models for decision making with respect to pest management. The models covered are the economic threshold model, marginal analysis (optimization) model, decision theory model, and behavioral model. Particular attention is given to the decision theory model.

118. Mumford, J.D., and G.A. Norton. "Economics of Integrated Pest Management," Crop Loss Assessment and Pest Management. St. Paul, MN: APS Press, 1987, pp. 191-200.

The authors consider pest management strategies to fall into two general categories, standard operating procedures (i.e. practices used regardless of infestation levels) and adaptive/responsive procedures. The costs and benefits of pest control are discussed.

Norton's equation for the economic threshold (PDAK > C) is presented. In this equation P is the per unit price of the crop; D is the yield loss from the pest per hectare per unit of pest attack; A is the untreated level of pest attack; K represents the treatment's effectiveness in reducing the level of pest attack; and C is the per hectare cost of the treatment. The variability of these parameters is discussed, including how to deal with nonlinear damage functions. Criteria for determining the expected value of the benefits of standard operating procedures are given.

Pest management from a public policy perspective is discussed, along with the influence the price inelasticity of demand for agricultural products can have on such policy. Pest management externalities are also considered.

119. Musser, Wesley N., Bernard V. Tew, and James E. Epperson. "An Economic Examination of an Integrated Pest Management Production System with a Contrast between E-V and Stochastic Dominance Analysis," *Southern Journal of Agricultural Economics,* Vol. 13, No. 1, July 1981, pp. 119-124.

The authors utilize E-V and Stochastic Dominance analyses to evaluate an experiment involving four pest control strategies. The concept that the amount spent on pesticides reflects potential environmental problems is adopted. E-V analysis revealed both high-level IPM and conventional strategies to be efficient management systems, although risk-averse producers will opt for conventional management. Stochastic Dominance revealed high-level IPM to be superior to all other strategies for all producers.

120. Musser, Wesley N., Michael E. Wetzstein, Susan Y. Reece, Philip E. Varca, David M. Edwards, and G. Keith Douce. "Beliefs of Farmers and Adoption of Integrated Pest Management," *Agricultural Economics Research*, Vol. 38, No. 1, Winter 1986, pp. 34-44.

T: "The purpose of this article is to present an interdisciplinary study of the relationship between risk and other perceptions of farmers and their adoption of IPM."

D: Potentially important economic and other consequences of decisions on pest control related to IPM were identified by a multidisciplinary team. These aspects are presented as "belief measures," a psychological concept. Belief data were collected on IPM, including a risk measure, for Georgia peanut producers in a 1982 telephone survey.

M: A multivariable analysis of variance F test was conducted on the eight belief variables across three producer groups (present IPM users, past IPM users, and producers who had never used IPM, i.e. nonusers).

R: The F test rejected the hypothesis that the means of each of the eight variables did not differ between groups. Differences in the producer groups' beliefs in IPM were significant at the 1% level for the yield, profit, and damage variables. The difference between the groups' beliefs regarding IPM and risk reduction was significant at the 5% level. Present users believed IPM had a positive effect on these variables relative to conventional pest management (i.e. IPM reduced damage, reduced risk, increased yield, and increased profit). The difference between past user and present user beliefs was less than that of present user and nonuser beliefs for the damage and profit variables, but greater for the risk and yield variables.

121. Napit, Krishna B., George W. Norton, Richard F. Kazmierczak, Jr., and Edwin G. Rajotte. "Economic Impacts of Extension Integrated Pest Management Programs in Several States," *Journal of Economic Entomology*, Vol. 81, No. 1, February 1988, pp. 251-256.

T: Assessment of the impact IPM has had on the level and variability of net returns to farmers and the aggregate benefits to producers and consumers from IPM programs. Determination of the relative importance of socioeconomic factors influencing IPM adoption.

D: Telephone surveys administered by Cooperative Extension Services in a number of states (IN, VA, GA, NY, NC, TX, MA, MS, and the Northwest region) collected data on general agricultural production practices, economic factors, social and demographic factors, and the distribution of specific IPM practices.

M: Average crop budgets were developed for each state and commodity, and for different levels of IPM adoption. T-tests were used to test the budgets for significant differences in mean return to management per hectare and mean pesticide cost per hectare; F-tests examined the variances of those variables.

Changes in consumer, producer, and total net economic surplus' from IPM programs were calculated assuming linear curves, a pivotal shift in supply, no imports or exports, and a perfectly competitive agricultural industry. The internal rate of return formula was used to calculate net benefits from IPM programs.

A trichotomous logit model was used to analyze distributional effects of IPM adoption.

R: High users of IPM received greater returns per hectare than low users and nonusers for each crop studied, except North Carolina tobacco. Pesticide costs were higher for high users of IPM than nonusers for each crop studied, except Northwest alfalfa seed.

"Consumer and producer surplus calculations were made only for the states with significant net revenue differences across all user groups (Texas and Mississippi). The resulting annual internal rates of return in investment in IPM were very high (452% for Texas and 300% for Mississippi). Most benefits were received by consumers due to lower prices."

"The adoption analysis indicated that in seven of the nine studies, a higher value of farm products sold annually, or a higher percent family income from farming, or both, contributed positively to the respondents' decisions to adopt IPM practices."

122. Norgaard, Richard B. "Integrating Economics and Pest Management," *Integrated Pest Management*, J.L. Apple & R.F. Smith, eds., New York: Plenum Publishing Corp., 1976, pp. 17-27.

"The objective of this paper is to introduce plant protection scientists to economic principles and problems related to the design and implementation of optimal pest management strategies that will also reduce the pesticide problem...Economics may enter into these strategies in three interrelated ways: (1) the pest management goals of farmers are largely economic; (2) as a science of resource allocation, economics can aid in selecting optimal quantities and combinations of pest management inputs; and (3) the economist's understanding of the incentives underlying farmers' behavior and the effect on these incentives of alternative social institutions can speed the adoption of new pest management practices." A review of how to identify profit maximizing input levels is given. The difficulty of integrating economic concepts with biological models is discussed. The distinction between the damage threshold and the economic threshold, and the difficulty in applying each to various crop and pest management techniques is articulated. Farmer risk aversion and its impact on profit maximizing behavior is addressed. A discussion of the costs and benefits of collective pest management, at a regional level, concludes the article.

123. Onstad, David W. "Calculation of Economic-injury Levels and Economic Thresholds for Pest Management," *Forum: Journal of Economic Entomology*, Vol. 80, No. 2, April 1987, pp. 297-303.

The abstract accompanying the article reads as follows. "General formulas for calculating economic-injury levels and economic thresholds are presented. Terms and variables are defined, and important underlying assumptions are explicitly described. Concepts regarding scheduling and temporal dynamics are presented to assist in proper use of the formulas. New formulas that consider expanded concepts of the economic-injury level and economic threshold permit calculation of multiple levels at a given time, dynamic levels that change over time, and multidimensional levels that consist of the densities of more than one life stage or species."

124. Osteen, Craig, A.W. Johnson, and Clyde C. Dowler. "Applying the Economic Threshold Concept to Control Lesion Nematodes on Corn," *Technical Bulletin Number 1670,* United States Department of Agriculture, Economic Research Service, Washington, D.C., April 1982.

The abstract accompanying this document reads as follows: "This bibliography, a listing and annotation of 123 papers, reports, and books concerned with the economics of pest control, covers (1) damages caused by pests, (2) benefits and costs of pest control methods, (3) comparisons of biological and chemical methods of control, (4) economically efficient applications of pesticides, (5) economic thresholds, (6) resistance to pesticides, (7) externalities of pesticide use, (8) impacts of risk on pest control decisions, (9) static and dynamic methods of analysis, and (10) institutional concerns such as pesticide regulation, implementation programs, and information distribution. General literature on principles of integrated pest management is also included."

125. Payne, Brian R., William B. White, Roger E. McCay, and Robert R. McNichols. "Economic Analysis of the Gypsy Moth Problem in the Northeast -- Applied to Residential Property," *USDA Forest Service Research Paper NE-285*, Northeastern Forest Experiment Station Forest Service, USDA, Upper Darby, PA, 1973.

"This paper presents a method for evaluating the dollar loss in residential property values from tree mortality caused by the gypsy moth." The method is appropriate for forested residential areas. The method was developed by comparing the value of properties with similar characteristics with and without trees. The authors found trees of 6" dbh and larger added to property values. The value added and number of trees followed a quadratic relationship. On 20,000 $ft.^2$ lots in Amherst, MA, 29 trees maximized the value added at $4,310. The authors then present guidelines for calculating value losses from gypsy moth attacks.

126. Pedigo, Larry P., and Leon G. Higley. "The Economic Injury Level Concept and Environmental Quality -- A New Perspective," *American Entomologist*, Vol. 38, No. 1, September 1992, pp. 12-21.

The goals of IPM are identified: to reduce pest status; to ensure producer profits; attain environmental compatibility; produce sustainable solutions to pest problems. Economic Injury Levels (EILs) are seen to be central to the development of IPM to date, and critical to the future development of IPM strategies. Traditionally, EIL has been expressed in pest densities. Recent work expresses EIL in injury units. The authors explain the following EIL variables and their relationship: cost of management tactic/production unit (C); market value/production unit (V); injury units/pest (I); damage/injury unit (D); and proportional reduction in pest attack (K). When there is a linear relation, this may be expressed as,

$$EIL = C/VIDK$$

To reduce pesticide use, EILs and Environmental Thresholds (ETs) must also be developed which evaluate the environmental impacts of management tactics in conjunction with user costs and benefits. "[I]t has been estimated that pest monitoring, establishment of ETs, and reduced pesticide dosage can reduce pesticide use by 30-50%." The paper examines "...the practicality of manipulating variables in the EIL equation to make pest management decisions more responsive to environmental concerns and to transform the conventional EIL into an environmental EIL."

C can be increased by, among other things, including the cost of potential environmental contamination. Contingent valuation is recommended to estimate these costs. Decreasing V will increase EIL. In a free market, however, there are many difficulties and dangers to manipulating V. Reducing I has unknown ecological ramifications. Decreasing D will require a lot of research, for D is not quantifiable for many pesticides. This area, however, has the most sustainable potential, as pests cannot develop resistance to a plant's ability to tolerate damage. The authors also propose "K is the proportion of total pest injury averted by the timely application of a management tactic," rather than the expected proportion of pest population killed, utilized by most practitioners.

127. Pike, David R., Kent D. Glover, Ellery L. Knake, Donald E. Kuhlman. Pesticide Use in Illinois: Results of a 1990 Survey of Major Crops. University of Illinois at Urbana-Champaign, College of Agriculture, Cooperative Extension Service, DP-91-1, July 1991.

This survey examines trends in pesticide application rates and timing for Illinois crops, but does not associate these trends with any particular pest management strategies. Integrated pest management is not mentioned specifically, however, the tables presented below illustrate the trend in acres of major field crops scouted for pests, and reveal a relationship between crop rotations and soil insecticide usage.

	Corn			
Type of scouting	1982	1985	1988	1990
	Percentage of Acres Scouted			
Professional Service	3	5	4	7
Farmer or Family	41	55	50	55

	Soybeans			
Type of scouting	1982	1985	1988	1990
	Percentage of Acres Scouted			
Professional Service	4	4	4	5
Farmer or Family	37	56	57	54

Type of scouting	Alfalfa 1982	1985	1988	1990
	----------------Percentage of Acres Scouted------------------			
Professional Service	<1	<1	2	4
Farmer or Family	10	10	23	33

1989 Crop Follwed by Corn in 1990	% of Corn Acreage	% Corn Treated with Soil Insecticides
Corn	26.3	88
Soybeans	66.7	13
Other	6	49

128. Pimentel, David, David Andow, Rada Dyson-Hudson, David Gallaham, Stuart Jacobson, Molly Irish, Susan Kroop, Anne Moss, Ilse Schreiner, Mike Shepard, Tom Thompson, and Bill Vinzant. "Environmental and Social Costs of Pesticides: A Preliminary Assessment," *OIKOS,* 34:2, 126-140, 1980.

"A study was made of the direct costs that result from pesticide usage in the United States. These costs included: 45,000 annual non-fatal and fatal human pesticide poisonings; $12 million in livestock losses; $287 million in reduced natural enemies and pest resistance; $135 million in honey bee poisonings and reduced pollination; $70 million in losses of crops and trees; $11 million in fish and wildlife losses; and $140 million in miscellaneous losses. The estimated total of $839 million annual losses attributed to environmental and social costs of pesticide use represents only a small portion of the actual costs. A more complete accounting of the indirect costs would probably be several times the total reported. The results of this preliminary assessment underscore the serious nature of the environmental and social costs of pesticide use." Tables present disaggregated estimates of the costs for most of the above categories. Incorporating the estimates provided in the article into a cost:benefit ratio for pesticides leads to a $3 return per $1 investment. The authors, however, stress the point that this is only a preliminary assessment and more research must be done in this area.

129. Rajotte, E.G., H.S. Baumes, Jr., R.M. McPherson, and W.A. Allen. *Soybean Integrated Pest Management: A Demonstration of Micro and Macro Economic Effects.* Department of Entomology, VPI&SU, Blacksburg, VA.

T: Evaluation of the cost effectiveness of pest management programs on soybean production in Virginia.

D: The study employs partial farm budgets before and after the institution of integrated pest management techniques. The costs of three cropping systems (full-season soybeans planted in May, double-cropped soybeans planted in mid-June after winter barley, and double-cropped soybeans planted in early July after harvesting winter wheat) and two pest management strategies (traditional chemical calendar treatments, and IPM using scouting, Mexican bean beetle parasites and timed chemical treatments) are compared.

M: "A linear programming model of U.S. agriculture is used to compare the economic impacts of IPM and traditional methods for insect control in soybeans...

...In order to delineate the effects beyond the farm gate of changes in IPM practices on prices and value of resources, a partial equilibrium sector model of U.S. agriculture (Baumes 1978) was utilized." Three pest management regimes were compared using this model: 1) all soybean producers used traditional calendar treatments, 2) Virginia soybean producers used IPM while the rest of the U.S. used traditional calendar treatments, and 3) all U.S. soybean producers used the Virginia soybean IPM strategy.

R: Selected data from tables with the following titles are presented below: "Budget for the Production of Full Season Soybeans in Virginia with Changes Reflected for Pest Management Components"; "Budget for the production of Double-Cropped Wheat/Soybeans Partial Budget Changes for the Pest Management Components of Wheat and Barley Systems"; "Production Summary of Commodities Under Each Insect Suppression Regime"; "Price Received Summary of Commodities Under Each Pest Management Regime"; "Summary of Land and Labor Effects"; and "Summary of Aggregate Pest Suppression Costs for Soybean Producers."

Crop-Pest Management System	Total Costs	Net Savings per Acre
Full Season-Traditional	$186.60	
Full Season-IPM	$178.66	$ 7.49
Double Crop (Wheat-Soybeans) -Traditional	$150.09	
Double Crop (Wheat-Soybeans) -IPM	$143.27	
Double Crop (Barley-Soybeans) -IPM	$135.10	$ 6.82

Item	Traditional	IPM in VA only	IPM in all U.S.
Production (bil. bu.)			
Soybeans	1.365	1.365	1.375
Price ($/bu.)			
Soybeans	6.32	6.32	6.11
Land (million acres)			
Soybeans	281.186	281.186	281.345
Land Value ($/acre)			
Soybeans	36.90	36.90	37.32
Total Aggregate Costs of Pest Suppression on Soybeans ($1000)	459,065.6	----	105,851.2

A complete discussion of the results of each scenario simulation is included in the report, along with the rationale for using the data which was employed in the study.

130. Rajotte, Edwin G., Richard F. Kazmierczak, Jr., George W. Norton, Michael T. Lambur, and William A. Allen. The National Evaluation of Extension's Integrated Pest Management(IPM) Programs, Virginia Cooperative Extension Service, VCES Publication 491-010, Blacksburg, VA, February 1987, 123 p.

This report is a comprehensive evaluation of IPM Extension programs throughout the United States. Measurements of agricultural, social, and economic impacts of IPM are presented. Information on how and why producers adopt IPM was collected by surveying Extension IPM personnel, Extension clientele, and private pest management consultants; these groups also provided demographic information about themselves. There is an extensive set of case studies presented covering nine crops in fifteen states. The crops examined, with the state abbreviations in parentheses include: corn (IN), apples (MA, NY), almonds (CA), cotton (TX, MS), stored grains (KY), peanuts (GA), soybeans (VA), tobacco (NC), alfalfa seed (OR, MT, WA, ID, NV), and urban IPM (MD). The findings of each survey and case study are reported. A small sample of the major findings cited in the executive summary include:

* "The most effective program delivery methods were perceived by Extension personnel to be print media";

* among Extension clientele, "the most important benefits from IPM were perceived to be those related to improved crop yield and quality. Although protection of health and the environment were also highly related";

* "in general, gross revenues and net returns tended to be higher for IPM users" than non-users;

* "considering only the approximately 3500 growers in this study...IPM users experienced a total difference in net returns over non-users in excess of $54 million per year";

* "virtually all [private pest management consultants] used a threshold concept, a cornerstone of the IPM approach, to make pest management decisions";

* "the Maryland study showed success in delivering IPM to the urban and suburban population. This population represents a large untapped clientele for the IPM program."

131. Ram, Shri and M.P. Gupta. "Integrated Pest Management in Lucerne (Medicago sativa L.) and its Economics in India," *Tropical Pest Management*, Vol. 36 (39), July/September 1990, pp. 258-262.

T: An examination of IPM strategies for controlling leafhoppers, lucerne weevils, and aphids in lucerne production.

D: Sixteen pest management strategies were replicated 3 times, in 1980-1 and 1981-2. Each trial was conducted on a 3m x 2m plot. The pest management variables were: fertilizer (optimum combination vs. no fertilizer); variety (local "S-932 vs IGFRI-244 (the least susceptible)); insecticide endosulfan (one application 15 days after first cut vs. no application); Bacillus thuringiensis Berliner (one application 15 days after first cut vs. no application).

M: The plots were scouted at 40, 55, 70, 90, 105, 120, and 135 days after sowing. The mean population of each pest was then calculated.

R: The use of improved cultural practices alone yielded a cost-benefit ratio of 1:2.16. When the insecticides were added to this strategy the cost-benefit ratio was 1:1.96. The authors conclude "it may be inferred that the pests of lucerne can be managed economically by adopting improved cultural practices, resulting in higher yields without the danger of insecticidal residues."

132. Ram, Shri and M.P. Gupta. "Integrated Pest Management in Fodder Cowpea (Vigna unguiculata L. Walp) in India and its Economics," *Tropical Pest Management*, Vol. 35 (4), Oct/Dec 1989, pp. 348-351.

T: An examination of IPM strategies for controlling leafhoppers, and the major cowpea defoliators (flea-beetles, semiloopers, tobacco caterpillars and grasshoppers) in the production of cowpea.

D: Seventeen different pest management strategies were each replicated three times, in 1980 and 1981. Each trial was conducted on a 4m x 3m plot. The pest management variables were: number of weedings (one vs. two); fertilizer (optimum combination vs. no fertilizer); variety (Bharari local vs IGFRI-450 (the least susceptible)); insecticide endosulfan (one application at 45 days vs. no application); Bacillus thuringiensis Berliner (one application at 45 days vs. no application).

M: The plots were scouted at 30, 45 and 60 days after sowing. The mean number of leafhoppers per 10 leaves was calculated, as well as the percent damaged leaf area.

R: "[A] combination of improved cultural practices: the least susceptible variety, and optimum fertilizer level and two weedings, was found to be highly effective against the incidence of leafhoppers and defoliators, resulting in higher green fodder and dry-matter yields of cowpea." The yields were further improved with the application of both insecticides, however, net returns were not significantly higher with the use of the insecticides. The authors conclude that the improved cultural practices are capable of economically managing the insect pests which attack cowpea without the unnecessary risk of introducing insecticides into the environment.

133. Rawat, J.K., K.L. Belli, S.M. Smith and J.C. Nautiyal. "A Pest and Timber Management Model: Jack Pine Budworm and Jack Pine," *Canadian Journal of Agricultural Economics,* Vol. 35, 1987, pp. 441-461.

The abstract accompanying this document reads: "A simple illustrative mathematical model for integrating forest pest control decisions with timber management is developed for a hypothetical jack pine forest infested with jack pine budworm. Subject to several assumptions made in the model, optimal quantities and timings of pesticide application and optimal rotation ages of the forest are determined under various sets of parameters such as cost of pesticide, stumpage price, pest population growth rate, and age of the forest at the time of pest infestation. The sensitivities of the optimal values to these parameters are examined. In general, the rotation age and hence harvesting schedule is affected under different pest situations, site conditions, and economic parameters. In addition, immediate pest control action following noticeable pest infestation in young crops may not always be the most profitable decision, particularly when only one pesticide application is permitted and when net return expected from a crop is low. These findings have implications for effective pest and timber management."

134. Regev, Uri, Haim Shalit, and A. P. Gutierrez. "On the Optimal Allocation of Pesticides with Increasing Resistance: The Case of Alfalfa Weevil," *Journal of Environmental Economics and Management*, Vol. 10, No. 1, March 1983, pp. 86-100.

A dynamic model is developed to determine the optimal allocation of pesticides when the possibility of resistance is considered. "The need is emphasized for regional organization or governmental intervention to reduce a portion of the negative externalities created by individual-grower pesticide use and technologies. Special attention is paid to the case of regional centralization with complete ignorance of resistance development....The conclusions drawn from the model...are twofold: (1) based on the assumption that alternative pest-control techniques exist, an optimal path of current pesticide practices may be found until the economy switches to one of the alternative technologies; and (2) if the central authority conducts its optimal policy only with respect to pest population while ignoring the effects of pesticide resistance, it is then preferable not to intervene by increasing pesticide use."

135. Reichelderfer, K.H. "Economic Feasibility of Biological Control of Crop Pests," BARC Symposium Volume 5: Biological Control in Crop Production, 1981, pp. 403-417.

Biologists were the most prolific scientists in examining the economic aspects of biological control, to date. While many of the studies generated impressive results, most were not rigorous from an economist's perspective. The author reviews several of these studies, presenting some major findings and indicating areas where more rigorous and comprehensive economic analysis is needed. The effect each of the following factors has on the economic feasibility of biological control programs is summarized: 1) yield versus quality effects; 2) severity of damage; 3) pest spectrum; 4) frequency of pest problem; 5) technical effectiveness of the biocontrol agent; 6) crop price; 7) risk; 8) price of the biocontrol agent; 9) cost of implementation; 10) total private costs of biological control; 11) benefits and costs of alternative control methods; and 12) community or regional organization. Some of the relationships among the factors are also discussed.

136. Reichelderfer, Katherine H. "Economic Feasibility of a Biological Control Technology -- Using a Parasitic Wasp, Pediobius Foveolatus, to Manage Mexican Bean Beetle on Soybeans," *Agricultural Economic Report No. 430,* United States Department of Agriculture, Economic Research Service, Washington, D.C., August 1979.

The summary attached to the article reads as follows: "Mexican bean beetle control options include conventional chemical control and biological control by a parasitic wasp. Both options can yield similar returns to pest control expenditures on soybeans. Biological control, through an organized regional program, could reduce the impact of pesticides on the environment without hurting farm revenues.

"Estimated profitability of biological control is highest in the Delmarva Peninsula (Delaware-Maryland-Virginia). The use of Pediobius foveolatus, a parasitic wasp, in conjunction with insect scouting to manage Mexican bean beetle on Delmarva soybeans, would lower insect control costs by an average, per treated acre, of $1.47. This would increase net revenue per soybean acre by $0.71 over that expected for conventional control. These estimates assume that biological control is equally as effective as use of insecticides.

"The Delmarva soybean grower could sustain a 0.21-bushel loss of soybeans per treated acre, given 1976 average soybean yield and price, without losing net revenue. The use of Pediobius plus scouting would compete with insecticide use to control Delmarva's Mexican bean beetle up to this loss point, assuming a yield change which is less than or equal to this 0.21-bushel break-even point.

"Results vary among other regions. The break-even yield required to equalize soybean growers' average net revenue per expected acre treated biologically ranges from -0.21 (Delmarva) to +0.21 (North Carolina) bushels per acre change from the average yield obtained under conventional control. Biological control of the beetle on soybeans, supplemented by insect scouting, would be economical within this range.

"Substitution of biological for conventional control of the Mexican bean beetle on soybeans would have little or no measurable effect on average U.S. soybean prices or the regional distribution of U.S. soybean production. Widespread adoption of this control technology would significantly reduce insecticide use on soybeans, but the value of the benefit of that reduction is unknown."

One table presents 1978 soybean acreage and production levels in the U.S., disaggregated by region and state. Another table shows "Insecticides on soybeans: Amount used and proportion of acres treated, by various chemicals and target pests, 1976." Other tables present soybean production budgets for Delmarva for conventional control, biological control, and biological control with scouting, and "Total soybean production costs and net revenue per treated acre, by MBB control method and region." Selected data are presented below.

	Conven.	Bio.	Bio + Scout
	\$/Acre		
Delmarva			
Total Prod. Cost	103.85	100.88	102.38
Av. Net Revenue	48.66	51.63	50.13
New Jersey			
Total Prod. Cost	114.99	112.02	113.52
Av. Net Revenue	60.17	63.14	61.64
IL-IN-KY			
Total Prod. Cost	160.64	158.17	159.67
Av. Net Revenue	41.08	43.55	42.05
South Carolina			
Total Prod. Cost	119.05	117.45	118.95
Av. Net Revenue	6.72	8.32	6.82
North Carolina			
Total Prod. Cost	127.84	127.79	129.29
Av. Net Revenue	10.82	10.87	9.37

"The substitution of biological control for the most typical conventional control treatment on all soybean acres treated would reduce insecticide use on soybeans by approximately 177,800 pounds (a.i.) of disulfoton and 336,400 pounds (a.i.) of carbaryl per year. Environmental effects of the insecticides' use would decline and the producers of the chemicals could experience an initial loss of revenue." Among the benefits of reduced insecticide use are: increased survival of the pests' natural predators and parasites; increased survival of other nontarget species, e.g. honey bees; decreased secondary pest outbreaks; general improvement in environmental quality; decrease in the rate of the pests' development of resistance to the chemicals.

137. Reichelderfer, Katherine, and Filmore Bender. *A Simulative Approach to Controlling Mexican Bean Beetle on Soybeans in Maryland.* University of College Park, Maryland, October 1978. (Also published in *American Journal of Agricultural Economics*, Vol. 61, No. 2, May 1979, pp. 258-267.)

The authors point out possible sources of bias in previous methods for evaluating the economic effect of pest control strategies. Such bias may arise from the use of a single, generalized pest population growth curve or damage function, or by assuming a homogeneous pest population. "In addition, cost functions may be difficult to estimate. This is especially true when external costs result from the pest control action."

"A microanalytic simulation approach was used in this study to evaluate the private and social cost effectiveness of various alternative methods of controlling the Mexican bean beetle on soybeans in Maryland. A computer simulation model was developed to generate average soybean yield response values from different pest control actions under identical crop-pest conditions. The major objective of its development was the simulation of soybean production as it is affected by Mexican bean beetle populations and their control. Both private and social considerations may easily be applied to the data generated by such a simulation model...The simulation model utilized in this study is composed of the following major groups of elements: simulation of soybean growth; simulation of the growth and development of a Mexican bean beetle (MBB) population; simulation of the consumption of soybean leaves by MBB; simulation of soybean defoliation; simulation of soybean yield loss." The report goes on to describe each of these components briefly.

The authors also conducted a Benefit/Cost analysis. Private costs of MBB control were assessed for prescribed spraying and biological control. The social costs were more difficult to quantify. The authors were unable to quantify the external cost of disulfoton use, or the effect of carbaryl on Maryland shellfish and fish populations and the environment at large. The average per acre value of bee losses from carbaryl use was estimated to be $0.006/acre. However, this did not account for the value of the benefit from the bees pollinating other Maryland cash crops. Therefore, the authors consider this the lower bound of the true cost. Biological control methods were assumed to impose no environmental costs. The "Benefit-cost ratios for alternative Mexican bean beetle control strategies" are presented in a table. Selected data from this table appear below. (CCC is conventional chemical control under the assumption of optimal timing of carbaryl application(s) and based on 1974 data; IPM (GS) is grower scouted IPM; IPM (HS) is IPM with hired scouts; BIO is biological control; BIO+ is biological control with disulfoton.)

	Control Strategy				
MBB Infestation level & Benefit/Cost Ratio	CCC	IPM	IPM (GS)	BIO (HS)	BIO+
Low					
Private B/C	0.15	0.44	0.68	3.85	0.23
Social B/C	0.15	0.27	0.34	0.58	<0.17
Medium					
Private B/C	1.40	2.71	4.20	23.84	1.97
Social B/C	<1.40	1.65	2.11	3.61	<1.48
High					
Private B/C	4.99	3.40	3.82	69.59	6.75
Social B/C	<4.98	<2.86	<3.12	10.54	<5.07

The free-rider problem with respect to biological control is also discussed. This phenomenon is likely to deter the private financing of a biological control program. The limitations of the study are presented at the end. Among those noted are: the risk associated with dedicating resources to control was not incorporated; constant weather factors were assumed; there was no accounting for the possible long-term consequences of the various control methods.

138. Reichelderfer, Katherine H., G. A. Carlson, and G. A. Norton. Economic Guidelines for Crop Pest Control, FAO Plant Production and Protection Paper Number 58, Food and Agriculture Organization of the United Nations, Rome, 1984.

The report begins with a presentation of the techniques used to collect and interpret data regarding the basic socio-economic characteristics of the pest control "market." Group, exploratory, and formal surveys are discussed, along with questionnaire design. A review of economic principles and concepts relevant to pest management decisions follows. Net returns, opportunity cost, budgeting, and fixed and variable costs are all defined. A section on the calculation of farm revenues and costs is also included. Marginal analysis and the economic threshold are introduced as means for choosing the best level of pest control to employ. A simple example of the use of probabilities to make decisions in the face of uncertainty is provided. Forecasting and scouting are presented as tools for avoiding disastrous levels of pest infestation. Break-even and cost effective analyses are discussed as methods for conducting economic assessments when data is a limiting factor. The construction of production possibility curves is illustrated. When assessing risk-related aspects of the use of resistant varieties the opportunity cost of loss of yield and/or quality, changes in variable production costs, and changes in the value of consumption characteristics (i.e. color, palatability, nutrient value, etc.) must all be considered. Partial budgeting is shown to be useful when comparing on-farm, short-run net returns to production of alternative varieties. The terms "externality" and "scale economy" are defined in the discussion of coordinating regional pest control. The mobility of most biocontrol agents makes their use more effective when implemented throughout a region. For biocontrol to be effective, the farm environment must be "enhanced" for the biocontrol agent. This can involve changing row spacing, planting dates, or other cultural practices. Each "enhancement" involves a cost the sum of which must be compared to the benefits of employing the biocontrol agent to determine the net benefits of such a strategy. Potential market effects of large-scale pest control are also discussed. Issues involved in using benefit-cost analysis (e.g. discounting, and distributional effects) are considered. The report concludes with a discussion of factors affecting IPM adoption and implementation, and a "key to assessing the need for supplementary economic input to integrated pest control and related programs."

139. Rogers, C.E. "Economic Injury Level for Contarinia Texana on Guar," *Journal of Economic Entomology*, Vol. 69, No. 5, October 1976, pp. 693-696.

Guar losses in Texas and Oklahoma have been extensive due to cecidomyiid midges. Pesticide use to control these pests is generally unprofitable. The author used analysis of variance to examine the data from experimental plots and generated a regression of yield loss on bud destruction. Stone and Pedigo's (1972) economic injury level (EIL) procedure was modified for the study. The EIL of *Contarinia texana* on guar was based on bud infestation rather than larval population. EIL was calculated from the Gain Threshold (management costs [$(acre)]/market value [$(lb)]), percentage yield loss and percentage bud destruction required to reach the gain threshold, and absolute bud destruction required to reach the gain threshold. "[T]he only time that destruction of buds significantly affected yield was when 30% or more of the buds were excised between 45 and 90 days post emergence...Table 1 shows the effects of projected yield and management costs on the theoretical EIL for C. texana in guar...Percentage yield loss required, percentage bud destruction required, absolute bud destruction required, and EIL are proportional to management costs but are inversely related to projected yield."

140. Rossi, Daniel, Pritam S. Dhillon, and Laura Hoffman. "Apple Pest Management: A Cost Analysis of Alternative Practices," *Journal of the Northeastern Agricultural Economic Council,* Vol. XII, No. 2, Fall, 1983, pp. 77-81.

T: An examination and comparison of the costs of conventional pest management and IPM for apple production in southern New Jersey

D: A survey of 20 New Jersey apple producers -- 12 IPM users vs. 8 non-IPM users -- growing late variety apples.

R: The total cost for IPM users was $1,840.28; and $1,856.69 for non-IPM users (less than 1% difference). The mean expenditures for IPM users who employed the alternate middle spraying technique was 175.41. The mean for IPM users who did not use alternate middle spraying was 200.17. The mean for non-IPM users was 218.07.

141. Rovinsky, Robert B., and Katherine H. Reichelderfer. *Interregional Impacts of a Pesticide Ban Under Alternate Farm Programs: A Linear Programming Analysis.* U.S. Department of Agriculture, Data Services Center, Economics, Statistics, and Cooperative Service, Washington, D.C., April 1979.

Pesticide use is a function of, among other things, crop location. The authors "summarize the results of a study that estimated economic impacts of a ban on the use of an insecticide [toxaphene] on cotton under two recent policies affecting U.S. cotton acreage. PESTDOWN, a linear programming model of U.S. agriculture, was employed to determine the cost minimizing geographical distribution of agricultural production activities under different agricultural policy-pesticide use scenarios." 135 producing and 21 consuming regions were defined. "Prices, cost, and yields used are those reflecting 1973 levels. FEDS (Firm Enterprise Data Systems) budgets were used wherever available to describe the costs of production for each commodity by produce region." Two acreage scenarios and two pesticide policies were run through the program (lower limit of 80% of 1973 cotton acreage allotment for each region vs. no lower limit, and 1973 pesticide use vs. a ban on toxaphene, respectively). Table 1 presents Cost and Yield Effects of a Ban on Toxaphene. One table shows variable costs of cotton production given differing policy scenarios. Selected data from this table follows.

	Acreage Restriction-Pesticide Use Policy			
Acreage restriction?:	NO	NO	YES	YES
Toxaphene loan?:	NO	YES	NO	YES
Average (variable) cost per pound of cotton lint produced (1973; cents/lb)	13.9	15.0	17.4	18.4

Other tables show changes in cotton acreage and cotton production. Without an acreage restriction cotton acreage would increase 4.1% while a 6.9% increase would occur in the presence of an acreage restriction policy. Production would not change under either scenario. The authors explain why these trends are seen and articulate the limitations and assumptions inherent to the model. Among the conclusions reached is: " Where acreage restrictions were assumed, a greater level of cotton production was maintained in the Southern U.S. after a ban, but at a $207 million higher aggregate variable cost."

142. Salkin, Michael S., Vernon R. Eidman, and William B. Massey, Jr. An Economic Analysis of Some Alternative Pest Control Strategies for Grain Sorghum in the Oklahoma Panhandle. Agricultural Experiment Station, Bulletin B-772, Oklahoma State University, January 1976, 58 p.

T: The study's objectives are: "1. To delineate feasible methods of greenbug control on grain sorghum in the Oklahoma Panhandle; 2. estimate the effect of using each method of control on producers net returns, and; 3. list the general effect of each method of control on the major exogenous factors of interest."

D: Appendices provide detailed production budgets for each of the production scenarios as well as the net returns data in the following table.

R: Net Returns ($) Per Acre

	Clay Land	Sandy Soil	11" Irrigated	24" Irrigated
Conventional Control	29.52	66.86	135.56	217.63
High Clearance Sprayer	30.46	67.80	136.49	218.56
No Control	20.07	44.92	88.79	145.47
Scouting & Full Chemical Dose	27.71	65.05	133.75	215.82
Low Chemical Dose	28.42	65.76	134.46	216.52
Insect Resistant Varieties	33.03	70.37	138.86	------

143. Scott, Douglas R., III, M. J. Cochran, and W. F. Nicholson, Jr. "Economic Analysis of Cotton Integrated Pest Management Strategies: A Comment," *Southern Journal of Agricultural Economics*, Vol. 18, No. 1, July 1986, pp. 169-71.

The article is a comment on the article by Liapis and Moffit which appeared in the July 1983 issue of the *Southern Journal of Agricultural Economics* (see above). "[T]his discussion presents the following criticisms: (1) the theoretical limitations of single-valued utility functions, (2) the problems in the estimation of the probability distributions, and (3) the faulty predictions based on the analysis."

144. Shoemaker, Christine A. "Integrating Population Dynamics with Economic Assessment in Alfalfa Pest Management," printed in Integrated Pest Management on Major Agricultural Systems, edited by Raymond E. Frisbie and Perry L. Adkisson, Texas A & M University, Texas Agricultural Experiment Station MP-1616. From a symposium sponsored by the Consortium for Integrated Pest Management and USDA/CSRS held October 8-10, 1985.

The abstract for this paper reads, "This paper discusses the importance of dynamic changes in pest dynamics and crop biomass and nutritive quality in developing cost effective pest management programs. Shortcomings of the traditional (one-dimensional) economic threshold are discussed and an example of a multidimensional economic threshold policy for potato leafhopper is presented. Several economic studies of alfalfa weevil conclude that early harvesting is an excellent management strategy and that there is seldom need in the north for insecticide use as long as the first crop is harvested at the recommended time."

145. Smith, Ray F. "Economic Aspects of Pest Control," Tall Timbers Conference on Ecological Animal Control Habitat Management Proceedings, 1971, 3, pp. 53-81.

The article discusses the complexity of pest control and the role economics can play in developing efficient pest control strategies. Topics addressed concern the microeconomics of pest control, economic injury levels, crop protection and agro-ecosystem change, microeconomics of commercial pesticide production, external costs and benefits of pest control, crop protection at the community and regional level, crop protection failure, and social costs and benefits in crop protection and the protection of the environment.

146. Stark, Alan J., Gerrit Cuperus, Clem Ward, Ray Huhnke, Loren Rommann, Phil Mulder, Jimmy Stritzke, Gordon Johnson, Jim T. Criswell, and Richard Berberet. Integrated Management Practices: A Case Study of Oklahoma Alfalfa Management, Cooperative Extension Service, Oklahoma State University, Extension Service -- United States Department of Agriculture, October 1990.

"This report discusses the formation, evolution, and current status of the Alfalfa Integrated Management (AIM) Program, producer attitudes and practices, and successes in intensive educational areas."

147. Starler, N.H. and R.L. Ridgway. "Economic and Social Considerations for the Utilization of Augmentation of Natural Enemies," Chapter 15 in Biological Control by Augmentation of Natural Enemies, Plenum Press: New York, 1977, pp. 431-450.

The paper addresses social and economic issues related to the augmentation of natural enemies for insect pest control. The issues considered include: 1) benefits and costs of biological methods; 2) the extent of production and cost of rearing natural enemies; 3) the extent of use and cost of augmentations; and 4) institutional options for encouraging the use of augmentations. Because of the preventative rather than corrective nature of this method, benefits of biological control are difficult to assess. In addition, a neighbor's use of chemical pesticides can be detrimental to one's efforts to implement a biological control program. Consumer attitudes toward the cosmetics of marketed produce can influence the adoption of biological control agents. For a private company "the profitability of such products as viruses, bacteria, and pheromones was limited because of (1) small market size, (2) small profit margin which is related in part to patentability, (3) temporal efficacy (how quickly the product acts) and (4) cost effectiveness." Issues related to biological control via private insectary's providing management services, pest management consultants, grower cooperatives, pest control districts, and state and federal programs are also discussed.

148. Sterling, Winfield L., Allen Dean, and Nabil M. Abd El-Salam. "Economic Benefits of Spider (Araneae) and Insect (Hemiptera: Miridae) Predators of Cotton Fleahoppers," *Journal of Economic Entomology*, Vol. 85, No. 1, February 1992, pp. 52-57.

T: The costs of cotton fleahoppers and the economic value of their predators in Texas cotton fields.

D: Weather, herbivore, predator, and cotton fruit data were collected from a Texas Department of Correction farm at Huntsville, Texas for 1978-1981, and from Snook, Texas, for 1989. The fields which provided the data were not treated with insecticides. The data was used to initialize the TEXCIM40 model.

M: The TEXCIM40 model is composed of three components: 1) a cotton plant component; 2) models of the cotton fleahopper, cotton bollworm, tobacco budworm, and boll weevil; and an economics component. Herbivore numbers are simulated on a daily time step. "The cost of crop loss attributable to cotton fleahoppers with all predators present was subtracted from the cost attributable to cotton fleahoppers when all predators were absent to obtain the net value of the total predator complex."

R: The costs of cotton fleahoppers and the value of their predators fluctuated from year to year. In some years farmers may choose to apply insecticides to control the cotton fleahopper and consequently destroy their predators, even with the risk of secondary pest infestations from the loss of predators. In other years it may be more profitable to allow the predators to control the fleahopper and the cotton pests that arrive later in the season. The estimated fleahopper costs and the value of the predator complex are presented below. (Web-spinning spiders were estimated to be the most valuable of the predators examined in all but one model year.)

Year	Fleahopper costs ($/acre)	Predator Value ($/acre)
1978	57.73	4.68
1979	12.73	2.61
1980	6.93	0.86
1981	48.83	15.50
1989	36.60	3.53

149. Stern, Vernon M. "The Bioeconomics of Pest Control," *Iowa State Journal of Research*, Vol. 49, No. 4, pt. 2, 1975, pp. 467-472.

The abstract accompanying the article reads as follows. "The narrowing of the genetic base in many crops and the indiscriminate use of pesticides have created problems in agriculture. The establishment of an economic threshold for pest species is a prerequisite to the development of sophisticated pest-management programs. This helps remove the uncertainty between a given pest density and its effect on crop yield. Insecticides have not solved pest problems; today more chemicals are being used and insect problems are greater than ever before. An increase in commodity price does not necessarily mean a greater need for crop protection."

150. Stern, Vernon M. "Economic Thresholds," Annual Review of Entomology, Vol. 18, pp. 259-280.

The article is a general discussion of the issues related to the development of economic thresholds. The author urges the development of economic thresholds for one or two of the key pests attacking a particular crop before secondary pests are considered. The point that economic thresholds fluctuate with climatic conditions, time of year, stage of plant development, crop variety, cultural practices, economic and other variables is raised. Controlled, specially designed empirical studies must be carried out, reviewed and readjusted. Sample and survey techniques are also reviewed, including yield samples, traps and sex attractants, remote sensing and aircraft reconnaissance.

151. Stern, V. M. *Significance of the Economic Threshold in Integrated Pest Control.* Presented at the FAO Symposium on Integrated Control, 1966.

To develop effective IPM programs, it is imperative to assess the economic thresholds (ET's) for relevant pests. The General Equilibrium Position (GEP) is defined to be "the average density of a population over a period of time (usually lengthy) in the absence of permanent environmental change." The ET is defined as "the density at which control measures should be determined to prevent an increasing pest population from reaching the economic-injury level." The Economic-injury Level (EIL) is defined as "the lowest population density that will cause economic damage." The inter-relation of these terms is discussed, e.g. the larger the difference between the ET and GEP, the greater the potential for biological control practices. That the magnitude of GEP, ET and EIL change depending on crop, season, area and the desire of man is also discussed. Three methods of establishing ET's are introduced: direct counts, observation when quantitative samples are not reliable, and marketing standards. The success of integrated control of the spotted alfalfa aphid, Therioaphis maculata (Buckton), is highlighted. Alfalfa pests, their natural enemies and the chemicals used to control the pests are also discussed. The issues regarding marketing standards represent "some of the most difficult problems of applying integrated pest control to many of our fruit and vegetable commodities...[The] rigid regulations and their strict enforcement by State and County officials essentially establishes an economic threshold of zero on many fruit and vegetable products as far as arthropod injury is concerned."

152. Szmedra, Philip I., Michael E. Wetzstein, and Ronald W. McClendon. "Partial Adoption of Divisible Technologies in Agriculture," *The Journal of Agricultural Economics Research*, Vol. 42, No. 3, 1990, pp. 20-26.

The abstract accompanying the article reads: "We have developed a dynamic theoretical model to investigate technology complements where the degree of adoption is a function of producers' prior technology levels. Based on this model, we used an empirical application to assess the adoption of integrated pest management (IPM) with and without irrigation. Results indicate that the degree of new technology adoption may depend on the extent of the risk. For example, strongly risk averse producers who use dryland technology may only partially adopt IPM. And producers who irrigate to significantly decrease variation in yield and returns may also only partially adopt IPM."

153. Talpaz, H., G.L. Curry, P.J. Sharpe, D.W. DeMichele, and R.E. Frisbie. "Optimal Pesticide Application for Controlling the Boll Weevil on Cotton," *American Journal of Agricultural Economics,* Vol. 60, No. 3, August 1978, pp. 469-475.

The abstract for the article reads as follows: "A simulation model of interaction between the boll weevil insect subsystem and the cotton plant subsystem is presented. Field experiments provide the basis for validation of the model. Pesticide control scheme is introduced, and optimal control is achieved by using a numerical nonlinear dynamic optimization technique. Results of sensitivity analysis with respect to price changes are provided. Optimal policy for a single producer calls for three applications. Timing is robust, but dosage levels are sensitive to price changes."

154. Talpaz, Hovav, and Ray E. Frisbie. "An Advanced Method for Economic Threshold Determination: A Positive Approach," Southern Journal of Agricultural Economics, Vol. 7, No. 2, December 1975, pp. 19-25.

T: A positive analysis procedure generating a measure for precise timing of pesticide treatment(s) against the cotton fleahopper.

D: The Texas Agricultural Extension Service compiled yield, insect population, damage, and insecticide treatment data for cotton fields in the Texas Blacklands. 1973 records of 141 cotton fields were used in the study.

M: Profit was expressed as a function of lint yield (lbs./acre), farm level price of lint, price of cotton seed, number of pesticide treatments, cost per treatment, and age of the plant. Maximization of net income was the assumed objective function.

E: Ordinary least squares.

R: The study illustrates the economic threshold is a dynamic measure. For 40-49 day old cotton, the economic threshold was calculated to be 68.1% damage (significant at 90% confidence level).

155. Taylor, Robert C. "The Nature of Benefits and Costs of Use of Pest Control Methods," *American Journal of Agricultural Economics,* Vol. 62, No. 5, December 1980, pp. 1007-1011.

The article is a mathematical exposition of a possible paradox resulting from industry-wide adoption of IPM: per acre pesticide use may decrease with IPM, but, due to increased acreage under production, total pesticide use may increase. As a result, net social welfare may decrease as more producers adopt IPM. This is demonstrated by taking the derivative of the social welfare function and the industry level profit function with respect to a proxy variable denoting pest control technologies and information systems. From these derivations one can examine the change in consumer surplus, surplus for input suppliers, and net social welfare associated with adoption of IPM systems. An equation representing the change in total pesticide use is also developed. The author urges analysts to employ general equilibrium points when integrating these equations for use in empirical studies. "Empirical estimates based on partial equilibrium curves....will give biased results."

156. Taylor, C. Robert, and Ronald D. Lacewell. "Boll Weevil Control Strategies: Regional Benefits and Costs," *Southern Journal of Agricultural Economics*, Vol. 9, No. 1, July 1977, pp. 129-135.

T: Estimates of economic impacts to farmers, regions and consumers of three proposed boll weevil control strategies: (1) an eradication program; (2) an IPM program based on practices currently available; and (3) an IPM program based on practices available on 5-10 years.

D: The change in per-acre costs and yield associated with adoption of the two IPM strategies was obtained from the Environmental Protection Agency's June 1976 Draft Report, "Alternatives for Reducing Insecticides on Cotton and Corn: Economic and Environmental Impact," by D. Pimentel, C.A. Shoemaker, et al. This data was supplemented by asking the same entomologists surveyed in the Pimentel and Shoemaker report to estimate per-acre cost and yield changes resulting from boll weevil eradication.

M: 147 producing regions and 21 consuming regions in the U.S. were included in an interregional activity analysis model of the production of 8 crops (cotton, corn, sorghum, soybeans, wheat, barley, rye, and oats). The objective function of the model was to maximize consumer surplus plus producer surplus minus transportation costs, subject to resource constraints. Demand functions for food grains, feed grains, and oilmeals for each of the U.S. consuming regions, and a cotton lint demand function representing both net export <u>and</u> domestic demand were incorporated into the model in a step-wise fashion. The three control strategies were evaluated by changing per-acre cotton production cost and yield and resolving the model.

R: Changes in per-acre costs and yields for the two IPM strategies and eradication are presented for each cotton state. Both IPM strategies reduced costs for each region reported, except for the High Plains of Texas where there was no change in costs from current control practices. Eradication also reduced costs for most regions, but resulted in no change for seven of the regions reported. Major changes in cotton acreage from the benchmark acreage appear in the table below. Also shown below are the changes in estimated annual land rent by state associated with the boll weevil control alternatives (NC, SC, GA, TN, and MO had no change for any of the control methods). And, finally, the present value of social benefits and costs into perpetuity for the control methods is presented.

	IPM currently available	IPM available in 5-10 years	Eradication
Acreage Changes:			
State			
Alabama	---	---	90% increase
Arizona	92% increase	---	---
Arkansas	34% increase	34% increase	---
California	14% decrease	8% increase	46% decrease
Louisiana	---	38% increase	38% increase
Mississippi	---	---	10% decrease
Oklahoma	28% decrease	28% decrease	44% increase
Texas	4% decrease	6% decrease	4% decrease
Annual Land Rent Changes:			
State		($1000)	
Texas	-69,989	-75,896	-93,832
Oklahoma	-10,573	-11,455	+23,006
Arkansas	+ 8,374	+ 5,689	+ 1,482
Alabama	0	0	+ 5,606
New Mexico	- 717	- 818	+ 4,798
Arizona	- 306	- 299	+ 112
California	+33,590	+30,716	-36,681
Mississippi	+ 868	- 753	- 7,677
Louisiana	- 5,197	+14,926	+ 3,684
Total	-43,950	-37,890	-99,502
Present Value of Social Net Benefits (Million Dollars)	+ 1,255	N.A.	+ 923

157. Taylor, C.R., Ronald D. Lacewell, and Hovav Talpaz. "Use of Extraneous Information with an Econometric Model to Evaluate Impacts of Pesticide Withdrawals," *Western Journal of Agricultural Economics,* Vol. 4, No. 1, July 1979, pp. 1-7.

Relevant supply curves are shifted via extraneous information to reflect technology changes. The derivation of supply shifts is illustrated under the following assumptions: farmers decision processes and the variables farmers respond to do not change; some technical parameters and variable levels do change; farmers have full information and act rationally. The logic of the derivation may be applied to simulate the supply shift under different assumptions. A multicrop national econometric model is used to simulate the banning of all cotton insecticides. "Browns derivate-free method was used to solve 16 simultaneous nonlinear equations for the market clearing price vector." Three tables present the results of the simulation. Table 1 shows estimated per-acre cotton yield and production costs both decrease after the removal of insecticides for each region (Delta, Southeast, Southwest, West). Table 2 presents "Expected Effect on Prices, Acreage and Production of Major Crops due to Withdrawal of Pesticides from Cotton." The crops examined are wheat, soybeans, grain sorghum, corn, oats, barley, and cotton lint. Prices went up for each crop except barley which did not change. Acreage went down for each crop except oats and barley which did not change, and cotton lint which increased. Production fell for each crop except for oats which increased, and barley which did not change. Table 3 presents estimates on changes in the average annual economic surplus to consumers and producers from the removal of cotton pesticides. Consumers lose $1,160.7 million, while producers gain $386.1 million.

158. Teague, Paul, and Robert N. Shulstad. "Integrated Pest Management: Is it Profitable for Cotton?" *Arkansas Farm Research,* Vol. 30, November-December 1981, p. 4.

T: Profitability of a community-wide cotton IPM program in Arkansas.

D: Ten cotton producers provided 1980 production data, six of whom participated in the community-wide IPM program in Ashley County, AR, and four located in Chicot County, AR, who did not employ IPM practices.

M: Budgets were constructed for each field using the production data provided by each producer.

R: There was no significant difference between IPM and non-IPM producers with respect to adjusted net returns, at the 10% confidence level. However, due to fewer pesticide applications, IPM participants had significantly lower variable costs than non-IPM producers.

159. Tew, Bernard V., Michael E. Wetzstein, James E. Epperson, and J. Douglas Robertson. "Economics of Selected Integrated Pest Management Production Systems in Georgia," *Research Report 395,* The University of Georgia, College of Agriculture Experiment Station, Athens, GA, June 1982.

Three cropping systems in Tift County, Georgia, were analyzed. Four pest management levels were established and replicated six times for each cropping system. Budgets were calculated using the Oklahoma State University Budget Generator. Gross returns were set equal to gross receipts, and net returns were set equal to gross receipts minus fixed and variable costs (excluding rent, overhead and risk). Data on yields, returns and pesticide costs were presented. Conclusion: IPM leads to generally lower yields, substantial reductions in pesticide costs and increased profits.

160. Thomas, T. W., M. A. Martin, and C. R. Edwards. "The Adoption of Integrated Pest Management by Indiana Farmers," *Journal of Production Agriculture,* Vol. 1, No. 3, 1988, pp. 257-261.

The abstract accompanying this article reads as follows: "Integrated pest management (IPM) is a system of pest control that uses a wide spectrum of cultural, biological, and chemical methods to maximize economic benefits while minimizing negative environmental impacts. This study examines the IPM practices for corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] adopted by Indiana farmers. The data used in this study were compiled from a questionnaire mailed to 7000 Indiana farmers in 1982. The data were analyzed statistically to determine the characteristics and behavior of farmers who hire scouting services (adopters) and those who do not (non-adopters). Adopters were found generally to be middle-aged farmers. Compared to non-adopters, adopters of IPM practices had more years of schooling, operated larger farms, were much more likely to use reduced tillage systems, planted and harvested their crops earlier, and reported higher yields. While the percentage of adopters applying several popular pesticides was generally greater than for non-adopters, the mean pesticide application rates were the same for both groups. Results of this study clearly indicate that farmers in Indiana who hire an IPM service, use a corn/soybean crop rotation, use chisel tillage, and plant and harvest earlier can expect to obtain higher yields. The positive relationship between the use of scouting information and higher yields could be used as a selling point by pest management consultants to encourage a farmer to hire a scouting service. Agricultural Chemical manufacturers also may find it advantageous to promote field scouting services. Since adopters of IPM practices are more likely to use soil conserving tillage practices, the excessive run-off of pesticides associated with soil erosion should be reduced on their farms."

161. Thompson, P., R.B. How, and G.B. White. "An Economic Evaluation of Grower Savings in a Pest Management Program," *HortScience,* Vol. 15(5), October 1980, pp. 639-640.

The article identifies the methods and results of an ongoing economic evaluation of a Pest Management program for pome and stone fruits in New York State.

162. Thompson, Peter, and Gerald B. White. *Linking Economic and Action Thresholds in Pest Management: Implications for Advisory Services*. Department of Agricultural Economics, Cornell University Agricultural Experiment Station, No. 79-38, Ithaca, NY, November 1979.

The paper utilizes the concept of the economic threshold and pilot project data from New York apple growers to examine various pest management practices. The authors begin with a discussion of economic threshold as defined by Headley (1972). They point out the divergence between economists' conception of optimum pest population and that of growers. They also articulate the assumptions inherent in Headley's definition, e.g. decisions are made in the absence of risk and uncertainty, and there is no accounting for intertemporal effects of pest management practices. The authors note that often spraying is used as insurance in the face of uncertainty. They suggest that information can help reduce uncertainty and point to a possible role for the government, i.e. provision of forecasting of potential pest responses to weather conditions. Such a service would likely lead to net social gains. A brief discussion of pest resistance follows, highlighting Carlson's (1977) perspective. The authors then define action threshold, noting that "the complex part of the action threshold is that it is not a consistent measure."

"That IPM projects have not successfully linked action thresholds with economic thresholds can be illustrated by the results of research to evaluate the New York State Tree Fruit Pest Management Program (NYSTFPMP)." The results of the 1978 study from Wayne County New York which compares per acre pesticide costs of 23 nonparticipants to 19 participants is presented in table 1. Selected data from that table appear below.

	Costs Per Acre (US$)	
	Mean	Range
Total Spray Materials		
Participants	67.67	29-96
Nonparticipants	93.39	46-248
Total Spray Materials and Participation Fee		
Participants	79.67	42-108
Nonparticipants	93.39	46-248

The table also breaks down the costs into insecticides, fungicides and miticides. Participants recorded lower costs in each category without yield or quality differences. The experiment illustrates the divergence of economic and action thresholds. The authors then raise possible grower objections to NYSTFPMP adoption: grower perception of large crop loss; bias toward maximum yields or quality.

163. Tillman, R. and K. Baum. "Integrated Pest Management, Economic Damage, Economic-Injury Levels and Economic Thresholds," Virginia Agricultural Economics, No. 304, July, 1979.

The article makes the fundamental distinction between economic injury levels (EIL) and economic thresholds (ET): the former is the lowest pest population level that inflicts economic damage on the producer; the latter is the pest population level at which control measures must be initiated to prevent pest population levels from reaching or exceeding the EIL. The ET is determined by the type of control measure employed. For example, the time lag associated with most biological control agents will cause the ET to be lower than if a fast-acting chemical pesticide were used. The EIL, however, is independent of the control method employed.

164. Toms, A.M. "Crop Protection Economics -- Today and Tomorrow," *World Crops,* Vol. 28, No. 3, May/June 1976, pp. 113-115.

"[I]n any assessment of the economics of crop protection it is preferable to consider that crop losses do not occur, that there is no such phenomenon, and that what is of prime importance is the balance sheet between the increase in monetary yield obtained, including fringe benefits, and the total cost of the application of the crop protection treatment." The author argues that expected yield increases from a control treatment cannot be deduced. The average increase in yield over time is the best estimate but is not necessarily relevant due to inevitable, and likely profound, differences in environmental conditions. Actual yield increases via biological control may be assessed because biological control usually affects only the target pest. Chemical control regimens, on the other hand, usually affect non-target species as well as target species. The author also asserts that state finance and authority are needed for successful completion of biological control programmes. When assessing changes in economic efficiency from herbicide use the author calls for accounting of the release of labor from the farm sector. That the profitability of agricultural chemicals is declining is also noted.

165. Trumble, John T., and Joseph P. Morse. "Economics of Integrating the Predaceous Mite *Phytoseiulus persimilis* (Acari: Phytoseiidae) with Pesticides in Strawberries," *Journal of Economic Entomolgy*, Vol. 86, No. 3, June 1993, pp. 879-885.

T: The economic potential of early, small releases of *Phytoseiulus persimilis* in controlling *Tetranychus urticae* in strawberry production. The compatibility of fentbutatin-oxide , abamectin, and hexythiazox with *P. persimilis* is also examined.

D: Horticultural data were obtained from a 1988-1991 experiment conducted at the University of California's South Coast Field Station in Santa Ana, CA. Economic data were obtained from the Federal-State Market News Reports by the California Strawberry Research Advisory Board.

M: Partial budgeting was used to conduct the economic analysis.

R: Selected results from the study appear in the table below.

Treatment	Harvest Value/ha	Control Costs/ha	Net Benefits of treatment
Control (1988-1989)	$42,377	0	0
(1990-1991)	$18,605	0	0
AB (1988-1989)	$47,797	358	5,062
(1990-1991)	$37,755	348	15,802
HX (1988-1989)	$47,801	NA	32,317
(1990-1991)	NA		
FO (1988-1989)	$47,107	329	4,401
(1990-1991)	$28,080	329	9,146

Treatment	Harvest Value/ha	Control Costs/ha	Net Benefits of treatment
Control + *P. persimilis* (1988-1989)	$45,333	786	2,170
(1990-1991)	$23,953	1,033	4,315
AB + *P. persimilis* (1988-1989)	$50,411	1,144	6,890
(1990-1991)	$39,692	1,352	19,705
HX + *P. persimilis* (1988-1989)	$49,541	NA	32,975
(1990-1991)	NA		
FO + *P. persimilis* (1988-1989)	$45,669	1,115	2,177
(1990-1991)	$32,437	1,362	12,470

166. Van den Bosch, Robert. "The Cost of Pesticides," *Environment*, Vol. 14, No. 7, pp. 18-31.

Excessive use of chemical pesticides has led to cotton yield reductions in Central and South America, Texas, Mexico and California. In addition, human health effects have been severe, including direct poisoning, death, accumulation of chemicals in mother's milk and malaria outbreaks.

Insect control costs for cotton in the San Joaquin Valley are calculated to be between nil and $60.00 per acre. A survey of Kings County, CA, showed pest control was exceeded only by irrigation in pre-harvest cotton production cost. Much of the insecticide applications in the San Joaquin Valley are seen as uneconomical. The author estimates, via data gathered from 5 experiments using 16 chemical control programs, the percentage of maximum production dollars lost to insect damage in the absence of chemical pesticides to be 15%. "[A]n overall figure of 20% of the total crop value of $132 million was selected (arbitrarily) as an estimate of the combined cost of insect control plus loss to insects under the current insecticide use practices." Microbial control, plant and animal resistance to pests, cultural control, and sterile insect control methods are discussed as means to decrease yield losses from insects.

167. Ward, Clement E., Alan K. Dowdy, Richard C. Berberet, and Jimmie F. Stritzke. "Economic Analysis of Alfalfa Integrated Pest Management Practices," *Southern Journal of Agricultural Economics*, Vol. 22, No. 2, December 1990, pp. 109-115.

"The objective of this study was to determine the economic returns within and between years resulting from combinations of alfalfa cultivars, end-of-season harvest methods, as well as insect control and weed control alternatives. Therefore, effects on alfalfa yields, forage quality, prices, and production costs were considered. Experimental agronomic data collected over a five-year period were analyzed by binary variable regression...Alfalfa production data were collected by Oklahoma's South Central Research Station (Dowdy). The experimental design was a split-plot in strip configuration with four replications of three alfalfa cultivars. Two cultivars (WL318 and Arc) had been selected for their tolerance to alfalfa weevils and resistance to some aphid species and alfalfa pathogens, while the third (OK08) had no selection for pest resistance." Four pesticide treatment regimes were examined: 1) insecticide only; 2) herbicide only; 3) insecticide and herbicide; and 4) no pesticide treatment. Among the results are: winter grazing increased adjusted alfalfa returns each year relative to other end-of-season options; herbicide applications increased adjusted returns as the stand aged; insecticide applications led to higher returns as the stand aged; the use of the improved cultivars, WL318 and Arc, resulted in significant increases in returns over OK08.

168. Weersink, Alfons, William Deen, and Susan Weaver. "Defining and Measuring Economic Threshold Levels," *Canadian Journal of Agricultural Economics*, Vol. 39, No. 4, 1991, pp. 619-625.

The authors begin by distinguishing the terms "economic threshold" and "economic injury level." The former is "the density at which control measures should be determined to prevent an increasing pest population from reaching the economic injury level"; the latter is "the lowest population that will cause economic damage." The different ways economists and entomologists define the problem of determining economic injury levels is then addressed. "The entomologist's definition involves asking the question, At what pest density level should a particular control be undertaken?, while the economist's definition assumes the pest population as given and asks the question, What level of control is most profitable for that particular density?" Finally, the data requirements for measuring economic injury levels is discussed. Crop and pesticide prices and the pesticide application cost are needed. In addition, the damage function, i.e. the relationship between pest density and economic damage, and the control function, i.e. the relationship between the rate of pesticide application and the level of pest control obtained, are essential.

169. White, G.B. "Economics of Plant Disease Control," Chapter 44 *IN* Challenging Problems in Plant Health, Edited by Thor Kommendahl and Paul H. Williams. St. Paul, MN: American Phytopathological Society, 1983.

The article addresses the inherent difficulties of applying the economic threshold concept and marginal analysis to plant disease management. The author suggests monitoring for the environmental conditions that are favorable to disease development to assist producers in decisions on the economical use of pesticides. IPM can incorporate disease control into strategies for controlling weed and insect pests at a relatively small incremental cost. The role computers can play in pest management systems, via simulation models and information storage, retrieval, and processing is also discussed.

170. White, G.B., and Peter Thompson. "The Economic Feasibility of Tree Fruit Integrated Pest Management in the Northeast," *Journal of the Northeastern Agricultural Economic Council*, Vol. XI, No. 2, Fall 1982, pp. 39-45. (The full report from which this article was derived is, An Economic Evaluation of the Potential for Tree Fruit Integrated Pest Management in the Northeast, by Peter Thompson and G. B. White, Agricultural Economics Research Report 82-14, Department of Agricultural Economics, Cornell University, Ithaca, NY, 1981.)

T: Evaluation of a pilot tree fruit pest management program in Wayne County, New York. The study had the following objectives: "1. To estimate costs and benefits for growers who participated in the Wayne County IPM program. 2. To assess the potential for grower adoption in the Northeast. 3. To estimate regional savings if programs similar to the Wayne County pilot program were implemented in the Northeast."

D: A technician collected data on the number, timing, and dosages of pesticide applications by 23 Wayne County tree fruit producers who did not participate in an IPM program. IPM participant data were collected by farm advisors on 26 Wayne County tree fruit farms. 33 blocks of fruit were then matched between IPM participants and nonparticipants. Data regarding potential grower adoption were collected thru 1,145 questionnaires mailed to growers in 1980.

M: An F-test was conducted to determine if the variance and mean of spray material costs were equal for participants and nonparticipants. A separate variance estimate t-test was also conducted.

R: The F-test and t-test rejected the hypothesis that the variances and means of spray material costs for participants and nonparticipants are equal, at the 5% level.

	Costs per Acre		
	Mean	Variance	Range
Total Spray Material and Participation Fee			
Participants	79.67	282.87	42-108
Nonparticipants	93.39	1452.47	46-248

The study results also reveal "Factors which will affect the adoption of IPM in other locations include the attitudes of growers, farm size, and the density of fruit production. IPM programs are economically feasible for several other areas of high tree fruit density in the Northeast."

171. Zacharias, Thomas P., and Arthur H. Grube. "Integrated Pest Management Strategies for Approximately Optimal Control of Corn Rootworm and Soybean Cyst Nematode," *American Journal of Agricultural Economics*, Vol. 68, No. 3, August 1986, pp. 704-15.

The abstract for this article reads as follows: " A dynamic programming model is used to determine approximately optimal management strategies for control of corn rootworm and soybean cyst nematode in Illinois. Decision alternatives for rootworm control include nontreatment, application of a soil insecticide, and rotation to soybeans. Alternatives for cyst nematode control are nontreatment, soil nematicide, resistant cultivars, and rotation to corn. State variables in the dynamic programming model are infestation levels of both pests, previous land use decisions, and expected product prices."

172. Zavaleta, Luis R., and Bruce L. Dixon. "Economic Benefits of Kalman Filtering for Insect Pest Management," *Journal of Economic Entomology*, Vol 75, No. 6, 1982, pp. 982-988.

T: The Kalman filter estimation technique is presented and applied to a life cycle model of the bean leaf beetle, *Cerotoma trifurcata*.

D: Ten samples were drawn, on four separate occassions during the 1980 growing season, from four primary sampling units (PSU) in the west-southwest district of Illinois. The sampling data was obtained by a two-stage sampling scheme.

M: The number of bean leaf beetles maturing to the adult stage, the stage responsible for most plant damage, was estimated as a linear function of the daily mean temperature above a certain threshold.

E: Nonlinear least squares using the Marquardt iterative process.

R: "For the particular data set considered, use of a model of bean leaf beetle dynamics results in substantial gains in estimate efficiency and a reduction in the number of fields required to be sampled."

173. Zavaleta, L. and W. Ruesink. "Expected Benefits from Nonchemical Methods for Alfalfa Weevil Control," *American Journal of Agricultural Economics*, Vol. 62, No. 4, November 1980, pp. 801-805.

T: The potential gains from biological control of and introduced host resistance to the alfalfa weevil, *Hypera postica*.

D: Ten year records from weather stations in Ithaca, NY, Bedford, VA, Rochester, MN, and Nashville, IL, (the major eastern U.S. alfalfa growing regions) provided daily maximum and minimum temperature and solar radiation data.

M: Dynamic computer models of the alfalfa crop and the alfalfa weevil were interfaced through a trophic process. "Changes in yield, insecticide use, and their monetary values were computed by comparing ten-year averages for a normative benchmark solution to averages obtained for different elements integrated in pest management methods."

R: Some of the estimates of the value of the parasite, *Bathyplectes curculionis*, and host plant resistance from the simulations are presented below.

Value of *B. curculionis* in reducing losses to alfalfa weevil in the Eastern United States

Annual Average	Ithaca, NY	Bedford, VA	Nashville, IL	Rochester, MN
Increased yield (T/ha)	.10	.23	.13	.10
Reduced insecticide use (# of applications)	.20	.90	.75	.10
Value of increased yield ($/ha)	5.00	11.50	6.50	5.00
Value of saved insecticide ($/ha)	3.00	13.50	11.25	1.50
Total economic value ($/ha)	8.00	25.00	17.75	6.50

Value of host plant resistance in reducing losses to alfalfa weevil in the Eastern United States

Total for Eastern Half of U.S.	Level of Added Mortality			
(5.1 million hectares)	20%	40%	60%	100%
Reduced Damage ($ million)	30.00	61.10	79.10	88.70
Reduced Insecticide (Tons)	2,260	3,743	4,268	4,268

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