Staff Paper

ECONOMICS IN THE DESIGN, ASSESSMENT, ADOPTION, AND POLICY ANALYSIS OF I.P.M.

Scott M. Swinton and Esther Day

Staff Paper #00-02 February 2000

Department of Agricultural Economics
MICHIGAN STATE UNIVERSITY
East Lansing, Michigan 48824

ECONOMICS IN THE DESIGN, ASSESSMENT, ADOPTION, AND POLICY ANALYSIS OF I.P.M.

Scott M. Swinton and Esther Day
swintons@msu.edu and eday2@niu.edu

ABSTRACT:

Economics in the Design, Assessment, Adoption, and Policy Analysis of IPM

During the past twenty years, economics has played a key role in technology assessment and policy analysis related to integrated pest management (IPM) practices. The paper reviews economic analysis of IPM as applied to evaluating expected profitability, *ex ante* and *ex post* adoption, social welfare impacts, returns to research, and policies that affect pest management generally. In specific cases, economic methods have contributed significantly to the development of threshold-based IPM decision support software. Two areas that need greater economic input are assessment of biological pest management practices and the measurement of returns to research in IPM.

29 pages

ECONOMICS IN THE DESIGN, ASSESSMENT, ADOPTION, AND POLICY ANALYSIS OF IPM

by

Scott M. Swinton and Esther Day[1]

Staff Paper 00-02

Department of Agricultural Economics
Michigan State University
East Lansing, MI 48824-1039

February, 2000

---

[1] Prepared for the Integrated Pest Management Task Force of the Council for Agricultural Science and Technology (CAST), January 2000. This staff paper will also be available on the World Wide Web at http://agecon.lib.umn.edu/msu/sp00-02.html.

[2] Scott M. Swinton (swintons@msu.edu) is associate professor at Michigan State University, East Lansing, MI. Esther Day (eday2@niu.edu) is agricultural and resource economist, American Farmland Trust, Center for Agriculture in the Environment, Dekalb, IL.

The authors thank Kenneth Barker, Jorge Fernandez-Cornejo, George W. Norton and Oscar Ortiz for helpful comments on earlier drafts. They also thank the International Potato Center, Lima, Peru, for institutional hospitality while the first author was on sabbatical.

ABSTRACT:

Economics in the Design, Assessment, Adoption, and Policy Analysis of IPM

During the past twenty years, economics has played a key role in technology assessment and policy analysis related to integrated pest management (IPM) practices. The paper reviews economic analysis of IPM as applied to evaluating expected profitability, *ex ante* and *ex post* adoption, social welfare impacts, returns to research, and policies that affect pest management generally. In specific cases, economic methods have contributed significantly to the development of threshold-based IPM decision support software. Two areas that need greater economic input are assessment of biological pest management practices and the measurement of returns to research in IPM.

ECONOMICS IN THE DESIGN, ASSESSMENT, ADOPTION, AND POLICY ANALYSIS OF IPM

Scott M. Swinton and Esther Day[1]

How economics relates to IPM

Why do farmers sometimes fail to adopt IPM practices that have succeeded on experiment stations? Would crop insurance encourage IPM adoption? How much should the government invest in promoting IPM? What is the value of IPM research?

These questions center not on pests and control methods, but rather on farmers and society -- what motivates human behavior and how we measure the social value of IPM products and services. Answers to these questions and others like them are central to the success of motivating individual decisions about IPM as well as evaluating public programs in IPM. The 18 years that have elapsed since the last CAST report on IPM have seen an explosion of economic analysis applied to IPM, reaching far beyond the private profitability analysis covered in that report (CAST, 1982, pp. 36-39).

Perhaps the most common question is whether IPM is worthwhile, from the perspective of the producer, the consumer or society at large. Benefit-cost analysis

---

[1] Scott M. Swinton, Department of Agricultural Economics, Michigan State University, E. Lansing, MI
Esther Day, American Farmland Trust, Center for Agriculture in the Environment, Dekalb, IL

The authors thank Jorge Fernandez-Cornejo, George W. Norton and Oscar Ortiz for helpful comments.

(BCA) is the tool most commonly used to answer this. Although it is simple in theory, BCA can become quite complex when costs or benefits are not easily measured, as is the case in many IPM applications. BCA can be divided into *financial* BCA, which includes only cash costs and benefits, and *economic* BCA, which includes the cost of alternatives not pursued and external effects on other parts of society. Since both individuals and society often care about attributes beyond average profitability to farmers, BCA sometimes calls for estimating the value of the seemingly priceless: clean water, biodiversity, or more stable crop yields, for example. BCA is used not only in project assessment, but also in assessing potential adoptability and in computerized decision support tools based on pest damage thresholds.

Understanding producers' objectives and constraints can help in the design of IPM methods that are more readily adoptable. IPM adoption research has identified traits associated with IPM adopters. Such information can guide extension education, new IPM technology development, and public policy design to encourage IPM.

Finally, aggregate effects of IPM adoption are of interest to both public and private sector decision makers. The value of changes brought about by IPM matters to government officials in determining if a program is worthwhile, whereas the same information may help a private firm decide how much to invest in research and development into IPM-related goods and services. Where social benefits are substantially greater than the private ones that growers realize, it may make sense to create public policies that encourage IPM adoption. Policy research helps to determine both what tools might be effective and how much the government can justify investing in them.

This chapter will review economic analysis as used in

a) designing IPM decision tools,

b) predicting private producer-level profitability of IPM strategies,

c) weighing IPM effects on broader producer objectives such as reducing risks to crop yields, human health, and environmental quality,

d) assessing IPM adoption patterns,

e) evaluating public IPM programs,

f) designing public policy related to IPM.

Benefit-cost analysis and pest damage thresholds

Answering the question, “Is it worth it?” is at the heart of any technology assessment. For IPM , the question is useful at three different levels: 1) design of pest damage thresholds, 2) potential adoptability for individual producers, and 3) public assessment of IPM projects and programs.

The original notion of an “economic threshold” (Stern et al. 1959) was based on the insight that sometimes the value of yield saved is worth less than the cost of spraying a pesticide. At the heart of the original IPM concept, pest damage thresholds exemplify a class of *ex ante* BCA, that is, they predict likely future value rather than measuring actual value after the fact.

The simplest analyses of benefits and costs use partial budgets. These assume typical conditions, no carryover effects, predictable prices and yield effects from pests, and that only profitability matters to the decision maker. Partial budgets evaluate whether benefits (due to increased revenue and reduced costs) outweigh burdens (due to reduced revenue and increased costs). Partial budgets are the central calculus behind the simple economic or action threshold for pesticide spraying (Stern et al. 1959; Pedigo et al. 1986; Cousens 1987). The "net gain function" illustrates the idea of gain in gross margin (added revenues minus costs that vary) in relation to pest density (Auld et al. 1987). When pest density is very low, pest control costs (PCC) outweigh benefits, but as the pest population rises above threshold density Ds* in Figure 1, benefits from yield protection begin to overcome costs of control. This is the kind of threshold that is most often behind the first generation of bioeconomic IPM decision support software described in Text Box 1.

Many IPM practices do have carryover effects over more than one season. Killing a pest today not only protects against damage the pest would have done, it may also prevent the pest from reproducing, protecting against damage the offspring would have done. This observation led to the definition of dynamic thresholds that take into account future effects, typically by predicting pest population dynamics, cropping patterns, and crop values, often using net present value methods to discount the value of future income (Pedigo et al. 1986; Cousens 1987; Auld et al. 1987; Swinton and King 1994; Taylor and Burt 1984). Dynamic thresholds for pesticide-based control tend to increase pesticide use because they factor in future as well as present benefits from pest control. The shift in the net gain function is illustrated in Figure 2. Apart from dynamic thresholds for chemical control of pests, multi-period BCA's are also useful for predicting the value of investment in biocontrol methods, such as release of parasitoids to control an insect pest.

Producer objectives other than profit maximization can sometimes be converted into monetary values to fit into a benefit-cost framework. Such attributes as aesthetic appeal (of a weedless field) or environmental costs (due to harmful pesticides) give rise to aesthetic thresholds and environmental thresholds (Cousens 1987; Higley and Wintersteen 1992). Figure 2 illustrates how including environmental costs (EC) have the effect of shifting down the entire static net gain curve by the amount of EC. This results in a higher pest density threshold (De*) before pest control becomes optimal.

The recognition that environmental thresholds may differ dramatically from ordinary economic thresholds has prompted a surge of attempts to measure producer willingness to pay for reduced pesticide risks (Beach and Carlson 1993; Higley and Wintersteen 1992; Mullen et al. 1997; Swinton et al. 1999b). Apart from producers' expressed willingness to pay for reduced pesticide risk, studies of pesticide-related sickness and death have found that by reducing farmers' pesticide exposure, IPM may reduce the cost of medical treatment and lost work days (Crissman et al. 1998), though IPM will not necessarily accomplish this (Antle and Pingali 1994).

A new frontier for IPM thresholds is the inclusion of spatial variability. Sensing and mapping technologies allow pesticides to be focused on areas where pests are present (Weisz et al. 1995; Johnson et al. 1997). Incorporating spatial information allows IPM thresholds to become more targeted. Given evidence that many pest populations follow highly skewed spatial density distributions (Johnson et al. 1997), significant areas may go unsprayed when pest control is targeted only to those locations where a threshold is exceeded. So far these spatial technologies have not reached the farm level, but preliminary economic analyses for weeds have shown that under certain circumstances, spatial pest management technologies may be profitable (Bennett and Pannell 1998; Oriade et al. 1996).

The threshold-based IPM methods described above chiefly rely upon chemical controls once the threshold is reached. The burgeoning field of biological pest control (Landis and Orr, 1996) has yet to benefit from economic analysis. Yet the U.S. federal government is invested significantly in biocontrols as well as area-wide insect eradication programs that are irrelevant to the threshold-based analyses described above. These will call for new research involving dynamic modeling of the component pest and predator populations, linked to measuring changes in the economic value of yield saved that results from using these methods instead of existing alternatives.

Crops that have been genetically modified for pest resistance or herbicide tolerance represent a new approach to pest control since around 1995. Economic assessments for these crop varieties are only began appearing in 1998-99. Of particular interest has been discovering whether farm profits actually increased after accounting for seed technology fees charged for the patented seeds. National survey results from 1997 found that whether U.S. farmers planted herbicide resistant corn or soybeans did not affect their profit level (Fernandez-Cornejo et al., 1999). A 1998 survey of Iowa farmers found similar results for genetically modified soybeans and for Bt corn (Duffy, 1999). However, U.S. cotton farmers did achieve increased profits from use of both herbicide resistant and Bt cotton varieties (Fernandez-Cornejo et al., 1999).

IPM and agricultural income risk

Pest attacks constitute one of the biggest sources of risks to crop yields. Not only can pests reduce yields, they can also reduce quality, exposing producers to quality-based price risk. Prophyactic use of pesticides can act as a form of insurance against pest attack

(Feinerman et al, 1992; Smith and Goodwin, 1996). That is, risk-averse producers may intentionally choose to use more pesticide than strictly necessary because it reduces the risk of crop damage. While IPM does not necessarily increase yield variability (Lamp et al., 1991; Napit et al., 1988), sometimes it does (Szmedra et al, 1990). More important yet, many growers perceive IPM as augmenting yield risk.

The yield risks from threshold-based IPM strategies come at two levels: prediction of pest infestation and actions to control it. Pest density thresholds are based on damage predictions. These, in turn, depend on accurate and timely pest demographic predictions. Such predictions can be faulty because of poor scouting, weather conditions that unexpectedly favor pest populations, or a poor predictive model. Even if the pest action threshold is predicted properly, poor weather or competing tasks may prevent the grower from timely treatment. Some growers view calendar spraying as less risky on these accounts.

Economic research has shown that insurance can insulate farmers from the income risk they perceive in adopting threshold-based IPM practices (Feinerman et al, 1992). Given the potential public benefits from reduced pesticide use that might result from more extensive adoption of IPM, public cost-share programs have been introduced to reduce the cost of adopting IPM practices, notably under the Environmental Quality Incentives Program (EQIP) of the 1996 Federal Agricultural Improvement and Reform Act. In selected U.S. counties, the EQIP program compensates participating farmers for certain IPM-related costs, such as scouting. However, these cost share programs do not address yield and income risk associated with the performance of threshold-based IPM methods. These risks have been addressed directly in the design of new crop insurance products for IPM users that have been developed under a collaboration between the U.S. Department of Agriculture’s Risk Management Agency and the Agricultural Conservation Innovation Center (see Text Box 2) (ACIC 1999).

Adoption of IPM: Why do growers adopt?

The public benefits from IPM – notably from reduced pesticide risks – have attracted government interest in fostering its adoption among farmers. Whereas the use of benefit-cost analysis for IPM thresholds focuses on the individual producer, IPM adoption research tends to focus on the aggregate producer population. This means not just measuring the effects of a set of IPM practices on a single producer, but also measuring what factors affect producer adoption and how many producers have adopted (or will adopt) those IPM practices.

The first step is to understand what factors encourage adoption. These adoption studies are typically cross-sectional surveys targeted at understanding why some farmers take up a given IPM practice while others do not.

Quite a number of cross-sectional studies of IPM adoption have taken place in the United States (Napit et al., 1988; Harper et al. 1990; McNamara et al. 1991; Caswell and Shoemaker 1993; Vandeman et al. 1994; Fernandez-Cornejo et al. 1994; Ferguson and Yee 1994; Fernandez-Cornejo et al. 1998). The characteristics that influence adoption can roughly be divided into four types, based on the technology, the farmer, the farm physical environment, and the farm institutional environment (Feder et al. 1985). In general, adopters of IPM practices have been found to be younger and more educated than average (Drost, et al., 1996). IPM adopters also tend to have less farming experience and are more prone to computer use (Leslie and Cuperus, 1993; Sorensen and Day, 2000).

Public program assessment

The economic methods discussed so far address the questions: "Would an IPM practice be profitable if adopted?" "Would it be risky?" and "What are characteristics of adopters?" Public program evaluation asks a broader question, "What is the net effect on social welfare of this IPM practice (or program)?" Answering this question calls for aggregating the individual-level profitability analysis according to the total number of IPM adopters and the timing of adoption. Since social welfare is not just about agricultural producers, a public program assessment must also integrate impacts on consumers and the natural environment. The literature on economic evaluations of IPM programs has become large enough to spawn published literature reviews (Norton and Mullen 1994; Fernandez-Cornejo et al. 1998).

The most comprehensive summary of private, producer-level economic evaluations of IPM programs to date was developed by Fernandez-Cornejo et al. (1998), updating the prior work of Norton and Mullen. Reproduced here as Table 1, the 51 studies summarized highlight the fact that while most IPM programs increased profits, increased yields, and reduced pesticide use, these effects did not occur universally. For no commodity group did IPM reduce pesticide use across the board. In fact, IPM in cotton increased pesticide use more often than not.

Measuring cumulative adoption of IPM practices

To predict longterm program impact, it is necessary to project future technology adoption trends. The diffusion of a new technology over time tends to follow a sigmoid curve (Rogers 1983), as in Figure 3. At first, only the daring, experimental few adopt it. But as the new technique becomes recognized as attractive, the rate of adoption accelerates. Then the pace of adoption tapers off as only a few laggards remain among those who might find the technology worthwhile. Most empirical attempts at estimating adoption curves have followed the lead of Griliches (1957), who fitted a logistic function.

Fernandez-Cornejo and Castaldo (1998) statistically estimated logistic adoption curves for a variety of IPM practices in the major fruits produced in the United States. Their work identified the target date for 75% adoption of each technique in each crop. They also studied factors affecting the rate of adoption. The stock of public and private research turned out to be the most important determinants of scouting adoption, and public research was the single significant determinant of reduced pesticide use.

Measuring the value of health and environmental impacts

As mentioned above, benefit-cost analyses for public IPM programs differ from individual-oriented ones not only in aggregating adopters, but also in measuring effects on other individuals. In particular, they factor in the unintended effects that economists call “externalities,” because they are external to the immediate interests of the decision maker. When a cotton farmer burns crop residues to destroy overwintering boll weevil eggs and the smoke triggers an asthmatic attack in a neighbor’s child, the asthmatic attack is an externality not considered by the farmer. Public policy analyses that aim to evaluate net social benefits attempt to estimate the value of changes in the level of such “external” effects (Carlson, 1989).

Attempts to measure the value of IPM methods in reducing health and environmental risk have spawned three major thrusts of research. The first aims to measure the effects of pesticides on human health. The large and growing literature in medical epidemiology of pesticide exposure is beyond the scope of this chapter. In general, the epidemiological studies are large and costly analyses of large samples of people that try to relate pesticide exposure to changes in probability of death or illness by different causes.

The very costliness of these methods has triggered the second research thrust which aims at developing low-cost indicators of both human health and environmental risk. The growing felt need for sound indicators of environmental and health risks spawned at least two major workshops in 1998 alone (Waibel et al. 1999; Day 1998). The big challenge is to strike a reasonable compromise between, on the one hand, the formidable expense of comprehensively measuring environmental impacts and, on the other hand, the inaccuracy of measuring health risk by facile impact indicators (such as weight of pesticide active ingredient per hectare which ignores toxicity and likelihood of exposure). No single indicator is widely used at present; alternative measure in debate include risk-ratios, scoring tables or rankings, and fuzzy expert systems.

The third research thrust related to externalities of pest management aims to develop economic measures of environmental and health impacts of pesticides and the related influence of IPM programs. These measurement attempts can be divided between those that try to place monetary value on human health and environmental impacts

(Harper and Zilberman, 1989; Beach and Carlson 1993; Antle and Pingali 1994; Mullen et al. 1997; Swinton et al. 1999b) and those that simply identify a risk-benefit trade-off (Bouzaher et al., 1992; Crissman et al. 1998). The valuation analyses have substantiated that both the consuming public and pesticide users are willing to pay to reduce pesticide risks, a goal to which IPM can contribute. But the specific numerical values emerging from the valuation studies are controversial, both ethically -- for pretending to place a value on what many consider priceless -- and also methodologically – since most of the studies omit certain types of risk. The trade-off analyses can be useful for decision making purposes, but they do not contribute usefully to measuring aggregate program benefits.

Overall returns to research and outreach in IPM

The difficulties in measuring and valuing IPM impacts may account for the scarcity of studies estimating the economic returns to public research and outreach activities in IPM. Moreover, many forms of IPM involve information use or subtle changes in the rationale for management practices, making their adoption much harder to quantify than is the case with discrete commodity-specific technologies such as crop varietal introductions (Alston et al. 1998, p. 308; Waibel et al. 1998, p. 59).

The only comprehensive IPM program assessments that we have found are Napit et al.’s (1988) evaluation of extension IPM impacts across nine commodity-state combinations in the United States and Waibel’s (1999) recent attempt at evaluating the returns to IPM research at the international agricultural research centers. Napit et al. (1988) found that across a diverse set of commodities and U.S. states, IPM mostly generated higher and less variable net returns to growers as well as economic gains to consumers. Unexpectedly, pesticide costs rose with IPM use in several states. Napit et al. (1988) conducted economic surplus analyses only in the two instances where they found statistically significant differences in net returns between both nonusers and low users of IPM and between low and high users of IPM – both in cotton. As a result, they calculated very high annual internal rates of return to IPM extension programs (452% for Texas cotton and 300% for Mississippi cotton). Although internal rates of return for the other IPM practices were not published, it can be inferred that they would be lower, since they would be calculated from smaller differences in annual net returns between non-, low and high IPM user groups. Unlike Napit et al. (1988), Waibel (1999) found it impossible to conduct a quantitative economic surplus analysis of returns to research in IPM. Instead, he relied on self-assessments by the scientists involved, reviewed publication productivity, and illustrated with economic case studies.

Public policy: Intended and unintended effects on IPM

U.S. government policies have affected IPM adoption and research through various channels, both direct and indirect. Direct efforts to foster IPM adoption include cost-sharing for selected adopters of IPM practices under the EQIP program, and federal subsidies for IPM extension and research under the USDA's regional IPM programs and regional research projects. As noted above, the USDA Risk Management Agency and ACIC are conducting a pilot IPM insurance program for corn rootworm management in the Midwest.

But the policies with *indirect* effects on IPM adoption probably have greater impact. For years, U.S. federal price supports and deficiency payments for wheat and feed grains had the effect of discouraging IPM by raising crop prices, which implicitly reduced the threshold for pest control (Reichelderfer and Hinkle 1989). Similar effects have occurred in other nations due to exchange rate misallignment that distorts the relationship between chemical inputs (often imported) and crop products (often exported).[2]

Environmental policy, notably federal pesticide policy, has had mixed effects on IPM adoption. Pesticide policy has been a bastion of rigid command-and-control rules during a period when much federal environmental policy was evolving toward more flexible approaches (Ogg 1999). Under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) and its successor, the Food Quality Protection Act (FQPA) of 1996, the U.S. Environmental Protection Agency is charged with registering pesticides for specified uses. But in banning some uses, the EPA applies a very blunt tool which removes those pesticides from the arsenal available to IPM practitioners (Zilberman and Millock 1997; Swinton et al. 1999a; Whalon et al. 1999). Although other EPA policies might be expected to encourage IPM adoption, such as those involving water quality, the difficulty of monitoring surface and ground water quality has so far discouraged serious attempts to curtail nonpoint source water pollution – the very kind which IPM has the greatest potential to alleviate.

---

[2] G.W. Norton, personal communication by e-mail, Jan. 12, 2000.

Private sector initiatives

Private sector and non-governmental organizations have recently begun using market methods to promote IPM. In response to surveys revealing consumer willingness to pay for foods with reduced pesticide residues or otherwise produced in an environmentally friendly manner, “eco-labels” have been developed to certify the quality of the production process (van Ravenswaay and Blend 1999). In Europe and the United States, a small number of food retailers have begun to use eco-labels on food products. Among these are IPM certification labels, such as those used on canned vegetables sold by Wegman’s food stores in western New York State. Such labeling practices can have two effects. If processors require IPM of their growers, then IPM is mandated by the market. If IPM is a voluntary activity that fetches a higher price, then its adoption is compensated. Either by stick or by carrot, there exists an inducement for producers to adopt those practices necessary to achieve certification. So far, the first case appears to predominate in the United States, that is, IPM is becoming a prerequisite for growers to obtain access to vegetable and fruit production contracts.

Meanwhile, non-governmental organizations and producer commodity organizations are collaborating on IPM certification programs. Such programs certify that growers are using best pest management practices in raising their crops. A current example is a joint project between the World Wildlife Fund , the Wisconsin Potato and Vegetable Growers Association, and the University of Wisconsin (see Text Box 3). The project encourages IPM adoption in tandem with use of less toxic pesticides. The three collaborating organizations are trying to develop an accompanying IPM certification label (Dlott, 1999).

Conclusion

During the past twenty years, economics has played a key role in IPM technology assessment and policy analysis. Economic analysis has been applied to evaluate expected profitability, *ex ante* and *ex post* adoption, social welfare impacts, returns to research, and policies that affect pest management generally. In specific cases, it has been significant in the development of threshold-based IPM decision support software.

For all that has been accomplished, important unfinished business remains in at least two areas. First, the economic assessment of biological pest management is scarcely developed. This will require 1) dynamic modeling of interactions between pest and predator or parasitoid populations, 2) changes in pest impacts on valued commodities, 3) comparison with non-biological benchmark pest control methods, and 4) assessment of impacts on profitability, human health, and environmental quality. Pest resistance development too will need consideration.

The second area needing more economic input is the measurement of returns to research. The daunting problems with defining and measuring IPM continue to dog attempts at comprehensive assessment of IPM research, and no major IPM extension assessment has been completed in the United States since the mid-1980’s. This failure to fully measure benefits is likely to deprive IPM programs of the public support that the scanty evidence available suggests they deserve.

References

ACIC (Agricultural Conservation Innovation Center), "Promoting Conservation Innovation in Agriculture Through Crop Insurance." URL: http://www.agconserv.com/toppage11.htm (As modified per e-mail from Megan Terebus to S. Swinton, Dec. 7, 1999), Charleston, SC: ACIC.

Alston, Julian M., George W. Norton, and Philip G. Pardey. *Science Under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*. New York: CAB International, 1998.

Antle, John M. and Prabhu L. Pingali. "Pesticides, Productivity, and Farmer Health: A Philippino Case Study." *American Journal of Agricultural Economics*. 76(August 1994): 418-430.

Auld, B. A., K. M. Menz, and C. A. Tisdell. *Weed Control Economics*. London: Academic Press, 1987.

Beach, E. Douglas and Gerald A. Carlson. "Hedonic Analysis of Herbicides: Do User Safety and Water Quality Matter?" *American Journal of Agricultural Economics*. 75(August 1993): 612-623.

Benbrook, Charles M., Edward Groth III, Jean M. Halloran, Michael K. Hansen, and Sandra Marquardt. 1996. *Pest Management at the Crossroads*. Yonkers, NY: Consumers Union.

Bennett, A. and D. J. Pannell. "Economic Evaluation of a Weed-Activated Sprayer for Herbicide Applicatioin to Patchy Weed Populations." *Australian Journal of Agricultural Economics*. 42(1998): 389-408.

Bolkan, H.A. and W.R Reinert. "Developing and Implementing IPM Strategies to Assist Farmers: An Industry Approach." *Plant Disease* 78(1994):545-550.

Bouzaher, Aziz, David Archer, Richard Cabe, Alicia Carriquiry, and Jason F. Shogren. "Effects of Environmental Policy on Trade-offs in Agri-Chemical Management." *Journal of Environmental Management*. 36(September 1992): 69-80.

Carlson, G.A. "Externalities and Research Priorities in Agricultural Pest Control." *American Journal of Agricultural Economics*. 71(May 1989):453-457

Caswell, Margriet F. and Robbin A. Shoemaker. "Adoption of Pest Management Strategies under Varying Environmental Conditions." Technical Bulletin No. 1827, Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture, Washington, DC. 1993.

CAST (Council for Agricultural Science and Technology). *Integrated Pest Management*. Report No. 93. Ames, IA: CAST, 1982.

Cousens, Roger. "Theory and Reality of Weed Control Thresholds*." Plant Protection Quarterly*. 2(1987): 13-20.

Crissman, Charles C., John M. Antle, and Susan M. Capalbo. *Economic, Environmental and Health Tradeoffs in Agriculture: Pesticides and the Sustainability of Andean Potato Production*. Kluwer Academic Publishers: Dordrecht, 1998.

Day, Esther. "Integrated Pest Management Measurement Systems Workshop, Chicago, Illinois, June 12-13, 1998." Working Paper CAE/SP 98-1, American Farmland Trust, Center for Agriculture in the Environment, Dekalb, IL. 1998.

Dlott, Jeff. Executive Director, Dlott & Assoc. Consulting, Watsonville, CA. October 23, 1999, email communication to E. Day.

Drost, Daniel, Gilbert Long., David Wilson, Bruce Miller, William Campbell. “Barriers to Adopting Sustainable Agricultural Practices.” *Journal of Extension*. 34(Dec. 1996). http://www.joe.org/joe/1996december/a1.html

Duffy, Mike. “Does Planting GMO Seed Boost Farmers’ Profits?” *Leopold Letter* 11(3)(1999):1, 4-5.

Feder, Gershon, Richard E. Just, and David Zilberman. "Adoption of Agricultural Innovations in Developing Countries: A Survey*." Economic Development and Cultural Change*. 33(1985): 255-298.

Feinerman, Eli, Joseph A. Herriges, and Derald Holtkamp. "Crop Insurance as a Mechanism for Reducing Pesticide Usage: A Representative Farm Analysis." *Review of Agricultural Economics*. 14(July 1992): 169-186.

Ferguson, Walter L. and Jet Yee. "A Logit Model of Cotton Producer Participation in Professional Scout Programs." *Journal of Sustainable Agriculture* 5(3)(1995) 87-96.

Fernandez-Cornejo, Jorge, E. Douglas Beach, and Wen-Yuan Huang. "The Adoption of Integrated Pest Management Technologies by Vegetable Growers in Florida, Michigan and Texas." *Journal of Agricultural and Applied Economics*. 26(July 1994): 158-172.

Fernandez-Cornejo, Jorge, and Christian Castaldo. “The Diffusion of IPM Techniques among Fruit Growers in the USA.” *Journal of Production Agriculture* 11(Oct-Dec, 1998): 497-506.

Fernandez-Cornejo, Jorge, Sharon Jans, and Mark Smith. "Issues in Economics of Pesticide Use in Agriculture: A Review of Empirical Evidence." *Review of Agricultural Economics*. 20(Fall/Winter 1998): 462-488.

Fernandez-Cornejo, Jorge, Cassandra Klotz-Ingram and Sharon Jans. “Farm-level Effects of Adopting Genetically Engineered Crops in the U.S.A.” Unpublished selected paper presented at the International Conference on ‘Transitions in Agbiotech: Economics of Strategy and Policy’ NE-165, Washington, DC, June 24-25, 1999.

Griliches, Zvi. "Hybrid Corn: An Exploration in the Economics of Technological Change." *Econometrica* 25(1957): 501-522.

Harper, C.R and D. Zilberman. “Pest externalities from Agriculture American Journal of Agricultural Economics 71(August 1989):692-702.

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*. 72(November 1990): 997-1005.

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 Level." *American Entomologist*. 38(1992): 34-39.

Johnson, G. A., J. Cardina, and D. A. Mortensen. "Site-Specific Weed Management: Current and Future Directions." In F. J. Pierce and E. J. Sadler, eds., *The State of Site-Specific Management for Agriculture*. Madison, WI: ASA-CSSA-SSSA, 1997. Pages 131-147.

Kells, James J. and J. Roy Black. "CORNHERB - Herbicide Options Program for Weed Control in Corn: An Integrated Decision Support Computer Program-Version 2.0." Agricultural Experiment Station, Michigan State University, East Lansing, MI. 1991.

Kidder, Daniel, Bruce Posner, and Douglas Miller. "WEEDIR: Weed Control Directory." AG-CS-2163, ver. 3.0, . Minnesota Extension Service, University of Minnesota, St. Paul, MN, 1989.

King, Robert P., Donald W. Lybecker, Anita Regmi, and Scott M. Swinton. "Bioeconomic Models of Crop Production Systems: Design, Development, and Use." *Review of Agricultural Economics* 15(May 1993): 393-405.

Lamp, W. O., G. R. Nielsen, and G. P. Dively. "Insect Pest-induced Losses in Alfalfa: Pattern in Maryland and Implications for Management." *Journal of Economic Entomology*. 84(April 1991): 610-618.

Landis, Douglas A. and David B. Orr (6 Feb. 1996). "Biological Control: Approaches and Application." In E. B. Radcliffe and W. D. Hutchison [eds.], *Radcliffe's IPM World Textbook*, URL: http://ipmworld.umn.edu, University of Minnesota, St. Paul, MN.

Leslie, A.R. and G.W. Cuperus (eds.). 1993. "IPM and Growers: An Evolution in Thinking." Chapter 9 in *Successful Implementation of Integrated Pest Management for Agricultural Crops*. Lewis Publishers, Boca Raton, FL

Lybecker, Donald W., Edward E. Schweizer, and Philip Westra. "WEEDCAM Manual." Department of Agricultural Economics, Colorado State University, Ft. Collins, CO. 1994.

McNamara, Kevin T., Michael E. Wetzstein, and G. Keith Douce. "Factors Affecting Peanut Producer Adoption of Integrated Pest Management." *Review of Agricultural Economics*. 13(January 1991): 129-139.

Mortensen, David A. and Harold D. Coble. "Two Approaches to Weed Control Decision-Aid Software." *Weed Technology*. 5(April-June 1991): 445-452.

Mullen, Jeffrey D., George W. Norton, and Dixie W. Reaves. "Economic Analysis of Environmental Benefits of Integrated Pest Management." *Journal of Agricultural and Applied Economics*. 29(December 1997): 243-253.

Napit, K.B., G.W. Norton, R.F. Kazmierczak Jr., and E.G. Rajotte. "Economic Impacts of Extension Integrated Pest Management Programs in Several States." *Journal of Economic Entomology* 81(Feb. 1988): 251-256.

Norton, G. W. "Benefits of U.S. Agricultural Research." Department of Agricultural Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA. URL: `http://warp.nal.usda.gov:80/pgdic/Probe/v2n2/bene.html` (Undated; accessed 9 Dec. 1999).

Norton, G. W. and J. Mullen. "Economic Evaluation of Integrated Pest Management Programs: A Literature Review." Virginia Cooperative Extension Publication 488-120, Virginia Tech University, Blacksburg, VA. 1994.

Ogg, A. Clayton W. "Evolution of EPA Programs and Policies that Impact Agriculture." In F. Casey, A. Schmitz, S. Swinton, and D. Zilberman, eds., *Flexible Incentives for the Adoption of Environmental Tecnologies in Agriculture*. Boston: Kluwer Academic Publishers, 1999. Pages 27-42.

Oriade, C. A., R. P. King, F. Forcella, and J. L. Gunsolus. "A Bioeconomic Analysis of Site-Specific Management for Weed Control." *Review of Agricultural Economics*. 18(October 1996): 523-535.

Pedigo, Larry P., Scott H. Hutchins, and Leon G. Higley. "Economic Injury Levels in Theory and Practice." *Annual Review of Entomology*. 31(1986): 341-368.

Reichelderfer, Katherine and Maureen Kuwano Hinkle. "The Evolution of Pesticide Policy: Environmental Interests and Agriculture." In C. Kramer, ed., *Political Economy of U.S. Agriculture: Challenges for the 1990s*. Washington, DC: National Center for Food and Agricultural Policy, Resources for the Future, 1989. Pages 147-177.

Renner, K. A. and J. R. Black. "SOYHERB: A Computer Program for Soybean Herbicide Decision Making." *Agronomy Journal*. 83(1991): 921-925.

Rogers, Everett M. *Diffusion of Innovations*. 3rd edition. New York: Free Press, 1983.

Smith, Vincent H. and Barry K. Goodwin. "Crop Insurance, Moral Hazard, and Agricultural Chemical Use." *American Journal of Agricultural Economics* 78(May 1996): 428-438.

Sorensen, Ann, and Esther Day. “IPM Education and Delivery, Barriers to Adoption and Evaluation,” unpublished manuscript drafted for CAST IPM Task Force, American Farmland Trust, Dekalb, IL, February, 2000.

Stern, Vernon M., Ray F. Smith, Robert van den Bosch, and Kenneth S. Hagen. "The Integrated Control Concept." *Hilgardia*. 29(1959): 81-101.

Swinton, Scott M. and Robert P. King. "A Bioeconomic Model for Weed Management in Corn and Soybean." *Agricultural Systems*. 44(1994): 313-335.

Swinton, Scott M., Sandra S. Batie, and Mary Schulz. "FQPA Implementation to Reduce Pesticide Risks: Part II: Implementation Alternatives and Strategies." Staff Paper 99-46, Department of Agricultural Economics, Michigan State University, E. Lansing, MI. 1999a.

Swinton, Scott M., Nicole N. Owens, and Eileen O. van Ravenswaay. "Health Risk Information to Reduce Water Pollution." In F. Casey, A. Schmitz, S. Swinton, and D. Zilberman, eds., *Flexible Incentives for the Adoption of Environmental Technologies in Agriculture*. Boston: Kluwer Academic Publishers, 1999b. Pages 263-271.

Szmedra, Philip I., Michael E. Wetzstein, and Ronald McClendon. "Economic Threshold under Risk: A Case Study of Soybean Production." *Journal of Economic Entomology*. 83(1990): 641-646.

Taylor, C. Robert and Oscar R. Burt. "Near-Optimal Management Strategies for Controlling Wild Oats in Spring Wheat." *American Journal of Agricultural Economics*.66(Febrary 1984): 50-60.

Vandeman, Ann, Jorge Fernandez-Cornejo, Sharon Jans, and Biing-Hwan Lin. "Adoption of Integrated Pest Management in U.S. Agriculture." Agriculture Information Bulletin No. 707, Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture. 1994.

Van Ravenswaay, Eileen O. and Jeffrey Blend. "Using Ecolabeling to Encourage Adoption of Innovative Environmental Technologies in Agriculture." In F. Casey, A. Schmitz, S. Swinton, and D. Zilberman, eds., *Flexible Incentives for the Adoption of Environmental Technologies in Agriculture*. Boston: Kluwer, 1999.

Waibel, Hermann. "Evaluation of the Impact of Integrated Pest Management at the IARCs." Document No. ICW/99/08/c, Consultative Group on International Agricultural Research - CGIAR, Washington DC (draft 30 Sept.). 1999.

Waibel, H., G. Fleischer, P. E. Kenmore, and F. Feder. "Evaluation of IPM Programs - Concepts and Methodologies." Pesticide Policy Project Publication Series No. 8, Papers presented at the First Workshop on Evaluation of IPM Programs, Hannover, March 16-18, 1998. 1999.

Weisz, Randall, Shelby Fleischer, and Zane Smilowitz. "Site-Specific Integrated Pest Management for High Value Crops: Sample Units for Map Generation Using the Colorado Potato Beetle (Coleoptera: Chrysomelidae) as a Model System." *Journal of Economic Entomology*. 88(October 1995): 1069-1080.

Whalon, Mark E., Barry J. Jacobson, Scott D. Rawlins, Donald Ricks, and Scott M. Swinton. "Agricultural Impact of the Sudden Elimination of Key Pesticides under the Food Quality Protection Act." CAST Issue Paper No. 11, Council for Agricultural Science and Technology, Ames, IA. 1999.

Wiles, L. J., R. P. King, E. E. Schweizer, D. W. Lybecker, and S. M. Swinton. "GWM: General Weed Management Model." *Agricultural Systems*. 50(1996): 355-376.

Wilkerson, G. G., S. A. Modena, and H. D. Coble. "HERB: Decision Model for Postemergence Weed Control in Soybean." *Agronomy Journal*. 83(Mar 1991): 413-417.

WWF (World Wildlife Fund). “WWF: Global Toxics: Program Areas: Agriculatural Pesticides: Finding Alternatives: Wisconsin Potato Growers,” URL: http://www.worldwildlife.org/toxics/progareas/ap/alternatives.htm. (As modified per e-mail from Sarah Lynch to Scott Swinton, 20 Dec. 1999.)

Zilberman, David and Katti Millock. "Financial Incentives and Pesticide Use." *Food Policy*. 22(1997): 133-144.

Table 1. The impact of IPM on pesticide use, yields, and profits—summary of empirical results (from Fernandez-Cornejo et al. 1998).

			Pesticide Use			
Commodity	**IPM Techniques**	**Total Number of Studies**	**Most common effect**	**Range (Percent)**	**Yield**	**Profits (Net Returns per acre)**
Cotton	Scouting only	10	Increase	-64 to +92	Increase[2]	Increase[2]
Cotton	Scouting/others[1]	9	Decrease	-98 to +34	Increase[2]	Increase[3]
Soybeans	Scouting only	5	Decrease	-21 to +83	Increase[4]	Increase[4]
Soybeans	Scouting/others[1]	2	Decrease	-100 to –85	n.a.	Increase
Corn	Scouting	1	Increase	+15 to +47	Increase	Increase
Corn	Scouting/others[1]	2	Decrease	-50 to +67	Increase[5]	n.a.
Peanuts	Scouting only	5	Decrease	-81 to + 177	Increase[6]	Increase[5]
Fruits/nuts	Scouting only	6	Decrease	-43 to +24	Increase[7]	Increase[7]
Fruits/nuts	Scouting/others[8]	4	Decrease	-41 to –12	same[5]	same[5]
Vegetable	Scouting/others[8]	7	Decrease	-67 to +13	same	Increase[5]

Sources: Norton and Mullen, Green and Cuperus; Fernandez-Cornejo and Jans (1996); Yee and Ferguson, Fernandez-Cornejo (1996-1997) – as cited in Fernandez-Cornejo et al. (1998), p. 480.

[1] Scouting plus other techniques or other techniques alone.

[2] Only 6 studies reported results.

[3] Only 8 studies reported results.

[4] Only 4 studies reported results.

[5] Only 1 studies reported results.

[6] Only 3 studies reported results.

[7] Only 2 studies reported results.

[8] All studies but one considered insect IPM only.

Figure 1: Static net gain function from pest control.

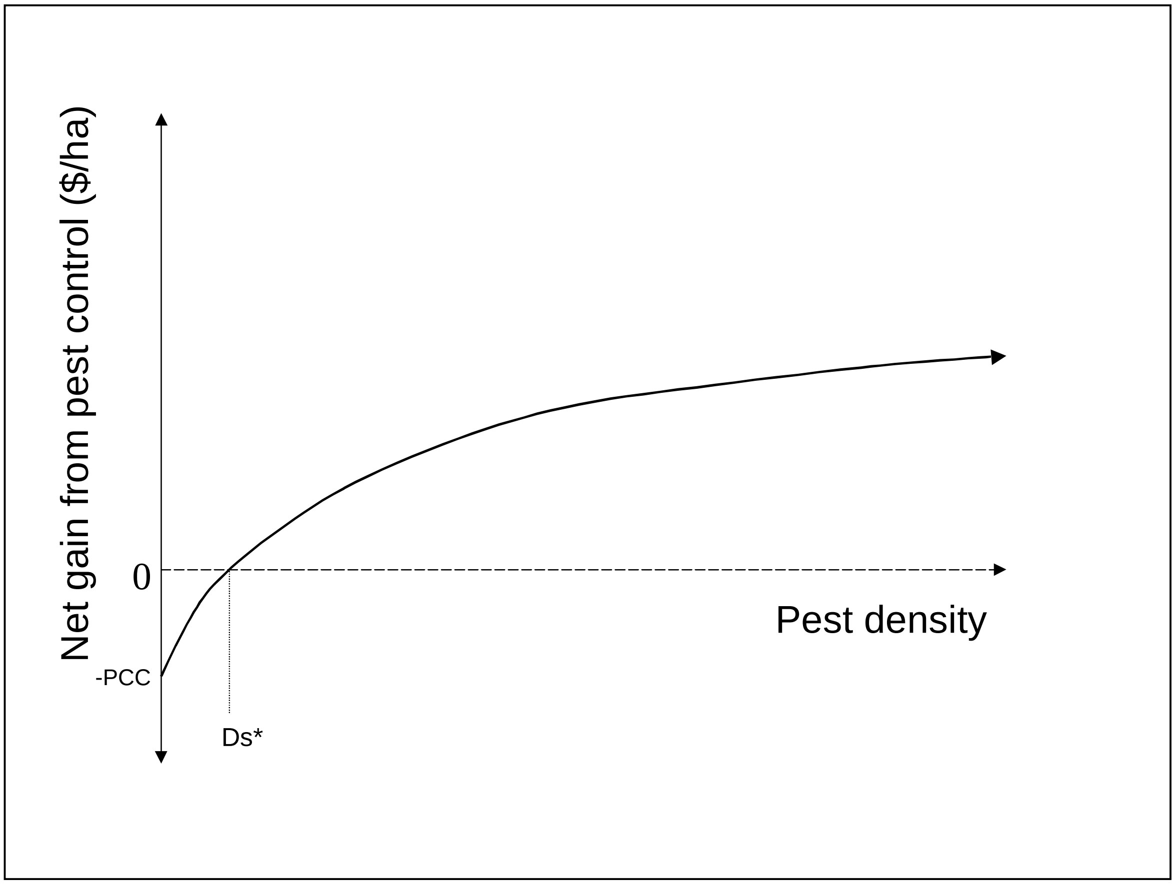


Figure 2: Dynamic and environmental net gain functions.

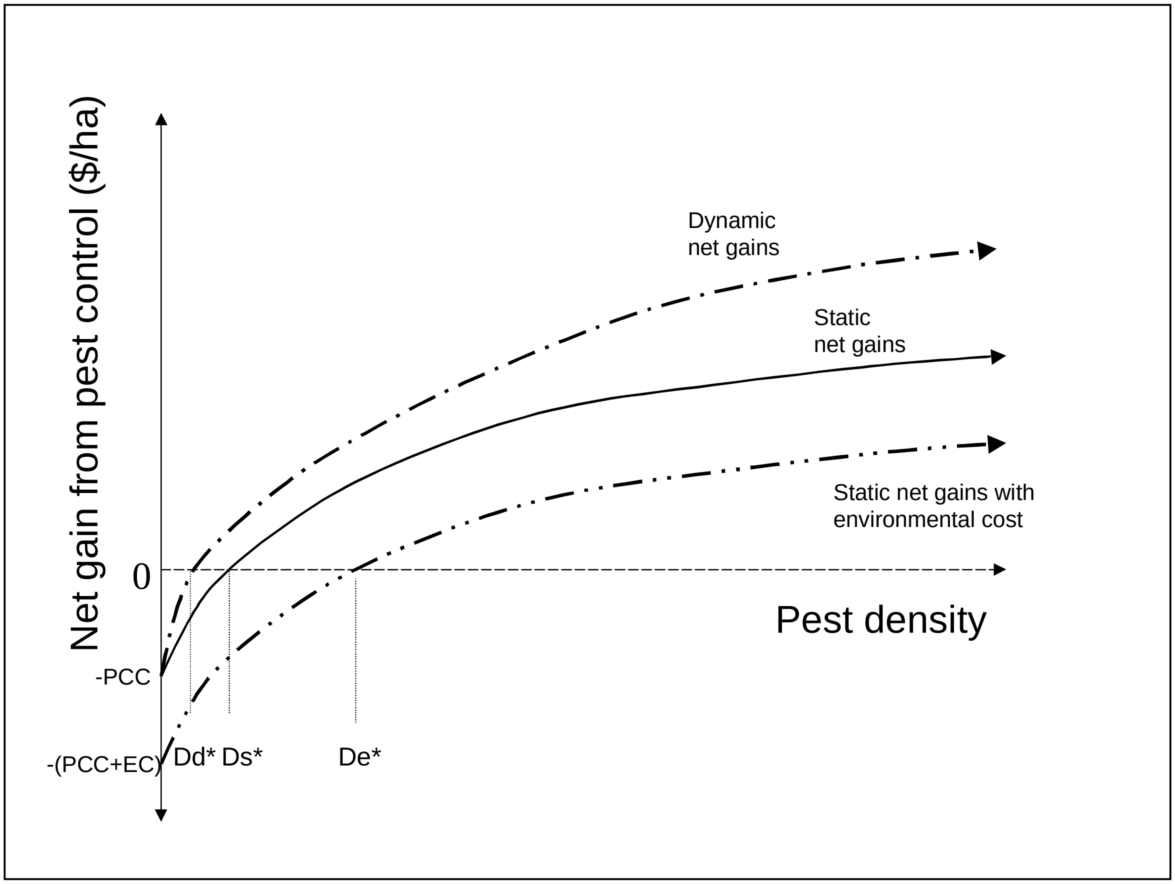
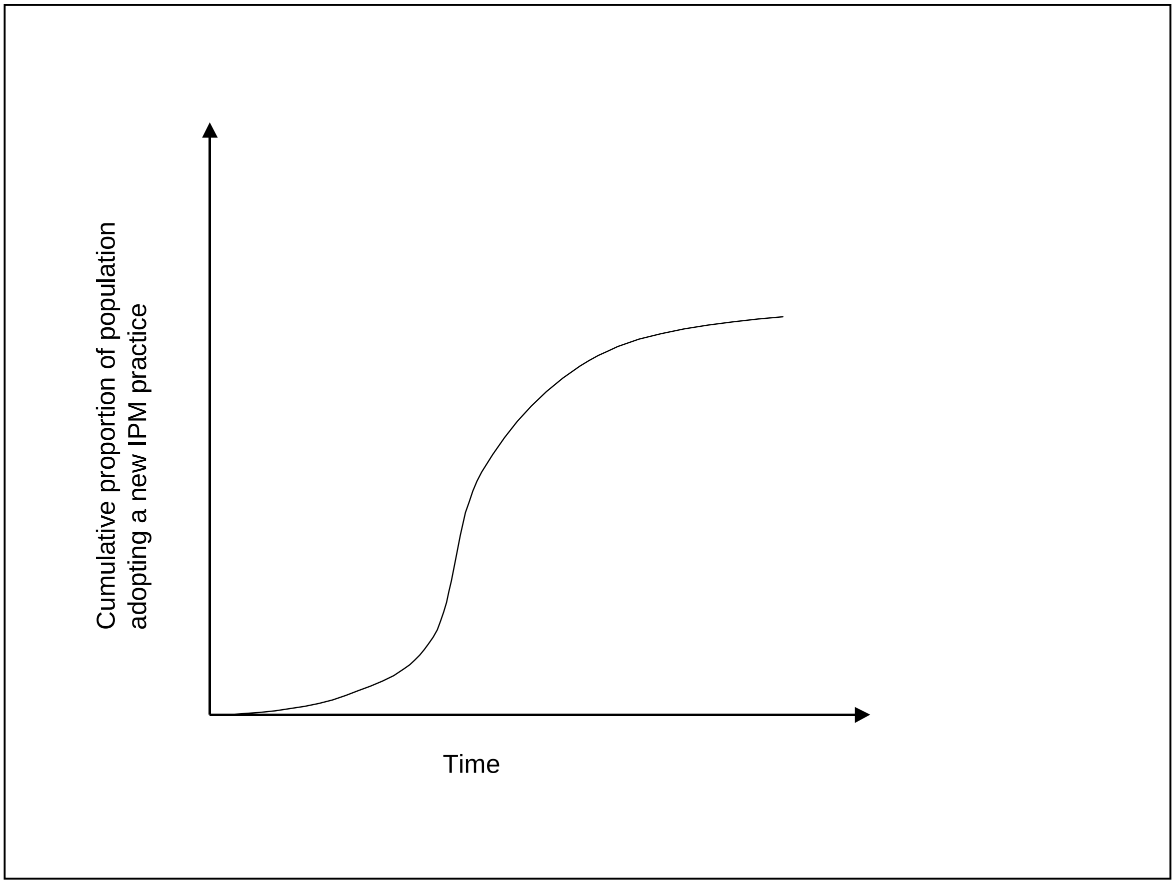


Figure 3: Curve illustrating cumulative technology adoption over time.



Text box 1: Economics and decision support tools.

Economics and IPM decision support tools

In the design of decision support systems (DSS), economics has contributed directly to the development of IPM technologies. DSS are computerized tools to assist managers with complex decisions (King et al. 1993). IPM thresholds can become very complex when they involve changing prices, multiple pest species, nonlinear yield reduction, multi-year effects, or environmental costs. All computerized DSS for IPM that we are aware of have been designed to implement threshold decision rules for pesticide application.

Although IPM thresholds were first developed for insects, weed management has led in IPM DSS development. The key reasons are that weed species vary in their susceptibility to different herbicides and yield-reducing effect on crops. Weed management DSS were first developed as herbicide selection models that identified which herbicides would most effectively kill a given mixture of weeds without harming the growing crop (Mortensen and Coble 1991). Most such DSS were developed for widely planted field crops such as corn and soybean (e.g., Renner and Black 1991; Kells and Black 1991; Kidder et al. 1989). The second generation of weed management DSS were the so-called “bioeconomic models” that predict yield effects from mixed weed populations and identify what treatment would maximize expected net gains from weed control, including the option of no control (Wilkerson et al. 1991; Lybecker et al. 1994; Swinton and King 1994; Wiles et al. 1996).

Text box 2: A corn rootworm IPM insurance policy

A Corn Rootworm IPM Insurance Policy

IPM insurance will be available in Spring 2000 for farmers following corn rootworm IPM systems under the trademarked name IPM-PLUS™. A farmer who relies on the advice of his crop consultant may insure the risk of a possible system failure with a new insurance policy. If the farmer wants to follow his consultant's "don't treat" recommendation but does not fully trust the scouting procedure or take the risk of its failure, he can purchase insurance. The insurance will cost about $5 per acre compared to a $12-15 per acre cost of the rootworm control application (enabling the farmer to capture two-thirds of the IPM benefit and forego one-third for the risk).

The policy will work as follows:

- Step 1: A certified crop advisor using approved scouting techniques and protocols scouts the field for corn rootworm beetles in July and August, and makes a "treat" or "don't treat" recommendation for the following corn crop.

- Step 2: The grower applies for the insurance from the IGF Insurance Company through a local insurance agent and follows the "don't treat" recommendation during the following spring.

- Step 3: A root rating analysis is performed in late-mid summer by the policyholder's crop advisor to determine if a significant rootworm damage has occurred. An insurance claim is made if the root rating is 3.5 or higher (based on a Iowa State University scale of 1-6).

- Step 4: The insurance company adjusts the claim by performing a second root rating analysis. If the root rating is 3.5 or higher, the loss is calculated according to the severity of the rating. The calculated loss plus the actual production may not exceed 132% of the historic average yield.

- Step 5: At crop maturity, if the root rating was 3.5 or higher and insured determines that harvest will be significantly slowed due to lodging of the insured acres, an additional insurance claim may be filed.

- Step 6: The company verifies the crop is lodged due to corn rootworm damage and an additional indemnity is paid to cover the increased harvesting expenses. Maximum additional harvest expenses are equal to the average custom-harvesting rate for the local region where the insured acres are located (i.e., maximum coverage is for the lodging to double the cost of harvesting.)

The corn rootworm treatment policy provides greater assurance to the adoption of the corn rootworm treatment IPM practice. The IPM practice cuts average corn rootworm control costs, reduces pesticide handling and use, saves application time, and improves bottomline returns.

Reprinted with permission from ACIC (1999).

Text box 3: Public-private partnerships: WWF and Wisconsin Potato Growers

Public-Private Partnerships:
World Wildlife Fund and Wisconsin Potato Growers

In 1996, WWF and the Wisconsin Potato and Vegetable Growers Association (WPVGA), an environmental organization and an agricultural commodity association established a precedent-setting partnership to work towards more ecologically-sound agricultural practices. WPVGA represents about 200 farmers who raise about 80,000 acres of potatoes each year. The goal of this unique collaboration is to promote development and wider use of economically viable farming systems that are safer for farm families, consumers and the environment....

Wisconsin potato growers' proactive approach ... shows that adoption of biointensive IPM can substantially reduce reliance on high-risk pesticides. The impressive first-year results of the collaboration -- a 25% reduction in pesticide toxicity in 1997 compared to the 1995 baseline -- bear testimony to the effectiveness of these efforts. The key components of this project -- setting ambitious IPM adoption and pesticide risk reduction goals, promoting research and extension on IPM practices, and agreeing on risk reduction indicators -- provide a promising model for other agricultural groups to apply in addressing their own pest management challenges.

Wisconsin's experience shows that committed growers, backed up by a proactive, organized trade association and a strong university research team, can innovate around pest and pesticide regulatory problems, assuring safer food for all and a healthier environment in areas also supporting intensive agricultural production.

Excerpted with permission from: WWF (1999).