# *Staff Paper*

**Assessing the Economic Impacts of Integrated Pest Management: Lessons from the Past, Directions for the Future**

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## Abstract

This paper reviews the literature assessing the economic impacts of integrated pest management (IPM). Definitions of IPM are categorized as input- or outcome-oriented, and an outcome-oriented definition is recommended for public program assessment. The literature on economic impact assessment of IPM is divided according to focus on expected profit, profitability risk, environment, and health. Measuring diverse impacts on the environment and health poses a challenge, as does placing a value on those impacts. Evaluation of environment and health variables has been accomplished either by comparing individual attributes (multiple criteria approach) or else by constructing a weighted index (index approach), which may be measured in monetary or non-monetary terms. While partial budgeting represents an accepted measure of short-term expected profitability effects of IPM practices, the three other focal areas are much more costly and complicated to measure. For routine IPM project assessments, simple indicators of health and environmental impacts are needed that can be used to extrapolate upon valuation measures from prior, published studies.

# ASSESSING THE ECONOMIC IMPACTS OF INTEGRATED PEST MANAGEMENT: LESSONS FROM THE PAST, DIRECTIONS FOR THE FUTURE

Integrated pest management (IPM) has been heralded as a means to enhance agricultural profits and human living conditions while reducing pesticide risks to human health and the natural environment. During the past two decades, government programs in the United States and elsewhere have sought to encourage adoption of IPM methods. These programs have expanded recently in tandem with policies designed to reduce human exposure to pesticide risks (notably the U.S. Federal Insecticide, Fungicide and Rodenticide Act as amended in 1988 and the Food Quality Protection Act of 1996). In 1993, Vice President Al Gore pledged that the United States would achieve adoption of IPM on 75% of its agricultural land by the year 2000.

The expansion of government-supported IPM programs has been followed by a call for accountability:

> Have the programs met their goals?
>
> Have they in fact boosted producer incomes?
>
> Have they in fact reduced risks to human health and the natural environment?

This paper catalogues prior efforts to assess the economic impacts of IPM. Although urban uses of IPM are proliferating the focus here is on agriculture. The paper begins by defining IPM. It proceeds to examine the IPM impacts that have been measured and to evaluate the methods used for measurement. The conclusion considers criteria for designing assessment tools that are practical for government IPM projects and programs of different sizes and designs.

## Defining IPM

Any successful assessment must begin from a clear definition of what is being assessed. IPM has been defined many ways since the idea was first introduced by Stern et al. (1959). Broadly speaking, the definitions of IPM may be classified as either input- or outcome-oriented. Input-oriented definitions specify IPM practices, whereas outcome-oriented definitions focus on desired results from IPM.

### *Input-oriented definitions*

Input-oriented definitions of IPM relate to the type(s) of pest management practice used. Table 1 conveys several examples of input-oriented definitions. Pest management practices can be broadly classified as biological, chemical, or cultural in nature (Stern, Smith, Bosch & Hagen, 1959). Chemical pest management, of course, centers on the use of pesticides. Biological pest management practices include the use of predators, parasites and allelopathic plants to control or deter pests (National Research Council, 1996). Cultural management of pests includes such practices as tillage, timing of planting or harvest, planting density and spacing. Growers typically combine more than one approach to pest management. The advent of biotechnology has intensified the mixing of approaches, as plants are bred to incorporate natural toxins or tolerance to herbicides.

Input oriented definitions of IPM are useful for identifying IPM practitioners and measuring how much IPM they practice. Measures of numbers of farmers using at least one IPM practice have been used to estimate the aggregate level of adoption of IPM (e.g., Vandeman et al., 1994) as well as to explain what factors affect adoption. In the past decade, with sharp increases in both consumer concern about pesticides and the number of farmers practicing some form of IPM, the measurement focus has shifted from a quantitative count of “whether IPM” to a qualitative measure of “how and how much IPM.” This shift is exemplified by the IPM continuum developed at World Wildlife Fund (Hoppin, 1996) to characterize IPM use on a scale from no IPM to chemical-based IPM to biointensive IPM (Benbrook, Groth, Halloran, Hansen & Marquardt, 1996). On this scale, higher level measures of IPM are associated with less reliance on chemical inputs and more reliance on information, cultural and biological inputs.

Input-oriented definitions of IPM have gained acceptance in many programs that either promote the adoption of IPM or else certify whether IPM practices are being followed. Massachusetts and New York have developed statewide IPM programs that provide IPM certification for many crops. Both programs rely on sets of practices related to management of insects, weeds, diseases, nematodes, record-keeping, and IPM education. A specific level of adoption is required for IPM certification. Such certifications can be used by growers for eco-labeling programs intended to communicate food production information to consumers (Vickery, 1997).

Grower associations and environmental groups have also developed guidelines for production practices that qualify as IPM. These guidelines cover much the same ground as the state IPM certification programs, although commodity grower associations, for example, will tailor the guidelines to pest management in their specific crops (e.g., cotton or potato). In some cases, the guidelines allow calculation of a total score that can be interpreted as a measure of how much IPM is being used. Such measures provide growers with a useful benchmark.

For the purpose of assessing the impact of public programs, input-oriented definitions suffer two important drawbacks. First, they tend to evolve over time with technology standards. The kind of pesticide-based economic thresholds proposed by Stern et al. in 1959 are viewed as very limited by contemporary observers such as Hoppin (1996) and Benbrook et al. (1996). A more important drawback of input-oriented definitions is that they ignore the fact that IPM is a means to one or more ends. To ignore the ends is to ignore the fundamental reasons for adopting IPM.

### *Outcome-oriented definitions of IPM*

While input oriented definitions of IPM are useful for measuring whether and how much IPM is used, they do not address the outcomes of IPM use. Yet expected outcomes of reduced environmental risk and enhanced profits are the chief justifications of public research and outreach on IPM.

Outcome-oriented definitions of IPM relate broadly to profitability, human health, and environmental quality (Table 2). Although the definition of IPM used by Stern et al. in 1959 focused on input use (Table 1), it was designed around the concept of an economic injury level (EIL, discussed below), which is inherently an outcome-oriented measure of expected profitability. Since that time, outcome-oriented definitions have evolved in domain of applicability (from agricultural crops only to livestock to urban settings) as well as in the kinds of outcomes. Profitability has played a role since the beginning, including measures of average profitability and risk to profitability from employing some IPM practice (Klein et al., 1990; Stern et al., 1959; Taylor & Lacewell, 1977; Ward, Dowdy, Berberet & Stritzke, 1990). Profitability impacts have been the primary outcome of concern for two reasons. First, profitability impacts are a major concern to farmers adopting IPM. Second, compared with environmental and health impacts, impacts on profitability are easier to measure.

The leading outcome-oriented measure of average (expected) profitability has been the economic injury level (EIL). The EIL measures the pest density at which management costs equal actual and potential costs from pest damage, contingent upon crop prices and a projected crop damage response function (Pedigo, Hutchins & Higley, 1986). Beyond the EIL, pest control is expected to enhance profits. While many elaborate and specialized EIL's have been developed, the basic logic behind them remains the same.

Apart from average profitability, an important subcategory of outcome-oriented definitions embrace stability of profits under IPM. Producers are concerned both with whether or not a practice is profitable, but also with the level of risk that it will not be profitable (Deen et al, 1993; Lazarus & Swanson, 1983; Swinton & King, 1994). Risk-efficient EIL's have been proposed to accommodate variability of profits under IPM (Lazarus & Swanson, 1983; Moffitt, Hall & Osteen, 1984; Osteen, Moffitt & Johnson, 1988).

During the 1990's a growing number of IPM definitions have emphasized environmental and health outcomes. Most of these are general, admitting various outcome measures of, e.g., "economic, public health, and environmental goals" (Cate and Hinkle, 1993). Others specifically allude to measurement criteria, such as reduced reliance on chemical pesticides (Kovach et al., 1992; Benbrook et al., 1997).

### *What Definition for Public Policy?*

For public policy purposes, an acceptable definition of IPM should address pest management issues of concern to society as a whole in addition to those of growers. It should also permit measurement of degree of IPM use. And it should encourage innovation toward safer, sounder pest management practices.

In general, input-oriented definitions fail to meet the needs of policy makers for three reasons. First, they do not address the many consumer concerns about impacts of IPM on the environment and human health. Second, national input-oriented definitions of IPM are impractical, as regional variations between areas producing similar products make patterns and form of IPM adoption quite variable. In some areas, national guidelines might be too stringent, while in others, guidelines might be considered conventional practice. Third, input-oriented IPM definitions – like the use of input standards in general for managing environmental problems – are allocatively inefficient, in that they do not encourage producers to adopt the most cost-effective practice (Segerson, 1988).

Outcome-oriented definitions of IPM are better suited to public policy than input-oriented ones. Outcome-oriented IPM definitions directly address the issues which concern the public, and hence policy makers. Broad outcome-oriented definitions of IPM accommodate flexible, cost-effective adoption of IPM. Outcome-oriented IPM definitions also overcome the uncertainty over the relationship between IPM practices and impacts.

With these points in mind, a working definition of IPM for assessment of public programs should have three essential qualities. First, it should embody the key outcomes that justified initiation of the public program. Second, it should characterize those outcomes in a fashion that can be measured with relative ease and a minimum of subjectivity, along a continuum or in levels (Norton, Mullen, and Rajotte, 1996). Third, it should encourage continual improvement. A proposed working definition of IPM for public program assessment is:

> *Compared with conventional pest management practices, IPM reduces risk to human health and environmental quality without seriously compromising normal producer profitability and security against the risk of financial loss.*

This definition intentionally includes the benchmark term “conventional,” recognizing that conventional practice evolves: Pest management practices that were considered IPM practices at one time will become conventional, while new IPM practices (or lately “integrated crop management” practices) will become the risk-reducing IPM alternatives.

## Measurement of IPM

Successful program assessment methods build from desired outcomes a set of objectively measurable attributes. How outcomes are measured is always important, but it is especially so when key variables are not directly observable and must be measured by proxy. With this in mind, we survey prior efforts to measure impacts of IPM for the three main outcome areas identified above: profitability, human health and environmental quality. Because the large number of studies on profitability divide between those that consider profitability risk and those that focus exclusively on expected profits, we divide the profitability measures accordingly.

***Profitability I: Expected profit***

The largest group of IPM economic impact assessments use some measure of expected profit, that is the mean profit that could be expected in a typical year. Various measures of expected profit are used. Some studies use gross revenue minus the costs of IPM adoption ("gross margin over pest management cost"), while others include additional production costs ("gross margin over variable costs" or "gross margin over specified costs"). A very few studies go beyond the individual firm to measure IPM impacts on social welfare, a special case of aggregate profitability using producer and consumer surplus. Table 3 summarizes the treatment of profitability in the studies examined.

Of the 27 studies examined that measured profitability impacts, 22 measured gross margin over pest control costs, and only five used gross margin over a wider set of production costs. Of these five, three included costs arising from the health impacts of pesticide use (Antle & Pingali, 1994; Crissman, Antle & Capalbo, 1998; Pingali, Marquez & Palis, 1994), one included averting expenditures to reduce exposure to pesticides (e.g., safety equipment; Harper & Zilberman, 1992), and one included variable production costs in addition to pest management costs (Boggess, Cardelli & Barfield, 1985).

Two studies examined the social welfare impacts of IPM adoption using changes in producer and consumer surplus. Klein et al.(1990) addressed the impacts of an intensive program to manage cattle grubs in Alberta, Canada. Impacts on social welfare were measured in terms of the damages avoided due to the eradication program minus the costs of administering the program. Taylor and Lacewell (1977) measured changes in regional consumer and producer surplus resulting from a boll weevil eradication program for fourteen southern states.

Measurement of expected profitability affects comparability of results across studies. Proxy variables for profitability in IPM impact assessment are gross margin over variable pest management costs and gross margin over selected production costs. Potential limitations of these approaches come from 1) improper cost accounting, and 2) dynamic adjustment effects.

Incomplete measurement of added labor and management costs is the leading cost accounting problem (see, e.g., Hara, 1990). Gross margins may also fail to measure fully the costs of adjustment and final equilibrium conditions when pest systems take more than two to three years to adjust to a steady state. One important dynamic profitability impact that has been omitted from many studies is the effect of pesticide management on pest development of genetic pesticide resistance (Higley, Zeiss, Wintersteen, and Pedigo, 1992).

### *Profitability II: Risk*

Most information-based IPM methods pick a control measure based on *expected* pest damage. But pest damage is somewhat unpredictable, so many studies have attempted to measure the impact of IPM on the variability of farm profits. Two general approaches have been used to measuring profitability risk. One is to develop a money-based measure of risk. This can be done if the decision maker's attitude toward risk is assumed to be known, so a risk-weighted "expected utility function" can be calculated. The second, more common approach, has been to use risk efficiency criteria which pertain to large categories of decision makers with common general attitudes toward profitability risk. Efficiency criteria allow for a partial ranking of choices or outcomes given certain constraints on the preferences of the decision maker and, in some cases, the probability distributions of alternative outcomes (Barry, 1984). The three efficiency criteria applied in most of the articles examined here were first-degree stochastic dominance (FSD), which ranks technologies according to profitability across many different production conditions; second-degree stochastic dominance (SSD), which ranks technologies according to profitability and outcomes under the least profitable conditions; and mean-variance (E-V) dominance (discussed below). Coefficients of variation were also used to measure profitability risk in the studies listed in Table 4.

Seven of the sixteen studies listed in Table 4 used FSD and SSD (Boggess, Cardelli & Barfield, 1985; Deen, Weersink, Turvey & Weaver, 1993; McGuckin, 1983; Moffitt, Tanigoshi & Baritelle, 1983; Musser, Tew & Epperson, 1981; Swinton and King, 1994) or else generalized stochastic dominance (Greene et al., 1985). Two other studies used expected utility functions to develop a money measure of utility (Liapis and Moffitt, 1983; Swinton and King, 1994).

Mean-variance dominance is the other efficiency criterion widely used in the studies reviewed (Table 4). Mean-variance dominance is defined such that, given an outcome with mean (E) and variance (V), that outcome dominates another outcome with mean (E’) and variance (V’) so long as E  E’ and V   V’, and at least one of these relationships holds as a strict inequality (Barry, 1984). In all, nine studies used mean-variance dominance to compare alternative outcomes under uncertainty (Lazarus and Swanson; Moffitt et al, 1984; Musser et al.; Osteen et al.; Swinton and King; Harper and Zilberman; Crissman et al., 1998; Yu et al.; Antle and Pingali). As indicated in the table, some studies used more than one measurement technique.

***Environmental Impacts***

Environmental impacts of IPM and other pest management practices touch upon a wide range of environmental media. In assessments of environmental risk, impact measures are almost exclusively mean values, such as the concentration of an aquatic toxin in that is lethal to 50% of some aquatic species (LC50). Thus, these measures are comparable to the expected value measures of profit. By contrast, none of the IPM assessment articles reviewed employed measures of environmental impacts that use probabilistic terms, such as those discussed above under profitability risk. In general, the research into economic evaluation of environmental impacts is much more scarce and more recent than the large body of work on profitability impacts.

<u>Environmental media measured</u>

Many different criteria are used to assess environmental impacts and risks. These include the quality of water, air, and soil, as well as the health of non-target species of mammals, birds, fish, insects, plants and other life forms (Table 5). Kovach et al.’s (1992), environmental impact quotient (EIQ) for pesticides, uses eight criteria in calculating the environmental components of the indices. Higley and Wintersteen (1992) followed by Mullen et al. (1997)

use five separate criteria to characterize environmental risks from insecticides and herbicides in calculating their environmentally adjusted EILs (EEILs). None of these studies include site-specific criteria, like soil types or depth to aquifer, in estimating environmental impacts or risks for pesticides. Instead, all criteria were based on previous studies that characterized specific non-target impacts or pesticide specific characteristics, like soil residue half-life and toxicity to bees.

The studies by Hoag and Hornsby (1992), Teague et al. (1995), and Crissman et al. (1998) approach environmental risk assessment similarly to the ones discussed above, but they add site-specific criteria. Hoag and Hornsby (1992) develop a trade-off frontier for pesticide costs and a groundwater hazard index (GHI). The criteria used to develop the GHI include pesticide specific criteria and site-specific criteria that might affect the likelihood of contamination of groundwater by pesticides. Teague et al. (1995) compare the EIQ with two other measures of environmental risk. The other two measures include site-specific estimates of environmental fate of pesticides, in addition to the toxicity and leachability measures in the EIQ. Crissman et al. (1998) also included site-specific information on soil types and rainfall in their measure of pesticide leaching risk.

Proxy variables for environmental impact measurement

Since direct measurement of some of the environmental impacts of IPM adoption is impossible, or prohibitively expensive, a wide range of proxy variables has been used to measure environmental impacts. The most common proxies are pounds of active pesticide ingredient (a.i.) applied or dollars spent on pesticides (Musser, Tew & Epperson, 1981; Moffitt, Tanigoshi & Baritelle, 1983). Both measures emerge from the very dubious assumption that environmental damage correlates with quantity of pesticide used, regardless of the specific chemicals and formulation. An even rougher proxy simply to measure whether or not pesticides are used in a production, based on the implicit assumption that any pesticide use must harm the environment (Reichelderfer & Bender, 1979).

The demand for more rigorous, qualitative measures of environmental impacts triggered development of a new generation of proxy variables. The EIQ, for instance, combines eight pesticide impact variables by weighting their relative importance into a single index of environmental risk. Hoag and Hornsby (1992) and Teague et al. (1995) also use weighted indices that incorporate the kind of toxicological and leachability criteria in the EIQ with site-specific measures of likely exposure.

***Human Health Impacts***

Studies of health impacts from IPM adoption can be divided into two broad areas. Imputed health risk studies use controlled laboratory experiments exposing small mammals to acute doses of pesticides, extrapolating from these to likely human health risks. Epidemiological studies use survey data linking human morbidity and mortality to life styles and exposure to risks sources, such as pesticide application.

Research on the human health of pest management has mostly focused on the acute toxicity effects of pesticides and pesticide exposure. A toxicity estimate commonly found in health risk assessments is the World Health Organization's index of acute mammalian toxicity, or LD50. The LD50 is the dose of pesticide that is lethal to half of the test population, typically composed of rats or rabbits. Most studies dealing with health impacts used LD50s as acute toxicity risk estimates (Higley & Wintersteen, 1992; Hoag & Hornsby, 1992; Kovach, Petzoldt, Degni & Tette, 1992; Mullen, Norton & Reaves, 1997; Penrose, Thwaite & Bower, 1994; Teague, Mapp & Bernardo, 1995). We are not aware of attempts to measure the risk of nonchemical pest management practices.

Risk of pesticide exposure depends on its propensity to move in the environment (e.g., water solubility, clay particle adsorption) and the characteristics of the setting in which it is released. The EIQ is a result of three separate calculations of likely risk and exposure for consumers, farm workers, and the environment. Likewise, Harper & Zilberman (1992) divide worker health risks according to form of exposure to aerially sprayed pesticides (mixers/loaders vs. pilots vs. flaggers on the ground).

More recent epidemiological research has begun to consider the chronic effects of pesticide exposure on carcinogenicity and the human neurologic, endocrine, immune, and reproductive systems (Blair, Francis, and Lynch, 1996). Epidemiological pesticide risk assessments have focused largely on risk to farmers and pesticide applicators (Blair & White, 1985; Hoar et al., 1986; Zahm, 1997). Most recent studies have focused on cancer mortality risks via Hodgkin's disease, leukemia, multiple myeloma, non-Hodgkin's lymphoma, and cancers of the lip, stomach, prostate, skin, brain, and connective tissues (Alavanja et al., 1996). In addition to epidemiological studies of acute effects of pesticide exposure in the United States (Blair, Francis & Lynch, 1997), several recent studies have been done elsewhere. Antle and Pingali (1994) and Pingali et al. (1994) evaluated the acute health effects of pesticide use by Philippine farmers; they further estimated the value of these acute impacts on farmer productivity. In a similar set of studies, Crissman et al. (1994, 1998) evaluated the acute health impacts of pesticide use by Ecuadorean farmers and calculated profitability tradeoffs associated with higher and lower levels of pesticide use.

<u>Proxy variables for health impact measurement</u>

The most commonly used proxy measure for health risks from pesticide use is the mammalian LD50. All of the studies that mixed multiple criteria for assessing pest management systems use LD50s proxies for health risk (Table 5). Other studies include variables that characterize the risk of exposure due to pesticide characteristics or site-specific variables as components of the proxy variables of health impacts (Harper & Zilberman, 1992; Higley & Wintersteen, 1992; Hoag & Hornsby, 1992; Kovach, Petzoldt, Degni & Tette, 1992; Mullen, Norton & Reaves, 1997; Penrose, Thwaite & Bower, 1994; Teague, Mapp & Bernardo, 1995). The epidemiological studies that evaluated average health risks measured health outcomes directly, but only for certain classes of mortality and morbidity associated with pesticides. Antle and Pingali (1994) and Crissman et al. (1994, 1998) also used actual medical records.

## Approaches to Combining Different IPM Assessment Criteria

Difficult as it is, measuring individual impacts of IPM is not enough. IPM assessment also requires that individual measures be combined in a meaningful fashion. There are two general approaches to combining criteria: 1) building a single index, and 2) creating a trade-off frontier based on multiple criteria. Studies using each approach are listed in Table 6.

The index approach calls for some way of weighting different criteria. Kovach et al.'s Environmental Impact Quotient uses a subjective weighting of relative environmental risk in an additive index constructed from eight pesticide impact variables. The resulting EIQ index can be compared only with EIQ's for other pesticides. The indices reviewed by Teague et al. (1995) and Penrose et al. (1994) are comparable. Another approach to building an index is to do it in monetary units. The contingent valuation studies of Higley and Wintersteen (1992), Mullen et al. (1997), and Owens et al. (1996) each used surveys to elicit farmer willingness to pay for safer pesticides. The results were used to adjust pesticide costs to reflect health and environmental costs in addition to cash costs. The adjusted cost can be interpreted as a monetary index that combines profitability with health and environmental risk factors.

The multiple criteria assessment approach keeps IPM evaluation criteria separate, but identifies "efficient" trade-off frontiers such that one criterion cannot be improved without sacrificing performance on another. Levitan et al. (1995) observe that this method typically compares profitability impacts measured in monetary terms with environmental impacts measured on some other scale. For example, Hoag and Hornsby (1992) graph a groundwater hazard index (GHI) against herbicide cost. The trade-off frontier represents herbicides that have the lowest GHI for their cost; hence, lower GHI cannot be obtained without increasing herbicide cost, and vice-versa. Teague et al. (1995) and Crissman et al. (1998) also construct trade-off frontiers combining multiple IPM impact criteria. The approach is similar to Pareto optimality or the mean-variance dominance criterion described above for profitability risk.

**Directions for Planning Economic Assessment of Public IPM Programs**

As IPM has evolved from a cost-saving practice for farmers to a risk-reducing practice for farmers and consumers, the appropriate way to assess IPM programs has evolved as well. The desired outcomes for most IPM programs are producer profitability, environmental quality and human safety. Gross margin measures of expected profitability are generally easy to do and adequate when the pest management systems being compared undergo similar or rapid adjustments to reach new steady state equilibria.

Much more daunting is the threefold challenge of how to assess profitability risk, environmental impacts and human health impacts. Compared with expected profitability, these attributes involve more criteria to measure, greater difficulty in observing what is to be measured, and greater difficulty in forecasting dynamic adjustments.

Where profitability risk matters, as it often does, the stochastic efficiency measures have the advantage over the expected utility functions that the former apply to broad categories of decision makers. However, they require information on pest management results under various states of nature. If these data are collected from the field, they can be slow and costly to acquire; if simulated, they may be of questionable validity.

Measuring environmental and health impacts poses difficulties that are analogous, albeit greater. For most of these, IPM program assessment will have to extrapolate from minimal measurements. Multiple criteria assessments have the political advantage of requiring few value judgements, but neither do they provide clear guidance for how to make trade-offs between points on the efficient frontier or trade-offs between pairs of the many points that typically lie off the frontier. Indexes, on the other hand, offer clear rankings, but they are subject to criticism for subjectivity in how they weight different impact criteria.

The difficulty inherent in measuring and placing values on environmental, health, and profitability risk impacts suggests that when economic assessments of IPM programs aspire to go beyond simple measures of expected profitability, they will be driven by constraints on budgets and time.  Minimal, prudent indicators of environmental and health impacts should be developed that can be used to extrapolate from prior studies elsewhere.  In special cases of large, well-funded programs, more extensive primary assessment data collection may be merited.

**Table 1: Examples of input-oriented definitions of IPM.**

| Definition (quoted from source text) | Source |
|---|---|
| Biointensive IPM ... relies on resistant varieties and promoting plant health, crop rotation, disrupting pest reproduction, and the management of biological processes to diversify and build populations of beneficial organisms. | Benbrook et al. (1997) |
| Integrated pest management (IPM) programs provide individual pesticide users with techniques proven to reduce pesticide use. The keystones of IPM programs are economic injury levels (EILs), which are objective criteria for determining when to manage pests | Higley & Wintersteen (1994) |
| Cotton IPM systems include such components as scouting to determine when control actions should be taken, planting trap crops, and using short season varieties of cotton. | Liapis and Moffitt (1983) |
| Integrated pest management (IPM) is a systematic approach to crop protection using increased information to make better pest management decisions. | Rajotte et al. (1987) |
| Applied pest control which combines and integrates biological and chemical control. Chemical control is used as necessary and in a manner which is least disruptive to biological control. | Stern et al (1959) |

**Table 2: Samples of outcome-oriented definitions of IPM.**

| Definition (quoted from source text) | Source |
|---|---|
| Integrated Pest Management is the judicious use and integration of various pest control tactics in the context of the associated environment of the pest...to meet economic, public health, and environmental goals. | Cate and Hinkel (1993) |
| By definition, IPM is a pest management strategy that uses a combination of methods (sampling, thresholds, forecasts, biological and cultural controls, etc.) to manage pests without solely relying on chemical pesticides to produce a safe, economic crop. | Kovach et al. (1992) |
| ...integrated pest management (IPM) strategies are being developed and implemented that combine biological, cultural, physical, and chemical control tactics to minimize economic, environmental, and health risks. | Mullen et al. (1997) |

**Table 3: IPM assessment articles grouped by measure of profitability.**

| Private Profitability | Social Profitability | Profitability Risk |
|---|---|---|
| **Gross margin minus pest control cost** | | |
| Deen et al. | | |
| Ferguson et al. | | Ferguson et al. |
| Greene et al. | | Greene et al. |
| Hara | | |
| Hoag & Hornsby | | |
| Klein et al. | Klein et al. | |
| Lazarus & Swanson | | Lazarus & Swanson |
| Liapis & Moffitt | | Liapis & Moffitt |
| McGuckin | | McGuckin |
| Moffitt et al. (1983) | | Moffitt et al. (1983) |
| Moffitt et al. (1984) | | Moffitt et al. (1984) |
| | Mullen et al. | |
| Musser et al. | | Musser et al. |
| Osteen et al. | | Osteen et al. |
| Rawat et al. | | |
| Reichelderfer & Bender | | |
| Swinton & King | | Swinton & King |
| Szmedra et al. | | Szmedra et al. |
| Taylor & Lacewell | Taylor & Lacewell | |
| Teague et al. | | |
| Trumble & Morse | | |
| Ward et al. | | |
| Yu et al. | | Yu et al. |
| **Gross margin minus production costs** | | |
| Antle & Pingali | | Antle & Pingali |
| Boggess et al. | | Boggess et al. |
| Harper & Zilberman | | Harper & Zilberman |
| Crissman et al. (1998) | | Crissman et al. (1998) |
| Pingali et al. | | |

**Table 4: IPM assessment articles grouped by measure of probabilistic risk.**

| Method | Profitability | Environment | Health |
|---|---|---|---|
| Stochastic Dominance | Boggess et al. | | |
| | Deen et al. | | |
| | Greene et al. | | |
| | McGuckin | | |
| | Moffitt et al. (1983) | | |
| | Musser et al. | | |
| | Swinton & King | | |
| Mean-Variance (E-V) | Lazarus and Swanson | | |
| | Moffitt et al. (1984) | | |
| | Musser et al. | | |
| | Osteen et al. | | |
| | Swinton & King | | |
| | Harper & Zilberman | | Harper & Zilberman |
| | | | Crissman et al. (1994) |
| | Crissman et al. (1998) | | Crissman et al. (1998) |
| | Yu et al. | | |
| | Antle & Pingali | | Antle & Pingali |
| | | | Pingali et al. |
| Coefficient of Variation | Ferguson et al. | | |
| Expected utility function | Liapis & Moffitt | | |
| | Swinton & King | | |

**Table 5: Environmental impact assessment criteria.**

| Environmental impact assessment criteria | Source |
|---|---|
| Aquatic organisms, beneficial arthropods, birds, ground water, human acute toxicity, human chronic toxicity, mammals, surface water | Higley and Wintersteen (1994); Mullen et al. (1997) |
| Acute human toxicity, chronic human toxicity, leachability | Hoag and Hornsby (1992) |
| Acute dermal LD50 for rabbits/rats, groundwater and runoff potential, long term health effects, mode of action, plant surface residue half-life, soil residue half-life, toxicity to bees, toxicity to beneficials, toxicity to birds, toxicity to fish | Kovach et al. (1992) |
| EIQ criteria from Kovach et al., plus leachability, percolation, acute toxicity, and human toxicity, and criteria for leachability and percolation adjusted using acute and human toxicity. | Teague et al. (1995) |

**Table 6: IPM assessment articles grouped by approach to assessing multiple criteria.**

| | Profitability | Environment | Health |
|---|---|---|---|
| **Indexes** | | | |
| | | Higley & Wintersteen | Higley & Wintersteen |
| | | Kovach et al. | Kovach et al. |
| | | Mullen et al. | Mullen et al. |
| | Penrose et al. | Penrose et al. | Penrose et al. |
| | | Teague et al. | Teague et al. |
| **Multi Criteria Dominance** | | | |
| | Crissman et al. (1998) | | Crissman et al. (1998) |
| | Hoag & Hornsby | Hoag & Hornsby | Hoag & Hornsby |
| | Teague et al. | | Teague et al. |

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