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Cinnabar moth larvae attacking the weed *Senecio jacobaea* L. (tansy ragwort) in Oregon.

USDA photo

Economics of Integrated Pest Management

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an interpretive review of the literature

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ECONOMICS OF INTEGRATED PEST MANAGEMENT: AN INTERPRETIVE REVIEW OF THE LITERATURE

Bruce A. McCarl

PREFACE

For a term and concept that was virtually unrecognized 10 years ago, integrated pest management (IPM) has leaped with amazing rapidity to the forefront of agricultural activities in many regions. The fact that it is not without merit nor free of controversy has doubtlessly contributed to its speedy emergence from obscurity.

IPM as a concept, or a group of concepts, stems from agricultural science wrestling with the challenge of designing evermore effective techniques for protecting crops from a host of antagonistic pests. Added to biological shifts--resistance of some species to chemical applications--have been social and economic evolutions that argued for expansion and innovation in the scope of crop protection practices.

A body of literature, not surprisingly, has emerged. One segment, economic analysis of IPM, forms the basis for this review and appraisal.

The ordering of sections somewhat reflects the author's inquiry process as he perused 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.

Several other documents serve some of the same purposes as this report: the annotated bibliography created at U.S. Department of Agriculture by Osteen, Bradley, and Moffet [1980]; the lists of references which arose from Darwin Hall [1975], Virginia Polytechnic Institute (obtained from Harry Baumes) and Marshall Martin (Purdue). There also are literature reviews on diseases (Carlson and Main [1976]) and systems analysis (Ruesnick [1976]).

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While saluting those who offered commentary and assistance, the document--its concepts, biases, and conclusions--remains the product of the author.

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SECTION I
WHAT IS IPM?

SOME DEFINITIONS

Integrated pest management (IPM) labels a concept obviously referring to management of pests in an integrated fashion. However, within this broad framework, many different meanings can be, and have been, inferred to minimize confusion. Therefore, a single precise definitionis needed. Examining components of the term integrated pest management can help in arriving at a suitable working definition.

A pest, according to Woods, [p. 1] is an organism which harms man or his property or is likely to do so. Further, the harm must be damage of economic significance. This far-reaching definition includes not only insects, but also weeds, animals, fungi, microorganisms, and viruses, any of which can cause crop damage. Excluded are those organisms involved with animal health as treated by veterinarians, human health as treated by physicians, or food spoilage as dealt with by food microbiologists. The definition, adopted herewith, coincides with a large segment of IPM literature.

The next term, management, infers the act or manner of managing, controlling, directing, etc. Managing implies, in this context (again referring to Woods), man's action is intended to ameliorate the harm caused by pests. However, in the broader view, management also embraces the judgmental process. Therefore, pest management defines a process aimed at amelioration of pest-caused harm, but where man exercises the decision over whether to apply ameliorating action. This broadened focus implies an active search for information as to whether control should be undertaken, but permits inactivity if control appears unnecessary.

Integrated signifies the act of putting or bringing together parts into a whole, and, in this case, the combining of various pest management techniques.

Lastly, the setting in which IPM occurs, the farm, must be considered. A farm is a complex production entity utilizing multiple inputs (land, labor, fertilizer, pest contols, etc.) to produce multiple outputs as influenced by the farm environment (weather, pests, general economic conditions, etc.). Pest management necessarily must integrate with the total farm equation. Therefore, "integrated" here refers to both the use of (potentially) multiple pest methods and the integration of these control methods into the total farming system.

The overall definition thus developed states that: integrated pest management considers any and all combinations of various techniques for the management of weed, insect, disease, and animal pest problems within the context of the farming system.

COMPARISONS WITH OTHER DEFINITIONS

Adoption of this definition leads to a comparison with other definitions. Rather than cite alternative definitions (virtually every IPM paper in the attached bibliography contains one), the following material compares viewpoints and cites possible reasons for differences.

First and fundamentally, the definition above permits consideration of any pest management technique. Pesticides are included. Historically, many IPM definitions have stressed non-chemical controls or excluded pesticides. Certainly, a major reason for IPM's prominence hinges on the desire to avoid environmental damage. However, IPM, in some circumstances, may be accomplished most effectively using shortlived specific pesticides in conjunction with other techniques.

Second, other definitions of IPM have (as implicit in the discussion immediately above) tended to confuse the objectives of IPM with the concept. These definitions state, in general, that "IPM is the use of pest management techniques in an environmentally and economically sound manner." Although the concept is consistent with IPM practice, the environmental and economic aspects are objectives and, therefore, point out how optimal choices should be made. The definition used herein explicitly defines IPM independent of objectives, so all pest management techniques will be considered.

Third, the definition above includes in its scope weeds, insects, diseases, and animals. Many previous definitions, particularly those related to the economic literature, explicitly or implicitly, have concentrated on insects only for several suggested reasons: a) insects, being mobile with multiple generations, require repeated treatments; b) insects, and the damage they cause, are far more readily evident and not as subtle as weed-caused problems; c) insects have shown ability to rapidly develop resistant strains that invalidate some control techniques; d) insecticides, generally more toxic, create more problems and economic externalities; e) repeated attack by environmentalists was slower to arrive on the weed scientists' doorstep; and, f) insect data are more available.

Fourth, the adopted definition involves neither eradication of pests nor living with pests. Rather, the definition involves the management of pests under which these actions are alternatives.

Fifth, the definition used herein encompasses pest management regardless of whether the problem is caused by one or many weeds, insects, or diseases. Thus, weed problems, insect problems, and/or disease problems, either in conjunction or in isolation, fit under this definition.

ECONOMICS OF IPM IN AGRICULTURE

Assuming IPM as defined, there follows a narrowing of focus to review economic elements, as well as a confinement to agriculture. Inquiries into other areas occur only as necessary to develop background. Finally, the scope here certainly reflects a subset of economics and will assume that:

1. Fundamentally, the decision at the farm level involves what control to use from a set, and how to apply it given timing and intensity possibilities. Subjects such as the development of response curves for pest kill or plant growth are not explicitly covered and are assumed known *a priori*. Stress falls on the management decision.
2. Fundamentally, the aggregate topic of interest is: what impacts will certain pest-related actions (policies, regulations, and technology development, improvement, or dissemination) have upon the economy.

SECTION II

WHY DOES IPM EXIST?

Numerous reasons underlie the recent arrival of integrated pest management as a prominent topic of interest among agricultural scientists. The principal reasons hypothesized here include: a) the existence and magnitude of pest damage, b) the complexity with which pests interact with the farming system, c) the diversity of available pest control measures, d) the existence of spillover effects from controls, e) the predominance of controls relying heavily on pesticides along with the evidence pointing toward overuse, f) the evidence for benefits from pest control, g) the uncertainty as to best pest control measure, h) the recent growth and current prominence of the anti-pesticide movement, i) the existence of institutions concerned with pesticide use, j) the governmental interactions with pesticide use, and k) the general food and income situation. Discussion of these points, particularly as they appear to an economist, follows.

PEST DAMAGE

Dialogue over pest control would be limited if pests did not cause important damage. Various estimates have been proposed which place the quantity of damage in the United States at approximately 33 percent of the potential crop production pre-harvest and 9 percent postharvest (USDA [1965a,b], and Pimentel [1976]). Such losses have led to an interest in pest damage reduction as a means of increasing food supply. Further, although pest damage is significant, many feel that pest damage, in percentage terms, has been increasing (Pimentel [1978]) in spite of pest control efforts (changing technology may be important). Thus, concerns over pest control are prominent because pests divert production and may be doing so with increasing efficiency.

In addition to the damage wrought by pests, another item stimulating emphasis on IPM is the concentration of losses. Assuming that chemical use relates to pest damage, then data from Pimentel [1978, p. 59] are rather interesting. Of total insecticide use in U.S. agriculture, 47 percent is on cotton, 17 percent on corn, 9 percent on fruit, and 7 percent on vegetables.

For herbicides, 45 percent is applied to corn, 16 percent to soybeans, and 5 percent to wheat. For fungicides, 60 percent is applied to fruit, 24 percent to vegetables, and 11 percent to peanuts. Crop loss, and the pesticide usage occurring as a result, is concentrated, indicating that efforts on a few crops may have large payoffs.

PEST INTERACTIONS

Pests exist within the total farming-agricultural sector context. Elements of this system (such as pest control measures) discourage pests. However, other technologies elements--specialization of production, irrigation, continuous cropping, as discussed in Pimentel [1978]--may tend to encourage pests. Further, pests interact with each other, with predators, and more generally, with the environment. These interactions reveal the complex nature of the pest management decision and the need for applicable information.

PEST CONTROLS

The complexity and extent of the problem necessitate further study of pest control because of the number of available pest control methods. Though chemical pest control is widespread, other pest control methods are well recognized. Pesticides have come into prominent use only in recent years, yet pests have existed for centuries.

Before the chemical era, if pests were managed it was by various methods including cultural and manual practices, and/or natural mechanisms. Subsequently, chemical and biological control methods were introduced. The pests' environment also may be altered. Cultural pest control consists of methods involving cultivation (i.e., plowing, post-emergent mechanical cultivation, etc.), crop selection, and crop rotation. Manual pest control refers principally to manual pest removal (i.e., weeding, picking pests off bushes). Natural pest control methods include pest control through predators, pest diseases, or other environmental factors. Chemical control is the application of pesticides to control pests. Biological control refers to pest control through actions such as release of sterile insects, release of predators, development of resistant crops, etc. The environment is modified by such activities as swamp draining, field burning, etc. With this wide variety of pest control techniques, the key management question remains: Which one should be chosen? This dilemma, and the fact that the alternatives potentially alter the production system, have led to the prominence of integrated pest management as an area of study.

SPILLOVER EFFECTS OF CONTROL

All the pest control measures mentioned have been used in one form or another. However, in the years since the early 1950s, chemical control has been prominent. In many cases, particularly those involving chemical control of insects, a complex interaction has been discovered among pests, control practices, and the environment. Generally, pest control measures in the short run have controlled pests. However, in the longer run, pest problems, in some cases, have increased (Carlson [1977] for evidence). This may have been caused by changes in crop technology along with the fact that chemical pest control has promoted resistant pests by killing all but those resistant to the pesticide (Adkisson [1972]), and thus contributed to their own obsolescence.

Chemical controls have affected non-target as well as target species. In some cases, predator populations (i.e., elements of natural control) have been reduced. Although resistant predators have survived, they faced a reduced food supply. Subsequently, when the resistant pest resurges the predator does not (Feder and Regev [1976]). Therefore, pesticides can reduce the effectiveness of natural pest controls and lead to outbreaks of resistant pests. Secondary pest outbreaks also have been caused when the effectiveness of natural controls on the pest population has been inadvertently reduced by pesticides (Adkisson [1972]).

Interactions with the environment, however, do not involve solely pests and their damage. Obeying the natural law that matter is neither created nor destroyed, residues from some pesticides, particularly insecticides, have spilled over into the environment, leading to degradation in land and water quality (Herfindahl and Kneese [1965], or Headley and Lewis [1967]). Residues also have led to human, livestock, and wildlife health problems and have even reduced production (in rare cases to the point of removing land from production). On the other hand, many pesticides degrade or are stabilized rapidly into the environment and have had little or no impact other than pest control. Thus, complex, unanticipated spillovers have led to the importance of IPM as an area of study.

PESTICIDE OVERUSE

Such complex interactions have led many to conclude that chemical pest controls are overused, particularily from the societal point of view (Carson [1970]. Some control measures are used in a prophylactic manner when a pesticide is applied on a schedule regardless of pest incidence. Such practices, along with pest resistance, influx of species, predator destruction, and other spillover impacts, have been cited as evidence on overuse.

One estimate, while reporting that herbicides and fungicides were not being overused, stated that as much as 50 percent of the insecticide and miticide use is unnecessary (Von Rumker et al [1975]). In addition, application by aircraft appears to be especially ineffective (Joyce [1969]).

Overuse has been a major argument in pesticide regulatory actions and the emergence of IPM. However, overuse is a complex topic. An objective view of the over-use question should consider the farmer's realized costs and benefits along with society's costs and benefits. Farmers well may "overuse" from society's viewpoint, but use the correct amount given their profit and risk avoidance objectives. Nevertheless, this again leads to interest in IPM.

BENEFITS OF PESTICIDES

A large share of public anti-pesticide initiative follows the lines of the above spillover arguments. However, a conclusion that pesticides should not be used, based on such arguments, ignores a number of factors. Chemical use and the conduct of IPM, particularly from an economist's viewpoint, must consider the reasons for pest control's importance.

First, pest problems are increasing, or at least not diminishing. This arises due to both current pest control practices and the fact that a more conducive environment has been created for pests by current technical practices. Agricultural practices have changed markedly in recent years. Such practices as continuous cropping have become more prevalent leading to increased regional specialization. The genetic stock also has become more uniform. These phenomena, in fact, have encouraged pest problems. Food for pests has been more abundant and continuous in supply, mobile pests have been able to move from treated areas to untreated areas, areawide uniform practices have fostered resistance, etc. Fertilization, irrigation, early maturation, and crop intensification also have modified the ecosystem, creating an environment more favorable to pests. Thus, cultural practices, in spite of and along with the controls, potentially have increased the magnitude of pest problems (Pimentel [1978], and Carlson [1977] for more discussion and references). Pesticides themselves have been key factors in allowing the use of many of these "advanced" practices and these practices, in turn, have been responsible for much of the recent productivity growth in agriculture.

Pesticides constitute a mechanism for substituting capital for labor and equipment services in agriculture. Within the context of production theory, pesticide use should increase rather than decrease given that (Table 1) pesticide prices (agricultural chemicals) have increased at a slower rate than either labor (wage rates) or machinery services (fuel and energy, tractors, other machinery). In fact, the aggregate usage of pesticides has increased in recent years (Figure 1).

The increase in pesticide usage not only has been caused by a shift in factor prices, but also by the productivity of pesticides. Ordinarily, economic theory would predict that an input would be used until its price equaled the marginal benefit (in profit) derived from its usage. Estimates of pesticide productivity, however, have consistently shown productivity three or four times cost (e.g., Headley [1968], and Campbell [1976]). Pesticides also may be risk-reducing with farmers using them to reduce income variability. These characteristics would seem to imply that pesticide use will increase. Thus, pesticides are profitable for the farmer, yet may have socially undesirable consequences. The question of optimum use then, is complex and of social importance leading to much concern with IPM.

Pesticide cost stands as another factor. In terms of variable costs of production in 1978, pesticide cost constituted 20.5 percent for cotton, 7.4 percent for wheat, 13.5 percent for corn, 12.1 percent for sorghum, 22.1 percent for soybeans, 23.7 percent for peanuts, and 10.3 percent for rice (USDA

TABLE 1. Percentage Changes in Prices Paid by U.S. Farmers to December 1980

	Changes from											
	1973 Annual	1974 Annual	1975 Annual	1976 Annual	1977 Annual	1978 Annual	1979 Annual	1980 Annual	1980 Jan.	1980 Apr.	1980 July	1980 Oct.
Wages	+ 86	+ 62	+ 50	+ 37	+ 27	+ 19	+ 9	+ 1	+ 7	+ 1	+ 1	0
Feed	+ 66	+ 37	+ 42	+ 39	+ 43	+ 45	+ 30	+ 16	+ 28	+ 27	+ 19	+ 6
Feeder Livestock	+ 47	+ 91	+110	+ 83	+ 78	+ 28	- 4	0	- 4	+ 4	+ 4	- 2
Seed	+ 89	+ 47	+ 29	+ 31	+ 21	+ 16	+ 10	+ 2	+ 7	+ 1	+ 1	0
Fertilizer	+142	+ 48	+ 14	+ 34	+ 36	+ 37	+ 26	+ 2	+ 11	+ 2	0	0
Agri. Chemicals	+ 74	+ 54	+ 14	+ 5	+ 17	+ 24	+ 22	+ 4	+ 21	+ 6	0	0
Fuels & Energy	+236	+145	+120	+108	+ 93	+ 84	+ 41	+ 3	+ 13	+ 2	+ 1	+ 2
Farm & Motor Supplies	+ 93	+ 57	+ 38	+ 41	+ 40	+ 35	+ 22	+ 5	+ 13	+ 7	+ 2	2
Autos & Trucks	+115	+ 94	+ 63	+ 47	+ 33	+ 26	+ 14	+ 8	+ 3	+ 11	+ 9	+ 9
Tractors & S.P. Mach.	+146	+109	+ 73	+ 55	+ 42	+ 30	+ 17	+ 4	+ 12	+ 6	+ 4	0
Other Machinery	+143	+113	+ 72	+ 50	+ 37	+ 27	+ 15	+ 4	+ 11	+ 6	+ 2	0
Buildings & Fencing	+105	+ 66	+ 46	+ 40	+ 31	+ 21	+ 11	+ 3	+ 6	+ 5	+ 3	+ 1
Services & Cash Rent	+107	+ 70	+ 42	+ 32	+ 22	+ 14	+ 6	0	0	0	0	0

SOURCE: Agricultural Prices, Crop Reporting Board, ESCS, USDA.

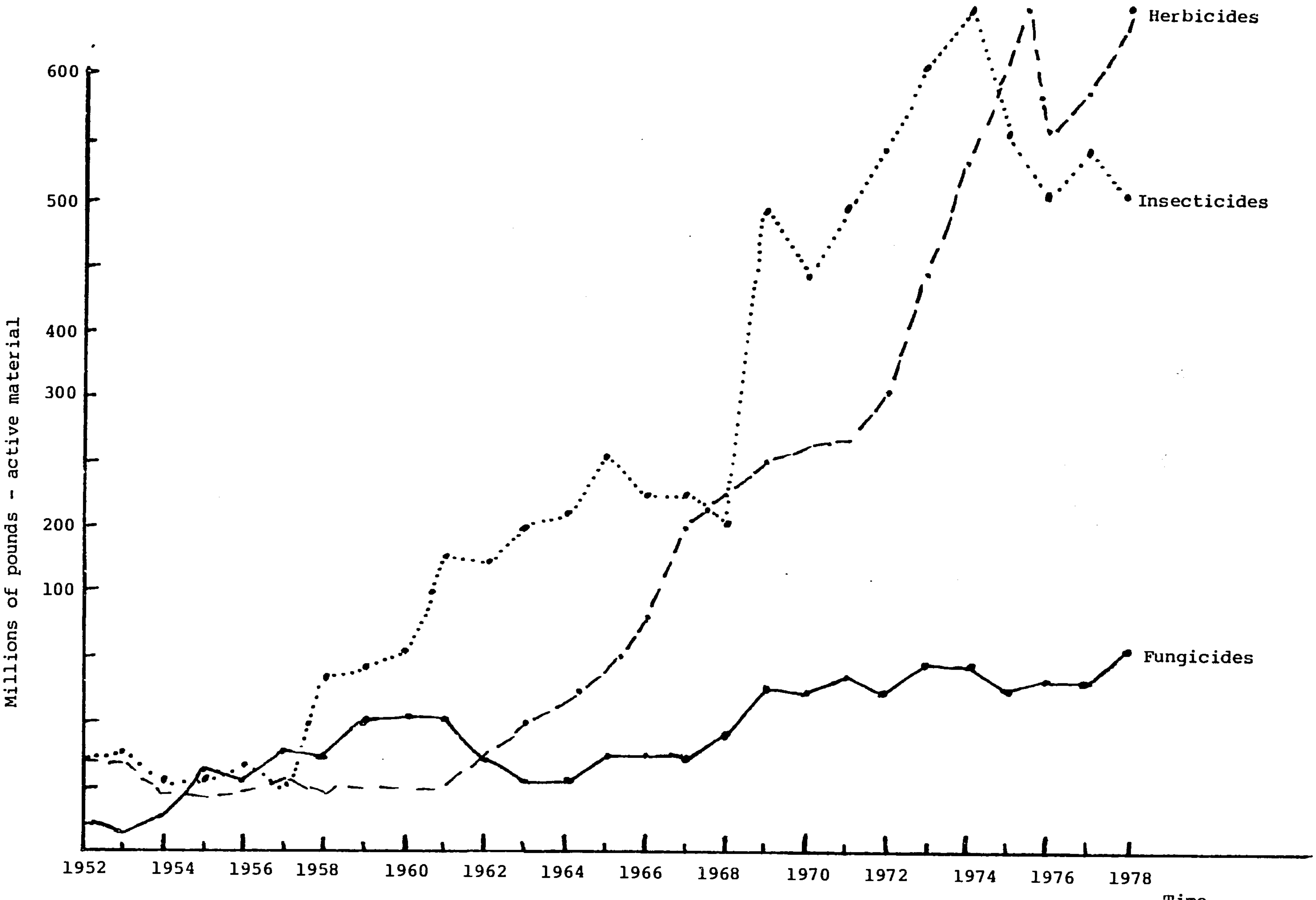

Figure I. Pesticide sales by class.

SOURCE: Carlson and Castle (1952-68) and USITCB Synthetic Organic Chemicals.

[1980]. Costs for use on fruit crops such as pears constitute as much as 25 percent of the variable cost. Considering fixed costs, these shares are relatively small and have led to wide use of pest controls. The relatively small share of total cost attributable to pesticides may not prevail as some entomologists expect a cost increase because of the increasing complexity of chemicals. Also, the immediate costs of IPM scouts are expected to fall because of wider availability of trained personnel. Thus, IPM interest has broadened.

Finally, pesticides have generated mainly consumer benefits through lower food costs; producers, in the longer run, likely have lost ground. The largest gains, in fact, flow to the low income consumer who spends the most on food (Taylor [1980], and McCarl [1981]).

WHAT IS BEST?

The benefits of agricultural pesticides, along with their spillover costs, have fostered IPM as an area of inquiry. In balance, total reliance on chemical control does not appear to be the most socially desirable course of action. Identification of the "best" course of action, however, is a difficult problem requiring study. When chemical pesticides were first introduced, little was mentioned or known about long-term impacts. Perhaps the same can now be said of non-chemical controls.

ANTI-PESTICIDE INITIATIVES

Strong anti-pesticide beliefs exist as evidenced by Rachel Carson's book Silent Spring and recent newspaper headlines about forest spraying. IPM thus has become a more important area of inquiry. Research must consider both the economic and environmental implications of using various crop protection strategies. A case may be established, in some situations, that spillover from chemical use has been extremely undesirable and raises substantial evidence for banning pesticides in these situations. The anti-pesticide movement has fostered IPM and may be the reason why IPM, in many cases, is identified with non-chemical controls.

INSTITUTIONAL FACTORS

The ultimate reasons for pest control can be summarized as: 1) an increase in the quantity and quality of food, 2) an accompanying lowering of food prices, and 3) a desire on the producers' behalf for an increase return. The social need for pest management derives from the demand for a quantity of low-priced, high-quality food. The private need relates to income enhancement and loss protection. Institutions enforce and reflect these needs. Numerous food items are faced with quality standards imposed by quarantines, grading requirements, marketing orders, etc. Many producers feel they must use pest control to sell their products under these standards (Pimentel, et al [1979]). Some institutions which contract with producers (e.g., crop insurance agencies, possibly some lenders, processing plants) require pest control performance. So the institutions, to some degree, mandate IPM.

GOVERNMENT

IPM's emergence can be credited in large measure to government and the accompanying political process. Government, through its policies, enters the pest management arena with many influences. Within the United States, the Environmental Protection Agency and its pesticide regulatory authority stand as an obvious example. The chemical cancellation and registration process has fostered the study of alternatives to chemical control. This regulatory process also has altered the economics of pesticide development by imposed evidence requirements that increase the cost of research and development.

Government also takes a direct role through public support of research directed at pest control alternatives and, in fact, has fostered IPM through research support. Further, the publicly supported Extension Service is involved in dissemination of pest control methods.

The governmental role, however, is not confined to its regulatory, research funding, and extension roles. Government actions also influence a number of other items, such as: a) crop choice (and thereby pest control demand), through such mechanisms as grain embargoes and farm programs, b) input supply (and thereby the substitution possibilities for pest control) through such mechanisms as job programs, minimum wages, energy price supports, and land retirement schemes, and c) intensification demand--through such things as land retirement schemes (which, it has been argued, directly increases the demand for pesticides, Headley [1972]).

Government, therefore, has stimulated the need to examine the aggregate consequences of decisions on pest management policy along with concerns as to the nature of policy that should be adopted.

FOOD AND INCOME

The last contributing factors mentioned here are food and income. The need for food has certainly led to a need for pest control. However, within the United States, the relative food security and small income share spent on food have led to more demand for "safe pest control" than is the case in other regions. When comparing IPM between countries, consideration of these factors is important.

SUMMARY

IPM exists and has become prominent because of many factors, all of which help provide background for the "IPM problem." Several objectives appear to be present, not all of them consistent:

1. Produce maximum food.
2. Produce high quality food.
3. Produce cheap food.
4. Allow farmers to make a satisfactory income (relative to non-farmers).
5. Minimize environmental degradation from pest control.

SECTION III

ECONOMIC, TECHNICAL, INSTITUTIONAL, AND ENVIRONMENTAL ASPECTS OF IPM AND IPM ASSOCIATED POLICY

Many issues are involved in the development, encouragement, use, or restriction of IPM strategies. Before beginning the literature review, it is worthwhile to present the issues involved so the contribution and relevance of the literature can be judged. This section will present these issues, concentrating on economic, technical, institutional, and environmental issues relevant to IPM. References are not entered but are held until after the review portion in the section, appraising the literature versus the issues.

ECONOMIC ASPECTS

Of the numerous issues to consider when examining IPM, the discussion begins with the more aggregate ones and works toward microeconomic issues. The ordering does not imply importance.

Welfare

Fundamentally, all decision-making related to the formation of public policy has at its heart the improvement of "public welfare." Unfortunately, in the IPM area, decisions generally do not lead to "Pareto Optimal" results (i.e., a decision made where all parties realize benefits). Virtually any conceivable IPM action will harm someone (consumers, producers, pesticide manufacturers, environmentalists, etc.) in terms of their perceived welfare. Also, there is a problem in quantitative definition of welfare. To sensibly consider one alternative against another, the costs and benefits of one action must be compared with the costs and benefits of the other. This implies the need for a common measure of value for the various cost and benefit components. The demand function for many potential dimensions of welfare, however, is not often revealed or known in practical cases (e.g., risk of loss of human life, release of cancer-causing agents, changes in soil erosion, build-up of chemical residues, change in aggregate farm income, or change in consumer price index).

Thus, several issues arise in IPM studies: 1) What are the appropriate dimensions of welfare? 2) How should these welfare characteristics be measured? 3) How should (or can) they be valued? 4) For those impacts which can and/or cannot be valued, how should they be presented to permit informed decision-making? 5) Who makes the decision? 6) What have been the welfare costs and benefits of the use of IPM? 7) When should undesirable features be tolerated to achieve other desirable results (for example, in a developing country, should the undesirable effects of DDT be tolerated so food availability is increased and starvation reduced)?

Distributional Concerns

Pest management situations often may be correlated with such factors as: 1) managerial ability, 2) quality and quantity of land, 3) production system, 4) location, and 5) farm capitalization. Consumers of products that use pesticides can be classified into groups using such factors as: 1) income level, 2) location, 3) percentage of income spent on food, 4) food preferences, etc. If "Pareto Optimal" decisions cannot be made (as alluded to above), some groups within these strata will be relatively advantaged and/or disadvantaged by a decision. Further, the distribution of impacts will change over time. Several issues which arise in an IPM study context are:

1. How are gains and/or losses distributed between various classes of people (for example, considering trade-offs between consumers and producers)?
2. How are gains and/or losses distributed regionally, commodity-wise, or among factor owners?
3. What might be the impact of an action in terms of strata within a class (e.g., farm size or income distribution)?
4. How do the distributional effects change with time?

Locus of Comparative Advantage

The location and incidence of pest problems are not regionally uniform. The development of pest management strategies or policies would seem to influence the regional distribution of production and factor usage either quantitatively or qualitatively. This would be true especially where pests or IPM strategies are location specific. Pest management actions would then have implications for the ability of regions to compete against one another, thereby altering the interregional distribution of welfare, income, and resource usage as well as the location, conduct, and performance of service industries (transportation, processing, etc.). Thus, IPM issues are: what are the differential regional impacts of an IPM strategy, and, what impacts will an IPM strategy have on the location of production?

Induced Impacts

The incidence of pests can radically alter economic activity within the agricultural production sector. This, however, is not the only result. The production sector obviously interacts with other sectors within an economy. The impact on these sectors also potentially can alter the interregional terms of trade. Several issues, in terms of economic relations within regions and trade between regions, can be stated.

1. Within a region, a) what are the induced effects of an IPM action upon the economy, and a related issue, b) is study of induced effects within a region worthwhile (at what level of aggregation)?
2. Between regions, what are the changes in trade patterns, capital flows, etc. (again, should these be studied)?
3. Across regions, how are the induced effects of IPM distributed and are they worth studying?
4. How has the use of IPM strategies stimulated the location of production to shift (statically and dynamically)?

Spillover Impacts

The use of pest management strategies leads to many results other than the management of pests. These affect other individuals (the classical case of externalities) and other activities on the farm. For informed policy-making, such impacts must be identified, quantified, and valued, if possible. These spillovers may be either undesirable or desirable. Further, their exact nature is usually uncertain. Some important types of spillovers are:

1. Effects on non-target species (direct and through residues) such as humans, non-target insects, animals, and plants.
2. Changes in the farm production function, both short and long run, stemming from IPM strategy use. For example, changes may occur in the level of yield, pest incidence, natural control capability (i.e., predators), and/or pest resurgence capability.

3. Adjustments in farm resource use and product mix.
4. Changes in environmental quality through chemical runoff or soil erosion.
5. Shifts in pest resistance and/or prevalent population.

In addition to discovering the scope of indirect effects, there is the question of reflecting back their true economic cost to the pest management strategy user. Restrictive regulations accomplish this by prohibiting use; however, other mechanisms (i.e., taxes and subsidies) may be involved. Finally, "biological" controls (or controls which do not rely solely on pesticides) have recently been strongly advocated, particularly as they will "remove" spillover impacts. This may not be true. Thus, issues in IPM are:

1. What is the economic consequence of the indirect effects embodied within an IPM strategy?
2. How can IPM users learn the true costs of the effects from their strategy decision (particularly in the case of undesirable spillovers)?
3. What are the spillover effects of non-chemical (biological, cultural, etc.) controls?

Markets for Agricultural Inputs

An important consideration for IPM studies (especially those involving aggregate impacts) is the effect on agricultural input markets of an IPM action. Agriculture consumes at least four inputs: land, labor, capital, and water, in direct (and active) competition with the non-agricultural sector. Each of these inputs clearly has alternative uses. Changes in demand for these inputs should be examined in terms of the inputs' alternative usages and in terms of prices. A set of illustrative alternative usages for major inputs follows.

1. Land

   a. Other agricultural use (i.e., substitute enterprises)
   b. Extensive usage in agriculture (livestock, fallow systems)
   c. Recreational use
   d. Greenbelts
   e. Residential or industrial use
   f. Mini farms (5 acres)
   g. Small farms (dissolution of large farms)
   h. Idle
   i. Diverted or retired under a farm program.

2. Labor

    a. Unemployed (possibly supported by a relief program)
    b. Out- or in-migration from other sectors or regions
    c. Underemployment
    d. Shift in quality dimension (migrant labor)
    e. Other agricultural usages
    f. Temporary (hired labor)

3. Capital

    a. Non-agricultural use
    b. Idle in short run
    c. Other agricultural use

4. Water

    a. Other agricultural use
    b. Recreational use
    c. Power generation
    d. Down-stream agricultural use
    e. Fisheries use
    f. Idle
    g. Aquifer replenishment (underground water to be used elsewhere).

Other inputs also should be considered when relevant. Potentially included would be energy, fertilizer, pesticides, scouting services, and farm machinery (which may or may not be regarded as subsets of the above categories).

Distributional impacts of changes in usage and input returns should not be ignored. In some settings, usage of and returns to inputs may be one of the key elements in an IPM strategy evaluation (consider labor in a lesser developed country).

The important issues then, are: a) When an IPM strategy is to be introduced and/or modified, how will input usage change? b) What shifting in inputs among various usages occurs? c) What happens to input prices? d) How are returns to input owners altered?

Time Rate of Social Preference

IPM method development, adoption, obsolescence, and/or regulation will occur over time, as will the resulting spillover effects. Similarly, welfare distribution will change over time. Thus, major issues in benefit and cost formation are: 1) What is the social preference for costs and benefits as they arise over time, and, 2) What is the time sequence of impacts involved with an IPM-related change? The issue involves not only the consequences of strategies, but also the profitability of research and development efforts and the comparison of current expenditures weighted against future benefits and costs. The question of future generations' welfare is intimately involved.

Quality and Grading

Although most theoretical economic inquiries assume homogeneous products, the market certainly discriminates on the basis of quality. Many dimensions of quality, in fact, are pest related; for example, consider quarantines, and insects or blemishes on fruit. One economic issue here involves whether grading systems, quarantines, marketing orders, and/or grower agreements which enforce quality standards are socially desirable considering the trade-offs between quality and spillovers created by IPM strategy use (more detail on this topic is considered under institutions below). A further issue is consumer acceptance of food as quality standards change.

Research and Development

The economics of IPM method development possesses interesting aspects. IPM method development clearly requires investment. Yet, once developed, many IPM methods (particularly some non-chemical controls) become public goods. It is difficult for any individual to fully capture the value of an IPM strategy. Some techniques would spread from individual to individual without adverse impacts upon availability to others (i.e., cultivation or scouting techniques). Supply of such an IPM strategy, then, would likely fall into public hands.

The public-good characteristics within non-chemical IPM are different from the problem in the pesticide arena. With pesticides, the gains have been captured by branding and patents. The relevant question then becomes: Is there sufficient public and private investment in IPM strategies? An answer would need to consider many issues such as the determination of the value of an IPM strategy and assessment of the demand for pest management. A further question can be posed: Are research and development expenditures on non-chemical IPM methods desirable from a social viewpoint?

Within the research and development area, a second major issue arises involving the interactions of regulatory and development activities. Private firms must make a return on their investments, research and development being one of these. The increased regulatory burden makes research and development of pesticides more expensive. This fact suggests concentration on larger markets that discriminate against narrow spectrum specific pesticides. Again, the issue, considering the regulatory burden versus social costs, focuses on whether research is proceeding at a socially desirable rate.

Farm Level Decision-Making

For an IPM strategy to be successful, it must enter the farm level decision-making process and be adopted as the course of action. Adoption will occur because a strategy ranks highest within a possible set of actions. An IPM strategy will be adopted, then, either because of profitability or because of constraints imposed. IPM strategies must be defined with this in mind. The issues involved are:

1. What dimensions of the farmers' perceived welfare are affected by IPM strategies? Examples would include profit, short-run risk, soil erosion, and long-run risk.
2. How are these dimensions valued by farmers in choosing the strategy to employ?
3. Does the resource usage pattern of the pest control match up with the resource usage and opportunity values of resources on the farm?
4. Which one of a set of strategies is "best" from a social standpoint (and what is "best")?
5. How may strategies be developed which will be "best" socially and privately; or how may an IPM strategy be efficiently imposed, if desired?

Technology Adoption - Rejection and Obsolescence

As alluded to above, farm level incentives to undertake or reject a strategy are important. An important issue above and beyond this involves the rate of technology adoption. The issues here involve asking at what rate will a proposed technology be adopted, and, at what rate will it later become obsolete? A question related to these is: What types of conditions facilitate technology adoption?

Risk Management

Farmers behave in different ways under exposure to risk. The prophylactic use of pesticides is potentially a risk-reducing strategy compared to some other types of methods. The issues involved here are: what is the long- and short-run exposure to risk under an IPM strategy? More importantly, what will be the expected farmer response? Economic issues also can be developed involving the potential for interjecting risk-reducing factors into the pesticide arena (i.e., pest insurance) as either a substitute or a complement to improved techniques (this issue is addressed in the Institutions section).

Pest Intervention and Information

One possible approach to restricting the use of "overused" pesticides is to substitute information-gathering activities for pesticide use, thus using pesticides only when necessary. The issues then involve how information is to be developed and when to act.

1. How does one find out the relative incidence of pests and the likelihood of an outbreak in an economic fashion?
2. How does one know, given an incidence and likelihood of an outbreak, when to intervene (i.e., treat the pests) and with what method?
3. Since pest populations often include several pests and/or predators, how should predators and pests be considered in management practices?
4. When is it sensible to eradicate?

Taken simultaneously, these issues involve the economics of information-gathering and the so-called economic threshold.

An additional information point relates to traditional extension program design, and the question: what is the most effective method of conveying an IPM strategy to farmers so that it receives proper consideration in the decision-making process?

Farmer Spillovers

The majority of farmers user integrated pest management. With chemical controls, problems have occurred when mobile pests or treatments have drifted, affecting adjacent farmers. Farmers applying pesticides, therefore, face benefits and costs associated with their pesticide expenditures that differ in many cases from society's total benefits and costs. Adjacent farmers, for example, may have had predators destroyed; these farmers then would be forced to change in their control strategy. On the other hand, some adjacent farmers have received benefits at zero cost (significant negative impacts also have been recorded on such parties as beekeepers). Such impacts easily could cause farmers to invest in controls at a rate different from the social optimum.

A potential issue in the farm use of non-chemical pest control measures relates to control mobility. Controls such as mobile predators or scouting information are potentially mobile. Thus, a farmer using these controls (when acting solely on an individual basis) may have to purchase more of the control than necessary. Examples here would be a situation in which 30 percent of the moths used as a biological control agent migrate to fields off-farm giving adjacent farmers a "free ride", and forcing the initial farm to purchase extra moths; or a scout says "treat now," and all surrounding farmers also use this information. The farmer hiring the scout, in effect, has subsidized his neighbors. The basic contention is that some non-chemicals are more mobile than chemical controls (drift certainly exists, but probably not to the same extent). Thus, farmers may be more likely to under-utilize non-chemical controls than they would chemical controls. This factor also seems to bias decision-making toward chemical controls.

Spillovers also occur with chemical pest controls (and possibly others) when a farmer's long run production is altered by the action of such things as residues retained in the soil, predator-secondary pest infestations, or resistance development. Spillover issues in terms of pollution, environmental degradation, etc., also must be considered.

The essential economic issues involved here are:

1. What relation exists between the benefits and costs a farmer receives, and the full benefits and costs of pest treatments?
2. More generally, how can the true cost/value of the use of an IPM strategy be reflected on the farm decision maker?

Scale Economies of Control Use

A question regarding the use of pest controls, especially across farms, but also in terms of use on a farm, involves potential scale (and/or size) economies of application. There is a fixed cost to apply a quantity of a chemical and a variable cost of quantity applied. Thus, applying quantity 2X an acre does not cost twice that of applying X. Scale economies potentially also exist when applying, for example, mobile pest controls (i.e., it is less expensive per acre to treat a large acreage than one acre). When mobile controls are prevalant (i.e., moths), multiple farm application strategies may be called for. Thus, the scale economic issues are: a) How should the fixed and variable components of application resources be considered in a decision, and b) What scale of operation is economically most efficient in applying various types of controls?

Diversification of Pest Controls

Pest controls exhibit different characteristics regarding kill efficiency, resistance development, toxicity to various pests, and performance variability. Therefore, should multiple pest controls be used simultaneously to achieve optimum control? This raises the economic question: Should this be done, and the technical question, Can it be done? Diversification of pest controls may be required or used to mitigate spillover impacts, and/or to treat multiple pests simultaneously.

Economic Interrelationships in Input Usage

Pest controls must fit with the overall farming system. The farming system conceptually takes multiple inputs (fertilizer, land, etc.), combines them, and creates multiple outputs. In such a system, the optimum level of any input is related to the optimum levels of all other inputs and outputs. The economic issues involved are:

1. How are pest management decisions related to other input supply and use conditions?
2. How are other input management decisions related to pest management decisions?
3. How do considerations of output level and demand enter these decisions?

Finally, there is the related issue involving the interrelationship of technical change and pest control usage, and the degree to which pesticide usage has allowed technical change to proceed along with the degree that technical change has stimulated pest control usage.

Substitution

One of the overriding factors within the context of IPM appraisals appears to be that of substitution. Clearly the cancellation of a pesticide can cause a series of substitution impacts. First, assuming a product requires a pesticide and that pesticide use significantly affects yields and thereby aggregate quantities and prices, the question of consumer product substitution arises, or, what products will the consumer substitute for a more expensive product? Complementary products also must be considered. Changes in relative prices, in all likelihood, also will lead to product substitution on the farm.

A second question relates to factor substitution. With a change in supply of an IPM strategy (IPMS), other IPMS's may be substituted either for or in place of it. Factor substitution also may be carried out through changes in product mix. The implicit broader question is: With an IPM action or restriction, what likely substitution impacts will occur on-farm in terms of pest treatment, factors of production, and products produced? The issues to be considered are: 1) What is the likely market impact of an IPMS? 2) What kinds of pest control method, factor, and farm production substitutions are likely to continue?

Regulation

Pest management is not devoid of regulation. Regulation is imposed as a technique to achieve increased social welfare, principally through distortions of markets to reflect the true cost of such things as externalities (the case of market failure). Regulations are a natural by-product of an unsatisfactory market solution, i.e., the existence of recognized socially "undesirable" spill-overs. Regulations consist largely of cancellations, licensing arrangements, and intricate registration or rebuttal review procedures. Some mandatory pest control measures also have been enacted, on noxious weeds in particular. A set of issues arises regarding the goals of the regulatory process, the impacts of the methods chosen (including regulatory impact and transaction costs), and the design of "optimal" regulation methods.

TECHNICAL ASPECTS

Although the issues above are broad and discussed at some length, there is an equally long, probably longer, detailed list of technical issues and/or factors which could be discussed. These are not as well understood by the author and, by necessity, will be much less complete. Discussion also will proceed in a more summary fashion. Topic selection is biased toward economic interrelationships.

Pest Treatment Methods

Many alternative pest treatment methods are available--use of a subset of these methods constitutes an IPM strategy. The essential issues involved are: What methods should be used? When should they be used? What quantities form the best pest treatment program on the farm from both an economic and technical view? Identification of methods, also an issue, predominantly rests in the physical scientists' arena. A second technical issue remains simply the need for impact information: What is the impact of an IPM strategy on crops, pests, resource use, and cost over time? Another concern: Can pest treatment methods effectively be combined to combat various problems (i.e., resistance, maintenance of natural controls, etc.)?

Pest Dynamics

Pest populations change in an interactive relationship with field conditions, weather, incidence of natural controls, IPM method, etc. These relationships must be understood for effective pest management. Thus, a key issue in IPM is: How can knowledge of pest incidence be used to develop an "optimal" pest treatment policy? IPM treatment designers require knowledge of pests and their relation to treatments as well as information on predators, secondary pests, etc.

Pest Interrelationships

Agricultural production often suffers from multiple pests interacting with each other. Hence, IPM must be sensitive to the form of the joint production function of pest damage considering multiple pests. Further, there is the issue of: How should pest interdependence be considered in treatment applications?

Treatment Effectiveness

Any analysis of IPM usage needs the response function of yield (or pest damage) to treatments. Lacking such information makes the analysis futile. The goal would be to determine how yield reacts to various treatment alternatives considering pest populations and environmental factors. A related point involves not only a static view of these responses, but also how they change over time. Rates of pest resistance development clearly are important. Finally, the interaction of the IPM strategy's effectiveness with other farming practices (i.e., fertilization, crop rotation, etc.) must be determined.

Crop-Li estock Dynamics

Immediate yield impact cannot be the sole focal point. Need exists to know how IPM strategy affects production performance in both the short and long run.

Risk

The impact of a pest management strategy must be examined in terms of yield and income stability, both in the short and long run.

Spillovers

One of the crucial issues involved in IPM is: What else does the IPM strategy do? Does it also affect non-target species, humans, land quality, water quality, etc.? Biological controls most likely have spillover impacts although the economic literature cited here does not greatly reflect this.

Pest-Predator Relationships and Resistance

Shortly after the development and ensuing use of DDT, entomologists reportedly (as mentioned in Stern) advised insect collectors that new insecticides were going to make many pest species extinct. Today that prediction has not come true. Instead, some pests have developed resistance to pesticides. Further, before pesticides were utilized, to some degree, pests were held in balance or were controlled naturally by predators. The use of pesticides has had some rather interesting impacts. Consider the following example: applying a pesticide extensively may destroy the majority of pests and their predators thus leading to selection of resistant pests and predators. The pest population is then small, but capable of expansion; food is still available and breeding has not been impaired. Resistant predators, on the other hand, find little food available and may die out. Pesticides can thus reduce the natural possibilities for control.

Consideration of how can, or should, resistance be incorporated into "optimal" application decisions, and the relationship of natural controls and IPM is essential.

INSTITUTIONAL ASPECTS

A careful enumeration of issues involved with IPM needs also to consider institutions. Institutions relate to pest management in at least three ways: there are institutions requiring pest management; there are institutions which have fostered the development of IPM, and, there are other institutions which play some role. All three appear to be important in any analysis, particularly where pest control substituting is anticipated.

Institutions Requiring Pest Management

Because of the nature of their operation, some farmers deal with institutions which require pest management. One example is the general federal and interstate agencies that grade agricultural products and impose quarantines in interstate commerce. Some grading standards directly concern pest damage or incidence, others indirectly, such as marketing orders. Quarantines on diseases or pests also are imposed. A similar type of institutional restriction involves quarantines or standards imposed by exporters or export agreements.

In a second group requiring pest control are those institutions contracting with growers. Growers, in contracting to sell their products to a processor (or marketing agent), frequently turn over some of the responsibilities for pest management to the processors' representatives. Grading standards imposed on the processor also enter here.

A third type of institutional arrangement involves crop insurance. Apparently before pest damage reimbursements are paid, some evidence of pest management must be shown. The allowable forms of evidence likely may be biased toward chemical controls.

The fourth example is not really an institution, but rather economies of size and specialization by processors. Economic size and prevailing location of processors influence specialization of farmers, which in turn encourages some pest populations and the need for treatment.

Within the institutional context here and below, the issues are: is the current set of standards "optimal" and, what will be the impact of changes in standards?

Institutions Fostering IPM

A discussion of the institutions fostering IPM must recognize those with regulatory functions. Action of EPA and other regulatory agencies has altered the demand for non-chemical or minimal chemical treatments. Through the registration and rebuttal processes, chemicals have been removed from the market, placed in danger of removal from the market, or kept off the market by the registration process. Further, the registration process, in part, has discriminated against chemicals which are exact substitutes (even though EPA is supposed to avoid making judgments of essentiality).[1/] On the other hand, EPA has made it more difficult for some IPM methods to be developed where the registration process has inhibited the development of narrow spectrum pesticides which could aid in IPM programs. Questions concern what is the impact of the current regulatory mix, and, with the objectives of regulations, what is the "optimum" regulatory strategy?

Environmental groups also have been a factor in IPM's rise to prominence. By raising questions about the safety of pesticide use, demand has been created for safer IPM methods.

Other Institutions

Other types of institutions may play a role within the IPM arena. Discussed below are insurers of pest damage, research sponsoring organizations, and the federal farm program.

One possible and important method of reducing the risk (or perceived risk) inherent in IPM strategies involves use of pest insurance, and pesticides appear

1/ This particular comment requires some reference. In a document concerning Amatraz (BAAM), Position Document 3 of USEPA Special Pesticide review decision, the argument is presented that Amatraz should not be registered on apples because such an action "would eliminate a small risk ... result in continued use of substitutes ... which (are) less hazardous, and ... have no effect on the economics of apple production." Further, the document states "since Amatraz costs more than the available alternative(s) use ... would probably have negative economic impacts." (page 64) The report also addresses briefly "separative" resistance impacts.

to be the most common form of insurance. An alternative is pest insurance; this is not being directly provided to the author's knowledge. However, all-risk crop insurance can be obtained. Can insurance be worked in as a substitute or a complement for IPM in the total pest management arena?

The institutions providing funds for the development and extension of IPM methods constitute a second important factor. Questions arise as to whether the regulations and practices influencing funding support, or its distribution, are sensible. Also what is the most efficient method to achieve the objectives of IPM through funding?

Yet another institution is the set of rules and regulations known as the "Farm Program." Farm programs frequently remove land from production and make it desirable to treat remaining land in a more capital intensive fashion. IPM is one of the forms of capital which allows more intensive management. An issue is: What is the impact of farm programs on IPM usage?

ENVIRONMENTAL ASPECTS

Clearly, environmental quality protection and degradation avoidance are crucial elements in IPM studies. In evaluating any IPM aspect, the effects on the environment through soil, water, or air pollution must be considered along with the impacts on human health and wildlife.

Indirect matters--recreation as it competes with agriculture; fisheries as affected by water pollution; soil runoff as influenced by crop culture; activities of multiple insect populations (i.e., bee pollination) as affected by IPM strategies--also must be considered.

SUMMARY

Many issues are important, but from the economist's viewpoint, several points appear to be worth noting:

1. The scope for economic work is broad, involving activities which cut across the traditional areas within agricultural economics. Further, the bulk of the work is by nature interdisciplinary.
2. The economic issues are deeper than those embodied in the traditional request from the physical scientist for an economist to calculate profitability or provide information on the returns to a particular line of research.

3. IPM is a complex subject. Pest management technology has had both negative and positive effects on food and fiber production, pest incidence, environmental quality, etc. Such things as resistance, predators, and spillover impacts enter complex short and long run decision considerations. Further, because of the many actors (farmers, politicians, environmentalists), the decision-making process can be highly emotional. It truly appears to be an area in which relevant research can contribute.

SECTION IV
A REVIEW OF THE IPM ECONOMICS LITERATURE

Studies involving the economics of IPM methods have ranged through many problem focuses and research approaches. The brief taxonomy of these studies that follows has two major classifications: studies involving the design of strategies for farm level pest control; second, studies involving the aggregate impact of IPM methods and/or IPM policy actions.

Farm level pest control strategy design studies further divide into two major types: first, work that attempts to optimize control performance of a certain pest control strategy by identifying optimum timing and application rate; second, studies involving choice of a strategy from a competing set of strategies (or simply a comparison thereof).

Under the topic of aggregate impact fall studies involving benefits and costs of IPM strategies, studies which assess the benefits and costs of policy actions, studies which examine alternatives to pesticides, and studies which consider alternatives to pest management.

This section reviews these studies in some detail referencing the contributions in the area.

FARM LEVEL ECONOMICS

Attempts to study the economics of pest management at the farm level have been numerous. Efforts that investigate optimal application strategy and those comparing optimally designed strategies appear separately. Other sections will include data, methods, and a brief synthesis.

Design of an Optimal Strategy

Management of pests by a particular application strategy involves numerous factors. Economists have conducted limited studies in the area involving questions such as: When should a pesticide be applied (i.e., at what level of infestation), how much should be applied, and many other questions. At first, economic efforts seemed aimed principally at determining the so-called economic threshold (i.e., at what pest incidence should a pesticide be applied). Later research involved the impacts of exogenous factors on the application decision and its outcomes. The research has been voluminous, with many factors considered or mentioned.

Economic Threshold. The concept of economic threshold long has been discussed by entomologists (for example, Stern [1966], and Smith [1971]). Basically, the threshold concept refers to the level of population at which treatment should be employed, but it was not clearly defined economically until recently (Hillebrandt in her 1960 work approached the concept but did not address it). Headley [1972] began a discussion on the economic threshold with the definition that it is the "pest population that produces incremental damage equal to the cost of preventing that damage" [p. 105]. Headley's work did not address control strategy, but assumed this would be determined technically. The Headley work did conclude that eradication is not economically justified.

Hall and Norgaard [1973] reviewed Headley's work and mention that Headley's threshold really indicated "the level to which the pest population should be reduced" [p. 109] and that Headley did not address the point of when to control. Hall and Norgaard then went on to formulate a two-variable model which incorporated these factors, defining the threshold as the population level which maximizes profits when the optimum timing and quantity of pesticide are considered. The Hall and Norgaard effort is limited to a single application of a pesticide. Later work (such as Talpaz and Borosh) treated multiple pesticide usages; however, it departs somewhat from the threshold and will be discussed in the next section. Before leaving the topic, two other topics need to be discussed.

The fundamental method used to investigate economic threshold by the cited agricultural economists is the formulation and optimization, through Lagrangians, of a simple mathematical model of the pest crop system. The users of this sort of approach have stated that the models abstract greatly from reality ignoring many important features (for example, see Hall and Norgaard [1973, p. 201] or Shoemaker [1973, Part III]). Talpaz and Frisbee [1975], however, approach the threshold problem from a different viewpoint. They estimate a "positive" threshold in which the response curves are econometrically derived (previously done by Lee and Langham [1973]) and then derive a threshold using classical optimization. The econometric equation they use predicts yield as a function of crop age, pest incidence, and variety. A profit maximizing threshold was then derived considering output price and pesticide cost.

Quite a number of alternative definitions of the threshold have been developed, often quite different in concept. Stern [1973] defines the economic threshold as the density at which control measures should be used to prevent an increasing pest population from reaching economic injury level [p. 260]. Stern then defines the economic injury level as the lowest population density that will cause economic damage. Headley, however, as pointed out by Hall and Norgaard, presents a definition which gives the level to which the pest population should be reduced. However, Hall and Norgaard are not fully correct. Headley's work determines the "optimal" level of pests assuming the pests have once gotten to this level and assuming that control may be instantaneously, effectively applied without fixed cost. Headley mentions that any greater population is non-optimal (as is reduction to any lesser population) and thus presents a pest population which is to be maintained. This is both a minimum and a maximum (assuming the population has once attained the minimum).

These various definitions, and the controversy surrounding them, point out the need to consider three populations of pests. These are presented in a simplified fashion in Figure II. (Much more complexity could be introduced involving such things as stage of plant growth.) Point A presents a level of pests which generally has been called the economic injury level. Above this point the marginal cost of pest damage exceeds the marginal cost of pest treatment and is the maximum pest population tolerated (actually this is Headley's definition, also contrary to Hall and Norgaard). Point B is a point at which pest control action is initiated assuming a delay between action and response of time $t_i' - t_i$. This is the entomologists' so-called economic threshold and is the practical threshold that a farmer would use. Point C is the population to which the pests are reduced. Reduction to the pest population below this point is simply not economic.

General Pest Control. While the early economic work on pest control concentrated on economic thresholds, later work has focused on optimal pest control considering factors such as resistance, predators, risk, etc. The concept of threshold has not been strongly adhered to by economists (who have not looked for a threshold, but have investigated many factors on which it depends) and later work has examined the implications of various factors on pest control use.

Shoemaker [1973], in a series of three papers, defined a rather general two-part pest control model. The first part consisted of an operational model which considered pests, predators, crop damage, pest-predator growth and insecticide cost-effectiveness. The second part consisted of suggestions for the incorporation of time and weather, multiple crops, residues, age-sex of pest, multiple pests, detailed crop growth, multiple seasons, resistance, and uncertainty. Shoemaker's model has not been used empirically. The list of Shoemaker's factors and extensions, however, does, with some aggregation and expansion, provide the topic outline for an organized view of the literature. The discussion below therefore considers contributions in the areas of risk, resistance, multiple applications, pest-predator interrelationships, pest-crop dynamics, spillover impacts, biological controls, and other input usage.

Risk

Risk is one of the principal reasons for pest control (Norgaard [1976]). Hillebrandt [1960, Part II] apparently (the author has not seen this) was one of the first contributors. Later, Carlson [1969, 1970] formally incorporated uncertainty in the evaluation of pest alternatives in a Bayesian framework. Many others have stated that consideration of risk is important (e.g., Headley [1976], Newton and Leuschner [1975], Norgaard [1976], Webster [1977], Miranowski [1979]). Recently, Feder [1979] performed a study in which he shows that an increase in uncertainty leads to an increase in pesticide use [p. 99], i.e., that pesticides have an insurance value. Carlson [1979a, 1979b] has presented data showing that pesticide use may lead to increased long-run variability of income. This finding, however, has not been factored into the farm level decision models.

Resistance

Entomologists, as discussed above, have long recognized the development of resistant insects. Considering weeds, species appear which are tolerant of herbicides. Economists recognized this in the early 1970s (Carlson and Castle [1972]) and began to investigate (Hueth and Regev [1974], and Taylor and Headley [1975]). Hueth and Regev state that the optimal application of pesticides implies management of both the pest and its stock of susceptibility [p. 543]. They formulated a model in which the future stream of profit is maximized considering pest incidence, pest resistance, and crop production. Their main

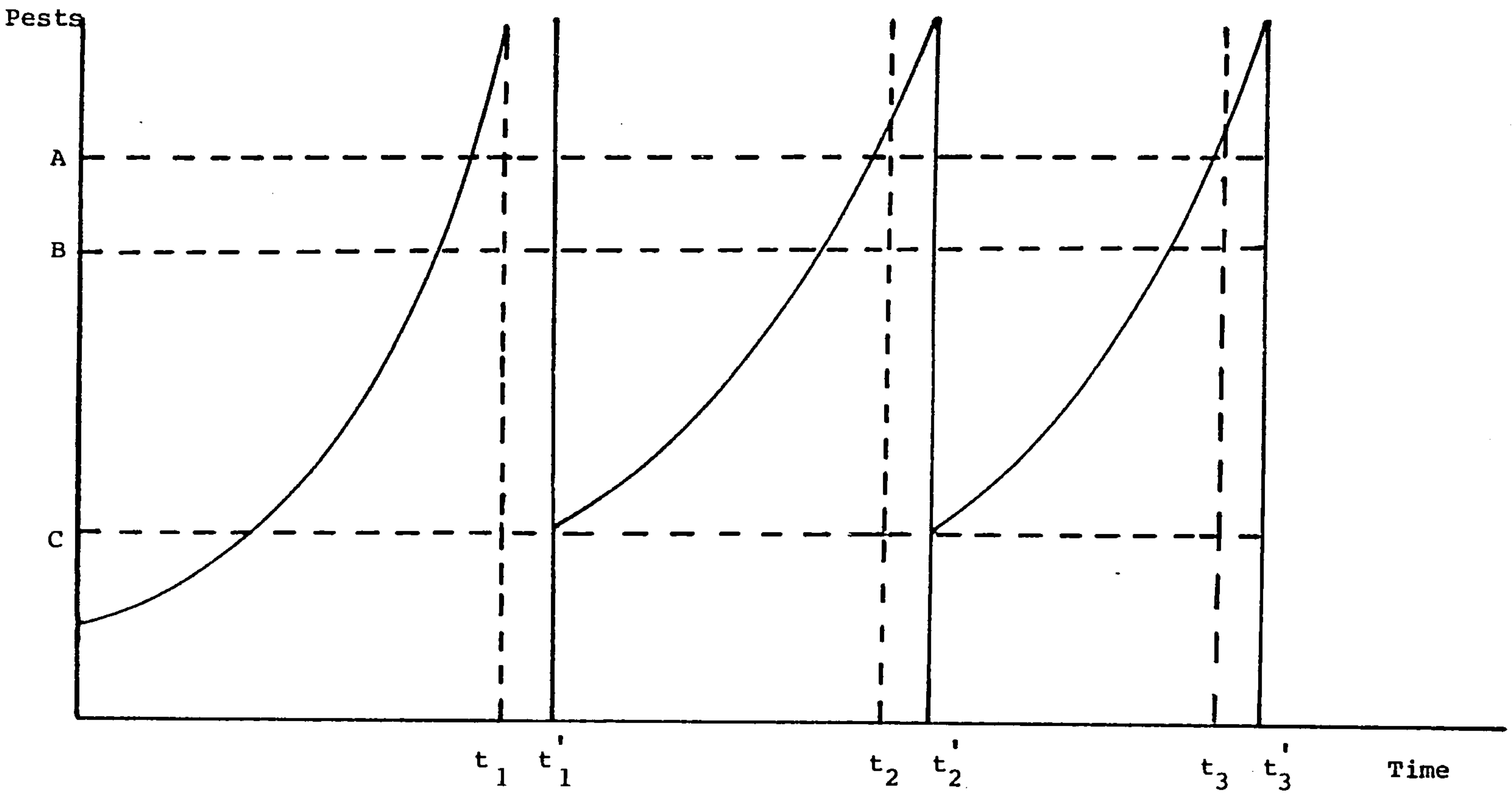

Figure II. A simple example of pest control.

conclusions, aside from suggesting their model for further use, are that 1) the economic threshold varies over time, 2) in some cases, the economic threshold increases with time, thus, more pests may be tolerated later in the growing season, 3) optimal pesticide use implies that marginal profits excluding susceptibility are equated to a user cost resulting from depletion of the stock of susceptibility (increases in resistance), and 4) only under very restrictive assumptions does the neglect of resistance result in overuse of chemicals.

Taylor and Headley [1975] also investigated the resistance question. Their efforts as published, however, consisted entirely of a suggested dynamic programming model and do not report any empirical findings. A more recent effort has been carried out by Regev, Shalit, and Gutierrez [1977]. This work apparently treats resistance in conjunction with the use of multiple pesticides.

The final inquiry the author found in the area of resistance is that of Carlson [1977] who states that if pest numbers are available and all other factors affecting crop yield are held constant, then changes in the marginal product of insectides will indicate a change in resistance. Carlson then estimates the production function for several points in time and discovers that for a given pesticide the marginal physical product has fallen substantially. Thus, he argues that resistance is important. Further, this shows that a natural consequence is that pest control costs will increase as time goes on. Carlson concludes his paper with observations that farmers underinvest in the common property pool of non-resistant pests and that regulation may be encouraging resistance by narrowing the pool of available treatment possibilities.

Multiple Treatments

Many farmers treat pests more than once during the season. Chatterjee [1973], Hueth and Regev [1974], and Talpaz and Borosh [1974] all presented economic models incorporating this feature at approximately the same time. Talpaz and Borosh deal with the multiple treatment case in more depth than the others and show in a simple example that, 1) multiple treatments were always employed; 2) ceterus paribus, the optimum number of treatments and quantity of pesticide fall as pesticide price increases, while the level of pests tolerated increases; 3) the number of treatments and total quantity applied increase as product price increases, while the number of insects tolerated falls; 4) the number of treatments falls as the fixed cost involved with a treatment increases but the optimum pesticide quantity employed is approximately constant with a few more insects tolerated, and 5) as the population growth rate after the first treatment increases, the number of applications fall, and the amount of pests tolerated along with the quantity of pesticides applied increases.

After the publication of these studies, analyses involving multiple applications became somewhat standard. Further discussion of results is held for other sections.

Pest-Predator Relationships

Many pests are subject to natural control by predators. The application of some pest control measures can reduce the population of predators. Shoemaker [1973], and Feder and Regev [1975] explicitly include this feature in their analyses. Shoemaker included predators as they relate to pests, factoring in survival and growth of both pest and predator along with their interrelationships. Shoemaker's results showed that the control decision is more sensitive to predator density than pest density. Feder and Regev followed Shoemaker and in a careful analysis concluded that a) an optimal decision rule for pesticide use would weigh marginal benefits with marginal costs of control plus the marginal costs arising from pest and predator stocks (residues also, although this topic will be discussed later), b) consideration of the predator impact provides theoretical support for empirical findings that pest populations may exceed pretreatment levels after initial successes [p. 84], and c) the decentralized solution by farmers may lead to socially non-optimal decision rules.

Pest-Crop Dynamics

Many pest control investigations have been performed. The models generally are simple mathematical models optimized through the use of mathematical analysis. The authors of these analyses generally have stated (e.g., Hall and Norgaard [1974]) that the models are too simple for realistic decision-making. However, starting with the paper by Regev, Gutierez, and Feder [1976], studies have used detailed pest-crop models attaching an economic objective function to determine optimal treatment. Their work involved a detailed model of the alfalfa weevil; secondary pests were also considered in a cursory manner (page 197 under pesticide cost). The model was solved for a steady state equilibrium. Conclusions were drawn relating to private versus socially optimum pesticide use. However, the objective functions used in the comparison appear to be improper (apparently it was assumed that individual farmers only look at single year implications of pest management, [Equation 10, p. 190] whereas, society looks at multiple year outcomes, [Equation 11]) although they do make some sense in a common property resource situation (individuals doing the best they can, but collectively generating a non-optimal social solution). The specific conclusions, therefore, will not be discussed (they do appear elsewhere in the literature) other than to note that time preference and consideration of common property nature of pests does alter treatment design. Regev, Gutierrez, and Feder do note that pesticides in their model are applied much earlier than in the real world and during the adult growth stage in the pest cycles.

After the Regev et al effort, Talpaz et al [1978] formulated a model which incorporated a complex pest-crop model for the cotton boll weevil. The pest-crop submodel in this case is a simulation type model and optimal pest control is simulated over 25 periods during a year. Conclusions from this work concentrated mainly on the model. A follow-up paper on this topic by Murty et al [1980] again dealt mainly with the model.

The final economic application with a detailed pest-crop model is that of Reichelderfer and Bender [1979]. This work involves a model of the Mexican bean beetle on soybeans. The model was used to simulate the impact of various control strategies. Biological controls were examined along with chemical controls. The paper's main conclusions (other than some on biological control, discussed below) related to the model.

Spillover Impacts

One characteristic of pesticides is their creation of "environmental externalities." Although these concepts are more frequently mentioned at the national or regional levels (e.g., Headley and Lewis [1967], Langham and Edwards [1969]) as will be discussed later, some researchers have tried to discover the farm level implications. Notable among the farm level investigations is the study by Feder and Regev [1975] in which the costs of environmental degradation were explicitly entered into the model. The conclusions were that a) there will be a divergence between social and private optimums, b) the costs considered in a social decision rule should include externality costs, c) that the stock nature of the externalities lead to non-optimal decisions and mandate public actions, and d) that a total ban on pesticides to gain these benefits could be disastrous.

Numerous other authors have mentioned the topic as an important subject or one needing further research (e.g., Shoemaker [1973], Murty, et al. [1980], Norgaard [1976a, b]).

Other Controls

Virtually all the studies reviewed have implicitly concentrated on pesticide use. Several other studies of farm level resources have examined the economics of other controls at the farm level. Taylor [1976] examined sterile male releases. His conclusions deal with the model developed, but only hypothetical results are presented. Hall [1977], Reichelderfer and Bender [1979], and Longworth and Rudd [1975] all studied other aspects of biological controls which will be discussed in the context of benefits below.

Other Inputs

Pest control measures enter the total production process on the farm. The optimum design of a pest control measure thus should mesh with the total production process. Classical production theory states that optimum use rates of all resources are interrelated. Most farm level pest control studies have held other inputs constant. Fox [1971] on the other hand presents, hypothetically, a multiple input case involving pest control and other inputs. His conclusions mainly relate to the need for an examination of these impacts. Lee and Langham [1973] also estimate a system where pesticide use is included along with other inputs (fertilizer, etc.); however, the study stopped with the model. Binswanger and Shelty [1977] also have studied this problem in a development context examining labor-pest control interactions.

Choice Between Strategies

Many factors considered important in the design of a strategy have been noted. Assuming the strategy will be used at some level and that its feasible alternative versions do not change resource use markedly, optimal design of a strategy can be accomplished in isolation. However, when comparing alternative strategies with different resource usage patterns, or when designing a strategy where the feasible alternative versions of the strategy imply significantly different resource usages, then the choice must be made within the total farm context. Further, in many pest applications, strategies may not be mutually exclusive and consideration must be given to strategy diversification. Resources, however, are not the only factors involved in the choice. Profitability and the additional concern of risk most assuredly are involved.

Economists have not been as active, at least in literature, in the choice area. This may be because most decisions have involved "best" entomological practices and, therefore, alternatives have not been present. The work done in the area can have a two-way classification applied. First, there have been studies simply comparing alternatives on financial criteria only and there have been studies of comparisons within the farm resource context. Second, there have been riskless studies and studies which incorporated risk.

Financial Studies - Risk Free. Many authors have done simple budgeting analysis in a risk-free environment. Quite a long series of USDA and EPA studies have examined the impact of possible regulatory actions, thereby considering the second best pesticide or pest control method. These studies are referenced under the regulatory analysis section. Studies also have been done by Reichelderfer [1979]; Reichelderfer and Bender [1978, 1979]; Hawkins, Slife, and Swanson [1977]; Salkin, Eidman, and Massey [1975]; Richardson and Badger [1974]; Longworth and Rudd [1975]; and Carlson and Main [1976]. Virtually all these studies utilized some form of simple budgeting and chose appropriate strategies.

Among the important statements and conclusions seem to be: 1) crop rotations do not greatly change herbicide expenditures or productivity on corn and soybeans (Hawkins, Slife, and Swanson [1977], p. 11); 2) use of substitute (i.e., alternating) pest control measures affects the life of a control measure in situations with resistance (Carlson and Main [1976], p. 391); 3) socially preferred pest strategies should not only be compared on direct economic grounds, but also on environmental grounds (i.e., value or cost of changes in degradation) and a weighting should be attempted to get total impact (Richardson and Badger [1974]); 4) results involving biological controls on pecans suggest an increase in net returns is possible with a decrease in pesticide use (Reichelderfer [1979]);

5) biological controls on soybeans appear to be economically feasible and adoptable (Reichelderfer and Bender [1979], p. 265); and 6) it may be profitable to augment natural controls with pesticides at the latter part of the growing season (Longworth and Rudd [1975]).

Financial Studies - Risk. Risk is an important factor in the adoption of pest management strategies. Some have suggested that risk is one of the dominant features in the adoption of active pest management (e.g., Norgaard [1976a, b]). Early studies of risk in pest management by Carlson [1969a, b, 1970] set up a Bayesian decision framework to choose a pest control strategy from alternatives. Carlson suggests in earlier papers [1970] that risk be included and presents results on the costs of bad decisions. In later papers, Carlson [1979] states that stabilization is a consequence of pest controls and suggests that a switch to scouting type techniques probably leads to more stability [p. 31] which is the earlier conclusion of Hall [1977].

Risk incorporation in models involving technology choice has received a lot of attention, although this attention most often involves simply a discussion of the issues (Headley [1975], Norgaard [1976], Newton and Leuschner [1975], and Webster [1977]). Miranowski [1979] shows risk differences among alternative strategies.

Resource Studies - Risk Free. When pesticide strategies imply differences in farm resource use, the proper perspective is from the context of the farming system. Economists have not been quite as active here and in a lot of cases appear to have ignored the question. Studies, however, have been done by Delvo [1971], and Cashman [1980] (also reported in Cashman, Martin, and McCarl [1980a, b, c]). The results of these studies are rather specific and the conclusions are not really generalizable. Significant changes in the factor returns (shadow prices) were found by Cashman which implies that ignoring resource availability is tenuous when considering alternative pest control measures in the cornbelt.

Resource Studies - Risk. The least studied of all the pest control choice areas appears to be the consideration of controls within the farm under risk. Contributions here are Cashman [1980], and O'Brien [1980]. Cashman's conclusions state that risk is not a terribly important concern. However, this may be because of the uniformity of controls considered (chemical only) in his work. O'Brien shows that risk is important in a developing agriculture (Philippines).

Data

Data considerations enter this review in two ways. First, are data needs then data synthesis methods. This section considers a list of data needed to carry out a farm level study, then discusses ways the data have been synthesized for economic studies.

Principal data needs may be separated into several categories; they all should be considered in a study, although not all these items may be necessary. The first category is data for the pest-crop system (Table 2). In this category, as in the data needs mentioned below, data are required for both the level and variability of the items and/or functional relations. The second category (Table 3) is pest control-pest-crop system interactions. The third category (Table 4) is the pest control-environmental interaction. The fourth category is the farm decision system (Table 5).

Data may be developed for a study through either experiments (as used in Hawkins, Slife, and Swanson [1975], Reichelderfer [1979], Cashman [1980]); statistics--through a survey (as in Talpaz and Frisbee [1975]); or expert opinions (as in many of the regulatory studies, e.g., Casey and Lacewell [1974]; also, Sackman [1976]).

Once obtained, data may be incorporated in the model directly or indirectly via estimated single equations (e.g., Talpaz and Frisbee [1975]), simultaneous systems of equations (e.g., Lee and Langham [1973] or Sarhan, Howitt, and Moore [1979]), through simulation models (as in Reichelderfer and Bender [1979], or Murty et al [1980]) and/or through calculation and approximation techniques (Cashman [1980]). General theory on the equation estimation methods is given in Intrilligator [1979]. Rausser and Johnson [1978] present a review of simulation. Data based on biological theory also may be directly incorporated (review in Ruesnik [1976]).

Methods

Many methods have been used in farm level studies. These methods fall into virtually all categories of economic analytical tools. Some broad characterizations are presented below with sample references to both theory and application and a brief set of advantages and disadvantages.

TABLE 2
PEST-CROP SYSTEM FARM LEVEL DATA NEEDS

Pests in Isolation

Types and initial incidence
Growth rate and major variables influencing growth
Natural controls active
Potential secondary pests
Growth of predators, natural controls, etc.
Inter-specific and intra-specific competition

Crops in Isolation

Yield response to various inputs
Prices of outputs and inputs
Relation to other crops on farm

Pest-Crop Interaction

Crop damage by various pests
Yield impacts of damage
Quality and/or price impacts of damage
Dynamics of interaction
Dynamics of damage and inter- or intra-specific competition

TABLE 3
PEST CONTROL-PEST-CROP SYSTEM FARM LEVEL DATA NEEDS

Pest Control Methods

- Possible practices (chemical and non-chemica
- Suggested practices
- Technical details on practices
- Costs of methods

Control Impact on Pests

- Mortality of pests, secondary pests, and predators
- Resistance development or resistant species in-migration
- Impacts of alternative timing of treatments
- Dynamics of populations after treatment
- Mobility of pests
- Control method interactions

Crop Impacts

- Residue uptake
- Long run yield impact

Resource Usage

- Land, labor, water, etc.
- Required degree of careful management

Profitability

- Short run
- Long run

TABLE 4
PEST CONTROL-ENVIRONMENT FARM LEVEL DATA NEEDS

Environmental Degradation in Short and Long Run
Soil
Water
Air
Non-target Species Impact
Human connection
Beneficial insects
Other animals
Crops and/or other agricultural activities on farm
Other External Impacts on Neighboring Farms

TABLE 5
FARM DECISION SYSTEM FARM LEVEL DATA NEEDS

Objectives
Weights and trade-offs between profit, risk, and externalities
Other objectives
Perceptions of Environmental Externalities and Attention Paid Them
Constraints and Resources
Seasonal value of resources
Resource limits
External limitations on pest control choice
Responsiveness
Response to risk
Willingness and ability to shift crop acreage
Ability to assume difficult management tasks
Technical Data
Resource usage of various crops
Policy Environment
Probable pest policies

The first method employed in farm level studies is classical optimization. Taking Headley [1972] as an example, an abstract model of the pest management technique is formulated, with an objective function attached. Optimization is then carried out through the use of Lagrangians (Hadley [1964] provides a good theoretical discussion) usually ignoring non-negativity (the Kuhn-Tucker conditions, as discussed in Hadley, would permit one to relax this assumption). The determined, analytical results are then discussed in terms of impacts on the pest treatment method (Feder and Regev [1975] is a good example of a study using this method).

The advantages of such an approach are that analytical results can be presented without real data problems and the properties of the model can be rigorously investigated. The disadvantages are that very simple pest-crop models must be treated in this manner. Thus, the studies are limited to a subset of the problem or the model becomes very difficult to deal with analytically. Further, the analytical nature tends to lead the researcher to only analytically tractable functional forms which do not necessarily correspond to reality. These models also generally are static-ignoring dynamics. Further validation is generally not possible.

The second method employed is that of optimal control theory. Although optimal control can be handled numerically, only analytical analyses are discussed (actually numerical versions have not appeared in the IPM literature). The classical case involving optimal control use in IPM is the study by Hueth and Regev [1974]. A model is formulated in a dynamic setting, the maximum principal applied, and optimal behavior determined (Clark [1979] presents a useful discussion of this technique). Advantages and disadvantages of this device as an analytical tool encompass those mentioned under classical optimization above. However, this technique accounts for dynamic behavior and is difficult to deal with analytically, requiring relatively simple models. Validation is again not usually even considered.

The third method which has been employed is a set of methods called numerical mathematical programming. The techniques used have been linear programming (Cashman [1980]), non-linear programming (Regev, Gutierriz, and Feder [1976]; or Talpaz _et al_ [1978]), and dynamic programming (Shoemaker [1973], or Taylor and Headley [1975]). These techniques employ a model of the pest-crop system which is numerically specified and optimized using standard algorithms. All these techniques require that data be matched to the model and, therefore, do not yield analytical results and general conclusions (except when, say, the Kuhn-Tucker theory is used to characterize the optimum solution). Some validation exercises may be attempted, however.

Linear programming (well reviewed in Hillier and Lieberman [1977]) requires all relationships to be cast in a linear form, thereby, in some cases, making it difficult to handle realistic relationships. Consideration of dynamics also requires simplifying equilibrium assumptions or leads to large models. Its advantages lie principally in its computational tractability and familiarity to many practitioners. Risk also may be included, as discussed in Anderson, Dillon, and Hardaker [1977].

Non-linear programming is an extension of linear programming with non-linear relationships permitted. It is applied to IPM studies in one of two ways: either a non-linear model is formulated, numerically specified, and then optimized, as in Regev, Gutierrez, and Feder [1976], or a submodel (often a simulation) is formulated which interacts with optimization technique numerically in the quest for an optimum, as done in Talpaz et al [1978]. This general class of optimization techniques is reviewed in Powell [1972]). The advantages and disadvantages of such techniques are similar to linear programming above, however, a) non-linear relationships may be handled, b) a major difficulty is the potential existence of local optimum solutions (Murty et al [1980]), and c) the models, especially larger ones, are potentially difficult to solve.

Dynamic programming (well reviewed as a technique in Nemhausser [1966]) is another technique used in IPM economic studies. It explicitly treats the dynamics involved in the IPM situation. Again, a numerical model is required; however, standard algorithms are not available for optimization (although optimality conditions are). Thus, problems may be difficult to solve if formulated this way.

The fourth method reviewed here is that of stochastic dominance. Stochastic dominance allows comparison of various alternatives without an explicit objective function, but with general assumptions on the decision makers' objective function (e.g., the decision maker prefers more profit to less, less risk to more, and is willing to take more risk as income increases). The technique was used by Cashman [1980] in screening alternative treatment methods using results of their multi-year performance. The advantages of this technique (well described and discussed in Anderson [1974]) are simplicity and reliance upon simple decision rules. Disadvantages lie in the fact that it is often difficult to establish dominance among distributions (Meyer [1977] provides a stronger form) and in the fact that it ignores covariance (amplified in McCarl and Tice).

The final optimization type technique mentioned here falls in the general area of decision theory (Schleiffer [1969]). Decision theory explicitly treats the uncertainty involved within the decision at hand (e.g., pest outbreaks, treatment efficiency, etc.). External factors (expert judgment, new information, etc.) also are included in the situation through Bayesian techniques (Carlson [1970] gives an IPM application along these lines). The advantages of this analysis lie in its consideration of uncertainty, its disadvantages in the difficulty of developing probabilities. One other shortcoming is the difficulty in explicitly including resource constraints (this, however, is done in discrete stochastic programming as described by Rae [1971a, b], and as used by O'Brien [1980]).

In addition to the optimization methods which have been used, comparative budgeting has been used to find the "best." Reichelderfer [1979] provides an example.

Synthesis

An overview of IPM farm level economics literature leads to observations on what is known (and several observations on what is not known although these will be held for the last section). Preconditioning these observations, is the fact that the literature, as it evolved, seems dominated by insecticide concerns. The vast preponderance of studies involve insects. Further, the applied literature has been confined to a few crops--cotton, alfalfa, corn, pecans, and soybeans, in particular. This, however, is consistent with the concentration of damage as discussed above. These preconditions aside, some observations can be made on the shape of the literature.

1. Economic thresholds were an early concept mentioned prominently by technical personnel involved in the pest arena. Economists entered this discussion with Headley [1972]. However, economic use of the term seems to have diminished.
2. One reason for lessened interest in the economic threshold concept seems to be difficulty of definition. The most appealing definition is the pest population at which to treat. Other definitions also have included the population at which "economic damage" occurs or the population to which pests are reduced.
3. Another reason for lessened interest in the economic threshold is its impractical nature. The optimal pest population has been seen to depend on many factors: a) dynamic factors, such as pest population growth rate, pest growth stages, crop growth, and pest migration rate; b) economic factors, such as pest control price, crop price, and, more generally, other input costs; c) pest-crop relationships including yield impact of damage at various times; d) pest control-pest relationships, such as kill efficiency over time, resistance development (or in-migration of resistant species); e) pest control-environmental interrelationships seen as destruction of non-target species, creation of undesirable residues--in general, spillovers into the ecosystem; f) pest control-predator interrelationships taking in destruction of natural controls and encouragement of secondary pests; g) risk factors and risk attitude; h) availability of other controls which may be used during the year, and i) multi-year time preferences of decision makers.
4. The specific rules and items in a threshold to be considered are pest and location specific.
5. Thus, the threshold is not "the threshold," but is predicated upon many factors which can change almost daily.
6. The general concept of "optimum" application is important, but more complex than the concept of the "economic threshold." More work is certainly required on optimum application. (McCarl [1981c] discusses this point and those above at length.)
7. There is an expected divergence between social and private optimum usage of pest controls.
8. Generally, pest eradication is not an economic goal, but there are conditions which have not been explored when eradication may be called for.

9. Choice between pest control strategies may depend on the time availabilities of resources, along with the risk attitude of the decision maker and the exogenous constraints imposed.
10. The majority of economic research published either has been aimed at general principles or methods. Specific research on crops, pests, etc., has not appeared to any great extent. Either this research does not exist or, because of publication policies, has not found publication outlets.
11. In some cases, pest controls have been shown to lead to an increase in pest numbers in the long run because of destruction of predators and resistance.

AGGREGATE STUDIES

Aggregate studies are subdivided into four areas: studies involving the benefits and costs of pest control (these are looked at in aggregate for all controls, then in terms of control of specific pests); literature oriented toward developing information on costs and impacts of regulation; investigations of alternatives to pesticides; alternatives to pest control. After these review portions are sections on data and methods. Summaries are after each major section when appropriate.

Benefits and Costs of Pest Control

Economists have been active in pest control research for many years. In the late 1960s, starting with Headley [1968], they began making serious efforts to assess the benefits of pesticides. Others also have studied costs of externalities and benefits of pest elimination.

Benefits of Pest Control. Benefits from agricultural pest control may be measured in several ways. Fundamentally, measurement may rely on a) the value of increased output resulting from pesticide use, b) the value of resources released by pesticides, c) the indication of people's willingness to pay for pest treatment (these three are drawn from Carlson and Castle [1972], p. 81), or d) the amount of "social welfare" change brought about by changes in pesticide availability.

Value of Increased Output

Headley [1968] began work on pesticides benefits by estimating the marginal product of the pesticide input, accomplished by fitting a Cobb-Douglas production function to data from the 1963 United States Department of Agriculture farm income and expense series. The Cobb-Douglas function is then differentiated the marginal product of pesticides on an aggregate basis is approximately $4 benefit for $1 cost. Headley [1971] updated this study with data from the 1964 Pesticide Use Survey. Regional marginal products are estimated for insecticides and herbicides independently. Regional marginal benefit estimates are given which possess the economically satisfying conclusion that insecticide marginal productivity is least where the use is most intensive [p. 82]. Headley's herbicide results are largely inconclusive, perhaps because of on-farm possibilities for exact substitution--herbicides may only save effort and cost, not increase output. Thus, a production function approach would find no impact.

Fisher [1970] presents an analysis for Canadian apples, essentially an identical analysis to Headley's, and Campbell [1976] provides another study on tree fruit farms. The marginal value product of pesticides in this study was between $3 and $13 (Fisher) and $12 (Campbell) for a cost of $1.

Carlson [1977] also provides a similar study to Headley's [1971] study in which regional benefits and productivity over time are considered. Carlson's work, however, is limited to cotton insecticides. A major finding [p. 545] is that the marginal value product of cotton insecticides is in most instances (except California) falling. Ranges for marginal productivity per dollar spent on insecticides were 32 to 2 in 1964, 17 to 1 in 1966, and 26 to 0.25 in 1969. Generally, Carlson found the marginal products did fall by at least 50 percent.

Another line of benefit analysis is also present in work such as Pimentel et al [1978]. The total value of U.S. agricultural production output is derived (ignoring price impacts) with and without pesticides. The difference is divided by the total expenditure on pesticides. Such an estimate leads to a measure which is an average product (which Pimentel et al incorrectly compare directly with Headley's marginal product). The Pimentel et al results indicate that the return (or average) per $1 spent is $4. Hawkins, Slife, and Swanson [1977] present a similar analysis at the farm level for corn and soybean herbicides which presents a return between $3.30 and $4.89. Cashman, Martin, and McCarl [1980] present an average return of $8 in a corn and soybean herbicide case. Shaw [1978] presents some aggregate estimates derived in essentially the same manner.

Results from value-of-output studies can be questioned for several reasons. First, the estimates are potentially misleading in that:

a) With the econometric approach, the data used are tenuous and do not incorporate information about such factors as risk, resistance, resurgence, secondary pests, land type, etc. Further, the data are cross-sectional and aggregated in nature. Thus, it is very difficult to uniquely identify the pesticide impact (Headley [1971] discusses this) with the data.

b) Aggregate estimates based on the method used in Pimentel rely entirely on data that are guesses of yield under zero usage of pesticides. Further, price effects are not considered.

Second, the theoretical and practical basis of the estimates is questionable in that a) the benefits are mainly private and not social, so may understate benefits; b) the benefits are attributed principally to producers which is very misleading--consumers have been the main beneficiaries of technological improvements (Taylor [1980] or McCarl [1981a]).

Value of Resources Released

The value of resources released due to production of food by pesticides is clearly an alternative measure of pesticide benefits. Within the literature, a thorough appraisal has not appeared relating to this topic. Carlson and Castle [1972] introduced this point and briefly dealt with it when discussing labor outflows and changes in relative factor use. The exact role of pest controls in this situation, and the value thereof, remain unstated.

Willingness to Pay

Willingness to pay for pest control on behalf of the populace is an obvious indication that benefits exist. Carlson and Castle again note this aspect of benefits, pointing out that expenditures on direct pest control and pest control research (through university employment of scientists) have risen. Eichers [1980] also presents recent information about pesticide use.

The willingness-to-pay aspect also has been used to estimate the demand for pest control. Carlson [1975, and 1976] with Debord [1977], has conducted this work, estimating demand curves for various pest controls based on expenditures.

Changes in Surplus

Average benefits of pesticides have been estimated using the producers' and consumers' surplus framework (as suggested in Headley and Lewis [1967]). The general framework is used in Taylor [1980] and McCarl [1981a] and reviewed by McCarl and Brokken [1981]. Empirical studies applying this framework mainly appear in conjunction with a mathematical programming model of the agricultural sector (e.g., Taylor and Frohberg [1977], Taylor and Lacewell [1977], and Burton [1980]).

The work in this area is more economically satisfying than the work in the other areas because both producer and consumer benefits are considered in a framework which develops price and quantity impacts and adjustments to market conditions. Taylor and Frohberg show that pest controls cause consumers to lose, but producers to gain. Distributional impacts also are shown. Taylor, Lacewell, and Talpaz [1979] present another similar analysis.

Alternative Benefit Measures

Pest controls may be viewed as a mechanism for more than just income enhancement. Carlson [1979d] studied the impact of pesticides on variability. He concluded that, in the short run, yield variability should be reduced by pesticide application. He leaves the long run impact unclear [p. 24]. Carlson [1979d] also reviewed evidence relative to variability of various practices and concluded there is a difference. Hall [1977] earlier showed a variability difference between types of consultants.

Young [1977] and Fonollera [1977] present analyses which look at the impacts of weed control through the factor markets. Their results point out the need to consider distributional impacts across farm sizes and labor classes, particularily in developing countries.

Benefits - Summary and Appraisal

Benefit estimates for pest controls have been derived by several authors and in many cases approach figures such as $4 for $1 invested. Estimates of this sort, while done in a scholarly fashion, can be questioned on several grounds involving both their derivation and use:

1. Empirical findings showing marginal benefits greater than marginal costs (as yielded by the studies using Cobb-Douglas functions) are inconsistent with theory. Theory would predict that the marginal returns should be close to or tend toward the marginal cost. Several explanations can be suggested: a) with resistance and technical obsolescence, farmers are continually in a learning stage and do not get to a true equilibrium; b) because of the data's cross-sectional nature, many factors (i.e., pest incidence, crop variety, etc.) are not in the model, thus creating unusable results; c) the aggregate nature of the data (i.e., statewide) leads to a poor base for estimation and may result in estimates of average rather than marginal product; d) the functional form may not be satisfactory and alternative functional forms may lead to very different impact conclusions; e) important variables may be omitted; f) farmers have recognized spillovers, etc., and restrict their usage based on these factors; g) risk plays an important role, and i) farmers consistently underutilize pest control.
2. Average estimates should be above marginal estimates. Thus, high average benefits do not necessarily suggest a need for increased pesticide use. In fact, the approximate equality of Pimentel and Headley's estimates (done 10 years apart) could lead to the conclusion that the marginal benefit of pest control has fallen considerably.
3. Studies performed suggest that stability is an important benefit.
4. Many estimates ultimately are based on estimates of alternative yield impacts which are uncertain without question. Paradoxically, the impact of fluctuations in these parameters has not been examined.
5. Use of equilibrium models such as mathematical programming (which assure marginal benefits equal to marginal costs) and the existence of marginal benefits which do not equal marginal costs are not exactly consistent phenomena.

Costs of Pest Controls. Pest controls have various sorts of costs. These costs may be considered under the categories of development costs, use costs, and spillover costs.

Development Costs

These occur in the process of developing a pest control. Accounting of such costs can be extremely difficult because it conceivably involves a separation of costs arising from several simultaneous activities. Allocation of development costs to a particular activity is difficult. Time value of money is also a factor.

Development costs of pest controls have not been widely studied by economists. Virtually all estimates of benefits and costs (outside the regulatory arena) have been made on a one-year basis so these costs often have been ignored. Harris [1979] provides a rather complete consideration of development costs for a control. Marnet [1977] and Smith [1972] also offer information on trends in development costs stating they are increasing rapidly, in part because of the regulatory burden.

Use Costs

Developing application cost estimates for pest controls is not extremely difficult nor is the literature concerning the topic extensive. Four short points can be noted. Hawkins, Slife, and Swanson [1977] provide a good example of cost development. When looking at costs, implicit opportunity costs of changes in resources easily can be ignored (Cashman [1980] provides an example of how these change with strategy). Third, certain costs, such as spillover costs, should be considered. Finally, consideration must be given, particularly in developing countries' settings, to the true cost of the resources employed (i.e., the shadow value of labor rather than a distorted wage rate).

Spillover Costs

Economic literature has addressed spillover costs of pesticides. Herfindahl and Kneese [1965] originally raised the issue, followed by a more detailed analysis in Headley and Lewis [1967]. This subject, in large part, involves the classical economic problem of externalities (as reviewed by Mishan [1971]). However, the spillover impacts are slightly broader than the topic of economic externalities. An externality fundamentally involves an effect brought about by one individual which alters another individual's utility. This definition does not appear to cover the case where a pest control measure inadvertently alters the farm's own production function (e.g., through resistance, predators, residues, etc.). The term "spillovers" is used to encompass these impacts.

Students of pest management have mentioned the importance of spillovers in pest management. Headley and Lewis [1967] discussed spillover impacts on human health, and fish and wildlife. Later studies have pointed out effects on crop production, insect resistance, and non-target insect species. Although many authors have echoed this theme (Richardson and Badger [1974]; Norgaard [1976]; Smith [1971]; Ridgeway *et al* [1978], etc.), few have pursued it.

Headley and Lewis [1967] made a serious attempt to determine impacts on human health and wildlife. Mainly, they quantified some spillover results. Pricing was not done although the issues involved were discussed.

The first serious effort to assess the total cost of spillovers was reported initially by Langham and Edwards [1969], then by Langham [1972], and in Langham, Edwards, and Headley [1972]. Using data from 1966-67, a point estimate was derived on the cost of externalities (ignoring long-term on-farm impacts) from the use of organic phosphates in Dade County, Florida. Spillovers were measured through personal interviews with growers, veterinarians, and biologists, along with investigations of insurance claims and examination of U.S. Public Health Service data on pesticide impacts (Langham, Headley, and Edwards [1972], p. 198-205). Consideration of externalities was shown to alter "optimal" decision making.

A second major effort at spillover measurement is that of Siebert [1980] who examined the interrelationship of bees and insecticide treated almonds. Siebert's results show that beekeepers suffer substantial losses when their bees, as non-target species, are subjected to pesticides. These losses amounted to more than 4 percent of annual California beekeepers' income. The impact of fewer bees on almond growers' income, however, was about .3 percent. Thus, while the beekeepers suffered substantially, the almond growers did not have the incentive to "correct" the situation. However, a bee protection program was adopted. Siebert further investigated the benefits and costs of the bee protection program and revealed that almond growers had to pay $255,000 more and beekeepers gained $977,890. Siebert's article does not report on externalities other than those involving bees.

The impacts on the farm production function have not been studied as extensively. As reviewed in the farm level portion of the report, the resistance and predator impacts have been studied theoretically. An empirical aggregate study of these impacts, which are more long run in nature, was conducted by Carlson [1977]. Carlson showed that cotton pesticide data are consistent with the theoretical result that such factors as resistance development would lead to diminishing marginal returns to pesticides and declining demand for a pesticide.

Pesticide residue effect on crop production has been mentioned (e.g., Carlson [1979], p. 237) and reportedly there are areas in which the extreme case of sterilized lands exist. Evaluation of some spillover also has become accepted fare in the regulation literature.

Finally, under the topic of spillovers, the existence of undesirable spillovers (cited in economics as market failure) has been used as an important argument for public involvement in the pest management arena (an implicit theme as early as Herfindahl and Kneese [1965] and a theme in the resources literature as evidenced by Fisher and Peterson [1977]). Theoretical inquiries (e.g., Feder and Regev [1975]) have pointed out a potential divergence between private and social optima.

Benefits of Controlling Pests. An alternative way of looking at the benefits question is to examine the benefits of controlling a pest. This area of research has not been examined in as much detail as the general benefit and cost concerns probably because of interrelationships among pests, controls and the environment, and the potential multicrop nature of pest infestation. Economists, however, have made several attempts in this area.

Again, excluding the regulatory studies, there are several efforts. First (in a series of studies which are not really economic in nature), there have been efforts made to quantify the magnitude of losses to pests (USDA [1965a, 1965b], University of California [1965], and Pimentel et al [1978]). These loss estimates generally have stated a 33 percent preharvest and 9 percent post-harvest loss. These, then, form an implicit measure of the maximum possible benefits to pest control.

More formal economic analyses focus on several pests. Carlson [1976] studied productivity of, and demand for, fire ant control. In a parallel effort, Carlson and Debord [1976] studied mosquito abatement policies. This study involved an examination of alternative mosquito abatement programs along with consideration of abatement demand and economies of size in treatment.

Taylor and Lacewell [1977] provide an analysis concentrating on the boll weevil. The analysis used a sector model measuring consumers' plus producers' surplus. The study considered four treatment possibilities: current practices versus two IPM practices versus eradication. The potential benefits of eradication discounted to current basis were naturally the greatest. However, considering costs, the IPM strategies were considered best. This study points to the economic unattractiveness of eradication. Lacewell, Larson, Rommel, and Billingsley [1974] present a related analysis.

Emerson and Plato [1978] worked on the control of witchweed. Consideration was given to the impacts on consumers' surplus and export earnings. The study considered continuation of the current containment program, expansion aimed toward eradication, or discontinuance of the program. The analysis is based on assumptions regarding present and future pest incidence along with estimates of the cost and yield impact. High rates of return were shown for containment (45 percent); eradication yielded lower rates of return. Benefits to all control practices were shown although spillover impacts were not considered.

Benefits and Costs - Summary. Conclusive summarization of the benefit-cost literature is rather difficult, but some general principles may be drawn:

1. Pest controls have been highly productive with an aggregate return of $4 per dollar spent (e.g., Headley [1968]) and specific returns have been shown to be even larger (e.g., Emerson and Plato [1978]). Benefits in terms of income stability also have been discussed.
2. Evidence has been gathered that for cotton (the crop which is the heaviest user of insecticides) diminishing returns to individual insecticides have been realized (e.g., Carlson [1977]).
3. Studies of the returns to pest controls really have not considered materials development costs (as done in Griliches [1958] or reviewed in Arndt, Dalrymple, and Ruttan [1977]). Further, the dynamic nature of returns and their distribution only have been considered infrequently (e.g., Taylor and Lacewell [1977]; Emerson and Plato [1978]).
4. Spillover costs are important and, when considered, have been shown to alter optimal decision-making.
5. Eradication has not been shown to be economically viable.
6. Resource opportunity costs, as they vary on a farm within a year, have not really been considered to any great extent.

7. Distributional impacts of pest controls have been studied revealing definite regional impacts with gains for consumers and losses for producers (Taylor and Frohberg [1977]). Distributional impacts have not been examined in great detail beyond this.
8. Need for public intervention has been argued, because of the existence of the spillover impacts (McCarl [1981], for more general arguments).

Impacts of Regulations

The Environmental Protection Agency (EPA) is the principal pesticide regulatory agency. EPA regulatory options revolve around pesticide registration (i.e., allowing one to be used) and include initial granting of registration, suspension of registration, and cancellation of registration. The execution of these options requires knowledge of the subject pesticide. Regulatory actions have led, principally through the Rebuttable Presumption Against Registration process (RPAR), to many studies on the economics of individual pest controls. Many of these studies have been concerned with the specific impact of registration cancellation; others also have considered the distributional impact on pest control use and pest control producers. Alternative policy actions also have been considered.

Specific Analysis of Potential Regulations. Analysis of potential regulations has led to the largest volume of pest economics literature. This literature body, luckily, has been reviewed by others (National Academy of Science [1980]; Council for Agricultural Science and Technology [1980]). Thus, this review only points out features of other reviews, the vastness of the literature, and some observations. Methods also will be scanned in a later section.

The vastness of the literature on the subject is best reflected by references to Table 6, a partial list of reports which have been or are being prepared in government agencies (USDA, USEPA, states), under the RPAR program, or by reference to the USEPA [1980] status report listing 9 pages of chemicals and their accompanying reports. This literature, in fact, grows daily with many chemicals under review or on the list to be reviewed. For this program, EPA has contracted with 8 universities to conduct analyses (Table 7). The bibliography of this report contains references to several regulatory studies. More current information is available through EPA or USDA offices of pesticide programs.

TABLE 6
USDA INDEX OF FINAL DRAFT BIOLOGIC AND ECONOMIC ASSESSMENT REPORTS--SHOWING CROPS AND OTHER USE SITES ANALYZED

Amitraz - August 1978

Pears
Apples

Benomyl - April 1979

Rice

DBCP - March 1978

Peaches
Citrus
Vineyards
Pineapples
Soybeans
Cotton
Peanuts
Vegetables

Diallate - August 1977

Major Crops:
Sugar Beets
Flax
Lentils
Peas

Minor Crops:
Potatoes
Barley
Soybeans
Corn
Alfalfa

Dimethoate - April 1979

Grapes

Endrin - February 1977

Apples - mouse control
Wheat - cutworm control
Conifer seeds - rodent control

Ethylene Dibromide (EDB) - January 1979

Tobacco
Pineapples
Citrus
Peaches
Forestry
Termites
Grain Storage
Flour Mills
APHIS Quarantine Program
Peanuts
Cotton
Vegetables
Honeycombs

Lindane - April 1979

Hardwood Logs, Lumber
Seed Treatment
Forestry
Livestock
Pineapples
Ornamentals
Christmas Trees
Pecans
Pets
Structures
Household
Cucurbits

Pronamide - June 1978

Lettuce
Alfalfa & Related Forage Legumes

Other Crops:
Woody Ornamentals
Bermudagrass Turf
Sugar Beet Seed
Berries

Toxaphene - November 1978

High Volume Uses:
Cotton
Soybeans, Sorghum & Peanuts
Beef Cattle
Wheat

Low Volume Uses:
Vegetables
Onion Seed Crops
Southern Peas
Alfalfa Seed Crops
Sunflowers
Corn
Sheep and Goats
Swine
Beef Cattle Quarantine

Trifluralin - August 1978

Field Crops:
Cotton
Grapes
Guar and Mong Beans
Mint
Peanuts
Soybeans
Sugar Beets
Sunflowers

Tree Fruits and Nuts

Vegetables:
Broccoli
Brussel Sprouts
Cabbage
Cantaloupes
Carrots
Cauliflower
Celery
Collards and Okra
Cucumbers
Dry Beans
Lima Beans
Peas
Peppers
Potatoes
Snapbeans
Southern Peas
Tomatoes
Watermelon

2,4,5-T - February 1979

Timber Production
Range and Pasture Forage
Rights-of-Way
Rice

SOURCE: Ted Kuntz, USDA.

TABLE 7
USEPA. COOPERATIVE AGREEMENTS FOR RPAR ECONOMIC IMPACT ANALYSIS AT STATE UNIVERSITIES, FY 79-80

University	State Focus (Principal Task II Sites Subject to Adjustment)	FY's of Effort (FY 79)
University of Arizona	Western Cotton Lettuce	7.0
University of California, Berkeley	Stone Fruit Pome Fruit Citrus Nuts Grapes Proc. Tomatoes Forestry	7.25
University of Georgia	Peaches Pecans Peanuts Wood Pres. Forestry	7.0
University of Illinois	Soybeans Corn Other Feed Grains Small Grains	5.25
University of Maryland	Turf/lawns Ornamentals Aquatic Weed Control	4.0
Mississippi State University	Eastern Cotton Rice Cucurbits/Melons Poultry Mosquito Control	7.5
University of Missouri	Hay Grass Seed Special Projects: - Econ. Risk - Health B/C	3.25
Virginia Polytechnic Institute	Apples Tobacco Eastern Fruits & Vegetables	10.25

SOURCE: Arnold Aspelin, USEPA.

A quick overview of cancellation literature yields a number of observations:

1. Literature has concentrated on many crops and chemicals, in many specific instances and, because of its immenseness and specificity, making general conclusions difficult to draw.
2. Authors of such studies frequently face a difficult task as data usually are not available. In virtually all cases an admirable job has been done of drawing together data relevant to the particular study. In fact, data probably are never available in sufficient detail for a regulation study until the need for most studies has past (i.e., with 20 years of detailed data, the pesticide to be appraised probably is technologically obsolete).
3. Economic analyses principally use subjective data based on a combination of experience and opinion (e.g., Casey and Lacewell [1973]), although experimental results have occasionally been used (e.g., Cashman [1980]).
4. Farm level behavioral components of substitution between pest controls (i.e., is this substitution feasible in the labor use pattern, and would maximization of utility lead to this choice? etc.) generally have not been integrated into analyses (Cashman [1980] is an exception), leading to inaccurate results.
5. Regulation studies fundamentally should consider substitution. Many studies simply have considered substitution of an alternative pesticide for one at hand. Other studies have gone further and examined substitution of alternative practices, considering impacts other than just revenue (e.g., the regional study of Reichelderfer and Bender [1979] and the farm level study of Cashman [1980]). Even more extensive studies have considered price impacts along with farm production changes or market level product and factor substitution (Taylor and Frohberg [1977]; Burton [1980]).
6. Regulation studies, in degrees, attempt to address spillover impacts. The requirements to do this effectively are extensive (e.g., Langham and Edwards [1969]; Siebert [1980]; or the requirements imposed by Richardson and Badger [1974]) and the data are generally unavailable (or difficult to obtain). In fact, a recent recommendation indicates less effort should be devoted to valuing human health effects (NAS [1980]).
7. Methodologically, a variety of measures and tools has been applied to regulation studies.

8. Regulation studies certainly have not been perfect predictors of regulatory impact (for example, the effect of the DDT ban was considerably overestimated).
9. Long run impacts of regulations are uncertain and not often examined.
10. Discounting has not been performed uniformly. The National Academy of Sciences [1980] recommends adoption of a 7 percent rate.
11. Carlson and Rodriguez [1980] have shown a large acreage change resulting from a mandatory pest control program.
12. Cancellations cause a leftward shift in the supply equation and lead to social losses which are balanced (hopefully) by gains from reduced spillovers. More socially efficient methods are possible conceptually.
13. Carlson [1976] has suggested, based on theory, price regulation may be better than cancellation actions (McCarl [1981]).

Long-Run Regulatory Impact. Regulations, interventions in the market system, carry various consequences for different segments of the system. The short run impacts have been considered in the regulatory studies. Long run impacts have not been considered as widely, yet assuredly affect production and pesticide producers.

Crop Production Impacts

Pest control regulation embodies short run impacts on crop production which obviously will be reflected in the long run. These have been dealt with in the RPAR cancellation literature--resources will be substituted, cost increased, etc. Several economic studies have examined or suggested other factors. Carlson [1977, 1979d] looked at the long run and suggested that regulation may worsen the pest resistance situation and alter agricultural stability. Carlson concludes, "It is ironic that deliberations (on restrictions) have given little weight to effects on future productivity of substitute compounds" [1977, p. 547].

Regulations not only take the form of EPA regulations, but also institutional regulations such as marketing orders, etc., that change the economics of IPM. Willey [1978] presents a study of such topics as does Pimentel et al [1979].

Pesticide Producer Impacts

A potential government restrictions spillover involves pest control manufacturers. Marmet [1977] and Gilbert [1978] both point out that regulatory requirements are making development of pesticides significantly more expensive. Several groups have studied this question (Wechler, Harrison, and Nuemeyer [1975]; Stanford Research Institute [1977]; Ruttan [1980]). Clearly an impact has occurred, is occurring, and will continue to occur. A Council on Agricultural Science and Technology (CAST) committee working in the area found a potential negative impact on the development of specific chemicals which would enter a narrow market (CAST [1980]). On the other hand, the regulatory removal of pesticides should expand the market for those remaining.

Regulatory Alternatives. Virtually every author who has discussed pest control policy has mentioned regulatory options. For example, Carlson and Castle [1972] propose the following options: a) socialization, b) administrative regulation, c) modification of incentives, d) tax on externalities, e) subsidies, f) redefinition of property rights (e.g., pesticide applicator licensing, changing grading standards), and g) market supply restrictions. Randall [1972] mentions that market solutions also are possible, but then indicates that excessive transaction costs make these undesirable.

While there are many other possible regulatory actions, apparently only administrative regulation and redefinition of property rights have been considered, along with subsidization of research. Seemingly economists, for the most part, have mentioned the alternatives and have not spent a great deal of time examining what is best. This is likely because of political realities and difficulties in quantifying costs of spillovers. Carlson [1976b] has indicated that, on theoretical grounds, there are potential gains from price regulations (taxes) versus cancellations.

The above statement may be too harsh as some effort has been devoted to regulation forms (at least implicitly). There is a continuum of possible actions between a total cancellation and an unrestricted market. Enforcement costs make many alternatives (i.e., cancellations on certain soil types) potentially difficult to enact, though selective registrations have been issued (i.e., registering a pesticide for certain crops only, not for others).

Alternatives to Sole Reliance on Pesticides

Treatment of pests can be achieved through a variety of techniques. While analysis of nonpesticide treatments has not been carried out to any great extent, several studies have been attempted. At the aggregate level, certain "IPMS's" (in quotes because of the inconsistency with our definition) have been examined by Pimentel and Shoemaker [1974], Taylor and Lacewell [1977], and Reichelderfer [1979a, 1979b]. Generally these controls have been shown to be socially or privately profitable relative to traditional chemical controls. Taylor [1980], however, has pointed out that private profitability may be tenuous depending on market impacts.

Scouting also has been a subject of great interest with studies by Hall [1977a, b, c], Grube and Carlson [1978], and Carlson [1979a]. Their conclusions: information from scouting may be profitable and risk reducing. Carlson [1980] also analyzed factors leading to the quantity of scouting services utilized in a region.

Carlson [1979a] suggests some organizational innovations which may aid in the general problem area. The final investigation noted here is that of Willey [1978] which points out some of the barriers to the adoption of alternative controls: technique availability, pest information, informed decision-making, risk, information delivery systems, profitability, and grading standards.

Alternatives to Pest Control

Pest control is only one factor in a multi-input production function. Several authors have looked at alternatives to pest control in production. The most popular alternative to examine has been the farm program. Numerous authors have examined how much new land would have to be brought into production to compensate for reduced pesticide use. Among these examinations were those by Headley [1971] and Fox [1971] followed more recently by Rovinsky and Reichelderfer [1979].

A second commonly mentioned alternative to pest control is the insurance alternative. This aspect has been examined by Miranowski, Ernst, and Cummings [1974] and by Carlson [1979a]. Miranowski _et al_ [1974] conclude that insurance appears questionable since, in their analysis, a high cost to society arose from its use [p. 1]. Carlson casts further doubts because of real world characteristics of the pest control environment and says that insurance should be more carefully investigated.

Data

Data required for an aggregate analysis within the IPM area are much more extensive than those required for a farm level study. Tables 8-11 include a

TABLE 8
AGGREGATE DATA NEEDS: MARKET PARAMETERS OF COMMODITY MARKETS

Market Interrelationships and Judgment on How Far to Extend Coverage

Current (in some cases, historic) supply demand balance for the commodities including domestic use, processing use, exports, stocks, imports, and other supply sources

Own, cross, and income elasticities of demand and supply by commodity in the various markets

Regional nature of market

Role of quality

Dynamic nature of the market, seasonally and over years

Base period equilibrium

Social nature of commodity consumption (i.e., by income class)

Factor Markets

Factor market interrelationships and judgment on how far, in terms of factors and alternative enterprises, to extend coverage

Identification of factor suppliers and users--local supply, national supply, migration possibilities, demand by other usages

Own and cross elasticities of factor supply

Regional nature of markets

Dynamic nature of factor supply, seasonally and over years

Base period equilibrium

Trade Parameters of Markets

Typical transportation routes and costs for commodities

Typical storage patterns and costs

Likely impacts of quality changes on transport and storage

TABLE 9
AGGREGATE DATA NEEDS: AGRICULTURAL PRODUCTION FUNCTION

Yield response to treatment alternatives based on producer behavior

Substitution possibilities for pest control inputs

- Factor usage implications of various pest control inputs
- Substitution possibilities between pest control and other inputs

Regional nature of production function

Substitution possibilities between crops

Quality response to treatment alternatives

Differences in production function across farm size

Seasonal value of resources

Currently employed production processes and their characteristics

TABLE 10
AGGREGATE DATA NEEDS: PEST CONTROLS

Treatment Alternatives

Description of controls

Complementary nature of controls

Substitution possibilities between controls

Long run outcomes of control reliance

Anticipated time path of adoption

Yield and factor usage

Impacts of Controls

Short run yield impact

Long run impacts

- Resistance
- Predators
- Residue
- Yield interactions

Spillover impacts

Residue retention in land and water

- Agricultural production implications
- Recreational implications

Human health

- Anticipated impacts on developers of pest controls
- Anticipated impacts on participants in marketing chain
- Anticipated impacts on applicators
- Anticipated impacts on persons in proximity of applications
- Anticipated impacts on consumers of products
- Anticipated impacts through secondary means
- Anticipated impacts on pests, through water, land, other

Non-target species

- Predators - secondary pests
- Bees
- Crops in close proximity
- Livestock uptake
- Endangered species

TABLE 11
AGGREGATE DATA NEEDS: MISCELLANEOUS

Spatial Elements

Regional location and degree of pest infestations

Regional location of crop production

Regional incidence of current crop treatment methods

Policy Elements

Likely policy actions

Dimensions of policy interests (i.e., farm income, labor use, consumer prices, etc.)

Information on importance of various outputs to policy maker

Institutional Elements

Pest related commodity standards

Institutional alternatives to pest control

Constraints on control application (i.e., applicator licenses)

Current regulatory practices and imposed constaints

Pest Control Development Parameters

Costs--static and dynamic

Foreseeable new control methods

Feasibility of various types of developments

Pest Information

Mobility

Anticipated spread in infestation

Resistance development potential

list of broad types of data needed for an aggregate study. The data needs concentrate mainly on inputs required, not on outputs used in the decision. Information is needed on the anticipated distribution when data are uncertain. These data needs supplement those of farm data presented in Tables 2-5. Aggregate data would be augmented most effectively with some farm level studies which would allow investigators to have good information on farm level response.

Methods and Measures

Aggregate IPM analysis has been conducted using varied methodologies to generate numerous measures. This section will address some of the desirable measures, then discuss methods to obtain the measures.

Measures. The fundamental measure involved in aggregate IPM is a measure of welfare. Welfare, however, has many dimensions; Table 12 gives a set of desired outputs. Data on these outputs could assist policy making. Information would be desirable on both a national and regional basis. In some cases, it would be beneficial to have distributional impacts across such things as farm size or consumer income class. These measures, however, are difficult to quantify to this level.

All measures in Table 12 are rather standard fare in the economic literature; hence, discussion would be repetitious, but four comments are necessary. First, the more information the better; second, obtaining information does have a cost, a cost which must be considered; third, income change or gross production value change should be used with care if it is the only measure (potential price effects should be considered); fourth, two pieces of evidence conflict. On the one hand, there is the precision of the measures (i.e., the cost of an action is $1,503,921 when this is really not known within 10 percent) whereas, on the other hand, there is the extremely uncertain nature of the data underlying these estimates. Thus, the measures employed have been too precise and uncertainty should be incorporated.

Methods. Many alternative methods have been employed in IPM economic analysis. Several authors (i.e., Reichederfer et al and CAST [1980]) have attempted to compare various methods. The efforts ahve been somewhat counterproductive for three reasons.

TABLE 12
DESIRED OUTPUTS

Consumers' Surplus

Producers' Surplus

Farm Revenue

Commodity Disappearance - production, imports, exports, domestic consumption, processing consumption, changes in stocks, feeding, etc.

Commodity Prices

Aggregate Laspayres and Paasche price and quantity indices

Factor Use

Factor returns

Factor payments

Revised production budgets

Transportation patterns

Pest control strategy use

Spillover impacts

- Anticipated future productivity of controls
- Human health
- Non-target species
- Residue retention

Pest control marginal and average product

Induced regional economic activity

Value of trade

Balance of payments

First, the choice of a method is a function of the method's desirable and undesirable characteristics and data availability, along with the method user's capabilities and time. Not all people can be expert in all things nor do they have time to do a 2-year study when the answer is required tomorrow. Often the "worst" method can be used very satisfactorily when used by one who understands it and its limitations, then correctly applies it to the problem.

Second, economists (probably because of the nature of journals encouraging "new" methods) have been method obsessed. The problem should be well understood first, especially with the complexity of problems in the IPM arena.

Third, many economists behave as if methods are complete substitutes for one another (probably because courses are taught by experts in the individual fields without "cross fertilization"). Quite the contrary, methods should be used, or at least considered, in many cases, as complements. Hopefully the methods section below will be read with these comments in mind, as it was constructed that way.

Methods can be separated into a hierarchy. For this portion of the review, methods will be separated into those for data development and those for experimentation.

Data Development

Data always have been synthesized in some fashion or another from a set of observations. These observations may be developed from current experiments or historical events. This question, however, will be ignored and the review will concentrate on two methods for deriving data from a set of observations: deductive accounting and econometric estimation (a rather fuzzy distinction).

Finally, before beginning, a general observation: all the studies and methods are hampered by the availability of data. The more complex the method, usually the more data required and the larger the potential for inaccurate results because of meaningless data.

Deductive Accounting: Deductive accounting involves the development of an estimate (of a point, a distribution, or a function) from a set of data through the use of an assumption based approach. The best way of clarifying this definition is through example, as in the following case: the yield impact of a new pest control may be deduced by having an experienced pest scientist examine the nature of the pest control, and then having the scientist estimate yield under this control. The profitability of this control is then deduced by taking this yield impact times current price minus the current costs of inputs. Thus, deductive accounting is a data synthesis technique which manipulates a set of data by an assumed procedure to derive other data. Such an approach is widely used in the IPM economics literature because it provides the base data in most cancellation studies and many other instances. The advantages of this approach are a) its seemingly logical approach to deriving data, b) the speed with which data may be derived, and c) the fact that larger data sets may be "deduced" from smaller data sets. The disadvantages of this approach are a) its susceptability to bad assumptions or bad initial data, b) its lack of statistical reliability, c) its potential lack of independent repeatability (i.e., having another person arrive at exactly the same data), and d) its difficulty in handling uncertainty.

Econometric Estimation: Data also may be estimated by econometric (or statistical) estimation techniques. Cross sectional and/or time series data are analyzed using statistical principles to yield a relationship based on statistical synthesis of history. The tools utilized involve all methods of statistical estimation including means, variances, single and multiple equation regression, and a multitude of related methods. These tools also have been used in the IPM literature, although not to the degree that deductive accounting has. Relationships may be estimated from historical experimental data, giving yield impacts (Hawkins, Slife, and Swanson [1979]), yield response functions (Cashman [1980]), and demand equations for pest abatement (Carlson [1980]).

Production functions also have been estimated with pest controls as an input (Headley [1968] or Carlson [1977]). Simultaneous values have been estimated a) relating pests and crops (Lee and Langham [1973]), or b) involving market equilibrium models for pest control decision making (Taylor, Lacewell, and Talpaz [1979]). Advantages of this approach lie in a) its ability to synthesize historical data statistically, b) its statistical properties, including an uncertainty description, and c) its reproducible nature. Disadvantages arise from its a) mechanical nature, i.e., the results do not need to make sense, b) reliance on functional form (changes which can vastly alter implications of variables), c) lack of a theory base on which exact functional form may be chosen, d) statistical problems among observations (i.e., heteroskedacticity, multicolinearity, autocorrelation), and e) reliance on historical or cross sectional data when dealing with technological change, where past observations cannot always be generated. Taylor, Lacewell, and Talpaz [1979] present an interesting combination of econometric estimation and deductive accounting to alleviate this problem.

Data-Using Methods

Once data have been gathered, they must be used. Both techniques above feed data into the analysis methods. The analysis methods presented here are classed into budgeting, mathematical programming, and simulation (really all are "simulation techniques"). Reiterating earlier points: a) these techniques do not all have to be substitutes; in an analysis, the techniques may be used for various components performing in parallel or in tandem, and b) a potential disadvantage of all methods is the underlying data base.

Budgeting: The logical extension of deductive accounting in terms of analysis tools is budgeting. One variant of the method is simply to continue the deductive process until the point that the ultimate outputs for the decision are reached, i.e., using the regional distribution of acreage to develop national yield impacts, similarily extrapolating income impacts. Budgeting (often called "simple budgeting") is a widely misunderstood analysis tool. Quite often, economists make statements that lack of consideration of price changes is a disadvantage, uncertainty is not incorporated, or the analysis is static. These statements can be either true or patently untrue depending on the deductive process used in carrying out the budgeting (for example, see National Academy Report [1980] which reviews studies and recommends procedures for handling uncertainty and price changes). Examples using simple budgeting include virtually all the cancellation studies (as reviewed in National Academy of Sciences [1980]) and the work by Hawkins, Slife, and Swanson [1977].

The advantages of budgeting appear to be a) its potential simplicity, b) its deductive nature, c) its adaptive nature (under this umbrella anything may be done), and d) its rapidity of application. The disadvantages are a) a lack of standardized technique, b) potential faults in the underlying assumptions, c) lack of worked-out validation techniques, and d) the complex nature of incorporating more sophisticated phenomena, e.g., product and factor substitution.

Mathematical programming: A second commonly used modeling method is mathematical programming. Mathematical programming (most frequently, linear programming) is a tool which maximizes an objective subject to a set of constraints. Such a tool has been used often on IPM evaluations.

Mathematical programming models at the sector level generally are used to simulate the impacts of exogenous impacts on the agricultural sector. Use of such models requires an objective function which is behaviorally consistent with sectoral performance. Early models used in IPM evaluations were cost-minimizing models of the agricultural sector which produced a fixed quantity of goods (e.g., Pimentel and Shoemaker [1974] and recently, Rovinsky and Reichelderfer [1979]). Subsequently, aggregate models have been used which have first order conditions consistent with individual profit maximization yet simulate market phenomena allowing for both supply and demand adjustments, using a conditional normative assumption (McCarl and Spreen [1980] for a general review and explanation). These models are the so-called surplus maximizing models and have been used in several IPM evaluations (e.g., Taylor and Frohberg [1977]; Taylor and Lacewell [1977]; and Berton [1980]).

Regional linear programs also were used by Langham and Edwards [1969], Casey and Lacewell [1973], and Sarhan, Howitt, and Moore [1979]. The advantages of the mathematical programming approach are, 1) its ability to incorporate microeconomic supply, interacting through an aggregation process with sectoral demand, 2) its consistent solution which possesses interrelated factor--product prices and quantities, 3) its analytic tractability, 4) its capability for accepting technical change, 5) its capability for accepting many features of the problem at hand, i.e., risk, dynamics, etc. (McCarl and Spreen [1980]), 6) its complete and detailed formulation (causing careful problem conceptualization, consideration and specification), 7) its ability to produce distributional impacts (by region, factor, product, etc.), and 8) its ability to capture detailed resource limitations.

Disadvantages of the approach are; a) possible violations of its conditional normative assumption; b) its response characteristics since such models often overreact to change relative to real world; d) its susceptibility to the frequent, yet incorrect, desire to put in unrealistic behavioral objective functions (i.e., minimizing environmental externalities); d) difficulties in validating its implicit assumptions, individually or collectively; e) its mechanical nature; f) its high cost of solution and demand for advanced computer software when working with large models; g) its relative complexity and an accompanying difficulty of comprehension by others than its developers when working with a large model; h) its large data needs and the implicit nature thereof (it is very difficult to check all data thoroughly and the data development process is more complex than under simple budgeting, using roughly the same input); i) its implicit solution characteristics leading to multiple answers (alternative optimals and/or degeneracies), and j) its rapidly increasing size as many phenomena are modeled (especially dynamic aspects).

Simulation: Simulation is an extremely nebulous term. Here, simulation using econometric equations will be the fundamental topic of discussion. Even so, the discussion is rather difficult. Primarily, the accuracy, advantages, and disadvantages depend on the quality and detail of the estimated equations, not the method.

Fundamentally, "simulation" using econometric equations involves solution of these equations given certain values of some exogenous variables. The simulation may be deterministic, in which case, random terms are ignored; or stochastic, in which case Monte Carlo techniques are employed. The simulation, if set up with recursive relationships, also may be dynamic in nature. Finally, through a combination of deductive accounting and econometric estimation methods, technological change may be incorporated (see Taylor, Lacewell, and Talpaz [1979] or Weisz, Miller, and Quinby [1979]).

Examples of the simulative approach include the applications done by Weisz, Miller, and Quinby [1979]; Cory, Gum, and Martin [1980]. The applications by Lee and Langham [1973] and Sarhan, Howitt, and Moore [1979] also bear on the topic.

Advantages of the simulation approach are, 1) its speed of application, 2) its ability to incorporate stochastic parameters, 3) its ability to simulate a recursive system (although the above two techniques easily can be used recursively with a simulation type superstructure), 4) its ease of solution method, and 5) its relatively small nature facilitating communication and explanation. Disadvantages are, a) difficulties in incorporating a comprehensive economic model, i.e., micro through macro phenomena; b) relative difficulty in incorporating choice decisions and constraints thereon; c) validation difficulties; d) frequent reliance on simplistic supply response models; e) lack of standardized techniques; f) lack of optimality criteria, and g) difficulties in developing sufficient data to build the model and parameterize the relationships.

SECTION V
THE LITERATURE VERSUS THE ISSUES

The literature on IPM economics is both vast and shallow (in spots) as potentially seen by the above review and the attached bibliography. Many pieces of work have been done, yet this work has not completely covered the issues enumerated above. The purpose of this section is to appraise this literature relative to the earlier issues. Before beginning this section, several general comments are in order.

First, the literature predominantly deals with chemical insect control. The integrated concept (both between controls and into the farming system) has not been extensively dealt with, nor has the non-insect pest. Second, the literature has essentially ignored post-harvest pests. Third, the literature tends to divide into a methodological portion and an applied portion. Pieces of work integrating these two arms have not appeared nearly as often as contributions in each of the arms. Methodological contributions have been inadequately based in pest realities, while applied contributions have relied on "weaker" economic methodology. The literature, however, is maturing rapidly in these areas.

Appraisal and categorization of the literature follow, using tables keyed to the order of topics in Section III. Each table covers one of the general issues; within the table, the specific issue(s) appear (some issues are best handled collectively). Under each specific issue, citations are presented for authors who have discussed the issue in the context of IPM, to the general economic literature related to the issue, and to authors who have examined the issue in an applied study. The citations in these tables, while not complete, should be representative of the work performed.

WELFARE

Analysis of welfare issues has produced a fairly large IPM economics literature (Table 13). The earliest contributors in the IPM field addressed and provided a framework for welfare issues. The regulatory studies are those in which the welfare issues have been addressed most frequently. The measures of welfare have been drawn from the traditional cost benefit literature and include both economic surplus and change in income type measures. Many authors have mentioned the need to move into an assessment of impacts broader than those measured in output space, particularly those items for which market value is not easily established (pollution, human life). However, these exercises have been few and far between and, in fact, the dimensions of the welfare issues warranting attention have not been well defined. Perhaps an application of multi-attribute utility theory, as discussed in Keeney and Raiffa [1976], would be appropriate.

The welfare measures utilized, to a great extent, have been rather partial; most frequently, only a single market is considered. Further, in many cases (as discussed in the NAS review [1980]) welfare changes have been ignored in favor of income changes.

Costs and benefits of pesticide use have been investigated by several authors. Many of the analyses have been either, 1) based on estimates of crop losses, circa 1965, and have ignored price impacts, or 2) based on rather aggregate cross-sectional data which may severely bias estimates. Further, these studies have uniformly ignored impacts other than short run yield impacts.

In this literature, opportunities exist for well conceived studies providing:

1) A definition of the dimensions of welfare;
2) An investigation of how, in a particular case, these dimensions apply and are valued;
3) An investigation of the total welfare impact in a case study;
4) An investigation of the impacts of neglecting related commodities;
5) A thorough investigation of the costs and benefits from pesticide use.

These studies could take several directions: a) farm level studies of the marginal impact of pest control in several important cases; b) aggregate studies of the impact of pest control in either a one-year setting (examining spillover impacts, factor market impacts, and product market impacts) or a multi-year setting (examining long run impacts, development costs, etc., along with the short run impacts); c) methodological inquiries on the reliability of the various approaches.

DISTRIBUTIONAL IMPACTS

Distributional impacts have been studied in several cases (Table 14). The distribution of welfare probably is more important than the change in welfare.

TABLE 13
WELFARE

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IPM Context
Dimensions of Welfare Who Makes Decision	Headley & Lewis [1967] Headley [1975] EPP *et al* [1977]	Keeney & Raiffa [1976]	Headley & Lewis [1967] Langham & Edwards [1969]
Measures of Welfare and Presentation of Measures	Headley & Lewis [1967] Nat'l Acad. of Science [1980] EPP *et al* [1978] Ridgeway *et al* [1978] CAST [1980]	McCarl & Brokken [1981]	Nat'l Academy of Science [1980] Taylor & Frohberg [1977] Emerson & Plato [1978] Langham & Edwards [1969]
Valuation of Welfare	Langham & Edwards [1969] Richardson & Badger [1974]	Haefele [1972] Keeney & Raiffa [1976]	Langham & Edwards [1968] Richardson & Badger [1974] Carlson [1975]
Costs and Benefits of Chemical Pesticide Use	Headley [1968]	Mishan [1976] Voorhees [1980] Freeman [1979]	Acadley [1968, 1971] Fisher [1970] Campbell [1976] Pimentel *et al* [1979] Voorhees [1980] Shaw [1978, 1979] Fisher [1967]
Trade-offs Between Undesirable Impacts & Benefits	Headley [1967]	Keeney & Raiffa [1976]	Numerous Regulatory Studies

TABLE 14
DISTRIBUTIONAL IMPACTS

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Author Who Investigate Issue in IPM Context
Distribution of Welfare Between Classes	Headley & Lewis [1967] CAST [1980] NAS [1980] Taylor [1980] McCarl [1981a]	Bonnen [1969] Haveman & Krutilla [1968] Mishan [1976]	Taylor & Frohberg [1977] Taylor & Lacewell [1977] Burton [1980]
Regional Distribution	CAST [1980]	Bonnen [1969] Haveman & Krutilla [1968]	Headley [1971] Casey & Lacewell [1973] Taylor & Frohberg [1977] Taylor & Lacewell [1977] Burton [1980] Rovinsky & Reichelderfer [1979]
Class Distribution	McCarl [1981a]	Bonnen [1969] Johnson [1973] Mishan [1976]	Young [1977] Fonollera [1977]

Following Bonnen's [1969] arguments, making policy without knowledge of distributional impacts may lead to a contradictory and improper policy mix. Studies of the distributional impacts have concentrated on broad groups (producers-consumers, landowners-laborers, regional groups). There is a small literature going beyond these broad groups into the consequences on farm size and/or income distribution (although some studies have shown that various size farms use different levels of pest control). This situation again opens possiblities for research carefully assessing the distributional impacts of an initiative in the IPM arena. This could take the form of either a current or historical study of the impacts of a cancellation on IPM usage. The dynamic aspects of distribution appear to have been totally ignored.

LOCUS OF COMPARATIVE ADVANTAGE

Change in locus of comparative advantage has been persuasively mentioned as a side effect of IPM techniques (Headley [1972]). The IPM economic literature (Table 15), however, has not really addressed this issue beyond showing that differential regional impacts are present, suggesting a number of possible extensions:

1) a historical analysis attempting to link IPM strategy use with shifts in production;
2) a current analysis concentrating on the differential impacts of pesticide use, given the location of production (for all pesticides, or on specific cases).

INDUCED IMPACTS

The investigation of induced impacts from pesticide use, while extensively covered in the regional economics and water literature, has not received much attention in IPM economics literature (Table 16), other than a brief mention in Headley [1972]. Research in this area basically could address the issues involving:

1) first and fundamentally, whether secondary benefits of IPM have been significant and/or the conditions in which they are significant;
2) a historical and/or current study of the impacts on terms of trade, both interregionally and potentially internationally.

TABLE 15
LOCUS OF COMPARATIVE ADVANTAGE

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issues in IPM Context
Differential Impact	Headley [1972]	Bressler & King [1970]	Pimentel & Shoemaker [1974] Taylor & Frohberg [1977] Taylor & Lacewell [1977] Burton [1980]
Location of Production	Headley [1972]	Bressler & King [1970]	

TABLE 16.
INDUCED IMPACTS

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issues in IPM Context
Within Region Benefits	Headley [1972]	Miernyk [1965]	
Are Secondary Benefits Worth Studying		Stoevener & Kraynick [1979]	
Impacts on Interregional Terms of Trade		Bressler & King [1970]	

SPILLOVER IMPACTS

Perhaps the topic which has received the most recent public attention in the IPM arena is spillover impacts. Paradoxically, in-depth economic work in this area has been rather sparse (Table 17). Many attempts have been made to develop the spillover impacts of certain strategies within cancellation studies. Very few attempts have been made to derive estimates of social cost arising from these impacts. What work exists forcefully points out a difference between private and social optimum usage; it also has been biased toward short run pesticide impacts. Longer run impacts have not been extensively studied (apparently because of data difficulties) nor have spillovers from "biological" controls.

This issue leads to a rich and significant agenda of possible further efforts:

1) The economic impact of IPM use in terms of spillover cost along with other costs and benefits should be measured either historically or currently.
2) The long run impacts of IPM strategies are in need of analysis.
3) "Biological" control spillover impacts should be examined.

MARKETS FOR AGRICULTURAL INPUTS

Impacts of strategies on agricultural input usage has been examined only indirectly (Table 18). The more macro studies generally note the difference in land use and land values in their models. Little has been done to examine use outside of agriculture, input migration, etc. Research obviously could dwell on who has or will obtain the returns to factors and how factors have shifted or will shift among uses and regions from IPM actions. Impacts of proposed policy on markets also could provide a wealth of areas for investigation.

TIME RATE OF SOCIAL PREFERENCE

The establishment of a time rate of social preference for use in any study has long been subject to debate. Although debate has not entered into the IPM literature (Table 19), a diversity of discount rates has been used; recently, an NAS study recommended 7 percent. This may be an area in which work should investigate what value should be used. Dynamic impacts largely have been ignored and provide a fruitful research area.

TABLE 17
SPILLOVER IMPACTS

Specific Issue(s) Economic Impact	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IPM Context
Humans	Headley & Lewis [1967]	Mishan [1971]	Numerous cancellation studies as reviewed in NAS [1980]
Nontarget Insects		Mishan [1971] Chueng [1973]	Siebert [1980]
Crop Yield	Carlson [1977]	Henderson & Quandt [1965] Anderson, Dillon & Hardacker [1977]	
Pest Presence	Adkisson [1972]		Feder & Regev [1975]
Predators	Shoemaker [1973]	Gordon [1954]	Feder & Regev [1975] Shoemaker [1973]

(continued)

TABLE 17 (continued)

Specific Issue(s) Economic Impact	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IPM Context
Environmental Degradation	Headley & Lewis [1967]	Ayres & Kneese [1969] Mishan [1971]	Langham & Edwards [1969] Feder & Regev [1975]
Pest Resistance	Carlson [1971]	Taylor & Headley [1975] Mishan [1971] Gordon [1954]	Hueth & Regev [1974] Gutierriz, Regev & Shalit [1979] Sarhan, Howitt & Moore [1979] Carlson [1977]
Reflecting Cost on Farmers	Carlson & Castle [1972] McCarl [1981a]	Mishan [1971] Randall [1972] Anderson *et al* [1977] Davis & Kamien [1969]	
Biological Controls	Carlson [1976] Norgaard [1976]	Mishan [1971]	

TABLE 18
MARKETS FOR AGRICULTURAL INPUTS

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IPM Context
Factor Use Impact	Headley [1972]	Henderson & Quandt [1965]	Taylor & Frohberg [1977] Taylor & Lacewell [1977] Young [1977] Fonollera [1977]
Factor Shift Among Uses			
Factor Prices		Henderson & Quandt [1965]	Taylor & Frohberg [1977] Taylor & Lacewell [1977] Young [1977] Fonollera (1977]

TABLE 19
TIME RATE OF SOCIAL PREFERENCE

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IPM Context
Time Rate	Nat'l Academy of Science [1980] Norgaard [1976]	Baumol [1968] Herfindal & Kneese [1974]	Emerson & Plato [1978] Taylor & Lacewell [1977]
Dynamic Impacts		Griliches [1958]	Cory, Gum & Martin [1980] Emerson & Plato [1980]

QUALITY AND GRADING

Quality standards for food products are often cited as one of the principal reasons for pesticide overuse. Economic studies involving this connection have really not been performed (Table 20). In fact, it was difficult finding applicable theory. Obvious research questions then involve the impact of grading standards on welfare type along with an analysis of the implications and acceptability of changes.

RESEARCH AND DEVELOPMENT

Although studies are under way (by CAST and proposed by Ruttan) on research and development within the IPM arena, detailed work has yet to appear (Table 21). A host of important issues only have been mentioned accompanied by relatively scanty detailed analysis. Paramount among the things that could be considered are:

1) A determination of the need for public action aimed toward either direct public research and development or indirect public support for research and development.
2) A determination of whether the current level of research effort is sufficient.
3) An investigation of the influences on research and development that the recognition of spillover impacts and accompanying regulation has had.

FARM LEVEL DECISION-MAKING

One of the least covered sets of issues in the literature is farm level decision-making (Table 22). Almost all IPM research has either used the concepts of comparative budgeting (in some cases, along with risk aversion) or assumed a shift in the aggregate farm budget and gone on. The micro economic foundation of much of this work is suspect. Comparisons between techniques have not considered resources and their value over time. Little work has been directed toward alternatives to regulatory cancellations for altering the farm decisions on IPM use. Finally, most studies requiring second best strategies for banned controls have identified the replacement strategy based on simple budgets without consideration of, for example, dynamics, resource availability, or to a lesser extent, uncertainty.

TABLE 20
QUALITY AND GRADING

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IPM Context
Pest Management	Pimentel et al. [1978] Willey [1978]		

TABLE 21
RESEARCH AND DEVELOPMENT

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IPM Context
IPM	Norgaard [1976] Harris [1979] Brady [1972] Carlson [1979a] Smith [1971] Ruttan [1980] Marmet [1977] McCarl [1981a] CAST [1980]	Arndt, Dalrymple & Ruttan [1978] Krutilla [1969]	

TABLE 22
FARM LEVEL DECISION MAKING

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IPM Context
Dimensions of Farmer Welfare	Norgaard [1976] McCarl [1981c]	Henderson & Quandt [1965]	
Valuation of these Dimensions		Keeney & Raiffa [1976]	Feder & Regev [1976]
Examination of Resource Compatability of an IPM	McCarl [1981c]	Henderson & Quandt [1965]	Cashman [1980]
Imposition of Desired Strategies	McCarl [1981d]		
Selection of "best"	Norgaard [1976] McCarl [1981c]	Henderson & Quandt [1965]	Carlson [1970] Reichelderfer [1979] Hawkins, Slife & Swanson [1977]

Rich potential again exists, involving questions such as:

1) What are the implications of assuming micro economic supply response in a macro economic study (i.e., a budget with and without pesticides)? This concern would be particularily relevant when the implicit behavior leading to the budget is assumed, not tested at the farm level.
2) What factors other than profit enter the farmer's IPM decision? Also, the related question: Might some of these factors explain the "high" marginal rates of return?
3) Considering transaction costs, farm profitability, resource availability, etc., what are the best policy methods for changing farmers' decisions regarding IPM?
4) Should IPM decisions be considered from a total farm viewpoint or is simple budgeting adequate?

TECHNOLOGY ADOPTION AND OBSOLESCENCE

The best technology in the world is not very good if no one uses it. The economics of adoption, however, really have not been examined for IPM strategies (Table 23). Some studies have investigated factors leading to differential adoption rates. In terms of obsolescence, other authors have said resistance development may be inhibited by alternating controls. However, a systematic economic investigation on how management decisions should account for this has not been done. Research may directly address the issues by, a) trying to discover how farmers make adoption decisions, along with how they may be stimulated to adopt; and, b) examining management options for delaying obsolescence.

RISK MANAGEMENT

Risk is a pervasive feature in the pest control area. In selected cases, investigations have quantified the magnitude of risk and examined potential management strategies. Most of the inquiries (Table 24) have focused on short run risk; only a few have involved long run phenomena. Detailed research has omitted how farmers react to the presence of risk. Work is possible under this issue:

a) Examining the amount of risk present with various controls; in particular, chemical versus "biological" would be interesting.
b) Examining both immediate variability and longer run induced variability.

TABLE 23
TECHNOLOGY ADOPTION AND OBSOLESCENCE

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IPM Context
Adoption Rate	McCarl [1981c]	Griliches [1959] Binswanger & Ruttan [1978]	Funk [1980] Carlson [1980]
Obsolescence Rate	Carlson [1977]	Bafta [1973]	Regev, Shalit & Gutierrez [1977]

TABLE 24
RISK MANAGEMENT

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IPM Context
Short-Run Risk	Carlson [1979d] Headley [1975] Southwood & Norton [1973] Norgaard [1976]	Anderson, Dillon & Hardacker [1977]	Carlson [1970, 1979d] Hall [1977] Mironowski [1979] Webster [1977] Feder [1979] Cashman [1980]
Long-Run Risk	Carlson [1977,1979d]	Bussey [1978]	Carlson [1977] Carlson [1979d]
Farmer Attitudes & Response to Risk	Carlson [1970, 1979c, 1979d]	Anderson, Dillon & Hardacker [1977]	

c) Examining not only how farmers should react (in a normative fashion) to risk, but also how they have reacted in terms of IPM strategy use.

PEST INTERVENTION AND INFORMATION

A lot of work has been devoted to optimal intervention (Table 25). It generally deals with how to treat a single pest optimally. Predators also have been studied. Thus, quite a number of issues remain unresolved. A brief list arising from the issues mentioned includes:

1) Unification between sampling theory and control application: there has been little consideration of the uncertainty implicit in pest counts in the when-to-treat analyses. Further, the complex and dynamic nature of the application decision needs to be factored into the sampling scheme.
2) Multiple pests have been ignored and need to be considered.
3) Conditions under which eradication is justified need to be developed.

FARMER SPILLOVERS

Spillover impacts begin with the IPM user, i.e., the farmer. Because of complexity and data limitations, few attempts have been made to truly examine the farm level costs and benefits (Table 26). In fact, the rate of technological obsolescence raises the question of whether data ever will be adequate. Nevertheless, there is the opportunity to assess the impact of IPM strategies and to evolve mechanisms for achieving socially desirable levels of farm use.

SCALE ECONOMIES

Scale economies have been hypothesized by economists dealing with IPM, yet not much work has considered them (Table 27). The studies have been limited to one which shows the impact of set-up time (and cost) on application policy at the farm level, and the demonstration of scale economies at the regional level. Some proposals also have been made for regional coordination based on assumed scale economies. Inquiries may be made along these lines to:

1) further incorporate the fact that the change in resource use is much less than proportional to the change in quantity applied as it increases;
2) develop information about the types of IPM strategies that have significant scale economies and mandate regional approaches;
3) develop or investigate alternative coordination procedures.

TABLE 25
PEST INTERVENTION AND INFORMATION

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IPM Context
Sampling	Carlson [1970]	Schlaiffer [1959]	Carlson [1970]
When to Intervene & How Much to Apply	Headley [1972] Talpaz & Frisbee [1975]	Taylor [1976] Henderson & Quandt [1971]	Headley [1973] Talpaz & Frisbie [1974] Talpaz, et al Regev, Gutierrez & Feder [1976]
Multiple Pests	Shoemaker [1973]	Henderson & Quandt [1971]	
Eradication		Henderson & Quandt [1971]	Headley [1972] Taylor [1976]
Predators	Shoemaker [1973]	Henderson & Quandt [1971]	Shoemaker [1973] Feder & Regev [1975]
Extension Method - Information Dispersal			Miranowski, Ernst & Cummings [1974] Carlson [1979a] Willey [1978]

TABLE 26
FARMER SPILLOVERS

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IPM Context
Farmer Benefits & Costs	Norgaard [1976] Davidson & Norgaard [1973]	Mishan [1971]	Langham & Edwards [1969] Siebert [1980]
Reflection of True Cost	Carlson & Castle [1972]	Baumol [1972] Davis & Kamien [1969] Mishan [1971]	

TABLE 27
SCALE ECONOMIES

Fixed Cost Element of Application		Bafta [1965]	Talpaz & Borosh [1974]
Existence of Scale Economies		French [1977]	Carlson & Debord [1976]
Economically Efficient Scale of Action	Carlson [1979a] Norgaard [1976] Norgaard, Seckler & Rodosevich [1971]	Sharp & Bromley [1979]	Carlson & Debord [1976]

DIVERSIFICATION OF CONTROLS

A farmer may use multiple controls either to minimize resistance progression, treat multiple pests, or reduce risk of control failure. Inquiries into diversification (Table 28) only have touched lightly on these possibilities. Research may be conducted on conditions under which control diversification is desirable.

ECONOMIC INTERRELATIONSHIPS IN FACTOR USE

A farm is a multifactor, multiproduct production entity; economic research, however, has not taken this situation into account (Table 29). Interrelationships among factors, product, and factor-products essentially have been ignored at the farm level, calling for more inquiries integrated into the farming system. There also has been a lack of historical analysis of the technical change inducing impacts (and interrelationships) of IPM availability.

SUBSTITUTION

A key assumption in IPM studies involves substitution possibilities (Table 30). The substitution impact examined in greatest detail involves chemical substitution, predominantly in regulatory (RPAR) studies, mostly by assumption, wherein a physical scientist is asked for the next best material. Market substitution has been viewed explicitly in some studies (or implicitly using price elasticities). Detailed farm level impacts or adjustment parameters [i.e., through factor, other than chemical, or product substitution] have been considered to a much lesser extent yet. Work concerning substitution *per se* is not needed, yet the substitution issue must be thought through carefully when examining other issues. Further, microeconomic studies should be undertaken to back up the substitution assumptions in macro studies.

REGULATION

The regulatory process is alive and flourishing in the IPM arena. However, outside of inquiries into the impact of chemical cancellations, the economic input has been negligible (Table 31). There has been little effort expended for appraising cancellations versus other actions. Certainly it is possible

TABLE 28
DIVERSIFICATION OF CONTROLS

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IPM Context
Diversification Possibility	Carlson [1976]	Anderson, Dillon & Hardecker [1977]	Regev, Shalit & Gutierrez [1977] Cashman [1980]

TABLE 29
ECONOMIC INTERRELATIONSHIP IN FACTOR USE

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IMP Context
Pest Management and Other Inputs	Norgaard [1976]	Henderson & Quandt [1965]	
Output Markets and Pest Management		Henderson & Quandt [1965]	Talpaz & Borosh [1974] Headley [1972] Hall & Norgaard [1974]
Technical Change and Insecticide Use	Carlson [1976] Miranowski [1979] Headley [1972]	Henderson & Quandt [1965]	

TABLE 30
SUBSTITUTION

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IPM Context
Market Impact		Leftwich [1970]	Taylor & Frohberg [1977]
Chemical Substitution	Carlson & Castle [1972]	Henderson & Quandt [1965]	Numerous ban studies Cashman [1980]
Factor Substitution		Henderson & Quandt [1965]	Cashman [1980] Taylor & Frohberg [1977]
Farm Production Change		Henderson & Quandt [1965]	Cashman [1980] Taylor & Frohberg [1977] Taylor & Lacewell [1977] Carlson & Rodriquez [1980]

TABLE 31
REGULATION

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IPM Context
Goals of Regulatory Process	USEPA	Gardener [1979]	
Economic Impact of Regulations - as Used	Fox [1971] National Academy of Science [1980] Carlson [1979d] McCarl [1981d]	Mishan [1976] Gardener [1979]	Casey & Lacewell [1977] Numerous Cancellation Studies Burton [1980] Carlson & Rodriquez [1980]
Economic Impact of Regulations - Alternatives	Carlson & Castle [1973] McCarl [1981d]	Randall [1972] Anderson *et al* [1977]	
"Optimum" Regulation	Carlson [1976]		

to examine regulatory alternatives and list the consequences. Optimum regulation (within the goals and constraints) may be a desirable area of investigation also. Studies of the long run impact of regulation on various entities (producers, consumers, non-target species, IPM strategy producers) would also appear to be desirable.

INSTITUTIONS

The study of institutions within natural resources has been a subject of debate (Castle et al [1980]) which has not been resolved. Institutional studies within the IPM arena have not been extremely prevalent (Table 32) and really have not begun to explore the impact of institutions or the desirability of alternative institutions. Inquiries need to address these issues specifically.

TABLE 32
INSTITUTIONAL ISSUES

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IPM Context
Quality Enforcing Agencies	Pimentel *et al* [1979] Willey [1978]		
Grower Contracts			Carlson [1979a]
Processors	Carlson [1976]	French [1977]	
Institutions Fostering IPM			
EPA Cancellations	CAST [1980] McCarl [1981b,d]	Gardner [1979]	
Environmental Groups			

TABLE 32 (continued)

Specific Issue(s)	Authors Who Discuss Topic	Authors Who Give Applicable Theory	Authors Who Investigate Issue in IPM Context
		Other Institutions	
Insurance	Carlson [1979a]	Arrow [1963] Ehrlich & Becker [1972] Zeckhauser [1970]	Miranowski, Ernst & Cummings [1974]
Research Funding Organizations	McCarl [1981b]		
Farm Programs	Fox [1971]	Gardner [1979]	Rovinsky & Reichelderfer [1979] Headley [1971]
General	Carlson [1979a] Norgaard, Seckler & Radosevich [1971]	Randall [1972] Seagraves [1973] Ostrom & Hennessy	

SECTION VI
CONCLUDING COMMENTS AND SUGGESTIONS FOR FURTHER WORK

The literature of IPM economics is diverse and addresses many relevant issues, though many issues remain unresolved. One way to support this statement is to return to the individual components of the words integrated pest management.

Pests, as defined, include not only insects, but also fungi, weeds, and other noxious animals. The literature, however, predominantly orients toward insects. Much less effort has centered on weeds and fungi. The economics of such things as small animal control has been largely ignored. The literature also concerns pests in isolation, failing to account for multiple pest situations. Finally, the literature totally slants toward pre-harvest pests, ignoring post-harvest phenomena.

"Integrated" probably signals the literature's greatest inadequacy. Economic studies simply have not been performed which integrate the management of multiple pests, multiple controls, or pest management into the total farming system. This observation also is true in terms of non-economic work; interdisciplinary research integration has not occurred to any great extent.

Management has been studied extensively although a consistent management framework has not evolved.

The scope of IPM economic work, in terms of commodities, is limited. Detailed micro studies principally concern cotton, alfalfa, soybeans, and corn. There is scope for expansion to other crops (although those studied are among the most important for considering pest control efforts). Aggregate studies have treated many more crops, but there is opportunity for investigation of other pest-crop systems at both the farm and aggregate levels.

Above and beyond the general comments on the IPM economics literature, there are several specific comments that seem relevant. First, at the farm level:

1) The concept of economic threshold becomes extremely tenuous in some cases. Such things as prophylactic pesticide use and multiple applications dependent on stochastic conditions, seem to place this concept

in jeopardy. This concept's relevance needs to be reviewed and its use restricted to a much narrower field of application. However, continued study of the economics of control application is extremely important.

2) A thoroughly conceptualized integrated model of IPM within the farming system needs to be developed and researched. The literature approaches have been partial (i.e., solely looking at IPM use under resistance) and complex interactions have been ignored. Choice among IPM strategies also should be considered more extensively.

3) Data for research are difficult to obtain and require considerable time and interdisciplinary efforts.

At the aggregate level:

1) The role of public action needs to be reviewed, particularly in the in-vogue area of biological controls. Classical economic arguments state that public action is required under conditions when either externalities, common property resources, and/or public goods are present. IPM inquiries contain all three elements to some degree.

2) Desirable forms of public action need to be considered. Many possible public actions may be undertaken. So far, total use restrictions, grading standards, and operator licensing have been used. Many other actions are possible and have been advocated. Information needs to be generated on the impact of various schemes.

3) Externality impacts warrant thorough investigation, at least in several of the cases. An unbiased analysis, anticipatory of future actions, could be extremely useful.

4) Conditions for eradication need to be explored, particularily in terms of current efforts.

5) There is undoubtedly need to continue with cancellation studies. However, economists viewing such work must realize several things: data for such studies are extremely difficult to obtain in the practical time frame, thus, complex models may not work out in reality; cancellations are a short term strategy and other methods of eliminating undesirable pest controls may be more efficient in the longer run.

Technically, the image of biological controls promising all positive results needs to be investigated. Certainly biological controls must be subject to some externalities, yet this discussion has not appeared.

Economists should become more involved from an extension viewpoint. Farmers must be given economic information about principles to consider in IPM strategy choice and use (i.e., what factors should enter their decision process and how to weight them). Too, this education should occur on a broader basis than simply the concepts involved in an economic threshold (for example, considering the factors mentioned in the farm level synthesis above). Also, the general public needs to be objectively informed of the issues and the consequences tied to various actions.

Overall, IPM economics provides an area for rewarding economic work. Investigation must be carried forth based on three principles: 1) the area is complex with many issues involved, all which must be considered; 2) the practitioner must keep sight of the role of IPM in the farming system including its current costs, value of resources saved, productivity benefits, and spillovers; and finally, 3) most of the work is interdisciplinary by nature.

SECTION VII

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