Approaches and Incentives to Implement Integrated Pest Management that Addresses Regional and Environmental Issues

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Abstract
Agricultural, environmental, and social and policy interests have influenced integrated pest management (IPM) from its inception. The first 50 years of IPM paid special attention to field-based management and market-driven decision making. Concurrently, IPM strategies became available that were best applied both within and beyond the bounds of individual fields and that also provided environmental benefits. This generated an incentives dilemma for farmers: selecting IPM activities for individual fields on the basis of market-based economics versus selecting IPM activities best applied regionally that have longer-term benefits, including environmental benefits, that accrue to the broader community as well as the farmer. Over the past several decades, public-supported incentives, such as financial incentives available to farmers from conservation programs for farms, have begun to be employed to encourage use of conservation techniques, including strategies with IPM relevance. Combining private investments with public support may effectively address the incentives dilemma when advanced IPM strategies are used regionally and provide public goods such as those benefiting resource conservation. This review focuses on adaptation of IPM to these broader issues, on transitions of IPM from primarily individual field-based decision making to coordinated community decision making, and on the form of partnerships needed to gain long-lasting regional and environmental benefits.
INTRODUCTION

There is nothing new to the statement that implementing integrated pest management (IPM) is challenging (22, 23, 108). Excellent presentations of the mechanics of IPM and recommendations to evaluate and accelerate IPM implementation are available in Volume 43 of the *Annual Review of Entomology* (71) and in IPM texts (73, 84, 86, 91). The first 50 years of IPM have paid special attention to the application of IPM to individual fields to increase economic competitiveness while minimizing adverse environmental effects. Concurrently, IPM strategies became available that are best applied with consideration of information and management actions beyond the bounds of individual fields. Theory and supporting empirical research show the potential for pest management enhancement when areawide application of appropriate IPM technologies are deployed (3, 5, 47, 72). Over the past several decades, new forms of public-supported incentives have begun to be employed to encourage the use of conservation techniques, including strategies with IPM relevance, with the intent of relieving environmental risks on agricultural lands and surrounding areas (21, 27).

This review provides background on 50 years of development and implementation of IPM on (a) the transition from classic field-based management to a broader management perspective to gain regional benefits. We then focus on advancements during the past several decades in considering (b) the broader landscape in implementing IPM and steps used to address the incentives dilemma when advanced IPM strategies are used to provide public goods such as those benefiting resource conservation, and (c) the expansion of public-supported conservation-based financial incentives as a specific example to enable farmer participation in conservation efforts that conceptually join conservation and agriculture interests, including IPM. Last, we propose refinements and partnerships of existing agricultural, environmental, and social and policy processes needed to encourage implementation of IPM needed to obtain lasting regional and environmental benefits.

FROM FIELD-BASED MANAGEMENT TO A BROADER PERSPECTIVE

IPM approaches and supporting decision-making tools have evolved since the initial focus of IPM on remedial measures, typically in the form of pesticides, to suppress pests below a level to prevent loss that exceeds the cost of controlling the pest. The economic injury level concept and an outline for its application (the economic threshold) to trigger insecticide use were formally presented by Stern et al. in 1959 (106). Thereafter, IPM approaches and supporting tools were refined for direct application to cropping systems, as presented in many *Annual Review of Entomology* reviews spanning the 1960s through the 1990s (71, 94, 110). In addition, a wealth of IPM strategies and supporting decision-making tools for specific pest-crop cases have been published in the scientific literature, as summarized in reviews in the *Annual Review of Entomology* (e.g., 81, 98) and in IPM texts (36, 73, 84, 86, 91).

A Focus on Field-Based Decision Making and Market-Based Incentives

Implicit in the conceptual development of IPM and explicit in most applications was the emphasis on timing of insecticides, used as a remedial measure to manage a pest expected to cause unacceptable damage, based on market standards and applied to an individual cropping field (22, 36, 106). A mathematical approach was introduced to calculate an estimate of insect activity or, less commonly, plant injury, termed the economic threshold, that when exceeded justified use of an insecticide to manage the pest. Economic thresholds are based on economic costs and values associated with applying pesticides, marketing the crop, and anticipating damage from understanding
pest density–crop damage relationships. Pest sampling methods and objective decision-making criteria were developed for cropping system applications to compare measurements taken in an individual field with economic thresholds expressed in the same unit of measure (94). A significant body of research on specific pest-crop cases occurred during the 1960s through the 1990s, and applications were summarized (36, 55, 92).

This approach was an excellent fit for private management entities such as individually or family-owned farms where owners, farm managers, and pest management consultants are responsible for individual fields or small clusters of fields. The incentive structure for implementing IPM centered on market-based costs and values. Agricultural management decisions occurred at the level of individual fields or clusters of fields on a farm, and near-term financial risks were carried by the farm management entity (93, 94, 108, 122). The following exceptions occurred that in good part reinforced the field- and market-based management orientation. Public-supported ministries, agencies, and agricultural research and extension arms of public universities implemented regulations of farm activities, such as pesticide use restrictions, and provided regional pest and environmental risk information and guidance that affected IPM within the field-based decision-making framework (71, 91). Advancements in host plant resistance, crop biotechnology, and pesticide technology related to pest management shifted some decision making before planting but still maintained the field-based focus (74, 104). Collective farming, either imposed or encouraged by governments or special communities, also affected IPM decision making in many parts of the world. Here some early and impressive strides in regional pest management occurred owing to indigenous knowledge or government-directed actions (3, 4, 23, 77, 82). But in large part specific actions to manage pests relied on field-based decision making to trigger pesticide use, especially in countries where much of the development of IPM occurred and where international markets and government relationships were dominant (9, 23).

This framework was applicable to predominant economic, technological, and social conditions of modern agriculture. It was arguably effective in encouraging IPM adoption, improving pest management, and minimizing adverse environmental effects associated with pesticide use. Reductions in pesticide use and associated reductions in human health risks and pollutants were seen when economic thresholds and supporting pest sampling were adopted in field, vegetable, and fruit cropping systems (52, 105). Significant use of IPM in high-value cropping systems measured by the same indicators was reported (103), especially when guided by independent pest management consultants (12, 13). Other policy-manifested actions were mandatory environmental and worker safety regulations tied to pesticide availability and use (9, 88, 100). These were preset conditions in which field-based management occurred. The strides in environmental protection when IPM was employed were arguably impressive, although counter-explanations associated with technology advancement and economic considerations have been offered (122). Regardless of the degree of success, IPM was advocated by agricultural, governmental, agribusiness, and environmental entities in many parts of the world (50, 82). The irony was that pesticide use, and possibly associated environmental risk, increased concurrently as agriculture expanded and intensified (23, 96).

Transitions to Broader Scales and the Incentives Dilemma

Others concluded that IPM adoption by these, in good part, pesticide-related measures was inconsistent with the evolving perspective of IPM to embrace multiple and more sustainable strategies that are well suited to manage pest complexes and maintain a healthy environment (4, 29, 122). This argument centered on ecological aspects of sustainability and environmental considerations of IPM. It recognized that advanced and more sustainable IPM strategies such as biological control and habitat manipulation had not been as readily applied in modern agriculture as pest sampling
and economic thresholds to support more judicious use of pesticides. Yet the ecological potential to enhance pest management and to be proactive in addressing environmental concerns was sound (3, 5, 47, 71). Therefore, other social and policy actions were desirable to aid farmers in their management choices affecting pesticide use and environmental protection, including different kinds of incentives and other policy instruments to address an incentives dilemma for farmers. Farmers largely carry the burden of selecting IPM activities for individual fields on the basis of market-driven economics versus selecting IPM activities best applied regionally that have longer-term benefits, including environmental benefits, that accrue to the broader community as well as the farmer. Regional IPM strategies also associated with public goods such as resource conservation were typically more costly in coordination, materials and technology, and deployment (9, 33, 102). One could arguably conclude that future advancement in IPM implementation at broader scales associated with public goods is bleak (29, 122).

Yet for IPM, the steps of transition to address regional and environmental issues began early in its development. Early IPM concepts recognized the importance of considering natural controls and adverse effects of pesticides on them (106). Inroads were made to include biological control and pesticide effects on environmental quality in the IPM decision-making process. The contribution to pest mortality through the action of biological control agents was estimated and used to modify economic thresholds for fruitworms in tomatoes (59), spider mites in almonds (120), caterpillars in alfalfa (49), and aphids in walnuts (109). Also, the potential adverse effects of selected pesticides were used to refine economic thresholds (56). These modifications focused on field-based management, in keeping with IPM decision making of the time.

A holistic perspective came from the framework of IPM as a hierarchy of approaches, scales of implementation, and types of incentives to achieve adoption. Kogan (71) provided an excellent review and synthesis, beginning with the use of economic thresholds and pest sampling that were oriented toward individual field application primarily by market-driven factors within a regulatory framework. The more advanced levels of IPM were based on using multiple strategies and monitoring activities that provided benefits across pest complexes, environmental quality concerns, and farm and regional scales. This advanced level of IPM required a greater knowledge base of agroecology, expanded community involvement, and new forms of incentives (71, 108). Other complementary views focused on lowering risks and raising sustainability by using multifunctional strategies, implementing nonconflicting agricultural and environmental policies, and engaging community networks of knowledge and leadership (9, 27, 63). Advancing IPM and addressing risk elements of pest management technologies through transitional phases were elements of these viewpoints (9, 71).

The foresight to ask “who pays?” was clear: Environmental and other societal and policy interests and market implications of the modifications were discussed and debated (33, 93). Unfortunately, the special needs for different kinds of incentives during much of the development of more advanced IPM strategies were limited largely to public-supported research, education, demonstrations, and special cases of public support for eradication and prevention efforts (9, 30, 62, 71). It was also argued that mandatory pesticide regulations were limited in scope in regard to environmental protection in many parts of the world, that government-sponsored market-support programs were offsetting costs of pesticides, and that indirect environmental and economic costs of pesticide use were not considered in policy and field-level decision making (9, 23, 93, 96).

A reasonable synthesis of the state of the science and practice of IPM during its first 50 years of modern development is that IPM adoption occurred most readily at the scale of the individual field. IPM adoption centered on pest sampling and economic thresholds for pesticide decision making, driven primarily by market factors within a pesticide regulatory framework. Implementation of more advanced approaches that utilize information and actions at broader scales is more
challenging. It requires additional societal acceptance, community cooperation, and different forms of incentives to encourage implementation (71). The pace of transition and the incentives dilemma for advanced IPM strategies that provide public goods are of special relevance, given the environmental impact of agricultural intensification including pesticide effects on nontarget organisms, loss of biodiversity, and degradation of soil, water, and air resources (39, 96). Yet the stage was set for consideration of broader ecological, economic, and social views to develop and support IPM that addresses regional and environmental issues.

CONSIDERATION OF THE BROADER LANDSCAPE AND GAINING ENVIRONMENTAL BENEFITS

Over the past few decades a detailed development of IPM approaches has occurred with a more regional orientation to enhance pest management and gain additional environmental benefits. However, as noted in the previous section, the vast majority of IPM strategies implemented successfully occurred at the local field level. At best, multiple organisms might have been considered in developing a solution, for example, choosing compatible target-specific pesticides, pheromone technology, or specific crop varieties that have multiple traits resistant to several pests (74, 101, 104, 113). More commonly, farmer-adopted IPM strategies responded to single-pest outbreaks within a narrow framework of time and space using pesticides and underutilized nonpesticide alternatives (29). Several concerns with this approach from a landscape perspective were notable. Local, individual pest management decisions did not necessarily affect the wider landscape, but accumulated outcomes from multiple field pesticide applications could cause regional adverse environmental harm to water and air quality and biodiversity (96, 101). Also, IPM actions applied with regional coordination could enhance pest management areawide and for longer periods than when applied in an uncoordinated field-by-field basis (72, 122).

Environmental Health Considerations and Mitigation

Perhaps the best documented examples of adverse regional environmental impacts when using pesticides over the past two decades are for surface water and groundwater. Between 1992 and 2001, pesticides were detected in nearly 90% of the streams and rivers surveyed in the United States (39). Pesticides in water and riparian sediment presented risk to aquatic invertebrates, fish, and humans (38). The primary routes of entry from agriculture were pesticide-laden water due to runoff caused by storm events and excessive irrigation, or due to drift from field to surface water. Groundwater was another resource affected by external farm inputs, both pesticides and nutrients. Pesticides were detected but did not exceed human risk benchmarks in 61% of samples from shallow groundwater used for drinking water and in 33% of samples from deeper aquifers (38). The broad detection of herbicides throughout the Midwest provided an excellent example of almost-uniform individual economic-driven decision making across a large agricultural region that resulted in regional resource degradation of the Mississippi River and Delta system (39).

In addition to pest management impact on water quality, IPM decisions involving pesticides applied in field-based management contributed to impaired air quality in limited areas. Six air basins in California were declared nonattainment areas for meeting national clean air quality standards, including the major agricultural regions of the San Joaquin and Sacramento Valleys (41). Additives present in selected fumigant and nonfumigant pesticides contributed volatile organic compounds (VOCs), which led to the formation of ozone. Adverse effects on biodiversity due to agricultural intensification were also well known, as exemplified in the major reductions of plants and animals occurring in the European countryside. Adverse regional effects were related
to both forms of intensification of agriculture: high chemical inputs including pesticide use and high concentration of land area devoted to a limited number of crops (6, 7, 65, 115).

A number of strategies with combined IPM and environmental value were available to mitigate these risks. Cultural practices such as winter sanitation in almond orchards reduced the need for midseason treatments of naval orangeworm (Amyelois transitella) (121), vegetative ground cover limited runoff of pesticides (61), and use of polyacrylamide, sediment traps, and vegetative ditch banks reduced the amount of contaminated sediment leaving a field (79). Improved application technology reduced pesticide drift (14, 70), and a shift to alternative pesticide products reduced risk to the environment (31, 44, 80) and human health (46). In Europe, strategies related to IPM were implemented with varying success in reducing risk to farmland birds and biodiversity. For example, field margins left unmowed served as habitat for native plants, birds, and insects including pollinators and biological control agents. They also served as filters for nutrients and pesticide runoff (25, 32, 64).

**Areawide Pest Management and Decision Making**

Areawide pest management was viewed by some investigators as a branch of IPM that stimulated detailed consideration of the broader agricultural landscape, whereas others emphasized its distinctiveness. It differed from IPM centered on application of individual on-farm actions by applying IPM strategies regionally in a coordinated manner to maintain the pest below economic-damaging levels for longer periods across broader areas (30, 122). Transitioning the individual nature of field-based decision making to the community nature of regional decision-making approaches began with an emphasis on areawide management of key pests on major crops that had special interest to groups of farmers, and had complementary private and public support (72). Areawide pest management programs varied greatly in the level of regional pest threat, technologies deployed, types of agreements, and level of private and public investment in the program.

Most successes of areawide management were aimed at a single key pest in a region, where the benefits and justification of the areawide actions were primarily pest driven, with secondary environmental benefits obtained if pesticide risk was reduced (30). This typically involved entering into voluntary or farmer-supported mandated agreements. In some cases, the goal was eradication, such as the boll weevil (Anthonomus grandis grandis) in cotton (2), or prevention of a new pest from invading a region, such as the potential introduction of pink bollworm (Pectinophora gossypiella) into San Joaquin Valley cotton (California) (53). These programs were structured around farmer-supported mandates. Others attempted voluntary measures to regulate the population of a key pest across an area to reduce the threat to any individual farmer. For example, mating disruption of the codling moth (Cydia pomonella) in pears (67) and vine moths in grapes (60) was adopted by a sufficient number of farmers to have the desired regional pest management effect. An arguably effective and simple case of an areawide approach was exemplified by the case of the silverleaf whitefly (Bemisia argentifolii) in Arizona. An agreement within a farmer community defined by the cropping system and insecticide use patterns specified voluntary adherence to guidelines for use of key active ingredients of insecticides in order to sustain crop protection (89). There are fewer examples that embrace management of multiple pests or across multiple crops, including an insect pest complex of tomato (113) and citrus insect pests (45, 122). Last, the development of more localized pest control districts functioned for decades as areawide biological control zones (45) (see sidebar Fillmore Citrus Protective District, 1922–2004). These programs benefited from a combination of technology advancement, grower collectives and agreements, and partially public-supported services.
FILLMORE CITRUS PROTECTIVE DISTRICT, 1922–2004

In 1922, a group of local citrus growers in the Fillmore citrus district (California) formed a pest management protective district. Threatened by invasive citrus pests, growers realized that only by banding together to share the risk could they individually survive. Giving up their individual rights for IPM decision making, they turned the decisions for pest management over to the District, allowing the District to place resources where they would do the most good for the community. Membership was strictly voluntary and services were paid through self-assessment of members. The spread of California red scale infestations was greatly limited within the District from 1922 to 1928. In 1926, a new pest arrived that was not effectively controlled with fumigation, and a District-financed insectary was built to provide a supply of natural enemies. Over the years, the Fillmore Insectary provided natural enemies for scale pests, moving away from reliance on pesticides to more biological control. Unfortunately, the citrus economic conditions in 2003 required a shift to fruit and vegetable crops, the common interests of the local citrus community dissolved, and the District and Insectary closed (45).

Above we focused on the agricultural pest threat and the regional process for areawide pest management decision making. An agroecological key to program success was considering the landscape in which the cropping system and pests coexist, as demonstrated by empirical evidence (6, 10, 114) and supported by metapopulation dynamics and landscape ecology theory (30, 78). The agroecological goal was to favor crop production at the expense of the pest with least interference to the ecosystem in which it is embedded, an approach also consistent with the concept of ecological engineering for pest management (47). The dispersal characteristics of the pest (17), the strength of individual plants to act as sources or sinks (19) and the potential for biological control (48, 114) needed to be understood to optimize cropping system planning. Planning included a combination of in-field local action to consistently manage pests in crops and noncultivated fields, regional action in shifting cropping patterns to those less favorable to pests, and both local and regional action in increasing the planting of food and shelter habitat for natural enemies and native pollinators (48, 72, 95). Cropping systems varied in these areawide programs: Crop mosaics shifted in time and space, continually changing advantage among various pests, their crop hosts, and the surrounding environment. The surrounding environment also varied in biodiversity and vegetation complexity, thus having an effect on biological control agents (10, 114).

Overall, the driving force of areawide pest management programs was the recognition that economical pest management was dependent on everyone working together. Success of such programs depended on this recognition regionally, adequate agricultural and ecological knowledge, availability of appropriate IPM technologies, social aspects of local leadership and community structure, and effective social and policy tools such as formal agreements and public support (30, 62, 99, 101).

Approaches to Address the Incentives Dilemma

Coordinated regional effort to obtain durable pest management effects was challenging. The desire for community cooperation and relinquishing control of some field-based management decisions must be greater than the desire to control individual fields and farms. Combined with strong agreements and common goals as presented above, various forms of incentives may assist in moving to this tipping point for community decision making (8, 11, 93).

The manner in which this incentives dilemma had been addressed in areawide programs varied from no public support beyond technical guidance from extension and research services, to
Conservation programs for farms: public-supported voluntary incentives programs, known as agri-environment schemes in Europe and conservation programs for working lands in the United States

substantial public investment because of the severity of the pest situation or because of proactive actions to gain additional environmental benefits. First, consider the case of the areawide eradication effort for the boll weevil in the cotton belt of the United States, which was implemented at a subcontinental scale progressively over 30 years and continues today. Based on regional insect pest suppression (68), this program benefitted from supporting incentives in the form of joined public and private financing and technical support, and farmer- and legislative-approved regulations. Pairing governmental and farmer-supported actions led to significant achievements, albeit not without ecological and economic controversy. The boll weevil now remains only in southern Texas (2, 108).

Second, consider the case of regional decision making facilitated by the size of the management entity. In this case, a single farming operation was of such a large scale that uniform crop and noncrop management actions could be taken across a broad area to influence the movement of the western tarnished plant bug (Lygus hesperus). The impact on susceptible cotton was minimized by placing sources (seed alfalfa and safflower) on the downwind margins of large cotton fields (42). Field sources of the L. hesperus were managed by timing insecticide application on safflower to suppress the population before they became winged adults (85). Alfalfa, a preferred host and sink, was introduced, and movement was mitigated by leaving strips of uncut alfalfa as preferred habitat (111). Finally, sources of the L. hesperus were concentrated to create the smallest perimeter-to-area ratio to minimize the border between cotton and safflower (43). Combined, all these steps resulted in minimal pesticide intervention for this key pest of cotton.

Third, consider the case of addressing pest complexes regionally with largely private investments coming from multiple management entities. The example of the Fillmore Citrus Protective District (45) (see sidebar Fillmore Citrus Protective District, 1922–2004) is an example of the rare creation of a voluntary district that had longevity, utilized private investments obtained from farmer self-assessments to run the program, and emphasized use of advanced IPM strategies with environmental benefits. Public support was limited to traditional extension and research of government agencies and affiliated universities. Last, the reader is referred to the following section for examples of utilizing public-supported incentives of conservation programs for farms to encourage farmer adoption of IPM-related techniques that provide additional environmental benefits.

Developing regional goals of agricultural benefits (less risk to income, production with reduced external inputs) and additional benefits contributing to the public good (improved environmental quality and countryside aesthetics) requires consideration of the landscape, regional decision making, and addressing the incentives dilemma. Single-entity management of large farms, farming community investment in local management districts, and public support have been used to overcome the incentives dilemma. Public support may come in the form of traditional technical assistance of public research and extension that provides the knowledge base needed for implementation, and financial incentives to offset costs associated with actions to gain regional and environmental benefits.

CONNECTIONS TO PUBLIC-SUPPORTED CONSERVATION FOR FARMS

As discussed above, IPM strategies with regional pest management value and expanded environmental benefits have presented the challenges of broadening the scale of entomological and environmental information gathered, incorporating it into a joint field and regional decision-making structure, and supporting it with broader-based incentives. In this section, major conservation programs for farms are introduced that may complement IPM and partly satisfy these challenges.
Conservation Programs for Farms

In review of the published literature, the major conservation programs devoted to agricultural lands were found principally in developed countries, especially in the United States and Canada (27, 88), the European Union and nonmember countries of Europe (27, 64, 66), and selected other countries (119). Set-aside programs sponsor taking agricultural lands out of production, which affects insect conservation and pest management (35, 54, 117). Here, we focused on programs for lands in agricultural production where public-supported financial incentives were offered to farmers to adopt conservation techniques that addressed resources in a state of current or potential degradation related to agricultural activities (27, 64, 66, 88). IPM complements this approach: Advanced IPM strategies provide various environmental benefits when properly implemented (8, 11). Moving resource conservation onto agricultural lands, especially in developed countries where intensive agriculture occurs, was encouraged in the ecological restoration literature. Ecologically, this was justified by the substantial portion of the land mass devoted to agriculture; recognition of declines in biodiversity and quality of soil, water, and air resources associated with agricultural intensification; and the need for connectivity of resources across natural and agricultural landscapes (6, 24, 87, 119). Economic support for this effort, in the form of conservation-based financial incentives to farmers, obtained wider policy support over the past two decades, as this form of agricultural financial assistance fits into the green box exception of World Trade Organization rules (27).

In Europe, a large group of conservation programs for farms became available as financially supported in good part by the Common Agricultural Policy of the European Union and by other public support mechanisms of nonmember countries such as Switzerland (27, 66). The primary conservation goals and the resources of conservation concern varied across countries, with a strong history and emphasis on farmland bird conservation in the United Kingdom; bird and other biodiversity interests in the Netherlands, Switzerland, Spain, Ireland, and other countries; and agricultural pollutant issues in Germany, Sweden, Denmark, and other countries. A common theme was that agricultural intensification adversely affected the quality of the countryside, and conservation efforts on agricultural lands could reverse this trend if properly applied (6, 16, 64, 66). In the United States, conservation programs for farms were also available, with the largest programs offered by the U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS). The USDA NRCS conservation programs were initiated to address soil loss from agricultural lands, and a significant expansion occurred to address a broad array of agriculture-related resources of conservation concern beginning in the 1990s. Soil loss and sediment loading of waterways, nutrient and pesticide loading of groundwater and surface water, and air pollutants from agricultural operations were major thrusts of the programs (88). Some state-level support was available in the form of technical assistance, regulations, and, in rare cases, special taxation zones (41, 76).

Key Issues Facing Conservation Programs and Relationship to IPM

The strong species degradation orientation of programs in Europe and the pollutant orientation of programs in the United States affected the connectivity of the programs to entomology and IPM. These contrasts in emphases resulted in some differences in the listings of techniques available to farmers in the programs. Program evaluations reported that some techniques addressed multiple resources of conservation concerns, whereas others were designed more with ecological considerations of targeted resources of special conservation concern, such as uncommon species and pollutants in a selected region where degradation of the resource was high (32, 58, 66). For example, natural vegetation field margins left unmowed served as filters for nutrients and pesticide...
runoff as well as habitat for native plants, birds, insects, and other species contributing to ecosystem health (25, 32, 58). In contrast, midfield refuges of perennial grasses placed in strips through cereal fields (beetle banks) provided stronger ecological benefits for targeted breeding bird species of interest (107) but had less utility as a filtering system. Entomology components of studies focused on insects as food to species of conservation concern, as indicators of environmental quality, occasionally as resources of conservation concern themselves, and uncommonly as pests (see sidebar Conservation of Farmland Birds and Links to Insects and references therein). In the United States, entomology interactions with the conservation programs were limited largely to expert opinion on the benefits of pesticide application technologies and advanced IPM strategies to address pesticide-related resource concerns of water and air quality (11, 57, 58) and to evaluation of farmer selection of conservation program techniques that had effects on insect management (41, 58).

The risk of degradation of the resources of conservation concern provided an informative contrast of likely factors associated with program progress and impediments and how the programs related to entomology and IPM. Conservation programs that achieved the greatest success in decreasing the threat to resources of conservation concern were those that made available to farmers well-designed techniques and typically involved resources under a high threat of degradation in specific regions where the threat occurred. The programs themselves may have addressed a broader array of resources of conservation concern but had targeted subprograms or flexibility to focus on local resources of special concern (32, 76, 90). Programs focused on broader resources of conservation concern commonly had greater variability of success in reducing threats to the resources across regions where the program was implemented (64, 66, 107).

Other ecological and agricultural issues associated with program structure affected program progress. Evaluation studies showed that technique effectiveness may vary across selected species of interest (34, 69, 107), in scale of implementation (83, 107), and in locality of implementation as affected by landscape diversity and farm management intensity and interests (115). For example, regional biodiversity benefits were greater in diverse landscapes than in landscapes that were relatively simple (115). See the sidebar Conservation of Farmland Birds and Links to Insects as an instructive example.

Social and policy viewpoints were also important in assessing the potential for IPM involvement in conservation programs for farms (9, 11, 18). When operational considerations were similar, farmers tended to select techniques with higher payments, which did not necessarily reflect greater environmental benefits in the Midwest. IPM techniques available to address farm pollutant concerns had low incentive payments and low farmer selection. In the United Kingdom,

### CONSERVATION OF FARMLAND BIRDS AND LINKS TO INSECTS

Conservation programs for farms in the United Kingdom and elsewhere in Europe have focused on farmland birds. Known habitat requirements and other ecological factors associated with species health were used to assess risk of farm activities and to design techniques to reverse species decline. Program efforts benefitted species of special concern such as the gray partridge (*Perdix perdix*) and cirl bunting (*Emberiza cirlus*) for which techniques were especially designed, had variable effects on other farmland birds, and had mixed to limited benefits to biodiversity (7, 16, 32, 64, 90, 107). Insects were found valuable as a food resource for species of special conservation concern (64, 118), as indicators of broader biodiversity health (7, 15, 34, 64–66, 69, 107), and as taxa of additional resource concern such as butterflies and pollinators (1, 28, 64, 83, 97). Explicit studies on pest management implications were more limited but impressive in detail. For example, conservation headlands and beetle bank techniques included pesticide use restrictions and partial reliance on biological controls to control pests in cereal fields (32, 107).
some techniques such as beetle banks were less selected by farmers when technique choices were available, because of the perceived technical difficulties and higher costs to implement beetle banks within the crop (107). In contrast, agricultural participation in program delineation of techniques and payment levels and local flexibility to provide reasonable accommodations to local farmer interests were valuable in encouraging use of IPM strategies to gain conservation benefits (8, 57, 58). Understanding goals and attributes of conservation programs for farms and their challenges was important in establishing positive interactions between the IPM community and conservation programs (11).

Overall, multiple viewpoints are valuable in assessing conservation program progress and impediments and opportunities to integrate IPM into the programs: a conservation view such as resources of conservation concern and the techniques available to address the concerns, an agricultural view such as farmer levels of participation and agricultural community involvement in decision making within the program, and a policy view such as complementary support from cooperating ministries, agencies, and private concerns (18, 21, 27). Issues identified in conservation program evaluations are in many instances similar to those facing IPM as it transitions to more use of IPM strategies with regional pest management value and expanded environmental benefits (see first two sections of this review). The value of IPM to the goals of public-supported conservation programs and their shared challenges in attaining regional goals and broad benefits becomes clear from this multifunctional perspective.

**NEXT STEPS TO IMPLEMENTING IPM THAT ADDRESSES REGIONAL AND ENVIRONMENTAL ISSUES**

Incentivizing people to implement IPM with regional pest management and environmental value reflects the age-old incentives dilemma as applied to agriculture. How do members of a community relinquish their near-term self-interests stemming from a market-based agricultural system to a less tangible and future good that has broad public benefits?

**The Nature of the Problem**

The examples reviewed demonstrate the challenge for individuals to transition from their market-based interests to broader interests that require community involvement and areawide decision making. This problem of individual freedom to access common resources (i.e., the natural resource base on which agriculture depends) is well described as the tragedy of the commons (51). In the example provided in Hardin’s essay (51), a community of herdsman utilize the same common grazing area. The system of sharing the resource without overexploitation works at lower herd population levels but breaks down when individuals begin to increase production capacity. Individuals attempt to gain the productive advantage over neighbors by exploiting commonly held resources.

Although Hardin’s argument (51) is aimed mostly at the need to feed an exploding human population, the dilemma remains the same for addressing regional and environmental issues as related to agriculture, including IPM (99). Individual actions to increase production and profit do not in themselves lead to wider environmental degradation; after all, the common resources of a healthy agroecosystem are resilient (3, 6). However, many individuals all acting in an arguably reasonable way in a market-driven system have adversely affected air and water quality and biodiversity, reducing the resiliency of the common natural resources system needed for individual success (38, 87).
Enabling Farmers Through Partnerships

This review has examined the literature for examples of communities working together in reducing agricultural and environmental risks through application of IPM strategies. This approach is consistent with conservation ecology interests of contributing to the resiliency of healthy agroecosystems (112) and with agroecology interests of implementing advanced levels of IPM (3, 29, 71). It places IPM as a supporter of landscapes with healthy ecosystem services, including provisioning (food, fiber, fuel, fresh water), which requires the supporting services (nutrient cycling, soil formation, natural enemies, pollinators) as well as the regulating (climate, flood, water quality) and even cultural (aesthetic, spiritual, educational, recreational) services (24).

A functional model to implement IPM strategies with regional and environmental value must be respectful of agricultural, environmental, and social and policy interests and in our view benefits from and requires partnerships. It must include social and policy aspects (both community leadership and individual motivation for addressing such issues) and economic and agricultural aspects (sharing near-term farm risks and long-term rewards of public goods through both market-driven and public-supported incentives) (21, 26, 40, 75). At some point, farmers must be enabled to move beyond their reactive posture of responding to individual problems and to begin to develop a process to address multiple issues. But they live in a largely market-driven and regulatory system with variable external support that is just beginning as of the past few decades to move from production-based incentives to conservation-based incentives. Are there transitional steps that lead to regional, multifunctional, nonconflicting efforts of farmers, public programs, and private organizations?

Depending on the number of issues confronting an individual farmer, diverse public agencies and private entities may require planning to address specific concerns related to agriculture and IPM. The planning process may target compliance of environmental regulations (88, 100), criteria to access public financial support related to conservation (11, 27, 66), and participation in performance-based assessments required in contracts with food and fiber processors (20). The plans may be simple best management practices adapted from technical support provided by extension and research services of ministries, agencies, and universities and may involve detailed third-party certification such as eco-labeling (37).

IPM can play a central role in addressing multiple environmental and human safety issues and in achieving its pest management goals through such planning processes. Ideally, these processes are linked to a combination of private and public-supported incentives (30). For example, in the United States, USDA NRCS and local extension and research services of public land-grant universities have created ad hoc partnerships to improve communication, establish pest management standards in conservation programs, and improve IPM skill sets through training of USDA NRCS staff and private contracted providers (11). In special initiatives, conservation planning and IPM planning are linked, and detailed farm plans are developed on the basis of best management practices including IPM (11, 57, 116). The purpose of such planning activities is to provide a reflective process for the farmer. The farmer, pest management consultant, and conservationist review IPM strategies currently utilized and their potential effects on soil, water, and air. They set farm goals to increase use of IPM strategies that reduce the risk to resources of conservation concern while meeting market-driven standards. In parts of the United States, this process is a prerequisite to obtain financial incentives from conservation programs for farms. In selected cases, the planning process itself is financially supported. However, these initiatives suffer from the ad hoc nature of the partnerships (11). In contrast, as presented in this review, partnerships are commonly solidified by strong agreements in successful cases of areawide pest management (72). We recommend solidifying the agriculture and conservation connections through formal agreements.
to ensure establishment of durable interaction and shared responsibility to attain agricultural and conservation goals. This is especially crucial when public funds are involved.

Regionalizing effort to attain long-lasting multiple benefits is a related challenge. Current efforts have had variable success by combining regulatory mandates with a voluntary system of technical assistance and financial incentives to encourage regional community action. Success has been most apparent when risks are high, resources and regions of interest are well defined, technologies for reducing the risks are well known, and financial support is available (30, 32). Said with some reservation and sadness, society may have now transitioned to the point that broader-based risks such as biodiversity loss and region-wide detection of water and air pollutants are of sufficient community concern to stimulate more regional activities, especially in areas of intense agricultural production. The growing suite of conservation programs for farms in partnership with agricultural interests such as IPM has a role to play in encouraging regional activities with environmental benefits (9, 11, 64, 66).

In this case as well as other partnerships, we encourage equal consideration of agricultural, environmental, and social and policy interests to ensure strong effort to attain unified goals when addressing regional and environmental issues. These partnerships should sponsor community-based decision-making processes and invite the coordination of technical and financial incentives from private and public entities. Specific to IPM, we envision joining interests and sharing risks and resources to enable farmers to implement more advanced IPM strategies at participation levels needed to attain long-lasting regional pest management and conservation benefits. This partnership requires farmers, environmentalists, public agencies, and private entities to think beyond their short-term objectives, establish effective agreements and common goals, and reconcile and join market-based and public-based incentives to attain multiple short-term and long-term benefits to agriculture and the environment.

**SUMMARY POINTS**

1. During its first 50 years of modern development, IPM adoption occurred readily at the scale of the individual field and farm, with the most common application centered on pest sampling and economic thresholds for pesticide decision making driven primarily by market factors within a pesticide regulatory framework.

2. As advanced IPM strategies became available for areawide application, farmers have been challenged to reconcile the additional costs and risks with benefits that are longer term and accrue to the broader community as well as the farmer, resulting in an incentives dilemma for farmers when IPM strategies are chosen. Implementation of these advanced IPM strategies has been slow compared with those associated with individual field-based market-driven management.

3. Single-entity management of large farms, farming community investment in local management districts, and public support have been used to overcome the incentives dilemma. Public support may come in the form of traditional technical assistance of public research and extension and financial incentives to offset costs and reduce individual risk.

4. Addressing the incentives dilemma for advanced IPM strategies that provide environmental benefits is of special relevance, given the impact of agricultural intensification including pesticide effects on nontarget organisms, loss of biodiversity, and degradation of soil, water, and air resources.
5. In the past several decades, public-supported, conservation-based financial incentives provided to farmers obtained wider public policy support consistent with international trade agreements. The major conservation programs providing these financial incentives were found principally in developed countries, especially in the United States and European Union.

6. The strong species degradation orientation of European programs and the pollutant orientation of U.S. programs affected their connectivity to IPM. Successful linkage to IPM has been most apparent when risks are high, relevant IPM technologies are available, and financial incentives are flexible and reasonable to address locally relevant issues that resonate with farmers.

7. We encourage private and public partnerships that give equal consideration to agricultural, environmental, and social/policy interests to enable farmers to address regional and environmental issues within a market-based and regulatory framework. Such a partnership requires thinking beyond short-term objectives, effective agreements and common goals, and reconciliation and joining of market-based and public-based incentives to attain multifunctional benefits to agriculture and the environment.

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96. Reviews the shortfalls of IPM and argues it still is the solution even if adding to environmental concern.

106. Outlines the fundamental concepts of IPM, which are still relevant 50 years later.


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