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Integrated pest management

This economical approach to environmentally sound pest control has dim prospects for increased federal support

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Experience with many pests—insects, weeds, microorganisms, rodents, and others—affecting a wide variety of resources has shown that no single arbitrary suppressive method will always give permanent control. The evolution of genetic strains of pests that cannot be controlled effectively with pesticides has dramatized this point (see bar graph). However, continued use of a single alternative method also may produce unexpected and undesirable consequences. The practice of plowing and cultivating, for example, may completely eliminate a perennial weed from a field, but an annual weed may invade the field and pose even more of a problem than did the target weed that was eliminated. The use of disease-resistant cultivars (plant varieties produced only under cultivation) may eventually give rise to new strains of disease organisms capable of overcoming such resistance. Pest organisms are remarkably adaptive; the intense selection pressures imposed by human manipulation of their environments accelerate the evolution of new strains that adapt to and override control methods.

Experience has also shown that the development of effective, long-term solutions for pest problems requires an understanding of the actions, reactions, and interactions of the components of the crop or other ecosystem to be protected. Change to a new variety, rotation to another crop, change in fertilizer, modified row-spacing or irrigation schemes, and change in pesticide use patterns may cause a rather drastic shift in the status of pest species in a given agroecosystem. The manipulations may reduce the numbers of a damaging pest, but they may also permit establishment of new damaging pest hierarchies. Even subtle manipulations affect the ecosystem. Only by studying these relationships can the pest control specialist devise ways to avoid ecological disruption and maximize the effectiveness of natural and artificial controls.

Also, experience has emphasized the need for harmonizing all the control practices for all the pests affecting a given resource into one cohesive system. A given crop, for example, is rarely confronted with a single pest problem, but rather with a complex of pest problems: different kinds of insects, mites, disease-causing organisms, weeds, and sometimes rodents, slugs, and other pests. Measures to control one pest may create or intensify other pest problems, which may also be exacerbated by extremes in weather. It is obvious, then, that pest control recommendations should not evolve independently for insects, weeds, nematodes, diseases, or other pests, nor can optimal control strategies be developed without considering the cropping system or other resource as a whole.

Finally, experience has shown that to provide effective long-term results, a pest control scheme must be integral to and compatible with the overall management and economics of the farm, forest, or other resource for which it was developed. Because pest problems, control technologies, economics, and human values are continually changing, the pest control system must be flexible and offer a variety of options.

The need for comprehensive, ecologically oriented, multipest management systems has given rise to an approach known as "integrated pest management" (IPM). Although originally articulated by entomologists as an integrated control approach for insects (*1*), integrated pest management is applicable to all classes of pests, and all pest control disciplines are sharing in its development and implementation. OTA, Bottrell, Huffaker, BioScience, Flint and van den Bosch, and IOBC are suggested for comprehensive discussions of recent developments in IPM (*2–7*).

IPM techniques

Integrated pest management uses a systems approach to reduce pest damage to tolerable levels through a variety of techniques, including natural predators, pathogens, parasites, genetically resistant hosts, environmental modifications, and, when necessary and appropriate, chemical pesticides. Generally, IPM programs first use nonchemical defenses against pests before altering the environment with chemical pesticides. After the ecology of the pests is known and the cost effectiveness and environmental suitability of the control measures have been determined, the IPM techniques are harmonized in an organized way.

Because development of a specific integrated pest management program depends on the pest complex, the resource to be protected, economic values, and the availability of personnel,

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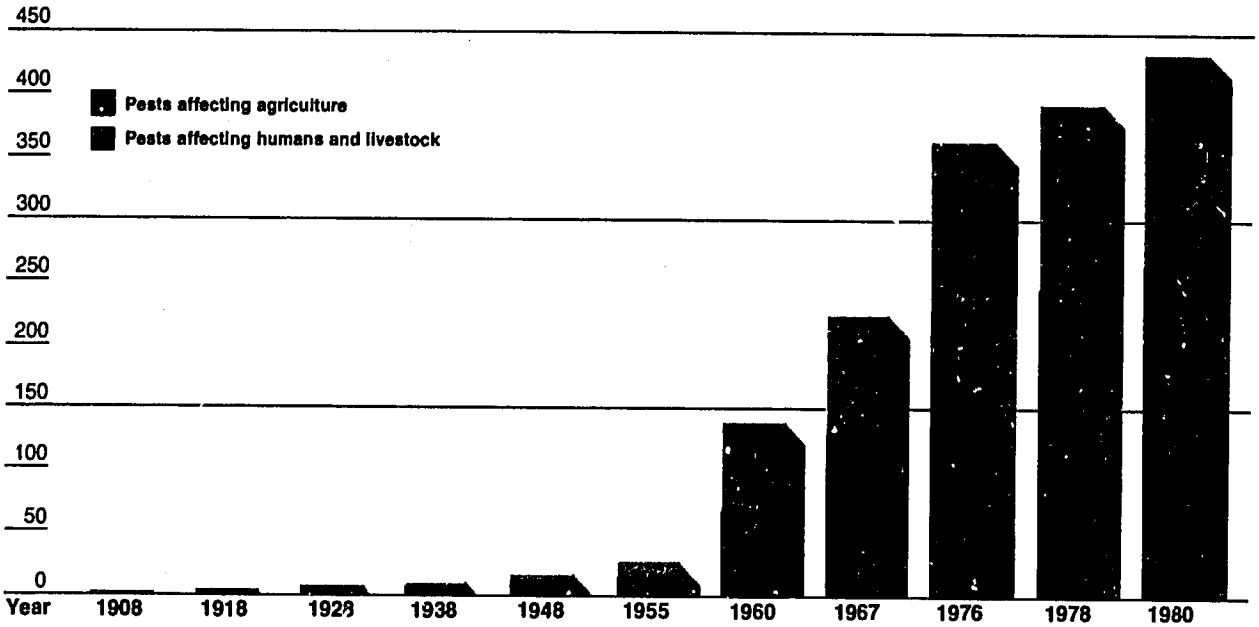
The number of species of insect, mite, and tick pests resistant to chemical pesticides has increased almost exponentially in the last 30 years



Source: Georghiou (20).

Significant groups of pests have evolved with genetic resistance to pesticides. The most serious problems of resistance have been encountered in the control of arthropods (insects, mites, and ticks). Resistance in these organisms has a 70-year history, but its greatest increase and strongest impacts have occurred in the last 30 years following the extensive use of synthetic organic pesticides. Worldwide, in 1980, 432 species of insects, mites, and ticks were known to have developed strains resistant to one or more chemical pesticides (*20*). The increase in resistance among these pests has been almost exponential in recent decades. Of the resistant arthropods on record, 261 are crop pests (including forest and stored product pests), and 171 are pests affecting human beings and livestock (mosquitoes, flies, lice, fleas, ticks). The resistant group includes some of the most serious arthropod pests in the world. Programs for the control of malaria are being seriously jeopardized in some regions because the malaria-transmitting mosquitoes can no longer be controlled with previously effective insecticides. The development of resistance in certain agricultural insect pests has crippled economical crop production. About 75% of California's most damaging crop insect and mite pests have developed genetic resistance to at least one pesticide, and some are resistant to two or more pesticides (*21*).

The most important problems of genetic resistance have been encountered in the control of arthropods. However, about 50 species of plant pathogens, five species of weeds, and two species of nematodes were known to have developed strains resistant to chemical pesticides in 1980 (*20*). Scattered populations of rats have developed high levels of resistance to some rodenticides. Resistance to anticoagulants (poisons that cause internal bleeding) in the Norway rat has created a serious problem in some U.S. cities (*22*).

it is difficult to establish absolute guidelines. However, certain general guidelines were developed by Bottrell to apply to the management of most pest situations (*3*) (see box).

Many of the control techniques suitable for integrated pest management have been known for decades. Some of the most effective nonchemical techniques (for example, biological control, pest-resistant crop varieties, tillage, crop rotation) were used widely before World War II but were deemphasized, particularly by entomologists and weed scientists, as effective chemicals became available after the war. Recent problems such as the development of pest-resistant species and the increased cost of pesticides have aroused new interest in the prewar control techniques. Promising new alternatives to chemical pesticides, including insect attractant chemicals, weed and insect disease agents, and insect growth regulators (hormones), are being developed; some are already being used on a small scale (*2–4, 6*).

The interdisciplinary requirement

Integration of these techniques into cohesive IPM schemes that provide long-term benefits requires the collaborative efforts of weed scientists, plant pathologists, entomologists, other pest control specialists, ecologists, agronomists, economists, sociologists, and system scientists. A variety of disciplines is usually required to collect the information, formulate the IPM strategy, execute the strategy, and evaluate the results. To be effective, the interdisciplinary team members must cooperate in a mode true to the "systems approach." They must integrate their activities completely from the time the initial research is performed through implementation and evaluation of the IPM strategy. Otherwise, they may complete their work only to find that the fragmented results obtained from the various components cannot be fitted together as a meaningful "whole." This horrendous outcome may be minimized by using systems scientists versed in the principles and applications of IPM.

Guidelines for the development of a specific IPM program (*3*)

One, integrated pest management rejects the notion that the presence of a pest necessarily justifies control. Therefore, for each of the reputedly injurious organisms, information is obtained on the population level that determines its "real" pest status, referred to as the "economic threshold"; this is defined as the density of a pest population below which the cost of applying control measures exceeds the losses caused by the pest. Economic threshold values should be based on assessments of the potential for pest damage and the ecological, sociological, and economic costs created by control measures (Figure 1). Pest damage potential is extremely complex to evaluate; it depends on the crop variety, soil type, fertilizer use and timing, and plant density, among other things.

Two, management schemes are devised for lowering the average densities of those pests that recur regularly at population densities exceeding economic threshold levels; these are known as "key" pests, and they are the focal point for IPM programs. Key pests are not to be confused with pests of secondary importance that attain injurious levels at less frequent intervals, sometimes only when provoked by human disturbances such as pesticide use.

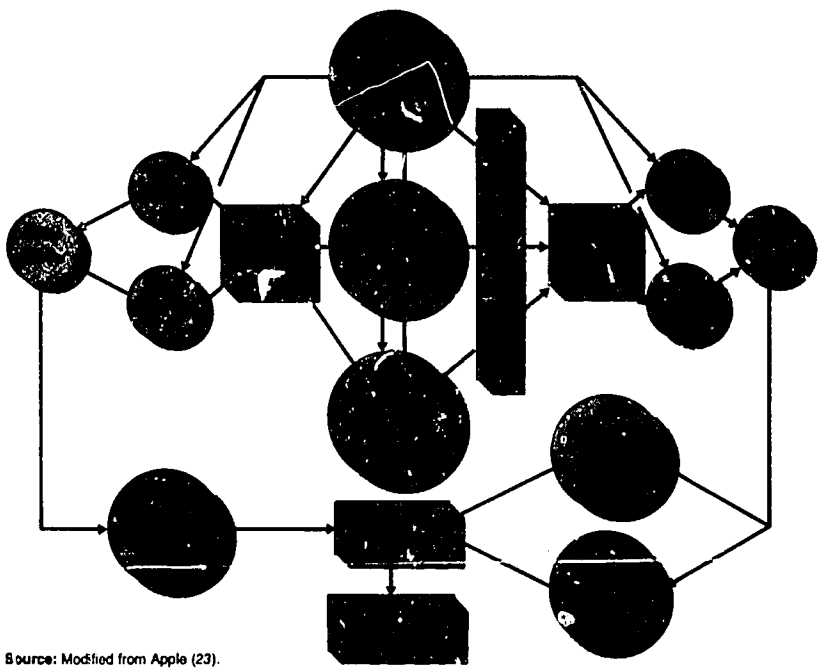
A key pest will vary in severity from year to year, but its average density, known as the "equilibrium position," usually exceeds its economic threshold. Integrated pest management efforts manipulate the environment in order to reduce a pest's equilibrium position to a level below the economic threshold (Figure 2). This reduction may be accomplished using three primary management components, alone or in combination:

- deliberate introduction and establishment of natural enemies (parasites, predators, pathogens) in areas where they did not previously occur
- use of pest-resistant or pest-free varieties of seed, crop plants, ornamental plants, orchard trees, forest trees, or livestock
- modification of the pest's environment to increase the effectiveness of the pest's biological control agents, to destroy its breeding, feeding, or shelter habitat, or otherwise render it harmless.

Three, during emergency situations, remedial measures that cause minimum ecological disruption are employed. The best combination of the

FIGURE 1

Many interacting variables determine the economic threshold for a plant disease



Source: Modified from Apple (23).

Computer models are useful for unifying and guiding research, and giving a clearer understanding of the various interactions in a pest's life system and ecosystem. The apparent utility of the models is that they can be employed, for example, to map out pathways for manipulating a crop (use of a particular combination of plant varieties, fertilizer, planting schedule, crop rotation, etc.) to achieve optimal pest management (*4*).

Status of IPM

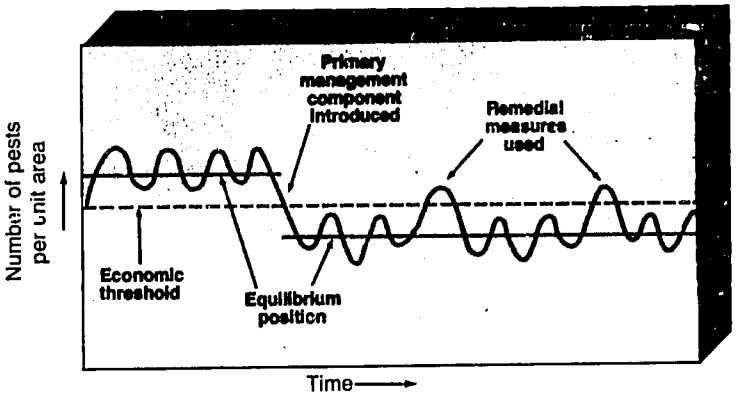
Farmers are becoming more interested in using the IPM approach, as evidenced by a recent upsurge in the U.S. crop acreage being regularly monitored and by the recent increase in the number of private pest management consultants in agriculture. Many states now have a large cadre of college-trained private crop consultants. They offer a wide variety of farm services, including soil analysis, fertilizer recommendations, crop variety selection, and advice on pest infestation, pesticide application, and alternative methods.

Favorable experience with IPM in Texas has led to the formation of a statewide, nonprofit farmer-administered organization, the Texas Pest Management Association, to promote increased use of IPM systems on cotton and other crops. Most cotton farmers in Texas now practice some form of IPM. This is demonstrated by the fact that insecticide use on Texas cotton—historically the largest consumer of insecticides of any crop—was reduced from 19.3 million pounds in 1964 to 2.3 million in 1976 (*2*). In California, the state legislature decreed by law that IPM must be employed "wherever feasible."

Since 1971 the Cooperative Extension Service has been demonstrating on a large number of farms the advantages of integrated pest management for a wide variety of field crops and livestock operations. For nearly every crop included in the demonstrations, pesticide use has dropped significantly without a sacrifice in yield or quality and with increased profit to the farmer. The demonstrations in cattle feedlots have shown a reduction in the use of chemical pesticides and an increase in the daily weight gain and feed efficiency of the animals. Equally encouraging results have been achieved by IPM programs directed

FIGURE 2

IPM may be used to lower the equilibrium position of a pest below the economic threshold value



Source: Rabb (24).

three primary IPM components—natural enemies, resistant varieties, and environmental modification—may eliminate the need for further action against key pests except under unusual circumstances. However, when the key pests have flared up or the secondary pests are out of control, pesticides may be the only recourse. Selection of the pesticide, dosage, and treatment time are carefully coordinated to minimize the hazards to nontarget organisms, the environment within the target area, and the surrounding ecosystems. The use of insect-attractant chemicals, weed and insect disease agents, and insect parasites and predators have shown promise as remedial measures in some IPM programs.

Four, the managed resource must be regularly monitored. Pest populations are dynamic, sometimes doubling in a day or less or decreasing at a comparable rate. Because weather, crop growth, natural enemies, and other factors that affect pest density are also changing constantly, pest populations and the components of the environment influencing their abundance must be inspected frequently in order to determine when to apply or relax various control measures.

Some sophisticated IPM monitoring schemes use computer terminals into which are fed data on pest densities, natural enemies, weather, and other relevant factors. The computerized system processes the information and then tells the farmer what steps, if any, should be taken to correct the pest problem. A number of these monitoring systems involve no special equipment and very little expense, having been designed for farmers, foresters, and others.

against pests affecting urban areas, public health, and forests (*3*).

Teamwork

To date, the largest research efforts to develop IPM have focused on cotton, citrus fruits, deciduous fruits, corn, soybeans, alfalfa, and pine trees. A major national research project, "The Principles, Strategies, and Tactics of Pest Population Regulation and Control in Major Crop Ecosystems," conducted from 1972 to 1978, focused on insects and mites attacking cotton, citrus fruits, deciduous fruits, soybeans, and alfalfa (*4*). Control of insects and mites on these crops consumes approximately 70% of the insecticides applied annually to U.S. cropland. It is estimated that national implementation of the prototype plans developed by the project could reduce the quantity of insecticides used for control of these pests 70–80%, with no reduction in crop yields (*3*).

Coordinated by the University of California at Berkeley, the project involved the cooperation of 18 universities, the U.S. Department of Agriculture (USDA), and private industry. Grants from the National Science Foundation, EPA, and USDA totaling $5.48 million during the six years represented only a portion of the total cost because each participating institution provided substantial support.

A sequel to this project, "Development of Comprehensive, Unified, Economically and Environmentally Sound Systems of Integrated Pest Management for Major Crops," was initiated in 1979 and involves research on IPM systems for cotton, apples, soybeans, and alfalfa. The project is coordinated by the Consortium for Integrated Pest Management (CIPM) through the Texas A&M University Research Foundation. It involves the cooperation of 15 universities, USDA, and various other collaborators. Grant funding for fiscal year 1982, from USDA's Cooperative States Research Service, totals $3 million.

The CIPM project represents an especially important trend toward more rational management of crop pests because it emphasizes the development of IPM systems for all pest complexes (insects, diseases, weeds, etc.) attacking the crops being studied. Multipest integrated management schemes, synchronized with and integrated into optimal crop production systems, are essential for long-term benefits. Efforts to develop such multipest IPM schemes have just begun in the U.S. with the CIPM project taking the primary lead. The project employs a unified interdisciplinary approach. It uses economists and system analysts, and emphasizes the development of IPM programs that provide maximum economic returns consistent with a policy of minimal environmental damage.

IPM in foreign nations

Other countries have also experienced encouraging results with integrated pest management. European nations, for example, have developed IPM programs showing considerable promise for grapes, corn, rape, citrus, and, to a lesser extent, wheat and vegetables. However, the programs generally have focused on a single pest or pest complex. Efforts to develop multipest IPM schemes, synchronized with and integrated into optimal crop production systems, have not progressed significantly (*8*).

IPM has made significant progress in some of the less developed countries (LDCs) (*7, 9*). In fact, a number of the earliest IPM programs were first introduced in the LDCs. Most of the efforts have been focused on nonfood crops—cotton, cocoa, etc.—and not on the basic food crops of the subsistence farmers; attempts to devise IPM programs for food crops have lagged. However, major projects have been recently undertaken by the Food and Agriculture Organization of the United Nations (FAO) to develop IPM systems for rice in South and Southeast Asia, and by FAO and the U.S. Agency for International Development to develop IPM systems for millet, sorghum, and other subsistence crops in the Sahel of West Africa.

Economics of IPM

Only rarely have IPM programs been evaluated in terms of the relative benefits of protection from pests and relative yields compared to the cost of the programs. There are few acceptable cost-benefit analyses, and they provide limited information. Furthermore, little empirical work has been conducted on the net social welfare aspects of pest control (*10*).

For those IPM programs that have been properly evaluated, the cost-benefit analyses generally have been encouraging, showing a reduction in pesticide use, increased profit for the user, and savings in energy cost (*11*).

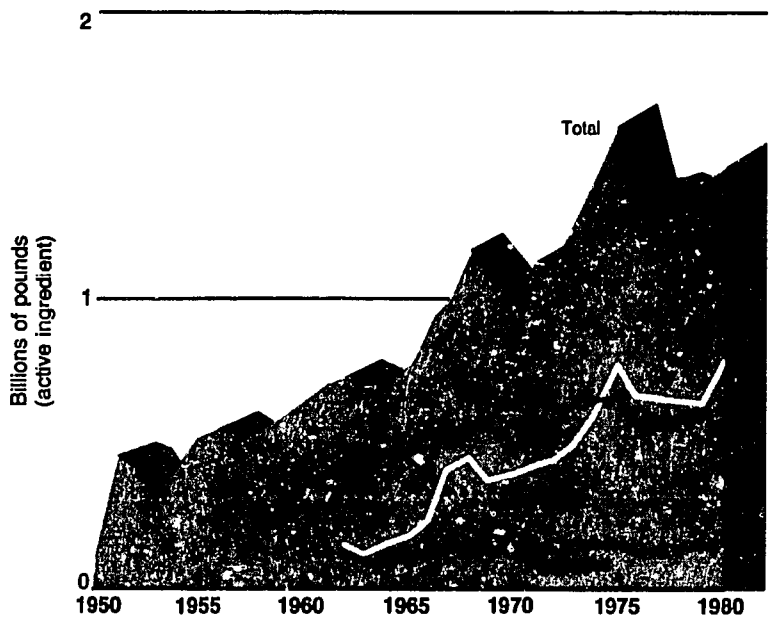
It has been demonstrated that on some Texas farms, cotton grown under a system of integrated insect pest management may be produced with 50–75% less insecticide. Moreover, the IPM system incorporates early maturing cotton varieties that require 80% less fertilizer and 50% less irrigation water than the late maturing varieties. The system has increased participating farmers' profits more than $100 per acre (from $62 to $170) (*12*).

Adoption of IPM over a wide area—as opposed to a small number of farms—may have a much different effect on farmers' profits, according to recent analyses (*11*, *13*). For example, if the best available IPM systems were adopted by all U.S. cotton farmers, economic studies show that cotton prices would decline and farmers' profits would decrease $593 million. On the other hand, the lower cotton price would mean a benefit to consumers of $2.024 billion. At an estimated cost of $176 million required to implement the IPM program throughout the cotton belt, overall benefits accrued to society would be $1.255 billion.

More evaluations of the economic and social effects—at both micro and macro levels—are necessary before the real impact of IPM is known.

FIGURE 3

After peaking in 1975, the synthetic organic insecticide production in the U.S. declined[a]



[a]Includes a small quantity of synthetic soil conditioners; does not include the fumigants carbon tetrachloride, carbon disulfide, ethylene dibromide, and ethylene dichloride, which have many other uses; nor does it include paradichlorobenzene (classed by the International Trade Commission as an intermediate) or inorganic pesticides.
Source: Agricultural Stabilization and Conservation Service of the USDA.

Of all the chemical pesticides applied worldwide in agriculture, forests, industry, and households, about one-third to one-half is used in the U.S., where consumption has risen notably in the past 30 years. Production of synthetic organic pesticides in this country rose from an estimated 464 000 pounds in 1951 to an estimated 1.47 billion pounds in 1980.

This increase has occurred for a number of reasons. Herbicides, for example, have been used increasingly to replace hand labor and machine cultivation for the control of undesirable vegetation in agricultural crops; in forests; on the rights-of-way of highways, utility lines, and railroads; and in cities. Agriculture in particular has become dependent on herbicides. Major U.S. farming enterprises now rely almost exclusively on these materials to do the job previously performed by hand labor and mechanical cultivators.

Agriculture consumes perhaps 65% of the total quantity of synthetic organic pesticides used in the U.S. each year. Homeowners, businesses, and governments also consume substantial amounts of the materials. Integrated pest management cannot be expected to completely eliminate pesticides in any sector. But it can significantly reduce the use of some pesticides and mitigate the undesirable side effects of the others.

Limitations and needs

Despite progress, IPM is in an initial stage even for the various agricultural crops where it has progressed most, and it will continue to proceed slowly unless much greater efforts are made at the state, national, and international levels. A number of technological, economic, institutional, and attitudinal barriers retard its development and implementation (*2*, *7*, *14*).

One important obstacle is that IPM technology has not been adequately researched and developed. In 1980, in the U.S., less than 5% of the total federal budget for pest control (nearly $850 million) supported programs involved in the development and implementation of interdisciplinary IPM systems. The bulk of USDA and state agricultural experiment station funds supported work on individual pests or approaches that involved the use of a single control (biological control, plant resistance, pheromones) and did not support holistic, multipest IPM systems (*14*).

A boosted research effort is needed to collect the information and perfect the monitoring techniques required for IPM implementation and to evaluate the results of IPM strategies. In addition, there is a real need for a mechanism that ensures that funds are allocated to the best scientists and that they work as units of interdisciplinary, holistic-program-oriented IPM teams. Basic biologists—ecologists, taxonomists, geneticists, and others—and social scientists should be included in these teams.

Even when an IPM strategy exists, it is often extremely difficult to sell to farmers who are accustomed to the simpler chemical control strategy that has a strong foothold in agriculture and other U.S. sectors (Figure 3). These individuals must first be shown

that IPM programs will adequately control pests at lower costs than those for chemical control. Then they must be taught how to acquire and apply information necessary to IPM implementation. Development and successful implementation of IPM depends heavily upon education at all levels—for research scientists who develop the technology, extension personnel who teach and demonstrate the use of the technology, farmers who demand the technology, and government regulators and elected officials who impose laws and regulations to effect its use. Inadequate educational programs are an important obstacle hindering progress with IPM (*15*).

In the U.S., major steps were taken during the last administration to advance research, education, and other activities required to overcome the variety of obstacles slowing IPM. In his 1977 message on the environment, President Carter requested that the Council on Environmental Quality (CEQ) recommend actions that the federal government might take to encourage the development and application of IPM techniques to all sectors. In his 1979 message, Carter established an "Interagency IPM Coordinating Committee," chaired by CEQ, to assure implementation of his 1977 directive and to oversee further development and utilization of IPM practices.

The U.S. Congress also took a major step to advance IPM during the last administration when Senator Herman E. Talmadge (D-Ga.), Chairman of the Senate Committee on Agriculture, Nutrition, and Forestry, requested the Office of Technology Assessment to evaluate IPM in the U.S., to identify obstacles hindering its progress, and to review the problems and impacts involved in the transfer of North American crop protection technologies to the developing world (*2*).

Despite these progressive steps taken by the executive and legislative branches during the last administration, the present situation is not encouraging. The Interagency IPM Coordinating Committee chaired by CEQ has been abolished, Congress has not implemented the recommendations of the OTA report, and the prospects for increased federal support of IPM are presently dim.

Special needs in the LDCs

Traditional agriculture, characterized by small farms, polyculture (growing of two or more crops simultaneously on the same field in the same year), local, unimproved varieties, little or no artificial fertilizers, pesticides, or other artificial imputs, and minimum tillage, is still practiced by a large portion of farmers in the less developed countries. Yields are very low, and there are no organized methods of pest control; pests simply are tolerated or controlled intermittently by natural forces and rare pesticidal treatments. The farmers have access to limited capital and technology, many of them are illiterate, and they have virtually no knowledge of the benefits or limitations of pest control practices (*16*).

However, high yielding varieties, irrigation, mechanization, fertilizers, and other modern innovations are being introduced into the traditional agricultural areas. The crop yields have increased, often significantly, and this has provided incentives to adopt other crop improvement techniques that maximize yields. Parallel with these modern innovations, pesticides, particularly insecticides and herbicides, are being used more and more. Pesticides have already been employed extensively in various LDCs and have created serious problems in some instances.

In the Gezira of Sudan, for example, heavy use of insecticides on cotton has led to secondary insect pest outbreaks, causing near bankruptcy of the cotton industry—Sudan's chief export industry and its primary source of foreign currency (*17*). Heavy use of insecticides on cotton in Central America is a special health concern. Insecticides have poisoned humans directly and caused significant contamination of foodstuffs (*18*). Applications of DDT to control pests on cotton in Central America and India have so modified the mosquito habitat that insecticide-resistant malarial mosquitoes have evolved and greatly increased their abundance, thus adding yet another dimension to the human health problems in these areas (*19*).

IPM specialists should become more active partners in efforts to increase crop production in the LDCs, especially in areas where the incentives for pesticide use are high. It is also important that agricultural programs in pest control be closely coordinated and synchronized with public health programs to minimize such problems as pesticide poisoning and contamination and the resurgence of malaria. The so-called "agromedical" team approach can contribute significantly to coordinating and synchronizing the efforts of agriculturalists and public health specialists, and to mitigating the pesticide problem (*18*). The U.S. universities and federal agencies can play an important role by cooperating with the LDCs to stimulate IPM and the agromedical team approach in the LDCs (*2*). The role of the U.S. Agency for International Development is especially important to these efforts and also to the development of more

Insecticide use on Texas cotton has declined sharply

rational policies concerning the export of pesticides to the LDCs. Many of the pesticides used in the LDCs originate in the U.S. or Western Europe. Some have been prohibited, severely restricted, or never registered for use in our country, yet under current law it is perfectly legal for U.S. manufacturers to sell the products to other countries.

Concluding remarks

Integrated pest management promises to provide practical, effective, and energy-efficient solutions to significant pest problems in agriculture, forestry, and other sectors, while minimizing potential hazards to humans, their possessions, and the environment. Yet the approach is not a panacea for all pest problems, any more than DDT was for all insect problems, and it may not be the most cost-effective approach for every problem. For example, use of herbicides to control weeds on cropland may be considerably cheaper than hand labor, mechanical cultivators, and crop rotation—the principal alternative IPM methods currently available to manage weeds affecting most crops. In the case of a recent foreign pest introduction, such as the Mediterranean fruit fly in California, for example, the economic factor was assigned a far higher value than the environmental factor. In order to prevent some foreign pests from becoming established and spreading widely, chemical eradication may be preferable to IPM.

The recent accomplishments of integrated pest management and continued public interest in alternatives to conventional pesticide programs have resulted in confusion about the concept and uncritical endorsements of IPM programs without regard to their feasibility. A number of individuals have erroneously interpreted IPM to mean pest control without pesticides, while others have erroneously interpreted it to mean any form of pest management that employs more than one control technique.

Pesticides have played—and will play—an important role in integrated pest management. In fact, some IPM systems may cause an increased use of pesticides because monitoring may in some cases provide a more accurate assessment of the losses induced by pests. However, most IPM systems should result in a significant reduction in pesticide use, and widespread adoption of IPM should greatly decrease the undesirable side effects and complications resulting from the use of chemical materials.

A control program that employs more than one control measure is not necessarily an IPM program. The combined use of sterile insects and insecticides in efforts to eradicate the Mediterranean fruit fly from California during the summer of 1981 was not IPM, although some newspeople erroneously labeled the control effort "IPM." The philosophy of eradication is the antithesis of integrated pest management. It is not surprising that some journalists do not know the difference, considering that a number of individuals in our plant protection professions do not know either. Some people may not understand the IPM concept, but they have adopted the term IPM, finding it useful when trying to attract the attention of public officials, granting agencies, and environmentalists. For many, IPM has become—as the term ecology became in the 1970s—a buzzword.

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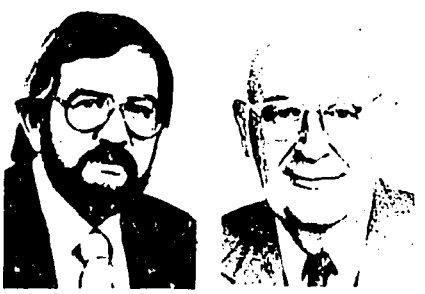

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