

A Quest for Ecologically Based Pest Management Systems

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ABSTRACT / The article presents a holistic approach to studying and applying crop protection in agricultural systems. A theoretical framework of integrated pest management (IPM) is presented that allows an understanding of pest population processes on a whole-agroecological-system basis. The need for and emergence of holistic research on agroecosystems is discussed, as are the current trends in ecological theory and pest management.

The search for ways to control the environment is a fundamental drive in human history. At the forefront of these struggles is the quest for ways to deal with agricultural pest organisms. People have experienced direct competition with arthropod pests since the beginning of agricultural activities. In those times, the operation of farms was an art based on field knowledge accumulated from years of experience and transmitted from generation to generation. Primitive farmers lacked elements of refined technology and the capability to produce at a high capacity. Nevertheless, their practices were to a large extent self-sustaining and efficient (Black 1971). Their crop systems were diversified, and nutrients and other resources were recycled. These farming systems still prevail in many areas of the tropics (Janzen 1973).

As scientific advances developed, the resulting technologies were incorporated into agricultural practices. Also, the expanding human population increased the demand for greater production capacities. This led to the increased intensification of agriculture, characterized by even sharper specialization in certain commodities, and a dependence on fossil energy and vast crop monocultures. The fact that the emerging modern crop systems are ecologically unstable and that serious pest problems can be anticipated in such systems has become very apparent (Southwood and Way 1970, van Emden and Williams 1974).

A desire for and expectation of finding a magical cure-all for pest problems fostered a persistent effort toward increasing use of synthetic chemical compounds at the expense of desirable cultural practices and biological regulation concepts (Van den Bosch and Telford 1964). A great deal of valuable ecological lore of the early farmers was lost in the midst of technological advances. Modern agriculturalists have not adequately balanced the pursuit of immediate maximization of crop yields

and profits with an appreciation of the importance of maintaining resource diversity and biological stability as a means of helping sustain relatively high yields on a long-term basis. Moreover, in our educational programs the agroecosystem has been largely viewed as consisting of components to be studied separately by various independent disciplines. Unfortunately, this orientation disregards the holism of the agroecosystem, masking features of the system that could be critical for understanding the complex system interactions that govern the production process. Plant protection is no exception; many recommendations for pest control have been based on considerations involving only the target pest and have not taken into account other components of the agricultural system. The shortcomings of a heavy dependence on conventional chemical pesticides have been well documented (Doutt and Smith 1971) and reveal the flaws of attempting pest management in a reductionist manner.

Despite those discouragements, scientists involved in plant protection have begun to agree that there is an urgent need to develop more effective and efficient procedures for pest management based on sound ecological principles. Many are becoming more aware that the various pest control disciplines impinge on matters of interest to other disciplines, and are realizing the need to mold their diverse viewpoints together as a coherent field of inquiry. This redirection has resulted in a strong revival in the search for biological strategies of pest regulation, including habitat manipulation (Komarek 1969) and system redesign.

The primary purpose of this article is to assemble the available information concerning the relationships between ecological theory and pest management and to present a holistic approach to studying and applying crop protection in agricultural systems. A theoretical framework aimed at understanding pest population processes in the broadest possible manner, involving the whole agricultural system, is offered to stimulate thinking along agroecological lines.

KEY WORDS: Agroecosystems; Integrated pest management (IPM); Holistic approaches; Ecosystem-oriented pest management

Emergence of Holistic Research on Agroecosystems

The Reductionist Approach

It is easy to visualize why reductionistic approaches to crop protection have been maintained within agricultural systems: 1) there has been an abundance of inexpensive fossil fuel to maintain high-energy systems; 2) the complex nature of the ecological, technological, and socioeconomic aspects of land use has made it difficult for most scientists to select an approach for studying agroecosystems; 3) and people have assumed that there is ample homeostasis within agricultural ecosystems and hence these systems can take a considerable amount of abuse and still be suitable for man to inhabit and produce crops.

Development of Agricultural Ecology

The continued maintenance of cultivated systems will probably be required if food and fiber needs are to be met. However, a number of far-sighted individuals have warned that the equilibrium in such systems is very fragile and can take only a limited amount of abuse. These concerns have emerged from a common root: agricultural ecology. Credit for much of the initial development of agricultural ecology belongs to Klages (1928), who suggested that special consideration should be given to physiological and agronomic factors influencing the distribution and adaptation of a particular crop species in order to understand the complex relationships between a crop and its environment. Later, Klages (1942) broadened his definition to include the historical, technological, and socioeconomic factors that determined what crops could be cultivated in a region and in what amount. Papadakis (1938) stressed that the culture of crops should be naturally based on crops' responses to the environment. Thus agronomy and crop ecology should be synonymous. However, the interrelating network between agronomy and other sciences necessary for this type of comprehensive approach is just emerging (Loucks 1977).

Regardless, the works of Azzi (1956), Wilsie (1962), Chang (1968), and Odum (1968) have served as a basis for recent moves toward an ecosystem approach to agriculture. Azzi (1956) emphasized that while meteorology, soil science, and entomology are distinct disciplines, their study in relation to the potential responses of crop plants converges as an agroecological science, which intends to discover the complex relationships among crop plants and their environment. Wilsie (1962) analyzed the principles of crop adaptation and distribution in relation to habitat factors, and he made an attempt to formalize the body of relationships implicit in crop systems. This effort was pursued further by Chang (1968); however, his approach was rather ecophysiological. He considered agricultural systems as photosynthetic systems, and he focused on basic aspects

of photosynthesis at the community level. Recently, various journals concerned with a holistic approach to agroecosystem management have emerged (for example, *Agro-ecosystems*, *Agriculture and the Environment*, *Agricultural Systems*) as well as several classic articles and books (Dalton 1975, Netting 1974, Van Dyne 1969, Spedding 1975, Loomis and others 1971, Cox and Atkins 1979, Vandermeer 1979, Altieri and others 1982). Potts and Vickerman's (1974) study of English cereal ecosystems is a magnificent treatise concerning ecosystemic analysis of agricultural systems.

Holistic Research

Work aimed at understanding the structure and function of agricultural ecosystems and their productivity problems has been undertaken by various researchers. In these studies farm systems are regarded as the fundamental unit, and in these systems, mineral cycles, energy transformations, biological processes, and socio-agroecological relationships are investigated and analyzed as a whole (Harwood 1979, Zandstra 1976). In Argentina, Zaffanella (1977) discussed six steps to obtain a global ecological synthesis of productivity problems in order to recommend the best strategy to solve the significant constraints of alfalfa production. Gastó (1978) and Maynes and others (1975) proposed a clinical methodology to solve agricultural ecosystemic problems, which would allow the definition of the state of an agricultural system and its transformation towards an optimal stage. The transformation and use of an agroecosystem should comply with three basic requisites: 1) conservation of the renewable resource, 2) adaptation of the biocenosis to the environment and habitat, and 3) achievement of a relatively high, but sustainable level of productivity.

Hart (1979) developed an agricultural systems model that can serve as a starting point for a multidisciplinary team interested in generating and integrating data necessary for defining agroecological relationships. He emphasized that agricultural systems should be viewed as exhibiting not only vertical hierarchical system interactions, but also horizontal interactions. Thus an agroecosystem is composed of a complex set of interacting subsystem flows.

Tropical ecologists were the first to emphatically point out the fragility of agroecosystems. Some have been overly critical of the dangers of introducing modern intensive agricultural technology into tropical areas. Replacement of polycultures by intensively farmed monocultures in the tropics enhanced possibilities for soil erosion, nutrient depletion, disease and pest incidence, inefficient water use, and reduction of local wildlife (Janzen 1973, Igzoburike 1971, Dickinson 1972, and Holdridge 1959). Gliessman and Amador (1979) indicate that many of the traditional agricultural systems still present in Latin America are not much different from those of the ancient Mayans. This is important to consider since these systems

evolved over a long period of time and have remained stable with low-energy input for hundreds of years. In contrast, the modern fossil fuel-dependent agroecosystems have been in existence for only decades, are less stable, are often environmentally hazardous, and are based on a finite supply of energy.

In Cost Rica, Ewell (1979) is developing crop system sequences that emulate the natural succession of the native vegetation by conducting spatial and temporal replacements of wild plants by botanically and/or structurally similar cultivars. In the humid lowland tropics of Mexico, Gliessman and Amador (1979) have studied traditional agroecosystems that combine high species, structural, and temporal diversity, large organic matter inputs, biological control mechanisms, efficient nutrient cycling and energy flow, and a complexity of intricate biological interdependencies. The International Council for Research in Agroforestry (ICRAF) in Kenya is conducting work in agroforestry, through devising systems of land management that combine the production of crops and forest plants simultaneously on the same unit of land (King 1979). These studies exemplify the emergence of novel agricultural research based on ecological principles aimed at achieving self-sufficient and sustained crop production systems.

Although tropical agroecosystems differ considerably from the less diverse temperate agroecosystems, they can be regarded as models to learn from by temperate system ecologists, since tropical systems have not yet been disrupted to the extent that temperate systems have. Some attempts to farm in harmony with natural systems are underway in the temperate United States at the Organic Gardening and Farming Research Center in Pennsylvania. As Harwood (1979) points out, the adoption of old practices of yesterday's agriculture expanded by present knowledge of natural systems, can lead to the development of a holistic, full-system approach to producing crops. Of significant importance is that a team of United States Department of Agriculture (USDA) scientists recently made a study of various ongoing organic farming practices and reported that many of them were of value and merited consideration in government-sponsored research programs (Smyser 1980). A recent study conducted in the midwest revealed that compared with conventional systems, many organic methods consume less fossil energy, cause less soil erosion, and ensure acceptable yields on a long-term basis (Lockeretz and others 1981).

Current Trends in Ecological Theory and Pest Management

Natural and Artificial Ecosystems

The ecological basis of pest management has been the topic of many review and journal articles during the past decade

(Southwood and Way 1970, Price and Waldbauer 1975, Pimentel and Goodman 1978, Levins and Wilson 1979). Most approaches contrast the structure and function of agroecosystems and natural, undisturbed ecosystems. Browning (1975) suggested that exclusive study of agricultural systems can lead to spurious, or at least skewed, conclusions about pest-crop interactions. He advised researchers to study natural ecosystems from which knowledge can be gained that is readily applicable to agroecosystems. Most ecologists agree that any pest management approach should try to develop an agroecosystem that emulates later stages of succession (that is, mature communities) as much as possible, for this is how biological stability should be achieved (Root 1973, van Emden and Williams 1974, Price and Waldbauer 1975).

The Need for Diversity

One means to succeed in the capture for agroecosystems of some of the stability properties of natural communities is to add selective diversity to crop systems (Murdoch 1975). Although the concept that increased biotic and structural diversity lends stability to an ecosystem has been challenged on theoretical grounds (Van Emden and Williams 1974), experimental evidence in tropical multiple cropping systems clearly shows that crops grown in monocultures usually suffer a higher insect pest load than those grown in diverse, structurally complex communities (Tahvanainen and Root 1972, Root 1973, Dempster and Coaker 1974, Litsinger and Moody 1976, Perrin 1977, Altieri and others 1977, 1978, Perrin and Phillips 1978, and Risch 1979). In addition to these papers describing the ecology of insect populations in multiple cropping systems, the papers of Bach (1980) and Risch (1981) depict some of the mechanisms explaining lower pest loads in polycultures. One of us found that beans grown surrounded by borders of grass weeds had lower densities of leafhoppers (*Empoasca kraemerii*) than monocultures without borders (Altieri and others 1977). Similar regulation of leafhopper densities was obtained when beans were intercropped with corn (Altieri and others 1978). Our recent research in California revealed that interplanting beans or allowing weeds to grow with collards considerably decreased flea beetle, *Phyllotreta cruciferae*, densities on the collards and minimized leaf damage (Table 1). Cruciferous weeds in collard mono- and polycultures diverted beetles from collards, and insect feeding was concentrated on the weeds instead of on the crop (Gliessman and Altieri, 1982). Moreover, plant pathologists have recognized that mixtures of different crop varieties (isolines) can buffer against disease losses by delaying the rate of increase of the disease and by reducing spore dissemination or by modifying microenvironmental conditions (Browning and Frey 1969). Crop mixtures with dense canopies can keep the soil shaded throughout most of the growing season, reducing densities of sensitive weed species and minimizing the need

Table 1. Densities of flea beetles (*Phyllotreta cruciferae*) in various collard cropping systems in Santa Cruz, California (Gliessman and Altieri 1982).

Cropping system	Number of flea beetles		Damaged leaves per collard ^c
	Per 10 collards ^a	Per 5 weeds ^b	
Collard monoculture			%
Weed-free all season	34.0 a	—	54.4 a
Weedy all season	6.6 b	25.0	29.9 b
Collard-bean polyculture			
Weed-free all season	2.3 c	—	34.1 b
Weedy all season	0.6 c	15.0	32.1 b

^aMeans followed by the same letter in each column are not significantly different ($P = 0.05$). (All means are averages of three sampling dates.)

^b*Brassica* spp. weeds.

^cPercent leaves in each collard plant with insect damage.

for weed control (Bantilan and others 1974). Elements of natural pest regulation undoubtedly exist in many mixed cropping systems; however, this is still inadequately understood. Unraveling the effects of differently structured crop mixes and capitalizing on knowledge of natural plant associations will provide a sound ecological basis for practical application of diversity in pest management (Way 1979).

Population Ecology

Price and Waldbauer (1975) view agroecosystems in terms of island biogeographical theory. Both Price (1976) and Mayse and Price (1978) showed that in soybean monocultures, resources for herbivores are sufficient, but for predators and parasites they are deficient. Herbivores efficiently colonized the fields early in the season, but their enemies increased only when the soybean canopy developed. In both experiments, colonization and extinction rates were higher at the field edges than in the center. Thus, Price (1976) suggests that one possibility for stabilizing beneficial insect populations in the system is to increase their colonization rates and reduce their extinction rates. This could be achieved by reducing field size, retaining uncultivated refuges in the fields, intercropping, or by improving canopy closure early in the season. However, Rey and McCoy (1979) warn of some inadequacies of premature application of equilibrium biogeographical theory to the pests of cultivated areas.

Conway (1976) suggested that the theory of r - and K -selection is of value in determining tactics for management of pest species. Effective control should correspond with the ecological strategy of a given pest species. Thus r -pests that exhibit high reproductive rates, short generation time, good dispersal activity, and wide food preferences should usually be approached by fast action methods (chemicals). K -species,

however, which exhibit lower reproductive rates, good competitive abilities, and longer generation times should be suppressed by cultural controls, host resistance, and sterilization. Conway's ideas have been disputed by Ehler and Miller (1978) who contend that in annual crops, r -pests can be effectively controlled by natural enemies that are adapted to habitats of low durational stability. What we must remember is that r - and K -species are artificial categories, and that it is risky to base management tactics solely on the population dynamics of a species without adequate consideration for its relationships within communities.

Unit of Study

The biogeographical region (for example, the farm system mentioned previously) rather than the single homogeneous field may often be the appropriate unit for pest management research (Levins and Wilson 1979). According to Rabb (1978) an agroecosystem (or farm system) should be conceived as an area large enough to include those uncultivated areas that influence crops through intercommunity interchanges of organisms, materials, and energy. Although excellent studies have been conducted on the role of uncultivated land on the biology of pests and beneficial insects (van Emden 1965), little is known about the influence of adjacent habitats on pest incidence in cultivated fields. Pioneer work on this subject by Dambach (1948) suggests that the more nearly vegetation in a field border is related botanically to the adjacent crop plants, the greater is the danger of its serving as a potential source of infestation by injurious insects. In general, it appears that less crop risk is involved in the use of woody field borders in areas where small grains and vegetables are the predominant crops. Studies in north Florida have shown that corn fields surrounded by complex weedy fields and annually burned pine-lands have a more diverse and numerous predator fauna than corn surrounded by annual crops (Altieri and Whitcomb 1980).

The understanding of wide-area population dynamics of insects, diseases, and weeds is very limited. Interchange of organisms between regions and even between crops has been only poorly evaluated (Fye 1972). How does the proximity of a cotton field influence the composition of beneficial arthropods in soybeans? To what extent do beneficial insects depend on hedges, ditch banks, old fields, and forests for their continued existence in agricultural areas, particularly during winter? Do weedy borders and other ecotones influence species diversity and abundance of entomophagous insects in adjacent crop fields? We have found (Altieri and Todd 1981) that the edges of soybean fields adjacent to weedy borders have more predators than the center of the field. In Hawaii, the effective range of the sugarcane weevil parasite, *Lixophaga sphenophori*,

within cane fields is limited to around 150–200 feet from nectar source plants in the field margins (Topham and Beardsley 1975). Also, little attention has been paid to the effects of regional manipulations of non-agricultural habitats on the general balance of the fauna of an agroecosystem. Could populations of beneficial insects be preserved or enhanced in an area by planting patches and strips of legumes, composites, and woodland plants to compensate for the amalgamation of small fields into large crop acreages? Could the herbivore-predator assemblages of an agroecosystem be manipulated by changing the vegetational composition of surrounding habitats through seasonal disturbances? We (Altieri and Whitcomb 1979) found that plowing uncultivated land at different times of the year affects the abundance of particular weed species, which in turn support high numbers of specific herbivorous insects. These herbivores serve as prey to different predators. For example, by plowing the land in December, populations of goldenrod (*Solidago altissima*) are stimulated, along with the predator-herbivore assemblage associated with goldenrod.

Directions for Ecosystem-Oriented Pest Management

All currents of thought brought up in this review agree that agricultural research should be composed of integrative studies, where component parts are assembled and tested in a holistic framework. Within this scope, pest management research should not only attempt to understand how the factors affecting pest population dynamics are related within the crop production process, but also the overall farm environment. Guidelines for developing a multidisciplinary team with a holistic farm systems orientation are available (Technical Advisory Committee 1978, Hildebrand 1979, Hart 1979, Norman 1979, Zandstra 1976, and Harwood 1979).

Obstacles to Multidisciplinary Holistic Research

Despite the considerable body of knowledge on agroecosystems, contemporary pest management has been slow to incorporate ecologically based theory into practice. The scarcity of agricultural scientists trained in holistic thinking and the sense of short-range urgency in applied, practical research can all be factors that prevent a closer integration of theory and application. Resistance based on protecting the status quo within pest management circles has also been suggested as a significant factor (Van den Bosch 1978). Private enterprises are reluctant to incur large expenses in developing alternative technologies for which the benefits cannot be captured by the developing enterprise (Just and others 1979). Unfortunately, biological

methods of pest suppression do not lend themselves as readily to massive manufacturing by agribusiness systems as do conventional pesticides.

Intelligent System Design

Understanding of natural ecosystems, especially those in which crop ancestors evolved, and their patterns of succession, community organization, energy budgets, and nutrient cycles could provide valuable clues on how agroecosystems should be structured for energy-efficient crop production and minimization of pest incidence. Incorporation of anthropological and socioeconomic analysis is fundamental in order to cope with the human factor and to evaluate the relevance of the proposed systems and technology to the needs of the people it should serve.

It must be understood that any large-scale changes in land use are certain to affect pest populations. In many cases, replacement of natural vegetation or diversified agriculture with large monocultures has caused general fauna impoverishment, yet certain species of phytophagous insects have become extremely abundant (Southwood and Way 1970). This suggests that many pest problems could be solved by properly designing crop systems.

Moreover, it is obvious that the organization of the fauna in a whole agricultural region inherently involves the organization of the vegetation within and outside the target crop fields. Diversification of cropping systems and management of uncultivated habitats should be planned together rather than sequentially or in isolation.

A pest should be defined as an “ecological disease,” and all ecological diseases express a certain degree of ecosystemic degradation or disruption. Therefore, the problem to be solved seems not to be the pests, but rather the design of the systems in which crops are grown.

Understanding Chemical Coevolution

The chemically mediated relationships existing among and within the various species and trophic levels of crop ecosystems have not been fully appreciated. This is largely due to the fact that most plant protection research is conducted in highly regimented programs within defined specialties with very limited consideration of the interactions with other components of the cropping system. For example, host plant resistance programs are generally designed for extensive breeding and screening, with evaluations made only on the basis of the interactions between the plant and phytophagous insect. Little, if any, consideration is given to the potential effects on the third trophic level. However, we know there are numerous ways in which changes in plant varieties could affect the performance of entomophagous arthropods (Campbell and Duffey 1979). Var-

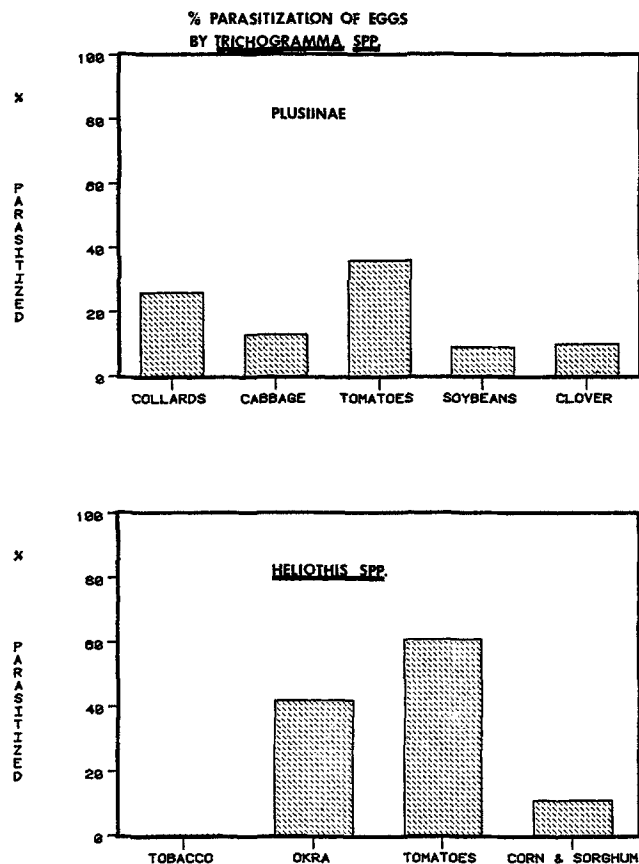


Figure 1. Parasitization of *Heliothis* spp. and *Plusiinae* eggs by *Trichogramma* spp. populations in various crop systems in north Florida (Martin and others 1976).

ious chemical and physical cues emitted by the plants are essential for effective location of the host habitat by entomophages (Monteith 1959, 1960). We know, for example, that *Heliothis* spp. and *Plusiinae* eggs suffer higher parasitization on tomato plants than on okra, corn, sorghum, tobacco, and clover (Martin and others 1976, see also Figure 1). This suggests that the host plant habitat probably affects the degree of parasitization obtained from augmentative releases of *Trichogramma*, regardless of the target insect pest. However, no attempts have been made to utilize plants and their volatiles to improve the habitat and host selection of parasitic insects. We have found that parasitization of corn earworm eggs by wild *Trichogramma* can be enhanced by spraying crop fields with extracts of *Amaranthus* sp. (Altieri and others 1981, see Table 2). Also, the host diet dramatically affects the body odor and consequently, the host-finding behavior of entomophages (Sauls and others 1979). The potential of kairomones to

Table 2. Percent parasitization of corn earworm eggs (*Heliothis zea*) by naturally occurring populations of *Trichogramma* spp. wasps in various crop systems sprayed with a water extract of corn, pigweed (*Amaranthus* sp.), or water (Altieri and others 1981)

Treatment	Parasitization of corn earworm eggs			
	Soybean	Cowpeas	Tomato	Cotton
	%	%	%	%
Pigweed	21.4 ^a	45.4 ^a	24.3 ^a	13.6 ^a
Corn	17.4 ^b	45.8 ^a	21.1 ^a	—
Water	12.6 ^c	31.6 ^b	17.6 ^b	4.2 ^b

^aMeans followed by the same letter in each column are not significantly different ($P = 0.05$)

manipulate and enhance the performance of beneficial arthropods is starting to be explored. The same is true with other semiochemicals such as allomones, synomones, and epideictic pheromones (Nordlund and others 1981).

Kairomones can be exploited in various ways to improve the flexibility and activity of entomophagous insects in augmentation and manipulation programs (Lewis and others 1976). Their greatest potential utility at this time appears to be for aggregating natural enemies or retaining released parasites in target locations (Table 3). As the complex chemical interrelationships among plants, herbivores, and entomophagous insects are more fully understood, the total habitat or agricultural ecosystem can be managed to increasingly meet the needs of beneficial organisms and to be detrimental to pests. This habitat management may include effective combinations of such practices as intercropping, and encouragement of certain non-crop plants within fields and/or along field margins.

Expanding the Integrated Pest Management (IPM)

Problems with Current IPM

The pressures for high quality and attractive produce and maximization of crop production together with other socioeconomic constraints contradict some of the basic founding principles of integrated pest management (IPM). Therefore, the extent to which alternative biological technology has been implemented as a component of the IPM programs is extremely limited, and most programs continue to be centered more on pesticide management than pest management. Scientists and industry and government people need to realize that the adoption of bio-environmental strategies in crop protection could result in long-term stabilization of yields rather than in short-term maximization of yields. In ecologically managed systems, productivity on a crop-unit basis might be reduced,

Table 3 Effect of kairomone treatment on parasitization by *Trichogramma pretiosum* Riley on cotton plots with simulated *Heliothis zea* (Boddie) populations of 4–5 thousand eggs per acre^a (Lewis and others 1976)

Replication	% of egg parasitization	
	Kairomone treated	Control
1	65	34
2	54	31
3	73	54
4	42	12
5	64	50
6	69	59
7	82	64
Mean ^b	64.1 ± 4.9	43.4 ± 7.0

^aKairomone was applied as impregnated diatomaceous earth particles of 40–50 mesh in size, at a rate of 10 particles per linear 0.3-m row.

^bMeans significantly different at the 0.01 level of probability.

but other desirable environmental and economic features, such as the multiple-use capacity of the habitat and reductions in the cost of pest control are enhanced as a result of the greater resource diversity and overall biological stability. Furthermore, energy shortages and economic inflation will probably result in the short-term money costs being more than compensated for by the consistent and sustained productivity capacity as well as a high quality environment for us and our posterity.

A Sound Approach to Systems Management

The IPM concept is based on the recognition that no single approach to pest control offers a universal cure-all, and that the best defense against pest species can be provided by a fusion of the various tactics into practices based on sound ecological principles to either reduce and maintain pest populations below damaging levels or to manipulate them in such a manner as to prevent their causing damage.

The philosophy contained in this paper implies the need to strive zealously for an equitable balance between the concern for the environment and more effective methods of pest suppression. But it also contends that the general orientation of IPM strategies should be to prevent outbreaks through ecological management rather than to suppress them with biocides once they occur. Components for reduction of pest densities should include cultural, biological, and biochemical tactics, but IPM should first rely heavily upon the inherent stability of cropping systems derived from proper habitat manipulations.

Integrated pest management systems should be planned approaches for organizing and regulating faunal and vegetational composition and abundance in a farm system. These systems should work with communities rather than with

populations and with biogeographic regions rather than with homogeneous crop fields. These approaches should be coordinated with broader, related systems of land and water management, resource conservation, environmental protection, and socioeconomic development. Their use should intend to maintain a balance of pest and beneficial organisms based upon known economic, social, and ecological consequences of doing so and not doing so. These approaches should be planned to promote positive effects and to limit negative effects on related agricultural and urban systems. Such approaches should also be programmed in conjunction with other agricultural management schemes so that action taken for other farm purposes will be consonant with pest management practices, and vice versa. Pest management systems should use the holistic knowledge of the agroecosystem and of dynamic economic, environmental, and energy cost/benefit ratios as the basis for selection of actions appropriate to assure harmonious pest regulation without undue costs to nature and society.

Ultimate development of this system will be multidisciplinary, involving not only the traditional plant protection fields but also social economic and political sciences. The development of such technology will come only with extensive investigation employing the talents of the most visionary scientists who have a broad appreciation of the complex and subtle interactions among the various components of agricultural ecosystems, and who are willing to interact freely across disciplinary lines to explore the effectiveness and soundness of imaginative pest management tactics.

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