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Insect conservation and pest management

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The issue of insect conservation in pest management has many conflicting aspects. For instance, it is desirable to conserve a pest residue in order to maintain natural enemy population and it is imperative to conserve natural enemies. However, conservation of pest species is not relevant if the pest species is an exotic invader and a candidate for eradication, mainly because eradication, if successful, achieves only regional extinction. Conservation of native pests depends, to a large extent, on whether the species is a direct pest of a high value crop or an indirect pest with an acceptable economic injury level. In this paper, integrated pest management is defined in terms of sustainable agriculture and the conservation of biodiversity, and give five premises that stress the level of disturbance of agricultural communities and the dynamics of pest status for arthropod species in the community. The possible impacts of the main integrated pest management tactics on arthropod conservation are tabulated and the results reached stress that diversification of agricultural systems through maximum use of native plants should benefit both integrated pest management and regional arthropod conservation.

Keywords: eradication; biological control; exotic pests; cultural control; pest–crop interactions

Introduction

The notion of insect conservation generally implies the perceived desirability of protecting local biological diversity. However, if the goal is simply to preserve or conserve species richness then, in theory, only numbers of species matter regardless of the origin of these species or their role in the community. However, the general thrust of conservation efforts is directed towards indigenous rather than non-indigenous species, although within agroecosystems, the operational battleground of integrated pest management (IPM), the partition between native versus exotic is further complicated; this is because non-native natural enemies are not only protected but even intentionally imported, whereas a native pest, under certain circumstances, maybe a candidate for eradication, with its consequent local extinction. In any event, the issue of conservation of insects is likely to raise ambivalent reactions for both the IPM researcher and the IPM practitioner (growers, consultants, extension advisors). The farmers in the Imperial

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Valley of California (USA) whose melon crops were wiped out by whiteflies probably would not care if the whitefly were extinct. The researcher, however, would see such outbreaks as opportunities to test population dynamics hypotheses and control strategies that normally would fall short of total eradication. In essence, the fundamental question that must be addressed regarding the conservation of insects in agroecosystems is the level of tolerance that the system has for the dominance of a handful of species that have a propensity to escape natural regulatory mechanisms and explode into damaging populations. The ethical, aesthetic or moral considerations (Samways, 1988a) are often perceived as secondary to the overwhelming economic components of agroecosystem dynamics. However, it is argued that the loss of biological diversity generally is detrimental to agroecosystem stability and preservation.

When dealing with agroecosystems rather than protecting a dynamic landscape, we are attempting to manage a simplified and highly perturbed environment, the ultimate existence of which is to efficiently yield plant and animal products essential for the survival of humans, hence the question: what are the limits for the application of species conservation principles to agroecosystems? There is no simple answer to this question, as is demonstrated in this paper.

One major problem is how to reconcile the economic imperatives of the agricultural enterprise and the philosophical principles underlying the notion of conservation of biological species. IPM is a process not an objective. The objectives of IPM are set by society. Conservation of insect species can be an explicit objective of IPM, just as profit maximization or pesticide reduction may be. Consider, for instance, such control tactics as eradication and biological control that diametrically differ in the spectrum of impacts on species conservation. Eradication probably represents the extreme of the non-conservationist approach to pest control. However, it is worth noticing that although biological extinctions happen with some frequency in nature, the intentional eradication of invading exotic pests has met with only limited success (Dethier, 1976; Knipling, 1979; Smith, 1982). Obviously, humans are perfectly capable of accelerating the extinction of a species, including their own, even when they do not intend to do so. However, if they plan an extermination programme (eradication) of a major pest they often fail. Failures of eradication programmes abound (e.g. medfly in California, boll weevil in Brazil, imported fire ant in SE USA (Smith, 1982) and they support the view that successful invaders are difficult to eradicate exactly because they are exceedingly well adapted to the conditions that prevail in the invaded zones (i.e. cultural steppes). Poor invaders, highly host and habitat specific species, perhaps K-selected, are much more vulnerable and easily led to extinction with the destruction of their habitats. To the credit of eradication, however, it must be stressed that targets invariably are invading non-indigenous species. Most conservationists would agree that there is little justification for conserving these species in areas recently invaded. At the other extreme, IPM tactics such as biocontrol and host plant resistance have more benign impacts on conservation of species. These tactics, with few exceptions (Samways, 1988b; Simberloff, 1988), seem congruent with the general objectives of conservation, which are the preservation of the native biodiversity.

The thesis that is explored here is that IPM is inherently a conservationist approach to plant protection. The concept of IPM and the basic tactical components of an IPM system will be discussed briefly and then an attempt to evaluate the impact of these tactics on biodiversity and the conservation of species will be put forward. As a basis for this evaluation, a series of premises will be presented, that are largely based on the authors personal experiences rather than on hard data or on available references. In fact, much of what is proposed is largely speculative because there are few experimental or even descriptive studies of agroecosystems that lend themselves to an analysis of the impact of IPM on species conservation or on the importance of species conservation to IPM.

Insect conservation

The conservation of insects is a large and diverse topic, large because of the vast numbers of insect species and diverse because of the enormous variety of life strategies these many species display and their consequent impact on human welfare. The sheer number of species places an unusual constraint upon any effort to conserve insects whether under natural conditions or under the constraints of a pest management programme. Such constraints require that we must consider the basic elements of diversity itself.

The possible number of species of insects varies with the author and ranges from a cautious 2 million to as many as 30 million (Erwin, 1991; Gaston, 1991; Stork, 1993). The extreme degradation of many habitats worldwide has alerted people to the realization that habitat destruction removes not only the environment itself, but its inhabitants as well. While most attention has focused upon the larger, showier species and their threatened state, others have recognized that literally tens of thousands of insects and other arthropod species are also at risk (Pimentel *et al.*, 1992; Wilson, 1992). The fact that most insects are small and inconspicuous means that they are often ignored or dismissed by many. Elsewhere, this situation has been referred to as the 'invisible diversity', (Asquith *et al.*, 1990). For example, arthropods comprise almost 85% of the diversity found in a temperate old-growth forest in western Oregon (USA), 3400 species, compared with 143 vertebrate species and 460 plant species (Parsons *et al.*, 1991). Thus, numbers of species of insects and other arthropods are plentiful and potential objects for conservation but the questions are what exactly do we conserve and why do we conserve them? Relevant to the present issue is if and how is insect conservation beneficial to IPM, and conversely, how does IPM contribute to insect conservation?

IPM: historical development

The early entomological literature used the expression 'pest control' to denote the methods used to protect crops against injurious insects. The expression was unambiguous and understood by all. The aim was to use any available method to bring pest populations under control, i.e. to neutralize their damage potential. Apparently the expression 'integrated control' was first used by A.E. Michelbacher based on concepts formulated as early as 1939 (see Farrell, 1990). It was Bartlett (1956), however, at University of California, (Riverside, CA, USA) who is generally credited with early efforts to reconcile the expanding use of the new organosynthetic insecticides with biological control by means of parasitoids and predators. He proposed 'integrated control' as an approach to attenuate the detrimental effects of pesticides on natural enemies. The next major step in the evolution of IPM was the paper by Geier and Clark (1960) in which they gave an ecological definition to the problem of pest population regulation. Geier (1966) used the expression 'pest management' to encompass that ecological approach to crop protection. Populations of pests were to be managed, as were other animal populations that had the capacity to impact either positively or negatively on human economy. The well established conceptual framework of 'integrated pest control' (FAO, 1966) was then readily expanded to incorporate the idea of pest management. The expression 'integrated pest management' (IPM) came to dominate the literature towards the end of the 1960s (NAS, 1969).

Numerous definitions of IPM have been proposed over the years (e.g. Smith and Reynolds, 1966; Rabb and Guthrie, 1970; Shepard, 1973; Glass, 1975; Metcalf and Luckmann, 1975; Bottrell, 1979; OTA, 1979; Huffalzer and Smith, 1980; Flint and van den Bosch, 1981; Rohwer, 1981; Levins, 1986; Pedigo, 1989). Each definition has attempted to stress the comprehensiveness of the approach and the need to consider the ecological, economic and sociological impacts of an IPM system. Despite these efforts for a comprehensive synthesis, much argument still exists about what IPM really is and when a pest control programme becomes a legitimate IPM system. Perhaps the most controversial component of the expression is the term 'integrated'. Kogan (1988) proposed that 'integration' included three hierarchically related levels.

(Level I) The integration of control methods for single species or species complexes (species/population level integration).

(Level II) The integration of the impacts of multiple pest categories (insects, pathogens and weeds) and the methods for their control (community level integration).

(Level III) The integration of multiple pest impacts and the methods for their control within the context of the entire cropping system (ecosystem level integration).

R.J. Prokopy (personal communication; Prokopy *et al.*, 1990) prefers to add a fourth level to include the political or economical forces of the agroindustrial society. Although most IPM programmes currently in use are at the Level I of integration, it is the advancement to Level III that is most likely to yield the ultimate beneficial results expected of the IPM approach. As ideas about the goal of increasing the sustainability of agricultural systems dominate the writings of crop ecologists in the early 1990s, it is suggested that the definition of IPM should incorporate the concepts of sustainability and the preservation of biodiversity, even though they are implicitly contained among the social, economical and environmental benefits of IPM.

General premises towards a conservationist approach to IPM

To consider the possible impacts of IPM on insect conservation we should discuss several premises that seem to account for some critical crop/pest interactions. These premises are based on the characteristics of the crops, the physical environment, and the associated fauna.

PREMISE I

Once the original plant cover in a given region is replaced with a crop that dominates the landscape, biodiversity is reduced and conservation is dramatically affected

Pest outbreaks are just a secondary manifestation of the extreme disruption of natural communities caused by plant cover replacement. It seems that the greater the ecological distance of the replacement cropping system to the original plant cover, the greater the disturbance and the vulnerability of the crops to pests. For instance, a system based on annual grasses (wheat, oats, corn, etc.) and legumes (beans, soybeans, etc.) replacing the original tall grass prairie community in the Midwest (USA) is likely to be less vulnerable to severe pests than a similar system replacing cleared hardwood forests or swamps in Louisiana (USA). Although variations in climate also contribute substantially to the observed differences, soybeans are vulnerable to injury by a complex of pests much more severe in southern Louisiana than in Illinois or Iowa (Newsom *et al.*, 1980).

Conservation efforts that increase the plant diversity around and within the disrupted landscape area may provide increased heterogeneity for arthropods, including beneficial species. Special attention should be given to the use of indigenous plant species. Conceivably multiple crop systems add to that heterogeneity, particularly if the crops have different phenological characteristics that could influence temporal and spatial variability. It is this variability that will increase biological diversity at the local level. Current emphasis on cover crops and the management of field borders seems to exploit these factors (Altieri, 1987).

PREMISE II

Once an introduced crop is established in a new region, the process of colonization by arthropods starts almost immediately. Over a period of years, the fauna approaches a dynamic equilibrium with its diversity positively correlated with the area under cultivation (Strong, 1979)

Arthropod pests in most crops originate from three major groups of potential colonizers:

(a) the first group consists of non-indigenous species that invade a new area and become established on the crop. A high percentage of the major pests on US crop plants are non-indigenous. Many of these pest species do not have pest status in their native land but their release from natural controls often allows them to achieve such status. Some, like the newly detected Asian gypsy moth *Lymantria dispar* (L.), are pests at home even with natural control. Some of the native USA forest pests, i.e. the spruce budworm, *Choristoneura fumiferana* (Clemens) and the Douglas fir tussock moth, *Orgyia pseudotsugata* (McDunnough) have periodic outbreaks and would be viewed as potentially serious pests by another country. Exotic pests are obviously undesirable species for conservation, because their establishment often brings about the demise of competing native species;

(b) the second group is composed of native oligophagous species that are preadapted to the natural defences of an exotic crop introduced into a new area. Perhaps the best example in this group is the Colorado potato beetle. *Leptinotarsa decemlineata*, Say, which was recorded in 1824 feeding on *Solanum rostratum* on the eastern slopes of the Rocky Mountains from Canada to New Mexico. As the potato, *Solanum tuberosum*, gained popularity with settlers, the beetle soon adapted to the crop and now is a major pest of potato in both North America and Europe (Biddle *et al.*, 1992). A less known example might be the plant bugs of the genus *Labops*. Several native species have become major rangeland pests, especially on the introduced species of crested wheatgrasses, *Agropyron* spp., that have been planted widely in western North America for range improvement. That those native insects should be able to feed on these grasses is not surprising since at least one species of *Labops*, *L. sahlbergi* (Fallén), native to

Central Asia, is known to feed on the grasses there. Several native species of *Labops* have been reported on wheat in western North America;

(c) the third group are native polyphagous species against which crop plants have few, if any, natural defences. Polyphagous native species often are major pests of non-indigenous crop plants. Perhaps the best example is *Helicoverpa* spp. that, by some accounts, are among the most important agricultural pests worldwide. The Nearctic species, *H. zea* (Boddie), has been recorded feeding or ovipositing on 238 species of plants belonging to 36 different families (Kogan *et al.*, 1989), certainly a highly polyphagous species. Nearly one third of the recorded hosts are in the Leguminosae and another third are in the families Solanaceae, Malvaceae and Compositae. These plant families include species with a wide spectrum of antiherbivore defences which, obviously, are innocuous to the highly successful corn earworm also known as cotton boll worm or tomato fruit worm. Plant bugs of the genus *Lygus* have become major pests on many introduced crops in North America. The bugs concentrate their feeding activities on the growing tip, developing flowers and seeds. Several polyphagous *Lygus* species are major pests of such crops as alfalfa, cole crops, cotton and a variety of tree fruits. Considering their many reported host plants (Fye, 1982), remarkably little is known about their true, native host plants chiefly because much confusion still exists over the correct identification of species, including the immature stages (but see Schwartz and Foottit, 1992). About 33 species of *Lygus* are found throughout most of North America with the greatest number occurring in the western part. Conservation of *Lygus* species is likely to provide continued pest problems wherever crops are grown in close proximity to host plants.

PREMISE III

Insect species become pests usually due to inherent characteristics that find maximum expression under particularly favourable environmental conditions that include one or more of the following situations.

The increased concentration per unit of area of a food resource (the crop plant) that is deprived of part or all of appropriate defence mechanisms against herbivores (Root, 1973)

High density plantings of conifer seedlings in forest service nurseries are often subjected to damage by insects that rarely feed on seedlings growing under natural conditions. Nurseries of douglas fir seedlings planted close to alfalfa fields often suffer damage by *Lygus* bugs when the alfalfa is cut, resulting in movement of the bugs into the seedling beds. High density plantings of yew (*Taxus* spp.) for the extraction of taxol or the growing of ornamental plants sometimes sustain damage by weevils and a few other insects whereas low level of insect activity is usually seen when the plants occur in their natural settings.

Decreased effectiveness of natural control agents (of native pests) or total escape from natural enemy regulation (exotic pests)

Many exotic species become pests when first introduced because many natural control mechanisms are left behind. The blue alfalfa aphid and the Russian wheat aphid, *Diuraphis noxia* (Mordvilko), recent invaders of North America, are examples of such releases from natural control. Alfalfa fields typically have a rich insect fauna, including a diverse fauna of natural predators that would feed upon virtually any aphid species. The wheat ecosystem on the other hand, has a very limited fauna of natural predators which might contribute to the greater pest status of the Russian wheat aphid.

Environmental conditions that favour full expression of the herbivore species-specific reproductive potential

Heavy fertilization usually maximizes nutritional suitability of crop plants for herbivores (Mattson, 1980; Tingey and Singh, 1980; Hunt *et al.*, 1992). Although the effect of N-fertilization on insects is variable, there is evidence that high N-levels in soil usually increase insect fitness. Dale (1988) cites various studies including a series of experiments conducted in India on nine crops. Of the 20 studies reported, N-fertilization increased insect incidence in 17 trials, decreased in one and had no effect in five trials.

Favourable conditions for dispersal coupled with an inherent ability to disperse

The Russian wheat aphid became a pest in the mid 1980s. It is a flighted species, parthenogenetic, and polyphagous, feeding on many grasses and grains, including several of the exotic species of wheat grasses widely planted for range improvement and on CRP lands. The great vagility of this species, combined with parthenogenetic reproduction and rather minimal predator pressure likely explains why it is already a serious pest in many parts of North America.

Favourable conditions for survival between successive cropping periods (overwintering, diapausing, recolonization potential, alternative hosts, and shelter

The availability of alternative hosts during periods when an annual crop is absent from the field is critical for multivoltive pest species that lack an obligatory diapause. The studies by Panizzi and coworkers in Brazil on the nutritional ecology of Pentatomidae associated with soybeans is beginning to provide an excellent foundation towards understanding the annual cycle and population dynamics of several important species,

Table 1. *Nezara viridula*: reproductive performance of females and survivorship of nymphs feeding on fruits of soybean and six alternative host plants at Londrina, Parana, Brazil (A. Panizzi, unpublished data)

Food source	*Nymphal mortality* (%)	*Females ovipositing* (%)	*No. per female*	
			Egg masses	*Eggs*
Leonurus sibiricus	25.0	73.3	1.6	91.7
Brassica kaber	35.0	56.2	1.3	61.0
Raphanus raphanistrum	43.3	53.4	1.5	67.5
Ricinus communis	60.2	60.0	1.2	68.8
Desmodium tortuosum	86.7	0.0	–	–
Acanthospermum hispidum	100.0	0.0	–	–
Glycine max	20–30	76.5	1.9	110.0

including *Nezara viridula* (L.), probably the most important pentatomid pest worldwide. As soybeans are harvested in May or June, *N. viridula* is observed feeding on *Acanthospermum hispidum* DC (*Compositae*), a weed abundant in soybean fields after harvest. Although the plant is an unsuitable host, and even toxic, some bugs do feed on the stems. Later in the winter, they move onto several species of crucifers, such as radish and mustard, that grow as weeds in wheat fields that follow soybeans in the rotation. Finally, part of the population moves onto castor bean, *Ricinus communis* L. (*Euphorbiaceae*), where they remain without reproducing until they migrate to weeds and shrubs such as *Leonurus sibiricus* (L.) (*Lamiaceae*), where they complete one generation before soybean is again available at the proper growth stage for recolonization (A. Panizzi, (C.N.P. Soja, Londrina); unpublished data). The relative suitability of these various plants as hosts for *N. viridula* is inferred from Table 1. It is apparent from these data that some plants are marginal hosts but still serve as shelter and may provide moisture for the overwintering adults and are essential for the transitional survival of *N. viridula* between cropping seasons.

Ability to out-compete for food and shelter other sympatric ecological homologues

The population explosion (outbreak) of one species of the pest complex on a crop often results in the competitive exclusion of most, if not all, other species in the same crop field. A crop field in which food resources have been virtually depleted by a single species outbreak seldom sustains populations of other species (Strong *et al.*, 1984; M. Kogan, unpublished observations of soybean fields under outbreak conditions of grasshoppers in USA and *Anticarsia gemmatalis* Hubner in Brazil). Resident species in such 'outbreak fields' usually migrate or die. Outbreaks of single pest species represent extremes of competitive exclusionary action. Competitive exclusion seems to operate even in more subtle ways at lower population levels with parasitoids (DeBach, 1966), but the role of competition at low population levels is not considered a powerful force in shaping herbivore communities (Lawton and Strong, 1981).

PREMISE IV

From a purely ecological point of view, a few key pest species that dominate the crop community have an impact on overall community diversity that is perhaps far greater than that resulting from direct human intervention through control procedures

The number of regionally important insect pests of most crops seldom exceeds ca 15 species (Table 2) and in most annual crops, a few key pest species usually account for over 90% of the insecticide use on that crop although the arthropod fauna associated with crops often includes several hundred species. Tropical agroecosystems generally have greater species richness than temperate agroecosystems, but the total number of major pests is not necessarily greater in the tropical ecosystems. The severity of those pests in the tropics, however, often exceeds the severity of similar pests in the temperate zones.

Table 2. Reported numbers of major arthropod pests of representative crops

Crop	*No. of major pests*	*No. of secondary pests*	*Source*[d]	*Reference*
Apple				
Nova Scotia	3	13	CRC	2
Washington	5	8	CRC	2
Michigan	12	7	CRC	2
Cassava[a]				
Africa, S. America	3	10	ARE	18
Citrus[a]				
USA	3	12	ARE	9
Cocoa[a,b]				
Prod. areas[c]	3	>100	ARE	15
Coffee				
Prod. areas[c]	2	8	ARE	13
Corn				
USA	3	9	ARE	19
Cotton				
USA	6	6	CRC	1
USA	2	36	ARE	6
Crucifers[a]				
USA	2	8	ARE	10
Forage				
USA	4	4	ARE	7
Fruits[a,b]				
Prod. areas[c]	5	>50	ARE	12
Grain Legumes[a]				
Africa	5	15	ARE	20
Pecans				
USA	3	19	ARE	23
Potatoes[a]				
USA	3	7	ARE	22
Rice[a,b]				
Asia	4	4	ARE	16

Table 2. Continued

Crop	*No. of major pests*	*No. of secondary pests*	*Source*[d]	*Reference*
Sorghum				
USA	5		ARE	4
Prod. areas[c]	4	9	ARE	17
		35		
Soybean				
USA	4	13	ARE	5
Central or S. America	3	14	ARE	5
East Asia	8	18	ARE	5
Strawberry				
USA	18	34	CRC	3
Sugar Cane[a]				
USA–Caribbean	2	4	ARE	14
Tea[a]				
Asia	3	7	ARE	11
Tomatoes				
California	3	10	ARE	21

[a]groups of pests (e.g. aphids, thrips, etc.).
[b]key pests cited in groups.
[c]non-specified world production areas.
[d]ARE: Annual Review of Entomology; CRC: Pimentel (1981), CRC Press.

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PREMISE V

Pest species have seldom, if ever, been intentionally eradicated from their entire geographic range, although localized extinctions may occur as a result of concerted control efforts

Efforts to eradicate the cereal leaf beetle, *Oulema melanopla* (L.) in the US have failed, but even if they had succeeded the species would still be conserved in its original European habitats (Haynes and Gage, 1981). Likewise, if attempts to eradicate the Asian gypsy moth from the Pacific Northwest of the USA do succeed, the species will not disappear from its Asiatic home. Consequently, the controversy about large scale eradication programmes results from criticism about their feasibility, cost–benefit ratios and environmental impacts other than those related to the possible extinction of the target pest throughout its entire range.

Impact of IPM tactical components on the phytophagous arthropod fauna

Instead of discussing the possible impacts of each IPM tactic on the conservation of insects, a qualitative rating of pluses or minuses is used (Table 3). No examples or references are provided to prove that the consequences are those proposed. Rather the rating is done on the basis of experience and logical reasoning. Although the literature contains evidence to support some of the assumptions, in some instances experimental or observational proof is wanting, thus suggesting areas in need of additional research.

Concluding remarks

Even the most casual examination of crop communities reveals highly simplified systems with only a few species involved, many of which are exotic (i.e. crops, weeds, pests and beneficials). This is a biological legacy that results from past practices based chiefly upon the reliance on extensive pesticide use. The concepts of IPM and more recently of sustainable agriculture, have shifted the emphasis toward programmes that promote a more diverse fauna and flora in the cropping system. The success of these programmes rests upon a melding of biological, cultural, and chemical control tactics and an understanding of multiple crop–pest–natural enemy interactions. The success of the biological and cultural controls depends largely on the skillful manipulation of a number of species of plants and animals in time and space. This shift in the control paradigm immediately results in increased biological diversity of both plants and animals. In theory then, the objective of conservation has been and is being achieved if numbers only are the objective. A further shift towards true conservation of species requires at least some reduction in non-indigenous species and the enhancement and encouragement of indigenous species.

The fact that most crops are exotic species cannot be ignored. This situation is not likely to change. Most weeds and many major insect pests are also exotic. At least some beneficial insect species are exotic too. By and large, there are more exotic parasites in cropping systems than exotic predators. The predator complex is more likely to be composed of indigenous species. If these generalities are true, there are several portions of the cropping system that present areas most likely to reduce exotics and enhance indigenous species. The functional group most likely to benefit from an IPM approach to conservation probably is the predator complex. It would appear that the greatest opportunity to enhance native insect conservation is if effort is put into increasing predator diversity and numbers. Since many predators feed on both native and exotic prey species, sustaining adequate population levels of predators usually involves maintaining alternate prey species as well, thereby further increasing insect diversity.

Another option to promote conservation of native species involves the reduction of the exotic non-crop plants through biological control agents, but biocontrol of weeds creates the dilemma of introducing more exotics into the system (e.g. insects or diseases). Instead, effective cultural control methods might be a more desirable action. What might

Table 3. Impact of IPM tactical components on the phytophagous arthropod fauna

IPM component	*Main features*	*Possible consequences*	*Expected impact on insect conservation*
Economic injury	Populations below thresholds are tolerated	Favour native predators and endemic natural enemies.	+
	Pest residual populations encouraged		+
Scouting	Assesses the extant populations and levels of injury	Reduce unnecessary insecticidal treatments and conserve natural enemies and non-pest herbivorous species.	+
	Recognizes role of natural control agents		+
Decision rules	No-treatment actions	Reduce unnecessary insecticidal treatments and conserve natural enemies and non-pest herbivorous species.	+
	Favour preventive methods		+
	Selection of optimal kind, rate and timing of remedial actions		+
Plant resistance	Tolerance	No interference-preserves all species.	+
	Antibiosis	Reduces pest and may affect host specific natural enemies.	+ or −
	Antixenosis	Drives pests away but does not eliminate.	+
Biological control (Classical)	Specific parasitoids or predators	Exotic parasitoids may displace native ones.	+ or −
	Generalist predators	Exotic parasitoids may displace native ones.	+ or −
Biological control (Inundative)	Selectivity	As insecticides or acaricies, but less so on the negative aspects.	+
	Broad spectrum		−
	Applied preemptively		+ or −
	Applied following EIL		+
Cultural control	Change crop ecology: planting dates, row spacing, plowing and cultivation system	Increase diversity of crop community. More feeding niches, greater diversity of both herbivores and natural enemies.	+ or −
	Cover crops and living mulches		+
	Trap cropping		+ or −

Table 3. Continued

IPM component	*Main features*	*Possible consequences*	*Expected impact on insect conservation*
Insectides	Selectivity	Spare natural enemies.	+
Acaricides	Broad spectrum	Destroy natural enemies	–
	Applied preemptively (on schedules)	and non-pest herbivores.	–
	Applied following EIL	Attenuate negative impact of insecticides.	+
Behavioural control	Mating confusion	Usually species specific with no effect on natural enemies or non-pest fauna.	+
Genetic control	Sterile male technique	Usually species specific with no effect on natural enemies or non-pest fauna	+ or –

also be examined, is the use of multiple cropping systems, using one crop as a competitor to weeds rather than the reverse. Cover crops and living mulches are gaining increased acceptance; if varied native rather than exotic plants are selected, increased plant diversity and enhanced native insect diversity is likely to ensure. These efforts will loop back to the diversification of the native plants in and around the cropping system, further enhancing biological diversity.

There will be practical limits to the extent to which native plants can be incorporated into the broader cropping system. It seems obvious, however, that the diversity of native insects can be increased with greater use of native plants and an effort to enhance the diversity and species richness of the predator complex. A diverse predator fauna, involving a broad spectrum of species, is likely to be more effective than relying on only a few exotic species often selected against a single pest species.

Remarkably, little attention has been paid to the complete predator complex in either natural or managed systems. Much needs to be learned here and the results of more comprehensive research on the impact of all the predators in either system is certain to be beneficial and unquestionably consistent with the goals of IPM and congruent with the objectives of the conservation of insects.

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