DIVERSIFICATION OF AGRICULTURAL LANDSCAPES— A VITAL ELEMENT FOR PEST CONTROL IN SUSTAINABLE AGRICULTURE

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During the early part of this century, U.S. agriculture was characterized by small farms, operated by a family and animal draft power. Crop yield depended mostly on internal sources and the recycling of nitrogen and organic matter, on built-in biological control mechanisms, and on rainfall. Nitrogen sources and pest control came mainly from rotating crops and legumes.

Agriculture was diversified. Crops and pastures were dispersed over the landscapes in combination with forests or grasslands. Therefore, extensive interface between adjoining crops, pasture, and native vegetation existed. Some insects we know today as major crop pests occurred, but their populations were balanced by the "background" of biological control dependent on the heterogeneous environment (Tothill 1958).

Economic and political forces, however, have reduced this agricultural heterogeneity spatially (the land devoted to single crops expanded within regions at the expense of natural vegetation) and temporally (through year-after-year production of the same crops on the same land) (USDA 1973). These trends toward monoculture have concentrated host resources for specialist herbivores and have increased the areas available for immigration of pests from adjacent habitats. Extreme monoculture implies not only vast acreages of one or two genetically uniform cultivars, but a lack of an age-structure. This simplification also has reduced environmental opportunities for natural enemies. Consequently, crop disasters can occur if large numbers of immigrant pests, or weather favorable for their rapid multiplication, occurs simultaneously with vulnerable crop stages (Altieri and Letourneau 1982). Humankind has received strong reminders from nature (i.e., the epidemics of race 15 B of *Puccinia* in

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wheat in 1954) that the ecological equilibrium in simplified crop communities is fragile: they lack the protective functions of nutrient cycling, soil conservation, and population regulation (NAS 1972).

We need to design self-sustaining and stable agroecosystems that are based on some existing models from which we can extract basic principles. One major frustration encountered by U.S. researchers is that significant interactions to develop alternative, sustainable agroecosystems simply are not present in current, heavily disturbed monocultures (Edens and Haynes 1982). It is very difficult to find sites that have minimal energy inputs, lack continuous disturbances, and have not yield as their main goal, but interaction between as many biological components as possible.

In the tropics, traditional farming systems have these attributes. Most peasants have developed or have inherited complex farming systems well adapted to the local conditions with which they have met their subsistence needs for centuries, even under adverse environmental conditions, without mechanization or chemical fertilizers and pesticides (Egger 1981). These traditional methods of farming basically rely on the farmer's local resources, hand and animal labor, natural enemies, and natural soil fertility. Natural enemies and soil fertility usually are maintained through bush fallow, polycultures, cereal-legume rotations, and manure (Gliessman et al. 1981). These diverse farming systems now are being scientifically proven to be "right" (Risch et al. 1983).

Sustainable agroecosystems must have a high degree of vegetational diversity which allows natural pest control to occur. Our greatest challenge as agricultural scientists is to identify plant assemblages that provide these functions, but that are also agronomically acceptable and economically viable.

In this paper, I will explore the linkages between agricultural diversity, arthropod community ecology, and the complex factors involved in designing sustainable agroecosystems. Specifically, I will discuss (1) the contribution of edges of natural vegetation to the dynamics of arthropod communities of adjacent cultivated areas, (2) the comparative ecology of insect populations in orchards under various successional stages and management intensities, and (3) the effects of within-field plant diversity in the form of polycultures, cover crops, and weed-diverse crop systems on arthropod abundance.

ADJACENT HABITATS

Many insect pests (i.e., aphids and leafhoppers) invade crop fields and orchards from edge vegetation, especially when the vegetation is botanically related to the crop. Forest edges, hedgerows, and patches of wild vegetation also provide hibernation and/or alternate feeding sites to natural enemies, which could lead to predators and parasites moving into agricultural systems (van Emden 1965).

In northern California, apple orchards are distributed within a matrix of natural vegetation, which provides abundant opportunities to study arthropod colonization and interhabitat exchanges of arthropods.

During the past three years, we have conducted comparative studies on the ecology of arthropod communities in four ecologically different dry-farmed apple orchards: (1) an "abandoned" orchard not managed or disturbed for 25 years, (2) two "organic" (not sprayed with synthetic pesticides) orchards, one clean-cultivated and the other with a mixed grass-legume cover crop, and (3) a "commercially" managed orchard (clean-cultivated and subjected to chemical fertilizer and pesticide treatments). These ecologically different orchards may constitute a "cultural evolution continuum" (Risch and Carroll 1982). In the abandoned orchard, stable relationships between arthropods and the local vegetation have developed probably because they are not disturbed. In the commercial orchard, high energy inputs are substituted for some plant-insect interactions. The organic orchards combine characteristics of both systems. All orchards have at least one bordering edge with multilayered communities of wild vegetation.

Colonization of Orchards

The magnitude of the exchange of predators and parasitic Hymenoptera between the orchards and the wild vegetation edges are shown in Figure 1. Except for Syrphidae, considerably more individuals move from edge to orchard in unsprayed (organic) than in sprayed orchards. Little exchange seems to take place between abandoned orchards and woodlands. Figure 2 shows the temporal dynamics of colonization of the different orchards by Coccinellidae. D-Vac® samples taken from

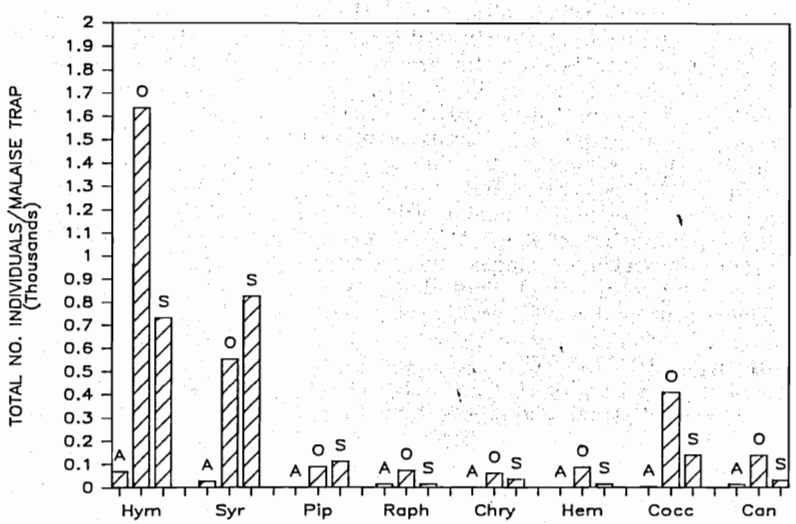

Figure 1. Seasonal mean number of natural enemies (Hym = parasitic Hymenoptera, S = Syrphidae adults, Pip = Pinpinculidae, Raph = Raphididae, Chry = Chrysopidae, Hem = Hemerobiidae, Cocc = Coccinellidae and Can = Cantharidae) caught in malaise traps placed in the interface between apple orchards (A = abandoned, O = organic and S = sprayed) and wild vegetation edges in northern California.

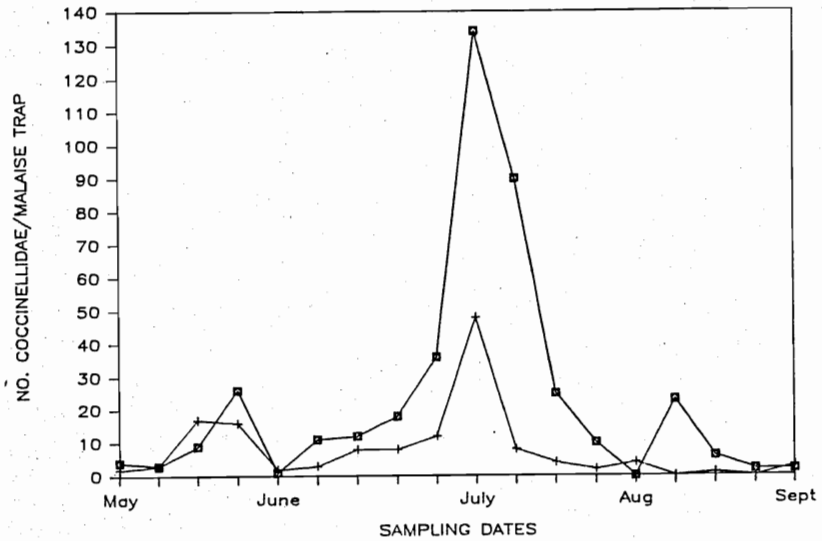

Figure 2. Mean number of adult Coccinellidae caught in malaise traps placed in the interface of woodlands and sprayed (□) and organic (+) apple orchards.

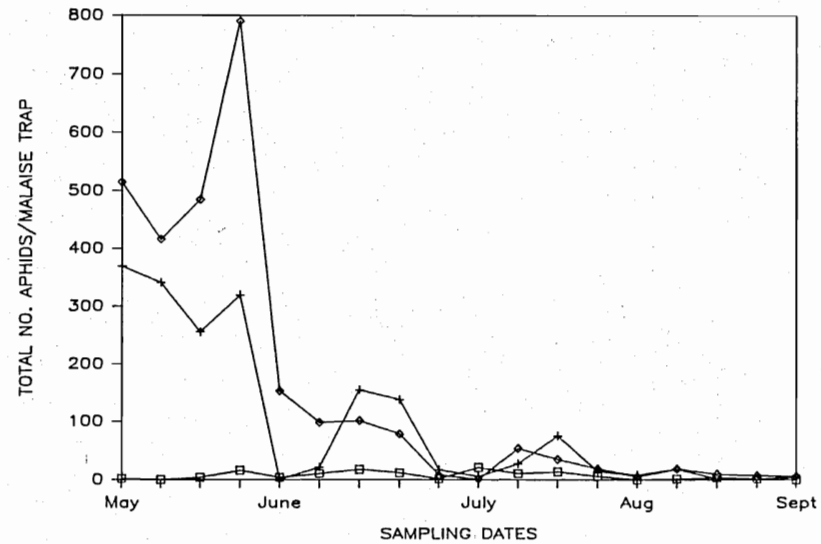

Figure 3. Patterns of aphid colonization from wild vegetation edges to orchards under various management intensities and successional stages (◇ sprayed, + organic, □ abandoned).

the shrub and herb layer of the edges revealed that edges of the organic orchards supported considerably more natural enemies than the edge of the sprayed orchard. In the early season, considerably more aphids invaded the sprayed orchards than the organic and abandoned orchards (Fig. 3).

Ground-Dwelling Predators

The ant species collected in the edges of the managed orchards also were found in the borders and centers, suggesting that part of the ant communities living in the wild margins colonized the planted orchards. Comparisons of mean ant abundances between edge, border, and center revealed major within-site differences. Throughout the season, more ants were caught in the edges of the sprayed and organic orchards, than were caught in the borders or vegetation-free centers (Fig. 4). Abundance gradually declined from the edge to the center of the orchards. In the abandoned orchard, however, ant species composition and patterns of ant abundance were more or less uniform from edge to center from mid-May on. These trends can be explained by the structural similarities of the centers and edges. The vegetational complexity of the center of the abandoned system was similar to the edge, unlike the centers of the clean cultivated systems which lacked the diversity of grasses and herbs characteristic of the edges.

More ants were found in the wild vegetation edges of the managed orchards than in the edges of the abandoned orchards. Ants were most

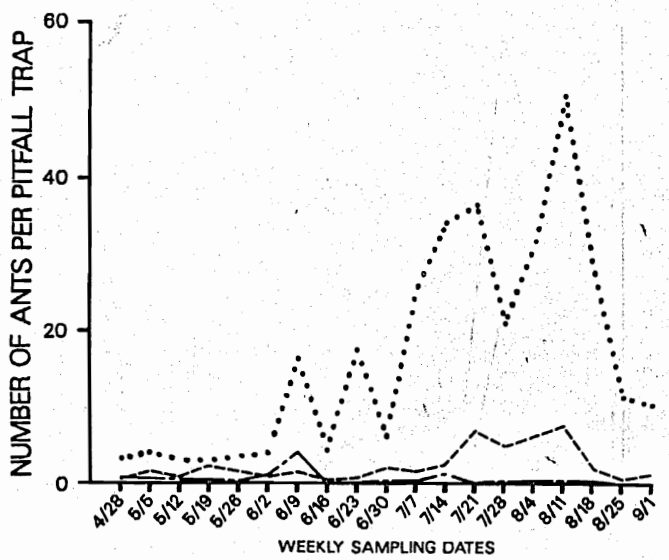

Figure 4. Mean number of ants caught in pitfall traps placed in the center (· · ·) and border (- - -) tree rows of an organic apple orchard, and in the adjacent vegetation edge (—·—·—·).

abundant in the abandoned edge early in the season, thereafter ant catches declined but stabilized. Conversely, ant catches in the sprayed orchard's edge gradually increased and surpassed the abundance levels of ants in the organic edge from July on.

Spider catches were significantly higher in the edges of the abandoned orchards than in the organic or sprayed orchard edges. From May 15 through July 15 more spiders were caught in the organic edge than in the sprayed edge.

Carabidae behaved differently than ants or spiders. Pitfall catches were higher in the center and border rows of apple trees than in the edges. This seems to be a normal pattern, as many Carabidae (i.e., *Agonum dorsale*) exhibit seasonal migration between field and edge. In fact, many Carabidae species depend on hedges for their continued existence in agroecosystems (Thiele 1977).

Predation Pressure

Predation pressure (mainly by ants), as measured by the removal rates of potato tuberworm (*Phthorimaea operculella*) larvae from cardboard sheets placed on the orchard floor (Table 1), was highest in the center of the abandoned orchard, followed by the organic orchards, and the sprayed orchard. Predation was greater in the center of the organic cover orchard than in the center of the clean cultivated one. On average, significantly more larvae were removed from the edges of the clean cultivated organic and sprayed orchards than in the centers of these same orchards. Removal rates, however, were similar in the wild vegetation edges and centers of the organic cover and abandoned orchards. Cultivation and insecticide applications probably disrupted ant communities in the centers of the clean cultivated and sprayed orchards, confining ant foraging to the edges.

On the trees, predation of artificially placed *Anagasta kuehniella* eggs was consistently higher in the edges than in the border or center trees of the managed orchards (Table 1). No differences in predation were observed between edge and center in the abandoned system. A clear gradient in predation pressure was observed in the centers of the orchards, declining from abandoned to sprayed.

Successional Stage of Orchards and Management Intensity

Most studies comparing the fauna of a continuum of orchards (from intensively managed to abandoned) have revealed that unmanaged and abandoned orchards contain a greater diversity of phytophagous and predaceous species, with most species at relatively low population levels. Oatman et al. (1964) noted approximately 760 arthropod species (about 100 plant feeders) in unsprayed orchards in Wisconsin. In commercial orchards in the same region, only 5 to 15 pest species were present at high densities, and most natural enemies were absent. Presumably, many of the imbalances typical of a commercial apple monoculture system are ameliorated in an undisturbed, vegetationally complex, orchard. However, within the range of orchard successional states, recently abandoned orchards, which retain appreciable effects

Table 1. Removal of potato tuberworm larvae, *Phthorimaea operculella*, (placed on the ground) and of mediterranean flour moth eggs, *Anagasta kuehniella*, (placed on the trees) by predators in the centers and edges of various northern California apple orchards.

Orchard System	% Eggs Removed[1]	% Larvae Removed[2]
Sprayed		
Center	21.0 ± 5.2	17.0 ± 6.2
Border	26.0 ± 8.0	
Edge	33.0 ± 10.2	32.7 ± 7.6
Organic		
Center	25.0 ± 8.0	61.5 ± 12.3
Border	34.1 ± 12.1	
Edge	43.1 ± 10.2	70.5 ± 13.9
Abandoned		
Center	38.0 ± 9.2	86.9 ± 14.5
Border	42.0 ± 10.7	
Edge	36.0 ± 4.2	84.6 ± 15.2

[1] Predation pressure on the eggs was estimated on four occasions by hanging twenty-five 8.5 x 11.0 cm paper cards (with 50 moth eggs each) from the branches of each of five trees in the center, border, and edge of each orchard.

[2] Means of 3 sampling dates. Larvae removal data were obtained by placing on the ground forty 22 x 22 cm cardboard sheets (20 in the center and 20 in the edge) each containing 20 glued 4th instar larvae. Predation pressure was measured by determining removal of larvae in an 18 hr period.

of fertilization and adequate moisture, usually harbor greatest diversity of plants and insects, therefore exhibiting intermediate stability (Croft and Hoyt 1983). In Massachusetts, the mite predator complex is especially diverse in recently abandoned apple orchards (Hislop and Prokopy 1979). Several predators exploited the still abundant phytophagous prey species. As the foliar habitat deteriorated nutritionally, supporting fewer phytophagous mites, the predatory mite complex narrowed in species composition.

In northern California, arthropod communities respond to plant successional features of the orchard depending on their degree of association with the ground plant cover and surrounding vegetation. Herbivores (mainly Homoptera) exhibited increasing densities with degree of orchard management and vegetational simplification (Fig. 5), as illustrated by leafhopper populations that reached higher densi-

ties in insecticide-treated and organic clean-cultivated orchards than vegetationally diverse (cover-cropped and abandoned) orchards (Fig. 6). Abandoned orchards were particularly characterized by very low and stable leafhopper populations. Aphids were present between April and July, reaching highest numbers in the organic disked orchard, followed by the cover-cropped and sprayed orchards. Aphids were virtually absent throughout the season in the abandoned orchard. Natural enemies (predators and parasites combined) were least abundant in the sprayed orchards and most numerous in the abandoned orchards. Spiders showed a similar but less marked trend. No between-orchard differences in abundance were revealed for parasitic Hymenoptera (Fig. 5).

WITHIN-FIELD DIVERSITY

Plant diversification in agroecosystems should increase environmental opportunities for natural enemies, and thus improve biological pest control (Altieri and Letourneau 1982). Agronomically plant-diverse cropping systems can be designed in several ways. One way is by manipulating the vegetation in ditchbanks, hedgerows, shelterbelts, windbreaks, and other adjacent habitats. Within-field plant diversity can be manipulated by designing polycultures of temporal and spatial crop arrangements. In orchards, ground cover management can alter the degree of vegetational diversity and complexity. Weed borders, alternate rows, or weed growth during certain periods of the crop

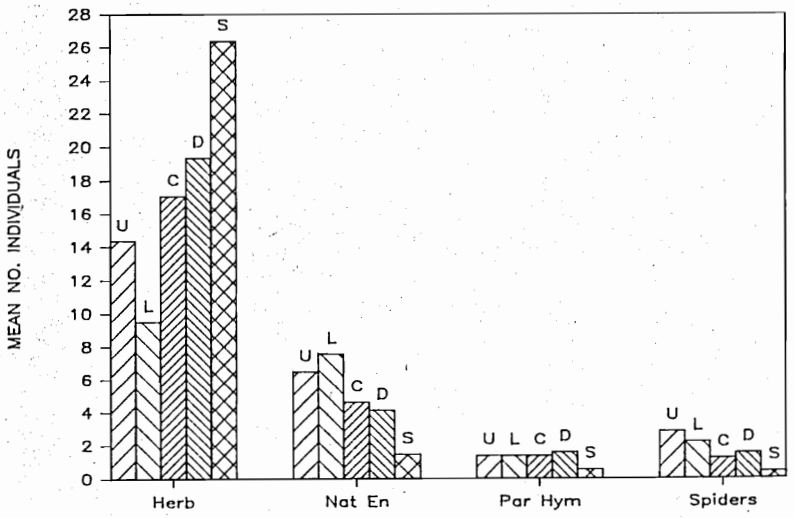

Figure 5. Seasonal densities of arthropods (Herb = herbivores, Nat En = natural enemies, Par Hym = parasitic Hymenoptera) on apple trees in orchards of varying degrees of management and vegetational complexity (U = abandoned with minimal management, L = abandoned unmanaged, C = organic with cover crop, D = organic disked, S = sprayed, no cover).

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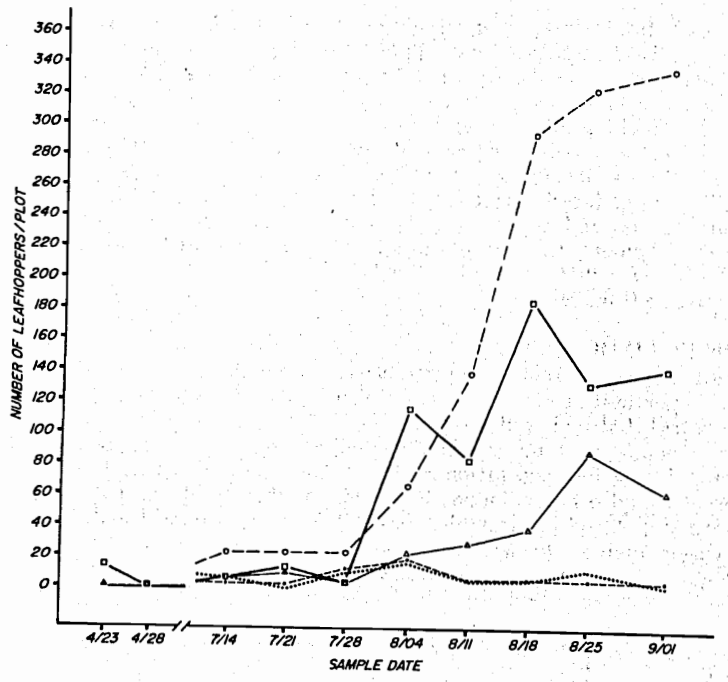

Figure 6. Population dynamics of leafhoppers (Homoptera: Cicadellidae) in sprayed (o—o), organic disked (□), organic with cover crop (△-△), and abandoned with minimal management (···) or unmanaged (·—·).

season also will provide weed diversity. In the last decade, many studies have explored the effects of these vegetation management systems on the dynamics of insect populations. In a recent review, Risch et al. (1983) examined 150 studies on agroecosystem diversification and insect herbivores. They found that 53% of the herbivore species decreased in the more diversified systems, 18% increased, 20% varied, and 8% showed no change.

Manipulation of Border Vegetation

The proximity of wild vegetation can have a fundamental effect on the occurrence of arthropods in agricultural areas. In Czechoslovakia, apple orchards surrounded by deciduous forests have a tenfold higher abundance of Coccinellidae than do orchards in simplified landscapes. In Florida, corn fields surrounded by complex semi-permanent borders (annually burned pinelands and weedy fields) have a more abundant and rich insect predator fauna than do corn fields surrounded by other annual crops (Altieri and Whitcomb 1980). Retaining complex, semi-

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permanent, uncultivated borders around corn fields increases early colonization of predators and, as suggested by studies in soybean (Altieri and Todd 1981), increases distribution of predators in the crop rows close to the natural vegetation border. Soybean rows close to a weedy ditch-bank or a wood edge harbor significantly higher numbers of predators. This enriching effect of the borders on the beneficial fauna extends toward the center of the field for approximately 40 rows. Soybean plants adjacent to a vegetation-free field have lower relative densities of predators (especially Coccinellidae) throughout the season, than soybean bordered by pea fields or weeds (Altieri and Todd 1981).

The dramatic effects of border vegetation on insect dynamics of neighboring fields have prompted a few researchers to manipulate natural border vegetation to encourage specific predator species. Altieri and Whitcomb (1979a) found in north Florida that changing the time of soil tillage affects the species composition and abundance of weed cover. By varying the dates of plowing, associations of specific weeds were increased. These changes in the abundance of host plants altered the populations of associated herbivores, which modified the populations of predators that fed on these insects. Predator species fluctuated according to availability of prey as determined by the presence of weed hosts and the season of plowing.

Also, each weed had a distinctive herbivorous fauna associated with well-defined predator guilds. Leaf beetles were the major herbivores on *Oenothera laciniata*, *Amaranthus* sp., *Heterotheca subaxillaris*, *Ambrosia artemisiifolia*, and *Chenopodium ambroisoides*. *Uroleucon* spp. aphids were the major goldenrod (*Solidago altissima*) and wild lettuce (*Lactuca canadensis*) herbivores. The predator component of the weed food webs included mainly ground beetles, predaceous stink bugs, ladybird beetles, assassin bugs, and herb-stratum spiders.

Based on these results, several management considerations were advanced by the authors. Since many of the predators likely to be increased through seasonal manipulation of selected weeds are valuable enemies of important crop pests, plowing strips of land within a crop or other important surrounding habitats in different seasons might increase populations of selected weeds, which would provide alternate prey to numerous important predators when the pest species become scarce in the field. Early in the season, some weeds may act as a reinforcement for natural enemies of crop pests, thus maintaining the natural balance of predator populations in the crop area before the outbreaks of pest species occur. Furthermore, certain weeds in habitats adjacent to crop fields can determine what species of predators will inhabit those particular crop fields, since predator species may disperse from weedy areas. For example, most of the predator species found in Florida fallow fields early in spring on *S. altissima*, *C. ambroisoides*, and *H. subaxillaris* also were collected in nearby corn fields, suggesting active dispersal.

In general, most beneficial insects present on weeds tend to disperse to crops, but sometimes the prey found on weeds can prevent or delay this dispersal. Allowing weeds to grow to assure concentrations of insects and then cutting them regularly to force movement could be an effective strategy. For example, by cutting patches of stinging nettle (*Urtica doica* L.) in May or June, predators (mainly Coccinellidae) are forced to move into crop fields (Perrin 1975). By cutting hedges of *Ambrosia trifida* infested with the weevil *Lixus scrobicollis*, boll weevil parasitization by *Eurytoma tylodermatis* is increased 10%. These practices should be carefully timed to the biology of beneficial insects. For example, in California the annual cleanup of weeds along the edges of alfalfa fields should be delayed until after mid-March when aggregations of dormant Coccinellidae have largely dispersed (van den Bosch and Telford 1964).

Manipulation of Ground Cover in Orchards

In the early twenties and thirties, several researchers observed that uncultivated apple orchards were less severely attacked by the codling moth, *Cydia pomonella*, than continuously cultivated orchards (Peterson 1926, Peppers and Driggers 1934). These findings were later confirmed by Leius (1967) who found that the presence of wild flowers in apple orchards resulted in an 18-fold increase in parasitization of tent caterpillar pupae, a 4-fold increase in tent caterpillar egg parasitism, and a 5-fold increase in codling moth larval parasitism over non-weedy orchards.

Soviet researchers found that the parasitoid, *Scolie dejeani*, was more strongly attracted to its grub hosts in the presence of honey plants, *Phacelia* sp. and *Eryngium* sp. These same plants increased the abundance of the wasp *Aphelinus mali* to control apple aphids and also improved the activity of *Trichogramma* spp. in apple orchards. The effectiveness of the San Jose scale parasitoid *Aphytis proclia* improved by planting a *Phacelia tanacetifolia* cover crop. Three successive plantings of the *P. tanacetifolia* cover crop increased scale parasitization from 5% in clean cultivated orchards to 75% when honey plants were in full bloom (Telenga 1958).

In the Yakima Valley, Fye (1983) established various small grain and crucifer cover crops in pear orchards and found that general predators (*Orius* spp., *Nabis* sp. and spiders) and pear psylla predators (i.e., *Anthocoris* spp. and *Deraeocoris* spp.) were supported by aphids and *Lygus* bugs present in the ground cover. Populations of predators were generally small due to insecticide drift and mowing of the cover crops. The optimum cover should be permanent and should provide a substantial complex of soft-bodied insects as alternate prey for predators.

In northern California, apple orchards with a mixed grass-bell beans cover crop sustained higher numbers of predaceous ants, spiders, Carabidae, and Staphylinidae than clean-cultivated orchards. Moreover, orchards containing cover crops had significantly lower numbers of fruits damaged by codling moth (22.7% in 1981 and 68.0% in 1982) than clean-cultivated orchards (44.8% in 1981 and 78.0% in 1982).

The choice of cover crop can have an important impact on the predaceous fauna. In Courtland, California, significantly more Carabidae were caught in salina strawberry clover and ladino clover cover crops. Conversely, Staphylinidae were mostly abundant in rye or natural weed cover crops. Table 2 provides a summary of the abundance levels of various arthropods associated with different cover crops in the region. Ladino clover and salina strawberry clover were the only cover crops that remained green and in full bloom until late summer. All other cover crops tested dried early and therefore did not harbor natural enemies towards the end of the season.

Table 2. Seasonal mean densities of arthropods (No. individuals/3 D-Vac* samples/plot) associated with six cover crops in northern California.

	Farmer's Rye	Ladino Clover	Mt. Barker Clover	Tetraploid Rye	Salina Clover	Natural Weeds
Predators	3.0 a[1]	4.0 b	2.0 a	2.0 a	2.6 a	3.8 a
Spiders	1.2 a	2.6 a	2.5 b	3.2 b	1.2 a	1.7 a
Parasitic Hymenoptera	15.9 a	32.6 b	9.1 c	12.5 a	32.3 b	33.2 b
Aphids	87.0 a	87.0 a	199.0 b	66.0 a	88.0 a	141.0 b
Leafhoppers	54.0 a	14.3 b	0.4 c	41.0 a	7.2 d	7.0 d

[1]Means followed by the same letter in each horizontal column are not significantly different at the 5% level by Duncan's multiple range test.

Ground cover also has a significant impact on the number of leafhopper vectors of x-disease in peach orchards. Most adult leafhoppers (*Scaphytopius acutus*) occur on trees in plots of red clover and rosaceous weeds. Few leafhoppers occur on trees in plots with orchard grass, an unsuitable host. Therefore, an invasion by leafhopper can be discouraged if the orchard floor is free of naturally occurring wild host plants and has a pure ground cover of orchard grass (McClure 1982).

Crop Diversity in Annual Agroecosystems

It has been proven that increased within field vegetational diversity reduces pest loads in agricultural systems. Also, the abundance of particular herbivores is reduced in diversified crops (polycultures) when compared with monocultures (Risch et al. 1983, Altieri and Letourneau 1982). Two ecological hypotheses, resource concentration and natural enemies, may explain why.

1. Resource concentration hypothesis: Insect populations can be directly influenced by the concentration or spatial dispersion of their food plants. Many herbivores, particularly specialists, are more likely to find and remain on hosts that are growing in dense or nearly pure stands (Root 1973), like monocultures. In diverse systems, the visual and chemical stimuli from host and nonhost plants affect both the rate of colonization of herbivores and their behavior. Usually, a herbivorous insect has greater difficulty locating a host plant when the

relative resource concentration is lower. For example the presence of a tall companion crop reduces the colonization and tenure time of herbivorous pests on a target crop (Bach 1980, Risch 1981).

2. Natural enemy hypothesis: Polycultures contain a greater abundance and diversity of natural enemies of pest insects than do monocultures (Root 1973). Predators tend to have broad diets and habitat requirements, so they encounter a greater array of alternative prey, pollen, nectar, shelter, and breeding and nesting sites in a heterogeneous environment. Relatively stable populations of generalized predators can persist in these habitats because they can exploit the wide variety of herbivores and resources that become available at different times or in different microhabitats. Moreover, specialized predators are less likely to fluctuate widely because the refuge provided by a complex environment enables their prey to escape widespread annihilation (Root 1973).

Many crop combinations are possible and each can have different effects on insect populations. The choice of a tall or short, early or late maturing flowering or nonflowering companion crop can magnify these effects. For example, adding a crop that bears flowers during a certain period of the growing season can attract beneficial parasites. Similarly, the inclusion of legume crops or other plants supporting populations of aphids that serve as alternate prey/hosts can improve survival and reproduction of beneficial insects. Early planting of an aphid-supporting legume in patches within the field can initiate the build up of parasitoids before the rest of the crop is planted and more aphids colonize the field. The presence of a tall associated crop plant can affect the visual stimuli by which insect pests orient to their suitable host plant, or may interfere with the herbivore's movement and dispersal within the system. Shading by the tall crop can also affect insect development; for example, low light intensities inhibit feeding in leafhoppers (Altieri and Letourneau 1982).

Weed Management

Weeds can reduce yields by directly competing with crops or by harboring insect pests and plant diseases. Certain weed species, however, are important components of agroecosystems as they offer many important requisites for natural enemies: alternate prey/host, pollen and nectar, and microhabitats (van Emden 1965). Also, outbreaks of certain crop pests are more likely to occur in weed-free fields than in weed-diversified crop systems (Altieri et al. 1977). Crop fields with a dense weed cover and high diversity usually have more predaceous arthropods than do weed-free fields (Altieri and Whitcomb 1979). For example, alfalfa plots infested with weeds have a less diverse substrate predator complex but a greater foliage predator complex that do weed-free plots (Barney et al. 1984). The carabid, *Harpalus pennsylvanicus*, is abundant in alfalfa fields where grass weeds are dominant. Foliage predators (i.e., *Orius insidiosus* and Nabidae) also are significantly more abundant in grass-infested alfalfa.

In weed-covered bean plots, populations of the leafhopper, *Empoasca kraemeri*, were reduced not because of the higher efficiency or abundance of natural enemies, but because of the chemical interaction between the grasses and the insect (Altieri et al. 1977). The grasses (*Leptochloa filiformis* and *Eleusine indica*) apparently repelled the leafhopper. Their regulatory effect was greater than that of broadleaf weeds such as *Amaranthus dubius*. Also, pure stands of *L. filliformis* reduce adult leafhopper populations significantly more than *E. indica* (Schoonhoven et al. 1981); this effect decreases when the weed is killed with paraquat (Table 3).

Table 3. Effect of two weeds with and without paraquat application on nymphal and adult populations of the leafhopper *Empoasca kraemeri*[1] (after Schoonhoven et al. 1981).

	E. kraemeri populations	
Treatment	Nymphs/leaf	Adults/m^2
Live *Amaranthus dubius*	6.3a[2]	16.9a
Control	6.1a	14.0ab
Paraquat-treated *A. dubius*	6.0a	14.6ab
Paraquat-treated *Leptochloa filiformis*	4.8b	12.1b
Live *L. filiformis*	4.3b	9.2c
No weeds with insecticide	0.7c	6.9d

[1] Average population in four replications found between 20 and 71 days after planting (eight observations).
[2] Figures followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

Weeds within a crop system can reduce pest incidence by enticing pest insects away from the crop. For example, flea beetles (*Phyllotreta cruciferae*) concentrate their feeding more on intermingled *Brassica campestris* plants than on collards (Altieri and Gliessman 1983). The weedy species has significantly higher concentrations of allylisothiocyanote (a powerful attractant of flea beetle adults) than collards, thus diverting the beetles from the crop (Table 4).

Andow (1983) designed an experiment to separate the effects of decreased pest attack (from *Epilachna varivestris* and *Empoasca fabae*) and increased plant competition that often occur simultaneously in weed-diversified bean systems. He observed that insect pest attack on beans decreased as the intensity of interspecific plant competition increased. At low levels of interspecific plant competition, the slight decrease in pest attack compensated for the increased competition, and bean yields were no different from the monocultures

Table 4. Mean flea beetle (*Phyllotreta cruciferae*) densities, weed and crop biomass in various collard cropping systems in Santa Cruz, California. Means followed by the same letter in each column are not significantly different (P = 0.05). All means are averages of three sampling dates (15, 30 and 45 days after transplanting) (After Altieri and Gliessman 1983).

Cropping system	Number of flea beetles (±) Per 10 collard plants	Per 5 *Brassica campestris* plants	Leaves in each collard plant with beetle damage (45 days after transplanting)(%)	Weed density (plants/m²)	Weed biomass (g/m²)	Whole-plant collard dry weight (g/m²)
Collard monocultures						
Weed-free all season	34.0 ± 2.6 a	--	54.4 a	0	0	213.6
Weed-free for 4 weeks after collard transplanting	29.3 ± 1.7 b	78.1 ± 16.3 a	44.6 b	42	52.3	361.3
Weed-free for 2 weeks after collard transplanting	29.0 ± 1.7 b	73.7 ± 20.1 a	44.5 b	52	55.2	243.0
Weedy all season	6.6 ± 3.8 c	25.0 ± 11.5 b	29.9 c	142	438.2	226.1
Collard-bean polycultures						
Weed-free all season	2.3 ± 1.1 d	—	34.1 c	0	0	334.4
Weed-free for 4 weeks after collard transplanting	1.6 ± 0.9 d	4.3 ± 3.3 c	10.9 d	28	25.7	324.0
Weed-free for 2 weeks after collard transplanting	4.9 ± 2.3 c	13.1 ± 6.5 d	6.7 d	84	93.2	309.4
Weed all season	0.6 ± 0.5 e	15.0 ± 7.8 d	32.1 c	85	234.5	115.2

with insects. However, at the highest level of interspecific plant competition, even though pest attack was the lowest, competition was so intense that it negated any effect the lower pest attack may have had, and bean yields were much lower than the monocultures (Fig. 7).

Thus, in some circumstances, encouragement of specific weeds in crop fields is desirable to improve natural control of certain insect pests (Altieri and Whitcomb 1979). Careful manipulation strategies need to be defined to avoid weed competition. This means that we must understand the factors affecting crop-weed balance within a crop season. Shifting the crop-weed balance so that crop yields are not economically reduced may be accomplished using herbicides, through selective cultural practices, or by manipulating crop combinations to favor crop cover rather than weeds. Tolerable levels of desirable weeds supportive of populations of natural enemies or that directly deter herbivores can be attained within fields by (1) designing competitive crop mixtures, (2) allowing weed growth only as alternate rows or in field margins, (3) using cover crops, (4) adopting close-row spacings, (5) determining periods of weed-free maintenance (e.g., keeping crops free of weeds during the first third cycle of their growth), (6) mulching, and (7) timing cultivation regimens.

Besides minimizing the competitive interference of weeds, changes in the species composition of weed communities are desirable to insure the presence of plants of entomological significance. The composition of weed species composition can be altered by (1) changing levels of key chemical constituents in the soil, (2) using selective herbicides that suppress certain weeds while encouraging others, (3) sowing desired species, and (4) timing soil disturbances and other vegetation management practices (Altieri and Whitcomb 1979b).

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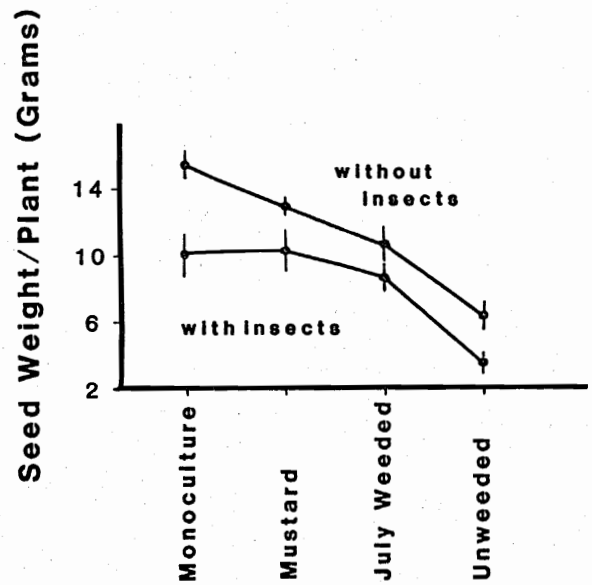

Figure 7. Yields of beans (as seed weight per plant) with and without herbivores, with and without weeds. The insects were eliminated with insecticides. The four levels of weediness were: 1) no weeds, 2) interplanted with 8200 clumps of wild mustard (Brassica kaber)/ha, midway between alternate bean rows, 3) natural populations of weeds for the first 35 days after planting and weeded from then on ("July weeded"), 4) natural populations of weeds for the entire growing season. (After Andow 1983).

CONCLUSIONS

Arthropod diversity and stability in agroecosystems is influenced by the (1) within-field plant species and structural diversity, including temporal and spatial arrangements; (2) composition, management, and permanence of surrounding plant communities; (3) distance of crops from sources of colonists; (4) permanence of crops, and therefore the time available for colonization, and (5) complexity of trophic relationships between crop and non-crop plants and herbivores and natural enemies.

Developing a base from which we can exploit the interactions between these various elements will require a fundamental exploration of agroecosystem design and management and an understanding of the relationships between all components of an agroecosystem. For example, measuring interactions in abandoned orchards can provideimportant ecological and design information for improving the stability of modern orchards. Orchard arthropod populations may respond to plant successional features depending on their degree of association

with the orchard trees, ground cover, and surrounding vegetation. Based on our results, the advanced succession in unmanaged orchards increases natural enemy abundance. Also, tree growth (new tissues, foliar levels of nutrients, etc.) affects herbivore reproduction. Interpretation of these changes may suggest new pest management practices based on frequencies of ground cover alteration, border vegetation manipulation, fertilization, and other techniques that affect orchard diversity and consequently tree growth and vigor. Realistically, the environment surrounding an orchard is usually difficult to manage since its dimensions extend beyond the farm boundary. Plant succession and degree of management and inputs (pesticides and fertilizers) are more amenable to management (Croft and Hoyt 1983).

Restoring natural controls in agroecosystems through vegetation management should not only result in pest regulation, but also should produce optimal nutrient recycling, energy conservation, and less dependence on external resources. This approach to agriculture will work only if it is economically sensible and can be carried out within the constraints of a fairly normal agricultural system. Therefore, recommended designs should reduce costs and increase the efficiency and economic viability of farmers. Economic benefits will mainly result if diversification favorably changes the balance between income and costs. Profits from lowered pest control costs should be greatest when plant competition between the component plant species of a polyculture is low. However, given the trend toward large-scale, specialized farm production units in the developed world, objectively there is not much room left for a fair implementation of a regional insect-habitat management program. Long-term maintenance of diversity requires a management strategy that considers regional biogeography and landscape patterns above local concerns of production. This is why we have repeatedly questioned whether the pest problems of modern agriculture can be ecologically alleviated within the context of the present capital-intensive structure of agriculture. Buttel (1980) suggests that many problems of modern agriculture are rooted within that structure. He asks us to consider major social change, research and extension reorientation, land reform, and re-design of machines in the agricultural sector to increase the possibilities of improved pest control through vegetation management.

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IMPACTS OF ORGANIC FARMING AND REDUCED TILLAGE ON FISH AND WILDLIFE

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The well-being and health of wild animals, domestic crops, farmers, and consumers are intertwined into a complex web. The purpose of this paper is to describe some of the interconnections and to show how conversion from conventional agriculture to the more sustainable alternative systems will benefit wildlife. The conversion will also benefit domestic crops, farmers, and consumers, but I will leave these analyses to other speakers.

INTEGRATING THE WILDLIFE COMPONENT

Wildlife influences farmers and farming in at least five primary ways. First, wildlife has aesthetic and recreational values. Most farmers take pride in the deer and geese on their farms and enjoy the morning calls of pheasants and doves. They like to hunt and many derive satisfaction from providing hunting opportunities for their families and friends. Many also take pleasure in the epicurean values of wild game.

The second value is derived from the first. Sportsmen will pay dearly for the privileges of hunting and fishing on privately owned lands; therefore, fish and wildlife can become cash crops. Wildlife production and payments from hunters have become major considerations for farmers and ranchers in parts of Europe, southern Africa, and the United States, and commercial fish farming is a major activity in the southeastern portion of the United States.

Third, wildlife can help control pests. Mice can compete with livestock for forage, but mouse populations are influenced, to some limited extent, by hawks, foxes and other predators. Likewise, many birds prey on insects pests.

The fourth interaction is the converse of the third. While wildlife can be beneficial, it also can create problems. Even in well managed agricultural ecosystems, deer can damage orchards in the winter and