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Weeds and Integrated Pest Management Systems

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Growing a single crop species (monoculture) has dominated agricultural systems in the United States in the last 50 to 75 years. Monoculture has been favored primarily because of mechanization with concomitant reductions in production costs. Some pest management specialists have thought that monoculture of crops may lead to increased insect, nematode, and disease problems. Weed management is probably more easily accomplished in large fields with monocultured crops than in small-scale farming employing polycropping techniques.

Any plant other than the primary crop adds to the complexity of the ecosystem. Allowing weeds to remain in the ecosystem, or growing weeds or crop plants other than the main crop as a living mulch, groundcover, or 2nd crop, can substantially modify incidence of pests. The critical questions from a pest management perspective is do such modifications create beneficial effects, are of no significance, or detrimental? These questions must be viewed at economic, environmental, and sociological levels. The value of weeds and/or interplants in the management of arthropod, nema-

tode, plant pathogen, and vertebrate pests is assessed in this review. No effort will be made to address sociological implications.

Definitions

A weed will be considered as any plant that was not intentionally sown; thus, it is a plant growing out of place and includes volunteer and "escape" crop plants. Interplants will be considered as any plant grown in addition to the crop but not harvested. The term "multiple cropping" (or polyculture) will be used when 2 different harvested crop plants are grown at the same time on the same land area.

Ecosystem considerations

Several review articles have been published in recent years concerning the general topic of impacts of background vegetation on pest management (3-5, 99, 111, 119, 146, 161, 167). Other authors have analyzed theoretical aspects of ecosystem diversity in relation

to pest management (95, 107, 108, 151, 156). Bibliographical compendia on weeds hosting nematodes (17, 91) and on weeds acting as reservoirs for arthropod pests that attack crops (16) provide useful lists of references. Each major class of pests other than weeds, including arthropods, pathogens, nematodes, and vertebrates will here be discussed from 4 aspects.

1) *Manipulation of vegetation in relation to its acting as a food source for other pests.* Any green plant in the agroecosystem is, within the energy/resource flow concept, a producer (84, 103). Weeds and/or interplants are therefore producers in the ecological sense (99). All pests other than weeds are consumers (99). Likewise, beneficial organisms are all consumers either at the primary level (when they feed directly on the producers) or at a secondary or higher level (when they feed on a pest species) (99). Complicated food webs thus occur for some beneficial organisms. Simplistic approaches to pest management may overlook potentially important interactions.

2) *Habitat modification.* Weeds provide shelter either in the form of protection from environmental extremes of temperature, relative humidity, air movement, and radiation, or through lack of visibility. Habitat modification frequently cannot be separated from vegetation serving as food source, and the 2 topics will be discussed together.

Habitat modification and provision of a food source are independent of the mechanism by which vegetation manipulation is achieved.

3) *Influence of herbicides.* Interactions with herbicides can occur as direct effects on other pests, or through alteration of the physiology of host plants. Alteration of cultural practices, such as polycropping vs. monocropping, may require changes in herbicide use, which would then alter interactions with other pests. Effects of herbicides per se are probably less significant in most instances than the changes in vegetation that result from their use.

4) *Control of other organisms affects weed management.* Tactics used to manage other pests may also inadvertently alter organisms that are feeding on weeds and providing at least partial biological weed control. Changes in the activity of these organisms could alter weed management.

ARTHROPOD PESTS

Food source interactions/habitat modification

Numerous reports (3-5, 29, 108, 153) of weeds or interplants acting to decrease the numbers of phytophagous insects or mites have been published (Table 1). These decreases are attributed to factors such as provision of food source, reduced host visibility,

Table 1. Interactions between weeds or interplants and insect or mite pests in various cropping systems.^z

Cropping system	Weed/interplant	Phytophagous insect/mite (reponse)	Beneficial insect/mite (response)	Crop yield	Literature cited
<i>Beneficial response^y</i>					
Alfalfa	Winter annual weeds	Egyptian alfalfa weevil (-)	N	=	102
		Alfalfa weevil (-)	N	N	163
Beans	Summer weeds	<i>Empoasca kraemeri</i> (-)	Leafhopper predators (=)	=/-	3, 123
Brussels sprouts	Mixed annual	Aphids, Lepidoptera (-)	Syrphids, general (+)	-	1, 128, 129
		Imported cabbage worm (-)	Predators (+)	-	30
	<i>Spergula arvensis</i>	<i>Mamestra brassicae</i> (-)	N	(-)	144
Cabbage	Several companion spp.	Cabbageworm (-)	N	-	70
Cole crops	Clover cover crop	Cabbage root worm (-)	<i>Trybliographa rapae</i> (+)	=/-	120, 121
	Intercropping	Cabbage aphid (-)	N	N	150
		Cabbage root worm (-)	Carabid, Staphylinid (+)	N	150
Collards	Various intercrops/ companion plants	Flea beetle (= or -)	N	-	75, 76
	Mixed weeds	Flea beetle (-)	N	+, -	2
	Mixed weeds	Green peach aphid (-)	Various (-)	-	55,56
Cereals	Annual bluegrass	Aphids (-)	General predators (+)	N	154
Corn	Carrot interplant	Corn earworm (-)	Assassin bug (+)	N	28
Cotton	Alfalfa interplant	<i>Lygus</i> bugs (-)	N	N	132
Cucumbers	Polycultures	Striped cucumber beetle (-)	Various predators (=)	-	12
Grapes	Blackberry	Grape leafhopper (-)	<i>Anagrus epos</i> (+)	N	34
	Johnsongrass	Willamette mite (-)	Predatory mites (+)	N	43
Orchards	Weeds	Mites (-)	Predatory mites	N	60
Pears	Mixed species + cover crop	Pear <i>Psylla</i> (?-)	<i>Nabis</i> , and Coccinelids	N	44
Peppers	Various interplants	Green peach aphid (-)	N	N	92
Potatoes	Various interplants	Colo. potato beetle (-)	N	N	92
<i>Detrimental responses^y</i>					
Alfalfa	Winter animals	<i>Lygus</i> bugs (+)	N	N	(unpublished observation)
Asparagus	Perennial weeds	Redback cutworm (+)	N	N	139
Beans	Pigweeds	Cutworms (+)	N	N	46, 47
bush	Several companion spp.	Whiteflies (+)	N	N	70
snap	Companion plants	Mexican bean beetle (- to +)	N	-	72
		Corn earworm (= or +)	N	-	72
Broccoli	Various interplants	Imported cabbage worm (+)	N	N	92
Brussels sprouts	<i>Spergula arvensis</i>	Imported cabbage worm (+)	N	N	144
Cabbage	Clover	Cabbage root worm (+)	<i>Aleochara bilineata</i> (-)	N	120
Collards	Companion tomatoes	Cabbage flea beetle (+)	N	N	90
	Companion plants	Various Lepidoptera (= or +)	N	N	73-75
Corn	Mixed weeds	Corn earworm (= to +)	N	N	28
Cotton	Palmer amaranth	Beet armyworm (+)	N	N/-	157
Grapes	London rocket	False chinchbug (+)	N	N	14
Orchards	Winter animals	Green peach aphid (+)	N	N	10
	Mallow, flixweed	Green peach aphid (+)	N	N	138,140
Pepper	Parsnip interplant	Green peach aphid (+)	N	N	28
Strawberries	Polyculture	Whiteflies (+)	N	N	39
Sugarbeet, tomato	Russian thistle	Beet leafhopper (+)	N	N	36

^zResponses are indicated as follows: + indicates population or yield increased; = indicates population or yield not changed; - indicates population or yield decreased; and N indicates no information provided.

^yBased on changes in the phytophagous insects/mites.

masking of olfactory guides, or reduced host density. Assessment of the ultimate benefit of decreases in phytophagous insects is frequently not feasible because crop yields were not reported, or crop yield was decreased due to the presence of the interplant species or by feeding of the remaining insects.

Many beneficial insects feed at 2 trophic levels, but are considered to be beneficial at the stage when they are feeding on another insect or mite. Adults of many beneficial insects feed on nectar in addition to feeding on insects (33). Examples include flies (78, 120), various wasps (28, 80, 125), and several other species (24, 135). This feeding at different trophic levels at different stages in the life cycle is a major reason for including weeds or interplants in pest management programs. Nectar-producing plants, such as wild carrot (*Daucus carota* L.), could thus attract nectar-feeding beneficial insects. Inclusion of such plants has not yet met with documented success for pest management (28).

Increases in phytophagous insects can result in increases in entomophagous (beneficial) insects on the basis of resource concentration or increased accessibility (12, 13, 56, 119, 136, 144, 150). Beneficial insects should always increase if pest (prey) species increase—provided a source population of the beneficial insect is available on noncrop or weed vegetation in adjacent areas. The latter is because phytophagous insects that feed on weeds can serve as prey for beneficial entomophagous insects or mites (4, 5, 15, 34, 43, 44, 134, 148). Manipulation of the weed vegetation can thus provide a means of increasing the numbers of beneficial insects moving into a crop. The endemic blackberry (*Rubus* spp.) system harboring the grape leafhopper (*Erythroneura vitis* Harris) parasite *Anagrus epos* (Girault) in California (34) is a good example. Observations by Horn (56) that parasitization of green peach aphid (*Myzus persicae* Sulzer) in collards (*Brassica oleracea* L. var. *acephala* D.C.) was higher in weed-free plots than in weedy plots is an example of resource concentration. The latter shows that weed-free conditions can lead to decreased insect pest attack, but both examples strengthen the argument for leaving “reservoir” vegetation around the borders of fields (4, 5, 107, 153). Leaving reservoir vegetation has, however, so far met with limited documented success. Growing blackberries adjacent to grape vineyards, for example, has not proved successful for increasing *Anagrus* populations because the vineyard does not duplicate the riparian habitat of wild blackberries in California (A.N. Kasimatis, personal communication).

Increased vegetation complexity may lead to increased problems with phytophagous insects (Table 1). Although several authors think that increased complexity should lead to an overall reduction in insect damage to crops (7, 8, 111, 115, 119), others argue that there is no inherent reason to expect that increased complexity will lead to decreases in insect damage (28, 39, 70, 95, 152, 153, 156). There may be a factor of scale that is not well understood—effects demonstrated where several small plots are adjacent to each other may not be the same as for entire fields. Increased vegetation complexity could have greater effects on polyphagous rather than monophagous insects, as has been suggested by Andow (7). Several authors report that companion plantings can attract polyphagous insects to the crop (70, 73, 92).

Weed vegetation can increase the population of a crop-damaging insect, which is then driven to the crop when the weeds die or are removed by control practices. Tamaki (137) concluded that the best way to manage aphids in peach orchards was to remove the weeds on which the pest populations increase (138, 140). Barnes (14) suggested removal of London rocket (*Sisymbrium irio* L.) before budbreak in grapes (*Vitis vinifera* L.) as a tactic to reduce damage by false chinchbug (*Nysius raphanus* Howard), which increase on the weed. Leius (80) showed, however, that weeds were beneficial in orchards in relation to control of codling moth (*Carpocapsa pomonella* L.) caterpillar, as parasites were maintained at higher levels. These conclusions emphasize the necessity of knowing the specific interactions in each ecosystem and ascertaining which interaction is economically the most important.

Other examples of insects increasing on weeds include cutworms (*Agrotis* spp.) on pigweed (*Amaranthus* spp.) (46, 47, 126), false chinchbugs on London rocket in cotton (79), fall armyworms (*Spodoptera frugiperda* Smith) on several grass species (106), tarnished plant bug (*Lygus lineolaris* Palisot de Beauvais) on mixed weeds (67, 130), and *Lygus* spp. on winter annual weeds in alfalfa (unpublished observations). Beet armyworm (*Spodoptera exigua* Hübner) moved from Palmer amaranth (*Amaranthus palmeri* S. Wats.) to cotton (*Gossypium hisutum* L.), which resulted in insecticide treatment of the crop (152).

A further problem is that researchers in different regions, or working with different crops, obtain different results. Koehler et al. (70) reported that several companion plants decreased the numbers of cabbage worm (*Trichoplusia ni* Hübner) on cabbages (*Brassica oleracea* L. var. *capitata* L.), but that the same companion plants increased the number of whitefly (*Trialeurodes vaporariorum* Westwood) on beans (*Phaseolus vulgaris* L.). Matthews et al. (92) noted that several interplant species decreased various insects on squash (*Cucurbita pepo* L.) and peppers (*Capsicum frutescens* L.), but increased the imported cabbage worm (*Pieris rapae* L.) on broccoli (*Brassica oleracea* L. var. *botrytis* L.). Weeds or interplants in cabbage reduced cabbage rootfly (*Delia brassicae* Bohé) (150), but lead to increases in various Lepidoptera (71, 73, 74, 92). Generalizations from one insect species to another may not be valid.

Weeds or interplants reduced cabbage rootfly in England (150), but the same type of experiment in Ireland led to increases in the same insect (120). Koehler et al. (70) reported that several companion plants reduced imported cabbage worms on cabbages in California, but Matthews et al. (92) showed the same companion species increased the insect on broccoli in Pennsylvania. Crepps and Ehler (28) reported that interplants of parsnip (*Pastinaca sativa* L.) increased green peach aphid on peppers, but Matthews et al. (92) showed that several companion plants decreased the aphid on peppers. Information developed in one region may not be transportable to other regions, as our understanding of the factors controlling how companion plants alter insect pest densities is currently inadequate.

Several authors who have studied weeds as backgrounds or surrounds, or investigated polycultures, have noted that environmental resources must be allocated to the interplant, which equates to less resources for the crop plant (76, 121, 144). Crop yield losses due to companion plants sometimes exceeded those expected by competition—allelopathic responses were suggested from French marigolds (*Tagetes patula* L.) (72) and tansy (*Tanacetum vulgare* L.) (75). A partial summary of the gains and losses in yield due to weeds or interplants is presented in Table 1.

Several reviewers conclude that there are more examples of decreased arthropod problems with polycultures, or systems using various levels of increased vegetation complexity, than there are examples of increased problems (7, 8, 107, 108, 115). Such a conclusion may be satisfactory for making a theoretical framework on which to judge interactions in the ecosystem. The conclusion may, however, be of limited use when considered in the context of a specific problem insect in a crop. It is not adequate for farmers to know that, on a theoretical basis, there is a chance that interplants or weeds will result in decreased insect levels. A farmer must determine whether that specific insect will reach damaging levels. One major pest that is not altered (or is increased) by inclusion of interplants or weeds in the system can negate the benefits from reductions in several other pest species.

Reviews such as those cited above (8, 107, 108, 115) have only considered interactions between plants and arthropod pests. Lack of inclusion of all types of pests may overlook serious problems caused by shifting from monoculture to some form of increased system complexity. Changes in disease, nematode, or vertebrate problems may occur (Fig. 1), in addition to increasing the complexity of weed management. The necessity of allowing for interactions among pest classes has been noted by Litsinger and Moody (85), Newsom (97), and Norris et al. (102).

Herbicide effects

Norris (99) reviewed many potential interactions between herbicides and insects or mites, and Tanke and Franz (141) investigated the effects of several herbicides on beneficial insects. Interactions

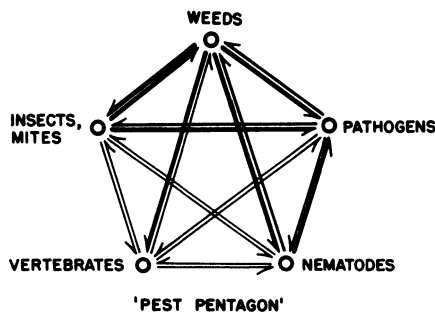


Fig. 1. The "pest pentagon"—a diagrammatic presentation to indicate the potential interactions between different classes of pests. [From Norris (99), by permission of Academic Press, New York, N.Y.]

between types of pesticides have been reviewed by Putnam and Penner (114).

Some herbicides can reduce beneficial insect or mite populations. Application of paraquat, terbacil, dalapon, or 2,4-D, for example, have been reported to reduce beneficial mites to a greater degree than phytophagous mites (117). Farlow and Pitre (41) demonstrated acifluorfen and bentazon increased the egg laying of the generalist predator *Geocoris punctipes* (Say), which could be argued to be a beneficial response to herbicide application.

Herbicides may also have insecticidal effects. EPTC reduced the fecundity of the cotton leafworm (*Spodoptera littoralis* Boisduval) in Egypt (40). Synergism between atrazine and insecticides increased the activity of the latter against fruitflies. (*Drosophila melanogaster* Meigen) and other insects (82).

Effects of other arthropods on weeds

Many weeds are used as food sources by insects or mites. Tobacco fleabeetles (*Epitrix hirtipennis* Melsheimer) feeding on nightshade (*Solanum* spp.) and groundcherry (*Physalis* spp.), 2-spotted mites (*Tetranychus urticae* Koch) on field bindweed (*Convolvulus arvensis* L.), omnivorous leafroller on redroot pigweed (*Amaranthus retroflexus* L.) and fillaree (*Erodium* spp.) have been noted (unpublished observations). Further documented examples include leaf miners in common purslane (*Portulaca oleracea* L.) (26, 48), armyworms on pigweed (148), a Chrysomelid beetle *Gastrophysa viridula* Degeer. on curly dock (*Rumex crispus* L.) (160), a weevil (*Perapion antiquum* Gyllenhal) on 3-cornered jack (*Emex australis* Steinheil) (61), and various insects on Scotch broom (*Sarothamnus scoparius* L.) (155). Many of these insects are capable of essentially eliminating further growth of the weed. Acceptable biological weed control can be provided by the insects if they do not attack the crop (9). Whittaker (159) emphasized that grazing by invertebrates has the potential to regulate completely the outcome of competitive interactions between plants.

Insect management practices, especially those relying on insecticides, may disrupt natural biological control of weeds. Insecticidal checks are used to ascertain the effectiveness of biological control agents (68) or to determine the extent to which insect feeding reduces growth of weeds (26, 101, 155, 160). Finlayson et al. (42) reported increased survival of weed seedlings when insecticides were used in mini-cauliflowers. Clement and Norris (26) showed that insecticide application essentially eliminated natural biological control of common purslane by purslane sawfly (*Schizocerella pilicornis* Holmgren) and purslane weevil (*Hypura bertrandi* Perris). Common purslane was not competitive with sugarbeets when attacked by the insects, but caused a 30% to 40% reduction of crop yield when aldicarb was used (101). Insect attack resulted in earlier death of Scotch broom plants and reduced seed production; insecticide application increased longevity and seed production of the weedy shrub (155). Likewise, Whittaker (160) reported that plants of curly dock kept free of the beetle *Gastrophysa viridula* Degeer. were larger and survived longer than plants grazed by the insects.

Insect predators eat weed seeds and contribute to the decline of the seed bank (9, 86, 87, 127). Decreasing the size of the seed

bank is probably the single greatest contribution to biological control of weeds by insects. The extent of this biological control is essentially undocumented, and the possibility that insect management practices may alter the rate of decline of the seed bank by predation has not been studied.

Insect feeding can reduce the effectiveness of herbicides applied for weed control. The weevil *Notaris bimaculatus* Fab., which feeds on quackgrass (*Agropyron repens* L.), caused a 50% reduction in the control achieved following application of glyphosate (158). Application of an insecticide 2 weeks before herbicide application restored most of the herbicide activity.

PATHOGENS

Food source interactions/habitat modification

The potential benefit of weeds and/or interplants for suppression of pathogens has been suggested whereby nonhost plants interspersed among host plants will reduce the rate of spread of the pathogen, because some of the inoculum is trapped on nonhost species (81, 108, 149, 156). This has been referred to as the 'fly paper' effect (149). This argument seems dubious due to the vast spore production by most pathogens. No unequivocal evidence has yet been presented that the effect occurs. Burdon and Chilvers (21) did show that interplanting of *Wimmera* ryegrass (*Lolium rigidum* Gaud.) among garden cress (*Lepidium sativum* L.) seedlings reduced the rate of advance of damping-off (*Pythium irregulare* Buisman) on the cress. They attributed the changes, however, to altered host density rather than the mixture of species present.

Interactions between weeds or interplants and pathogens that require insect vectors are indirect and depend on factors (discussed in the previous section) affecting the populations and movement of the vectors.

The available evidence indicates that weeds or interplants increase the difficulty of disease management by acting as hosts of pathogens (36, 89, 145, 146). New examples are reported in almost every issue of relevant journals. Increases in herbicide use, with concomitant gains in levels of weed control attained, have led to decreases in the severity of disease problems (64, 65). This is attributed to reduced numbers of source inoculum plants, to reductions in the necessity for tillage (164, 165), and to changes to less favorable microclimate for pathogen spread and infection. Removal of weed vegetation, as a means of inoculum reduction, is accepted as a necessary component of many virus management programs (36, 147). Growing weeds for other pest management reasons could have detrimental affects on such virus management programs. Infected weeds are frequently symptomless carriers—dallisgrass (*Paspalum dilatatum* Poir.), for example, is a symptomless carrier of Pierce's disease of grapes. The practice of leaving weeds is thus particularly hazardous when judged in relation to pathogen management.

Herbicide effects

Katan and Eshel (63) pointed out that herbicides can interact with pathogens through direct toxicity to the pathogen, by altering the virulence of the pathogen, by altering the virulence of competing microorganisms, or by changing the physiology of the host plants. In most cases of interactions between herbicides and disease incidence it is not possible to determine which interaction has occurred.

Several examples of herbicides reducing the severity of diseases have been reported (6, 99). The now classic example of trifluralin being used to suppress *Aphanomyces* in peas has recently been reconfirmed (58). Some herbicides also possess fungitoxic capabilities, which may aid in suppression of disease. Paraquat, for example, decreased the number of spores of *Rhynchosporium secalis* (Oud.) Davis on barley (*Hordeum vulgare* L.) stubble (131).

Herbicides can increase the severity of diseases (6, 63, 77, 94, 98). These increases are almost certainly due to herbicide damage to the host plant, which results in greater susceptibility to the attacking pathogen. Such herbicide-induced damage probably leads to leaking of plant cell contents, which are then used as a growing medium by the pathogen (6).

No pattern is apparent in the interactions between herbicides and pathogens or diseases. Each combination of herbicide, pathogen, and host must be assessed on its own merit.

Effects of pathogens on weeds

Many host-specific pathogens attack weed species (22, 36). Such pathogens have the potential for providing partial biological control of weeds, but the extent of this control is largely unrecognized. Considerable effort is, however, being expended to develop weed-specific pathogens for biological control (22, 142, 143).

Klerk et al. (69) have recently shown that use of fungicides may at least partially negate the control achieved with the mycoherbicide based on *Colletotrichum gleosporioides* (Penz) Sacc. f. sp. *aeschy-nomene*. Phatak et al. (109) likewise reported chlorothalonil reduced infection of the rust [*Puccinia canaliculata* (Schw.) Lagerh.] on yellow nutsedge (*Cyperus esculentus* L.) and substantially reduced control of the weed by the pathogen. Applications of fungicides to protect crops thus have the potential to decrease both natural and augmented biological control of weeds by pathogens.

NEMATODES

Food source interactions/habitat modification

Weeds are hosts for many species of nematodes (17, 53, 91). Examples include numerous weed species as highly susceptible hosts for the rice root nematode (*Hirschmanniella spinicaudata* Sch. Stek.) in Nigeria (11) and several parasitic nematodes of rice in India (113); nutsedges (*Cyperus* spp.) and johnsongrass [*Sorghum halapense* (L.) Pers.] for several nematodes of cotton and soybeans (*Glycine max* L.) (19, 50); lesion nematode (*Pratylenchus* spp.) on several weeds (45); and silverleaf nightshade nematode (*Nothanguina phyllobia* Thorne), which also attacks tomatoes (*Lycopersicon esculentum* Mill.), peppers, and eggplant (*Solanum melongena* L.) (116). Interactions between weeds and nematodes seem to be overwhelmingly negative in a pest management sense.

The value of rotation away from a susceptible crop as a means of nematode management can be negated if weeds growing in other crops in the rotation are hosts for the nematodes (11, 25, 53, 59). Redroot pigweed, for example, is known to maintain high populations of plant parasitic nematodes (71). Cooper and Harrison (27) suggested, however, that nematode-susceptible weeds in tobacco (*Nicotiana tabacum* L.) could reduce the incidence of tobacco rattle virus in the crop because the nematode was more likely to attack the weed than the crop. Long-term benefits are dubious if the nematode population is increased by the weeds.

Interplants and/or companion plants that do not host nematodes must be considered separately from weeds when assessing impacts on nematode management. An interplant or cover crop that does not support nematodes that attack the crop can be a useful method for suppressing such a nematode. This approach appears to have greater potential in orchard crops than in annual row crops due to the relative stability of the orchard ecosystem. Caution must be exercised in the choice of cover crop, as some species used can support crop-damaging nematodes (18, 37, 38). Sudangrass [*Sorghum bicolor* (L.) Moench.] does not support *Pratylenchus penetrans* [(Cobb) Allen & Sherr.], whereas rye (*Secale cereale* L.) increased the population of the nematode (37). Hairy indigo (*Indigofera hirsuta* L.) supports the burrowing nematode [*Radopholus similis* (Cobb) Thorne] in *Citrus* (18); *Crotalaria* spp. do not support the nematode but are less desirable as a cover crop. Intercropping with grain legumes has been reported to increase *Pratylenchus brachyurus* (Godfrey) (38). The long-term implications of the intercrop must therefore be considered.

Interplant species that suppress nematode populations or the use of such species between crops has been suggested. French marigolds will suppress certain nematodes (88, 93), although economic benefits appear to be uncertain on a large scale due to the land area that must be devoted to the noncrop plants. Rotations that normally include fallow periods may be an exception.

Herbicide effects

Romney et al. (118) reported that DCPA reduces attack by root-

knot nematode (*Meloidogyne* spp.) on beans and onions (*Allium cepa* L.). More recent work has demonstrated that oryzalin can reduce cotton and tomato infection by root-knot nematode (104). In contrast, trifluralin increased the effect of root-knot nematode on alfalfa (*Medicago sativa* L.) and tomatoes (118). In most instances, these changes in attack are attributed to changes in the growth or physiology of the host plant rather than to direct nematicidal effects of the herbicide. These reports emphasize that herbicides do have the potential to alter the severity of nematode problems on crops.

Effects of nematodes on weeds

Damage to weed species by nematodes has been recorded only in a few cases, and the potential for biological control is thus poorly understood. Hollis (51, 52) clearly showed that application of a nematicide decreased the control that *Criconemoides onoensis* (Luc.) was exerting on yellow nutsedge, which then grew better and was more competitive with rice. The potential for control of silverleaf nightshade (*Solanum eleagnifolium* Cav.) by nematodes has been investigated (116). Indications were that use of nematicides will decrease such control. Fiddleneck (*Amsinkia* spp.) is attacked by *Anguina amsinkia* (Steiner and Scott), reducing growth and seed production of the weed (96). The potential biological control (of these weeds) is also being investigated (105). Weed control may have to be increased by other means if control of crop-damaging nematodes also results in decreased biological control of weeds.

VERTEBRATES AND MOLLUSCS

Food source interactions/habitat modification

Weeds increase the likelihood of a vertebrate pest problem (49). No examples of weeds leading to decreased vertebrate problems could be found in the literature. Differences in relative food value and/or palatability between species may alter the degree of rodent invasion in relation to food source, but virtually any weed species can provide cover. Strip treatment with herbicides along tree rows in orchards is used to decrease rodent invasion and damage, yet provide vegetative cover between the rows for cultural and pest-management reasons. Rat damage in rice was more severe in weedy than in weed-free plots (35). Meadow mice (*Microtus* sp.) lived in weedy seedling alfalfa, but foraged into adjacent weed-free alfalfa (unpublished observations).

Weed or interplant vegetation also provides food and cover for nonpest vertebrate species. Removal of weed vegetation in a monocrop culture may lead to decreases in wildlife (112). The level to which weeds or interplants can be left for wildlife or game purposes is difficult to assess, but should be considered in regional pest management programs.

Slugs and snails are not normally considered to be a problem in row crop culture. Available evidence, mainly from minimum- or zero-till management experiments, suggests that increased vegetation complexity will lead to increased problems with slugs and snails (62). No evidence could be found to indicate that slug or snail problems would be decreased by increased vegetational complexity.

Effects of vertebrates or molluscs on weeds

Depletion of the weed seed bank by vertebrates is a major component of the loss of seeds (127). Management of vertebrates thus has the potential to alter weed seed bank dynamics.

Slugs and snails feed on many weed species (23, 31). Slugs grazed preferentially on shepherd's purse (*Capsella bursa-pastoris* L.) in comparison with annual bluegrass (*Poa annua* L.) (32). The extent to which such selective feeding might contribute to biological control of weeds has not been assessed, but control of mollusc pests does have the potential to alter weed survival.

INTERACTIONS AMONG CLASSES OF PESTS, AND OVERALL MANAGEMENT STRATEGIES

It is imperative that integrated pest management consider all potential interactions in the agroecosystem in a truly multidisciplinary sense (85, 97, 99). The inclusion of interplants or leaving weeds

in the agroecosystem increases the diversity of the ecosystem and increases the complexity of the weed management needed. Factors that must be considered prior to adoption of weeds or interplants for pest management should include those outlined below.

Interactions among classes of pests

Each situation must be judged on its own merit with the use of the "pest-pentagon" (Fig. 1) philosophy. Only when all potential interactions have been considered will it be possible to make the best pest management decision. Leaving weeds (or growing interplants) as a means of reducing the population of one pest may be of no benefit if another class of pest is increased.

Modification of cultural management

Polycropping, or growing interplants or weeds for pest management purposes, will be difficult in mechanized agriculture if the cultural practices do not coincide for all species and will not be adopted unless significant benefits exist. The cotton and alfalfa system for control of *Lygus* bugs in California (132) is a classic example of this dilemma. The system works, but it has not been adopted by California cotton farmers because irrigation and harvesting requirements of the 2 crops differ.

Tillage has profound effects on soil-borne organisms (20, 57, 110, 165, 166). Reductions in tillage have been shown to result in increased survival of various insects, such as the grape root borer (*Vitacea polistiformis* Harris) (66, 122), 2 *Heliothis* spp. (54), and the cereal leaf beetle (*Oulema melanopsis* L.) and its parasites (83). Survival of several diseases has been altered with reduced tillage (64, 124, 164). Habitat destruction by disking is considered to be a control tactic for vertebrate pest management. Growing weeds or interplants must be judged in relation to the necessary alteration of cultivation and its role in modifying pest populations.

Modification of weed management and hand labor

Weed management is almost always easier in a monoculture than a polyculture in agricultural systems that rely on cultivation with tractors or use herbicides. Systems that use hand-labor for weeding will not, however, require any substantial change in weed management in order to leave weeds or interplants. The potential for invasion of a polycrop or interplant system by weeds requires that the management techniques for such weeds must be resolved prior to initiation of the polyculture.

Growing interplants or weeds for pest management reasons will probably increase the need for hand-weeding in annual row crops. A recent assessment of the possibility for adoption of organic farming methods in the United States (151) noted that the need for hand-labor would be increased. This increase may not be an unacceptable burden in situations where hand-labor is available. It is unlikely, however, that sufficient hand-labor would be available for weeding if polycropping were adopted for mechanized annual row crops in the industrialized countries.

Changes in weed management should not cause undue difficulty in crops where the interference between the different plant species can be minimized (such as orchards), and in perennial crops where the interplant can use temporal differences in growth.

Cosmetic damage and yield of primary crop

Differences in numbers of pests or beneficial organisms due to vegetation management may only be of intrinsic interest unless accurate and statistically reliable yield and economic data are available. Intercropping and polycropping systems using temporal and spatial differences to produce 2 different plants on a single piece of land typically do not affect the yield of either crop to any significant degree (162). The total yield per unit of land would therefore be greater than if either crop was grown alone (149, 162).

The potential for primary crop yield loss must be considered when weeds or specific interplant or companion plants are used for pest management reasons and do not themselves produce any useful yield. Authors testing weed backgrounds for pest manipulation have noted that crop land must be diverted to growing the weed (144),

that the weeds may have to be managed [e.g., mowed (30)] to reduce competition with the crop, or that the crop yield is reduced by competition (72, 76) or inferior pest control (70). Crop losses may not be significant to a home gardener [where yield reduction may be tolerable if a useful gain in pest management (e.g., less insecticide used) is obtained], but such losses may not be economically acceptable to a commercial grower. The lower numbers of pests resulting from the use of weeds or interplants may not cause yield loss but may, however, still result in commercially unacceptable cosmetic damage to the crop.

Changes in weed seed bank

Weed management in one season has the potential to affect cropping for several years. Increases in the weed seed bank is of prime concern to weed management (100). Weeds such as redroot pigweed, which may be used as habitat or a food source for beneficial insects, have an enormous potential for increase in the seed bank. One redroot pigweed plant is capable of producing over 2.5×10^5 seeds, and many other weeds have equally high seed production (100, 135). Weeds with high reproductive capacity should not be allowed to produce seed, and probably should not be used for pest management purposes. The possibility that management practices for pests other than weeds may alter weed seed bank dynamics also needs to be considered.

Overall economics

Any pest management strategy is significant to agriculture if the overall economics of the strategy leads to increased net return. This net return must include all costs (inputs) to the system, and should also include, to the extent feasible, social and environmental impacts. Much of the work reported in the literature on ecosystem stability and diversity does not include reliable information on yield responses (see Table 1), or document alteration in total inputs to the production system, and thus cannot be judged on an economic basis. It is imperative that future work on the use of weeds and interplants in pest management assess the overall economics of the system.

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