The Potential Use of Weeds in the Manipulation of Beneficial Insects[1]

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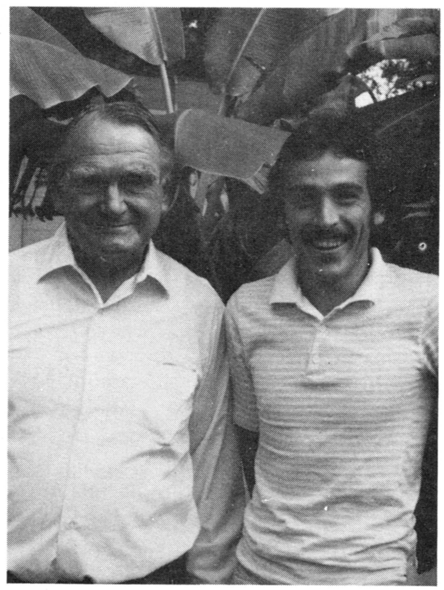
Certain weed species play an important role in the biology of many beneficial insects. Relevant examples from the literature show that many weeds contribute to the population regulation of various insect pests of crucifer crops, beans and orchards. These examples emphasize the potential of weeds for implementing pest management systems. Although there is enough information concerning weed manipulation methods, there is a need for more formal research on how to encourage the presence of beneficial weeds in crop fields for the purpose of increasing entomophagous insect populations. Demonstration of improved biological control in weed diversified cropping systems represents the initial step toward improved pest management systems based on ecological principles.

Subject to attempted exclusion from agroecosystems, weeds are thought of primarily as competitors with crops which cause subsequent yield reductions (11). Weeds are also focused upon as hosts of insect pests, however certain weed species play an important role in the biology of many beneficial insects (69). The objectives of this review are: 1) to illustrate the potential of certain weeds to serve as alternate food sources for beneficial insects, and 2) to propose, from an insect pest management viewpoint, weed management strategies based upon the response of beneficial weeds to both environmental factors and cultural practices which encourage acceptable population levels of certain beneficial weed species.

Weeds contribute to the population regulation of various insect pests of crucifer crops (*Brassica* spp.) and beans (*Phaseolus vulgaris* L.) (2, 50, 58, 65). The achivement of such regulation is hypothesized to be caused by complex interacting factors such as an increase in associational resistance (58), reduction of crop apparency (18) and an increase of beneficial insects (2, 9, 15, 20).

The manipulation of weedy habitats surrounding crops appears to be beneficial because of improved synchronization between populations of pests and their natural enemies (41, 46, 68). Although there is considerable knowledge in weed manipulation methods and weed population thresholds, there is a lack of information on how to encourage the presence of specific weed species within crop fields for the purpose of increasing entomophagous insect populations.



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WEEDS AS SOURCES OF BENEFICIAL INSECTS

Supplementary food from pollen and nectar

Although insect prey provide the diet for most entomophagous species, results of several studies demonstrate additional requirements for amino acids and carbohydrates from plants (10, 24, 40 63). These nutrients usually are provided by nectar and pollen and sometimes through leaf feeding and sap-feeding (63). Pollen and nectar may be provided by either the crop plant such as cotton (*Gossypium hirsutum* L.) (49) and peaches (*Prunus persica* B. and H.) (52), or more commonly, from weeds within the crop or in surrounding areas.

Wolcot (75) described how successful establishment of the parasitoid, *Larra americana* Sause, introduced into Puerto Rico from Brazil to control the cricket, *Scapteriscus vicinus* Scudder, depended on the presence of two weeds, *Borreria verticillata* and *Hyptis atrorubens*. These weeds provided nectar for the adult wasp. Where these weeds were absent or scarce, the wasp failed to survive.

Van Emden (68) demonstrated that certain Ichneumonidae, such as *Mesochorus* spp. must feed on nectar for egg maturation, and Leius (39, 40) reported that carbohydrates from the nectar of certain Umbelliferae are essential in normal fecundity and longevity in three Ichneumonid species. Syme (64), in studies of the parasitoids of the European pine shoot moth, (*Rhyacionia buoliana* (Schiff.) showed that fecundity and longevity of the wasps, *Exeristes comstockii* (Cressen) and *Hyssopus thymus* Girault were significantly increased with the presence of several weeds. Syme emphasized the role of weed nectar sources in allowing the adult parasitoids to bridge a critical period when the host is unavailable.

Umbelliferae flowers tend to be preferred by hymenopterans. For ex-

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ample, in Japan *Tiphia popilliavora* Roh., a parasite of the Japanese beetle (*Popillia japonica* Newman) fed solely on the blossoms of two Umbelliferae, *Libanotis ugoensis* Keidz. and *Patrinia scabiosaefolia* Fisch. (13). Imported into the U.S., this parasite fed on flowers of another Umbelliferae, the wild carrot (*Daucus carota* L.) (13). King and Holloway (37) emphasized that satisfactory establishment of *T. popilliavora* required an abundance of wild carrot at the release sites.

Van Emden (68), after studying 6 different habitats, found that the proximity of certain flowering weeds (*Angelica sylvestris* L., *Urtica dioica* L. *Rumex acetosella* L., *Taraxacum officianale* Weber, *Cirsium vulgare* (Savi) Ten., *Ranunculus repens* L., *Trifolium repens* L., *Chenopodium album* L., and *Anthriscus sylvestris* L.) increased the activity of parasitic Hymenoptera in wheat (*Triticum vulgare* Vill.), and cabbage fields (*Brassica oleracea* L.).

Spectacular parasitism increase was observed in apple (*Malus domestica* Boreb.) orchards with rich undergrowths of wild flowers (41). Parasitism of tent caterpillar eggs and larvae and codling moth larvae was 18 times greater in those orchards with floral undergowths than in orchards with sparse floral undergrowth (41). In sugarcane (*Saccharum officinarum* L.) fields of Hawaii, the tachinid parasitoid *Lixophaga sphenophori* Villeneuve fed upon nectar from several weeds of the family Euphorbiaceae (38).

Considerable work has been reported by researchers of the Soviet Union on the role of nectar plants in increasing the effectiveness of biological control agents. Telenga (66) informed that *Scolie dejeani* Lind. was attracted to its grub hosts by sowing honey plants, *Phacelia* and *Eryngium*. These same plants have been shown to increase the abundance of the wasp *Aphelinus mali* (Haldeman) for the control of apple aphids and improve the activity of *Trichogramma* spp. in apple orchards (67).

Soviet researchers at the Tashkent Laboratory (66) cited lack of adult food supply as a reason for the inability of *Aphytis proclia* Wlker. to control its host, the San Jose scale (*Quadraspidiotus perniciosus* Comst.). The effectiveness of the parasitoid improved as a result of planting *Phacelia* cover crop in the orchards. Three successive plantings of *Phacelia* cover crop increased scale parasitization from 5% in clean cultivated orchards to 75% where honey plants were grown.

Russian researchers also noted that *Apanteles glomeratus* L., a parasite of 2 species of cabbageworms (*Pieris* spp.), on crucifer crops, obtained nectar from mustard flowers. The parasite lived longer and laid more eggs when these weeds were present. When quick-flowering mustards were planted in fields of cole crops, parasitization of the host increased from ten to sixty percent (44).

Nectar sources appear to have a role in parasite survival during periods of low host density. In such cases many female Hymenopteran parasites (i.e. Pteromalidae) enter a long resting period during which they eat only carbohydrates (21). These nutrients are usually supplied by nectar and pollen from weeds growing in the area (39).

Weed flowers are also important food sources for various insect predators (69). Sugar feeding requirements have been demonstrated in some species of lacewings (*Chrysopa* spp.) (16, 24). This requirement is satisfied by aphid honeydew or nectar feeding. Killington (36) reported a preference of lacewings for flowers of the Compositae. Pollen appears to be instrumental in egg production of many Syrphid flies and is reported to be a significant food source for many predaceous Coccinellidae (67). Several aphidophagous coccinellids, *Coccinella* spp., *Adalia bipunctata* L., and *Cycloneda sanguinea* L. have been reported to feed on the extrafloral nectarines of peach trees (52). Large amounts of pollen from the blossoms of dandelion, *Taraxacum officinale* Weber have been found in the alimentary canal of the coccinellid *Coleomegilla maculata* (De Geer) (52). Putnam (52) emphasized the role of weed flowers in allowing the predators to survive the midsummer period when hosts were scarce.

Pollen is an important alternate food for certain predaceous phytoseiid mites (30). One species, *Amblyseius hibisci* Chant was able to develop completely on pollen alone. Clausen (12) mentions several other examples of predaceous insects that feed on plant materials at least in one period of their life cycles.

Hagen (24) reported that cattail (*Typha* sp.) pollen applied in vineyards in California increased the abundance of non-pestiferous tyiid mites which served as important alternate sources of prey for the strictly predaceous mite *Metaseiulus occidentalis* (Nesbitt). This allows *M. occidentalis* to survive periods of low populations of the target pest, the willamette mite (*Eotetranychus willamettei* Ewing).

Hosts of alternative prey

At times it is advantageous to increase non-pestiferous herbivorous insects in crop fields. Such insects serve as hosts to entomophagous insects, thus improving the survival and reproduction of beneficial insects in the agroecosystem.

The weeds present in crop fields constitute important elements to increasing the herbaceous insects and associated predators and parasitoids. The entomofauna of several weeds which occur in several crops in many parts of the world have been extensively surveyed. For example, Goeden and Ricker (22) reported the phytophagous insect fauna of several species of *Ambrosia* in California. Stegmaier (61, 62) listed some insects associated with *Eupatorium coelestinum* L. and ragweed (*Ambrosia artemisiifolia* L.) in Florida. In Colombia, Figueroa (19) observed 172 insect species on 70 weeds. Needham (45) studied the insects on the flowers of spanish needle (*Bidens pilosa* L.) and Romney (57) the insect community associated with pepperweed (*Lepidium alyssoides* L.)

Taxonomic observations such as those mentioned above comprise a basic step in developing strategies to increase the activity of certain parasites, especially when generations of the host and parasite fail to coincide. For example, the effectiveness of the tachinid *Lydella grisesens* Robinesis-Desvoidy, a parasite of the European corn borer (*Ostrinia nubilalis* (Hubner)) can be increased in the presence of an alternative host, *Papaipema nebris* Guenee, a stalk borer on giant ragweed (*Ambrosia* spp.) (64).

Several other authors have reported that the presence of alternate hosts on ragweeds near crop fields increased parasitism of specific pests. Examples include *Eurytoma tylodermatis* Ashmead against the boll weevil (*Anthonomus grandis* Boheman) (49) and *Macrocentrus delicatus* against the oriental fruit month (*Grapholita molesta* (Bosch)) (8). The parasite *Horogenes* spp. used the caterpillar of *Swammerdamia lutarea* (Haworth) on the weed *Crataegus* sp. to overwinter each year after emergence from diamondback moth (*Plutella maculipennis* (Curt)) (69). A similar situation occurs with the egg parasitoid *Anagrus epos* Girault whose effectiveness in regulating the grape leafhopper (*Erythroneura elegantula* Osborn) was greatly increased in vineyards near areas invaded by wild blackberry (*Rubus* sp.). This plant hosts an alternate leafhopper *Dikrella cruentata* (Gillette) which breeds in its leaves in winter (15).

In New Jersey peach orchards, control of the oriental fruit moth was increased in the presence of ragweed, smart weed (*Polygonum* sp.), lambsquarter (*Chenopodium album* L.) and goldenrod (*Solidago* sp.). These weeds provided alternate hosts for the parasite *Macrocentrus ancylivorus* Roh.

When Johnson grass was allowed to grow in grape (*Vitis* sp.) vineyards in California, there was a buildup of alternate prey mites which supported populations of the predatory mite

Metaseiulus occidentalis which in turn restrained the Pacific mite (*Eotetranychus willamettei* Ewing) to non-economic numbers (20).

Weeds with their numerous associated aphids serve as an important reservoir of beneficial insects. For example, Bombosch (9) found high numbers of various predator species feeding on aphids of different weeds. *Pastinaca* sp. and *Achillea* sp. were consistently attractive for coccinellids and hymenopterans.

In north Florida, the goldenrod (*Solidago altissima* L.) supports more than 75 different predator species that feed on aphids of the genus *Uroleucon* in spring (Altieri and Whitcomb, unpublished data). Similarly, in England a wide range of natural enemies fed on the stinging nettle aphid (*Microlophium carnosum* (Bukt.) (46). The proximity of aphid infested nettles to bean fields increased the numbers of Coccinellidae on bean plants (4).

Hodek (27) suggested that by planting belts of honey plants, the control of the bean aphid (*Aphis fabae* Scop) could be improved. These plants were hosts of economically indifferent species of aphids which in turn were alternative hosts of effective parasitic wasps (Hymenoptera: Aphidiidae) of *A. fabae*.

Hemenway and Whitcomb (26) found associations between weeds, leaf beetles (Chrysomelidae) and ground beetles (Carabidae) of the genus *Lebia* Latreille. For example, *Lebia grandis* Hentz was often found in association with *Leptinotarsa decemlineata* Hentz and the weed *Solanum carolinense* L. *Lebia atriventris* Say was found on camphorweed (*Heterotheca subaxillaris* (Lam)) feeding on larvae and eggs of *Zygogramma heterothecae* Linell. *Lebia analis* Dejean was associated with *Disonycha glabrata* Fabr. on *Amaranthus* spp. *Lebia viridis* Say fed on the larvae of *Altica foiacea* Lec. on two species of evening primrose, *Oenothera laciniata* Hill and *O. biennis* Linn. Practical implications from these observations become obvious since many of these ground beetles are predators of important crop pests (72). *Lebia viridis* Say was observed consuming eggs of corn earworm (*Heliothis zea* (Boodie)) (73). *L. viridis* was also observed preying actively on grapevine flea-beetles in vineyards (31). *Lebia grandis* Hentz preys upon the Colorado potato beetle (*Leptinotarsa decemlineatea* Hentz) and *Lebia analis* Dejean preys on immature stages of fall armyworm (*Spodoptera frugiperda* (J.E. Smith)) and eggs of the bollworm (26, 73). By introducing or removing *Solanum carolinense* L. or *Amaranthus* sp. from potato (*Solanum tuberosum* L.) or corn (*Zea mays* L.) fields respectively, *L. grandis* and *L. analis* can be encouraged or eliminated. This fact might be important in other crops such as beans, soybeans (*Glycine max* (L.)) corn and alfalfa (*Medicago sativa* L.) since persistent populations of *Lebia marginicollis* Dej., *L. viridis* and *L. analis* have been reported to occur in such fields (72).

In general, most beneficial insects present on weeds tend to disperse to crops, but in a few instances the prey found on weeds could prevent or delay this dispersal (69). In such cases, 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 dioica* L.) in May or June, predators (mainly Coccinellidae) were forced to move into crop fields (46). Similarly, cutting the grass weed cover drove Coccinellidae into orchard trees in southeastern Czechoslovakia (27). By cutting hedges of *Ambrosia trifida* L. infested with the weevil *Lixus scrobicollis* Boh, a 10 percent increase of boll weevil parasitization by *Eurytoma tylodermatis* Ashm. was obtained in two test plots of cotton adjacent to the hedgerow (49). These practices should be carefully timed based on 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 (67).

POSSIBLE METHODS OF MANIPULATING WEEDS

This review lists several examples which emphasize the role of specific weeds in the biology of predators and parasites. Encouraging the presence of specific weeds in crop fields seems a logical approach to improve biological control of certain insect pests. Naturally, careful manipulation strategies need to be defined in order to avoid weed competition with crops and interference with certain cultural practices. In other words, economic thresholds of weed populations need to be defined, and also factors affecting crop-weed balance within a crop season should be clearly understood (5).

Changes in the composition and abundance of weeds in crop fields can be accomplished by various methods of manipulation:

Changes of the levels of key chemical constituents in the soil

Hoveland et al. (29), studying in Alabama the response of various weeds to different levels of P and K concluded that the local weed complex can be indirectly affected by the manipulation of soil fertility. Fields with low soil K were dominated by buckhorn plantain (*Plantago lanceolata* L.) and curly dock (*Rumex crispus* L.), whereas fields with low soil P were dominated by showy crotalaria (*Crotalaria spectabilis* Roth.), morning-glory (*Ipomea purpurea* (L.) Roth.), sicklepod (*Cassia obtusifolia* L.), *Geranium carolinianum* L., and coffee senna (*Cassia occidentalis* L.).

Corn grown in unfertile soils in north Florida are dominated by *Richardia scabra* L. and *Diodia teres* Walt. Fertilized fields are dominated by *Cassia obtusifolia* L. (Altieri and Whitcomb, unpublished data). In heavily fertilized fields in southern Illinois, *Ambrosia artemisiifolia* L. plants attained heights of more than 1.3 m, whereas in poorly fertilized fields they were usually no more than 0.6 m high (6). Dry matter production and height of *Portulaca oleracea* L. rose with an increase in the level of applied nitrogen in Phillipines (5). These results show that different soil nutrient levels may also affect the vigor and productivity of individual weed populations which in turn can influence insect populations. For example, nitrogen fertilization of wheatgrass plots increased populations of the plant bug *Labops hesperius* Uhler, because the fertilized grass was probably of better quality than unifertilized grass (33).

Soil pH can influence the growth of certain weeds. For example, weeds of the genus *Pteridium* grow in acid soils while *Cressa* sp. inhabits only alkaline soils (44). Other species (many Compositae and Polygonaceae) grow in saline soils (44).

Many weeds exhibit allelopathic interactions with certain crops and other weeds. By the release of chemical compounds from other plants, the abundance of certain plants can be regulated in a field (56). For example, some strains of cucumber (*Cucumis sativus* L.) many inhibit the growth of certain weed species by 87% (53). Fresh foliage of *Tagetes patula* L., *Amaranthus dubius* Mart, *Manihot esculenta* Crantz, and *Phaseolus vulgaris* L. can drastically inhibit the germination of *Sorghum vulgare* L. and *Ipomoea hederifolla* (L.) under greenhouse conditions (3). Barley (*Hordeum vulgare*) has been used as a smother crop for weed suppression (56). Although allelopathy has some general implications for weed management, there is a need for further research in this area, before farmers might utilize allelopathy to increase the competitive ability of crops over co-existing weeds.

Continuous use of certain herbicides

Horowitz et al. (28) observed weed population shifts after 4 years of applying repeated herbicide treatments in the same plot. *Anagallis caerulea*

Schreb. was eliminated with the use of substituted ureas, whereas the population of bindweed (*Convolvulus arvensis* L.) was increased. Hausen *et al.* (25) reported reducing the populations of yellow nutsedge (*Cyperus esculentus* L.), crabgrass (*Digitaria sanguinalis* L. Scop.) and cocklebur (*Xanthium pennsylvanicum* Wall), but increasing the population of spurge (*Euphorbia maculata* L.) after several crop rotations and chemical methods. In Colombia, Piedrahita and Doll (47) obtained a 21% increase in broadleaf weed cover in soybeans after four applications of the herbicide linuron. Buildups of morningglory (*Ipomoea tilliacea* Willd) and *Cucumis melo* L. are obtained by continuous applications of alachlor in corn. In southwestern Germany birdseye speedwell (*Veronica persica* Poiret) became dominant in plots annually treated with MCPA or 2,4-D, whereas *Lamium purpureum* L., chickweed (*Stellaria media* L.) and bedstraw (*Galium aparine* L.) all increased in abundance after MCPA-treatments only (55).

Perhaps one of the most valuable tools to suppress certain weeds while encouraging others is the use of herbicides used in crop-weed competition studies. Buchanan (11) published a list of herbicides, and recommends rates of application safe to use in growing certain weed species in particular crops. For example, by applying a maximum rate of 0.6 kg/ha of trifluralin (preplant incorporated), populations of velvetleaf (*Abutilon theophrasti* Medicus), jimson weed (*Datura stramonium* L.), venice mallow (*Hibiscus trionum* L.), and prickly sida (*Sida spinosa* L.) can be grown in cotton and soybeans without the presence of unwanted weed species (11). Although most examples cited by Buchanan (11) concern the enhancement of noxious weeds for weed control studies, the method implicates possibilities for enhancing particular beneficial weeds to achieve early increases of predator populations.

Direct sowing of certain weeds in the field

In experimental plots in Colombia, Altieri (1) attempted to regulate the total weed cover in bean and corn fields by differential sowing of six weed species. A mixture of constant volumes of weed seeds was sowed in each plot. This amount of seeds varied according to the area to be covered, but the proportions were kept constant. Twenty days after planting, the soil coverture was corrected by differential hoeing.

Lack of water (rainfall) was a definite limiting factor in attempting to grow 1-meter wide borders of grass weeds (*Eleusine indica* (Gaertn) and *Leptochloa filiformis* Lamb (Beauv.) around bean fields (1). Once the borders became established, the colonization and reproductive efficiency of leafhoppers in bean plots (*Empoasca kraemeri* Ross & Moore) were effectively reduced (2).

In another experiment, the establishement of strips of *Amaranthus dubius* Mart. between bean rows was not accomplished when the weed seeds were covered by a soil layer (1). Similarly, when deeply buried seeds of foxtail and smartweed species were uncovered, they germinated freely (43). One-year-old seeds of wild carrot and redroot pigweed (*Amaranthus retroflexus* L.) purchased from California failed to germinate in corn fields in north Florida (Altieri and Whitcomb, unpublished data).

Putwain (54) introduced seeds of sorrel (*Rumex acetosa* L.) and red sorrel (*R. acetosella* L.) in grasslands of North Wales obtaining high germination. However, one to two weeks after germination a crash in seedling population density was observed.

The application of this direct sowing method demands that certain weed seed germination requirements must be carefully investigated. Most weed seeds have specialized requirements for germination, and some remain in the condition of enforced dormancy and will not germinate until certain environmental conditions become available. For this reason it is often difficult to sow weeds for experimental purposes (71).

Buchanan (11) published a complete review on the germination requirements of weed seeds and methods to stimulate their germination. Among the most useful methods are mechanical scarification, sulfuric acid treatment, chemical stimulators of germination (i.e. Potassium nitrate) and stratification (period of low temperature after ripening). Before sowing the viable weed seeds in the field it is important to make sure that the supplies contain pure seed so that new weeds are not introduced.

Soil disturbance

Soil disturbance is of major importance in the initiation of secondary successions in agricultural lands (43). Plowing destroys the existing plant cover, creating open niches for the invasion of new plants.

The role of soil disturbance in weed seed germination is not well understood beyond the obvious effects of tillage on soil moisture and aeration. The actual number of seeds that germinate at a particular time of the year as a result of a specific season of disturbance is determined by the specialized conditions that are necessary for germination of seeds in various stages of dormancy (43). The germination of the exposed weed seeds after disturbance depends on the existing environmental conditions and the dormancy state of the seeds (71).

Table 1. Species composition of pioneer weed communities of lands subjected to agricultural disturbances in different regions of the U.S.

Region	Pioneer weed species	Reference
Colorado	*Setaria viridis* L. (green foxtail) *Chenopodium album* L. (lambsquarters) *Solanum nigrum* L. (black nightshade) *Amaranthus retroflexus* L. (red root pigweed) *Verbesina encelioides* (Cav.)	32
North Carolina Piedmont	*Digitaria sanguinalis* L. (crabgrass) *Erigeron canadensis* L. (horseweed) *Diodia teres* Walt.	35
Idaho	*Aristida dichotoma* Mich. (three awn grass) *Salsola kali* var *tenuifolia Tausch* (russian thistle) *Bromus tectorum* L. (brome grass)	48
Michigan	*Ambrosia elatior* L. (ragweed) *Polygonum convolvulus* L. (wild buckwheat) *Lactuca scariola* L. (prickly lettuce) *Agropyron repens* L. (quackgrass) *Poa compressa* L. (bluegrass)	7
Central basin of Tennessee	*Erigeron strigosus* Muhl *Gnaphalium obtusifolium* L. (fragrant everlasting) *Ambrosia artemisiifola* L. (common ragweed)	43
South Carolina	*Rumex acetocella* L. (red sorrel) *Oenothera laciniata* Hill (evening primrose) *Linaria canadenis* L. (toad-flax) *Specularia perfoliata* L. (venus' looking glass) *Gnaphalium purpureum* L. (purple cudweed) *Festuca subaxillaris* (fescue)	74
Southern Illinois	*Solanum carolinense* L. (horsenettle) *Ambrosia artemisiifolia* L. (common ragweed) *Digitaria sanguinalis* L. (crabgrass)	6

Where natural vegetation is disturbed, the first pioneer plants arise from dormant seeds stored in the soil rather than from fresh dispersals (7, 35). Soil disturbance may alter the microenvironment of seeds in many ways. For example surface germinators may simply respond to better aeration or to exposure to normal periods of daylength (11, 43).

In general, recently disturbed fields are quickly covered by a variety of annual plants. The species composition of pioneering weed communities is highly variable (6, 7, 35). Infinite combinations exist, depending upon the seed source, season of disturbance, previous agricultural practices, moisture, soil conditions, and other habitat characteristics. The colonization patterns are affected by various factors, but seem to be governed mainly by the rate of habitat colonization by each species and by environmental changes caused by colonizing plants themselves (35).

Table 1 reflects the considerable variability in species compositon of the pioneer weed communities of disturbed lands in different regions of the U.S.

Understanding the relationships between soil disturbance and weed succession is an important tool for insect manipulation. For example, after analyzing the differences in species composition of early weed stages in different fields of Idaho, Peimeisel (48) suggested that insect populations could be controlled by changing and/or improving the plant cover. He found high populations of beet leafhoppers (*Eutettix tenellus*) (Baker) in fields dominated by russian thistle (*Salsola kali* var *tenuiffolia* Tausch), but low numbers of this insect in fields dominated by brome grass (*Bromus tectorum* L.) Of further interest are the studies of Menke (42) and Kay *et al* (34) in North Florida which show that the season in which the soil is disturbed affects both the density and species composition of the vegetation. Such changes exert important influences in the population of herbivorous insects. For example, populations of the leaf beetle *Altica* sp. were numerous in plots plowed in August and October because these treatments enhanced the abundance of this insect's preferred food supply, the evening primrose *Oenothera laciniata* Hill (42, Altieri and Whitcomb, unpublished data). Further research by Altieri and Whitcomb (unpublished data) in experimental plots at Tall Timbers Research Station (34, 42) in north Florida, showed consistent associations between weeds, herbivorous insects and predaceous arthropods (Table 2). Specific dates of plowing affected the abundance of particular weed species, which in turn affected the abundance of particular weed species, which in turn affected the abundance of their associated herbivorous entomofauna. These insects served as alternate prey to many native predators which responded numerically to the seasonal increases of prey on specific weeds.

CONCLUSIONS

This review has emphasized the role of certain weeds as a reservoir for beneficial insects. The fact that weeds are ever present within and around crop

Table 2. Selected examples of associations between herbivorous and predaceous insects occuring on specific weed species which respond to particular dates of plowing in north Florida.*

Weed species	Date of soil disturbance that enhances the weed population	Herbivore(s) associated with the weeds that serve as alternate prey to various predators	Predaceous arthropod(s) associated with the herbivore(s) on the weed
1. *Oenothera laciniata* Hill (early evening primrose)	August	*Altica* sp. (leaf beetle)	*Lebia viridis* Say (ground beetle)
2. *O. biennis* L. (evening primrose)	December	*Altica* sp.	*L. viridis*
3. *Amaranthus* sp. (pigweed)	April	*Disonycha glabrata* Fab.	*Lebia analis* Dej. (ground beetle)
4. *Heterotheca subaxillaris* (Lam.) (camphorweed)	October	*Zygogramma heterotheca* (L.) (leaf beetle)	*Lebia atriventris* Say (ground beetle) *Sinea* sp. (assassin bug) *Pselliopus cinctus* Fab.) (assassin bug) *Perillus bioculatus* (Fab.) (stink bug) *Stiretrus anchorago* (Fab.) (stink bug) *Peucetia viridans* (Hentz) (lynx spider) *Oxyopes salticus* Hentz (lynx spider) *Theridion* sp. (spider)
5. *Chenopodium ambrosioides* L. (mexican tea)	December	*Z. suturalis* (Fab.) and other leaf beetles	*Callida decora* Fab (ground beetle) *L. viridis* *Hippodamia convergens* Guerin-Menev. *P. biocultus* and other stink bugs *Orchelimum* sp. (long horned grass-hopper) *Tetragnatha laboriosa* (Hentz) and other spiders
6. *Solidago altissima* L. (goldenrod)	December	*Urolecon* spp. (Aphids)	*H. convergens* and other ladybeetles *Condylostylus* sp. and other long legged flies *Micromus* spp. (brown lacewing) *Chrysopa* spp. (lacewing) *Podabrus* sp. and other soldier beetles *P. viridans* and other spiders *Zelus cervicalis* Stal. and other predaceous Hemiptera

*Altieri and Whitcomb (umpublished data)
Description of study, plots, treatments and methods are reported in the literature (34, 42).

fields makes them an important agroecosystem component which can be manipulated to manage pests and their natural enemies. Results presented above indicate that certain weed species should be introduced into crop systems, because these weeds have potential for greatly increasing populations of beneficial insects, thus improving the biological control of pests. However, there is an urgent need for information on weed manipulation, especially concerning methods on how to enhance the presence of "useful weeds" and how to distribute them in the field so that they do not compete with crops. Providing weeds as borders around small fields or as alternate strips within cultivated areas might be useful. Among the various methods mentioned above, season of soil disturbance and direct sowing appear to be the most practical methods to determine the presence of specific weed associations in crop fields at different times of the year. By plowing the land in different seasons, populations of certain weeds can be increased in the field and the phytophagous insects associated with these weeds will be increased. It also results in an increase of predators and parasitoids that attack these phytophagous insects. By proper manipulation (i.e. periodic clipping) beneficial insects can be forced to move from the weeds into the crops and thus act upon economic pests (46).

Understanding basic crop-weed-insect interactions occuring in a geographical area might provide important clues on how agroecosystems should be structured to minimize pest incidence, not only within the cultivated field but also at the regional level. It should be emphasized that an agroecosystem must be defined large enough to include the crops studied but also the surrounding matrix of uncultivated land which constitutes a vital part in the life systems of many entomophagous arthropods (27, 67). Weeds provide much of the plant diversity within and out of crop fields, improving the availability of alternate food, breeding sites, and shelter for many important beneficial insects (2, 27, 46, 67, 69).

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