Introduction

The term pest includes pathogens, weeds, nematodes, mollusks, arthropods, and vertebrates. One category of pests does not occur in the absence of pests in other categories, yet most IPM systems are designed around a single category of pest. For full implementation of IPM it is essential that all categories of pests be managed in an integrated manner. Allowances for the interactions that occur between the categories of pests be incorporated into the IPM decision making process. Interactions between pest categories can be diagrammed in the form of a ‘pest hexagon’ (Figure 1). Not all interactions between all categories of pests are of equal significance, but due to the trophic position of weeds in the ecosystem weeds have the potential to impact all other categories of pests.

Weeds presence in agricultural systems can vary from essentially none in a highly managed monocropping system, such as that used for cotton in the San Joaquin valley, to very diverse mixture of species in small field cropping systems interlaced with hedges, fence lines, stream banks, and woodlands. Such contrasting agricultural systems provide very different habitats for all other organisms present in the systems. At the farm level there is a large difference in habitat for all organisms between fence lines that are weedy and those that are maintained weed free. Similarly, within orchards there can be large habitat differences between those managed with a weed-free floor versus those managed with vegetation cover.

There are several different mechanisms by which interactions can occur between categories of pests, including:
1. Trophic relationships
2. Alteration of habitat/environment
3. Physical factors
4. Control tactics
   4.1. Non-chemical
   4.2. Caused by pesticide use.

Trophic relationships

Ecologically organisms can be divided into two major types. One group comprises green plants that can use the raw ecosystem resources such as water, sunlight, mineral nutrients and carbon dioxide and convert them into the biochemicals that support all other forms of life. Plants
are referred to as producers in ecological terms. The second group includes all other organisms that depend directly or indirectly on green plants as their food source; they are referred to ecologically as consumers. The simple food chain concept shown in figure 2 depicts these relationships. Weeds are thus unique among pest organisms as they are producers, whereas all other categories of pests are consumers.

The ecological difference between weeds and other categories of pests means that weeds can serve as a food source for all consumer organisms (Figure 3), which results in numerous interactions between weeds and other categories of pests. Weeds can support herbivore organisms that feed directly on them, and they can support beneficial organisms that feed on the carnivores. Some beneficial arthropods feed both as carnivores and herbivores at different stages in their life cycle.

Simple food chains do not represent the complexity of real ecosystems. Ecologists attempt to represent this complexity in the form of food webs, which are a depiction of who eats whom. A simplistic food web for an agroecosystem is presented in figure 4. A few of the types of interactions between weeds and other categories of pests that are included in this food web include:

1. Weeds can serve as alternative hosts for herbivore pests (A and D). Note that pest D is supported on a plant outside of the managed crop ecosystem; this type of trophic connection is important for areawide pest management.
2. Weeds can serve as alternative hosts for a beneficial insect B through provision of prey living on the weed that is growing within the crop agroecosystem. Similarly, herbivore prey that is feeding on a plant outside the managed ecosystem supports beneficial D. Plants growing outside of the agroecosystem may be important for areawide pest management.
3. Weeds can serve as direct food sources for beneficial organisms, for example weeds within the crop are food for beneficial A, and plants outside the managed ecosystem are food for beneficial B.
4. The crop has multiple herbivore pests, and the likelihood that any of the pests will be a significant problem depends on what beneficial organisms are present. Pest organisms A and D are maintained on weeds or non-crop plants. Pest A might be root-knot nematodes that are able to parasitize weed hosts such as pigweed and lambsquarters. Pest D might be lygus bugs, or a virus like lettuce mosaic, living in or on weeds in areas that surround managed fields.
5. Beneficial organism B might not be very effective, because the following could alter its population dynamics sufficiently to stop the population from ever increasing to the point where it provides effective control of pest organism B:
   5.1. Beneficial B requires plant food, such as nectar or pollen, and the appropriate food-source plants may or may not be present.
   5.2. Beneficial B is a food source for a hyperparasitic tertiary consumer (B).
6. Hyperparasites from outside the managed ecosystem could limit the effectiveness of beneficial organisms.
7. The activity of beneficial D may be modified by what entomologists refer to as a tritrophic interaction, which involves the passage of plant-derived chemical compounds across trophic levels. The vertical arrow within pest organism D represents the passage of chemical compounds derived from the crop plant to the next higher trophic level.

In reality, most food webs involve many interactions and so are much more complex than those described above.

*Alteration of habitat/environment*

*Resource concentration*

Entomologists theorize that insects are more like to be attracted, or immigrate, to uniform stands of host plants that to areas where host plants are mixed with non-host plants. It is also argued that insects are less likely to leave, or emigrate from, areas of more uniform host plants. In many agricultural situations weeds are interspersed with the crop and thus effectively decrease the concentration of the crop host, which could lead to changes in pest and or beneficial numbers on the crop.

*Apparency*

Related to resource concentration is the concept of apparency. Mobile pests, particularly arthropods, must be able to find suitable host plants using vision or olfactory cues. The presence of weeds, especially in situations where weeds represent a large proportion of the biomass, as discussed in the next section, could result in mobile pests being able to find their preferred host less easily.

*Microenvironment*

The presence of a plant canopy alters the microenvironment, such as temperature, light intensity, humidity, and wind speed. Changes in these parameters can alter the performance of pests living in the habitat. Presence of a plant canopy also provides shelter; many pests cannot survive in the open and need a plant canopy to provide protection from environmental extremes and from predators.

Weeds can represent a major component of the plant canopy in some systems, and thus can interact with other categories of pests through alteration of apparency and through provision of appropriate microenvironment. Prior to postemergence cultivation or other weed control practice weeds may represent most of the canopy present in annual row crops. In dormant perennial crops like alfalfa and orchards, weeds provide most of the living canopy present in the field during the dormant season. Many of the plants in non-cropped areas such as fence lines, ditch banks and roadsides are often weeds, and thus provide not only food but also suitable habitat per other categories of pests in these areas.

*Physical factors*

Interactions between pest categories that are driven by physical factors typically do not involve weeds, and are not considered here.
Control tactics

All the preceding interactions occur regardless of the control tactics used as they are driven by ecological changes brought about by the pest or the control tactic. Some interactions do, however, occur in direct response to the control tactics used.

Non-chemical tactics

Tillage impacts all soil-borne organisms. Tillage, for example, provides partial mechanical control of some arthropods, which have the pupal stage in the soil, such as cotton bollworm. Changes in intensity of tillage have been shown to alter the survival of such pests. The ultimate interaction with tillage occurs in no-till systems, in which there is essentially no habitat destruction, and no physical impact on pests. No-till systems need special attention to pests that are controlled with tillage, such as slugs and snails.

Interactions through pesticide use

There are several ways in which pesticides used for control of one category of pest may impact pests in a different category. The simplest of such interactions occurs when the pesticide is directly toxic to another category of pests. Several herbicides, for example, weak fungicides. If a pesticide has sufficient activity against another category of pests to provide usable control then it will be registered for such use.

Herbicides are intended to alter the physiology of weeds sufficiently that they are killed. Selective herbicides that do not kill the crop often cause transitory changes in the physiology of the crop. These subtle, non-lethal, effects on the crop can lead to alteration in how other pest organisms react to the crop. Phenoxy-herbicides have, for example been shown to increase aphids on corn.

Insecticides are not usually considered to have any direct toxic impact on the crop, but there are several insecticides that do alter physiological processes in the crop. The most important of these to the use of herbicides in IPM systems are the organo-phosphate insecticides, several of which can lead to loss of herbicide tolerance in the crop; examples include propanil on rice, and metribuzin in soybeans.

Tank mixtures of pesticides intended for control of different categories of pests can sometimes result in synergism or antagonism of activity; atrazine, for example, potentiates several insecticides applied for fruitfly control. An IPM program must anticipate and allow for such interactions.

Summary

A comprehensive IPM program must consider all categories of pests and manage them an integrated fashion. The presence of weeds and the control of weeds have potential to interact with all other categories of pests. Knowledge of, and allowance for, such interactions are essential if an IPM program is to achieve true integration of control.
Figure 1. The pest hexagon; a diagrammatic representation of the interactions between different categories of pests.

Figure 2. Example of a simple food chain showing ecological terminology.
Figure 3. Example of simple food chains for a crop and a weed.
Figure 4. Diagram of potential food web connections. Vertical dotted line depicts boundary between managed ecosystem (to left) and organisms external to the managed system.