INTRODUCTION TO INSECT PEST MANAGEMENT

THIRD EDITION

Edited by

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THE PEST-MANAGEMENT CONCEPT

William H. Luckmann and Robert L. Metcalf

I. WHAT IS PEST MANAGEMENT?

The past decade, beginning about the mid 1980s, has been a period of voluntary and involuntary change in U.S. agriculture. The thinking and practices of many people in the public and private sectors of agriculture have been changed by new laws regulating the use of pesticides, pest resistance, changes in soil microflora that enhance pesticide degradation leading to poor control, the financial viability of many farms, concerns about soil erosion and about the environment, new initiatives such as Low Input Sustainable Agriculture (LISA) and Alternative Agriculture (AA), and the contamination of surface and groundwater sources of drinking water with nitrates and pesticides. While many practices in agriculture are still intuitively derived from past experience, more farmers now realize that much can be gained through the purposeful manipulation of crops and production techniques to reduce pest problems. There is still much to be done but much has been accomplished in insect pest management since this book was first published 20 years ago.

Led by entomologists, researchers in the 1950s began to identify problems associated with the overreliance on insecticides. They defined concepts and developed new terms, leading to what is now called insect pest management. The concepts were not new to applied entomology, but, alarmed by developing pest resistance and pesticide transfer and magnification in the environment, insect control scientists urged a return to sound fundamental principles of control. This approach to pest control, which seeks the compatibility of control interventions, has acquired various names. *Integrated control,* originally coined to define the blending of biological control agents with chemical control interventions (Bartlett, 1956), has now assumed wider meaning. Geier and Clark (1961) have called this conception of pest control

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the *protective management of noxious species,* or *pest management* for short, in which all available techniques are evaluated and consolidated into a unified program to manage pest populations so that economic damage is avoided and adverse side effects on the environment are minimized (NAS, 1969).

The term *pest* is an arbitrary label that has no ecological validity. Some insects can be considered pests at certain times and beneficial at other times. An insect is usually considered a pest when it is in competition with humans for some resource, and when significant numbers are present. Because of the complexities of human society, it is usually impossible to eliminate pest problems by ceasing the activities that encourage them, but clearly we have often been too hasty and inclusive in our definitions and too impetuous in our efforts to exterminate and eradicate. Pest-management concepts dictate a tolerant approach to pest status. Indeed, it may be that not all pests are bad and that not all pest damage is intolerable. Furthermore, we can readily use an old practice such as crop rotation and call it pest management, so long as the manager accepts and understands the philosophy of pest management. This, more than anything else, will determine the fate of insect pest-management programs. Insects can be managed, but management is people-oriented, and successful pest management depends largely on influencing the people who control the pest. The pest-management philosophy is relevant in all pest-control actions.

There are many definitions for integrated pest management (IPM). Pest management is the intelligent selection and use of pest-control actions (tactics) that will ensure favorable economic, ecological, and sociological consequences (see Rabb, 1972). Pest-control tactics include the monitoring of pest increase, the judicious use of a pesticide, or the effective communication that no action is necessary. Integrated pest management is the optimization of pest control in an economically and ecologically sound manner (Apple et al., 1979). This is accomplished by the use of multiple tactics in a compatible manner to maintain pest damage below the economic injury level while providing protection against hazards to humans, animals, plants, and the environment. In agriculture, pest management should ensure a strong agriculture and a viable environment. In public health it should ensure the protection of humans and domestic animals, and the maintenance of a suitable environment in which they may live. The practice of pest management has been described by Geier (1966) as doing the following: (1) determining how the life system of a pest needs to be modified to reduce its numbers to tolerable levels, that is, *below the economic threshold;* (2) applying biological knowledge and current technology to achieve the desired modification, that is, *applied ecology;* and (3) devising procedures for pest control suited to current technology and compatible with economic and environmental quality aspects, that is, *economic and social acceptance*. Apple et al. (1979) enumerate the components of pest management in agriculture as follows: (1) identify the pests to be managed in the crop production system, (2) define the management unit, (3) develop pest-management strategy, (4) develop reliable monitoring techniques, (5) establish economic thresholds, and (6) evolve descriptive and predictive models.

This book is about insect pest management, but the philosophy, many of the concepts, and the practice of pest management can also apply to many other kinds of pests. The emphasis in this book on meshing pest control with crop production to gain pest management is as applicable to weeds and plant pathogens as it is to insects and mites. Other recent books that have described insect pest management in detail include those by Mathews (1984), Burns et al. (1987), and Pedigo (1989).

II. WHY PEST MANAGEMENT?

A. Collapse of Control Systems

The enormous success of synthetic organic insecticides such as DDT and BHC following the conclusion of World War II began a new era of pest control. These two products were followed by hundreds of effective synthetic pesticides: acaricides, fungicides, herbicides, insecticides, nematocides, and rodenticides. The number of registered insecticides increased from less than 30 to more than 200, and the annual U.S. production from about 150 million pounds to more than 660 million pounds in 1975 (see Chapter 6) (*Pesticide Review,* 1979).

This growth was to be expected, since the new chemicals are effective and easy to use. In the first flush of enthusiasm it seemed that exclusive reliance on broad-spectrum insecticides could eliminate pest problems as far-ranging as those involving the housefly, *Musca domestica* L., in cities, the gypsy moth, *Lymantria (= Porthetria) dispar* (L.), in eastern forests of the United States, and malaria on a worldwide basis. As a result regular spray programs were developed on a routine preventive basis, which provided a shield of pesticide protection whether the pest was present in damaging numbers or not. The onset of insecticide resistance, first experienced worldwide with DDT in the housefly within 2 years after its widespread use (Brown and Pal, 1971), demonstrated the first flaw in the exclusive reliance on insecticides. This was followed by a 20-year struggle in California to control floodwater mosquitoes, *Aedes* spp., by the successive use of DDT, lindane, aldrin, dieldrin, toxaphene, EPN, methyl parathion, fenthion, temephos, chlorpyrifos, carbamates, and finally insect-growth regulators such as juvenile hormone analogues.

A parallel struggle was taking place in California citrus orchards against the citrus red mite, *Panonychus citri* (McGregor), and in apple orchards against the European red mite, *Panonychus ulmi* (Koch). Mite predators were eliminated, and resistance to various acaricides developed almost seasonally.

Perhaps the most alarming example of the endless spiral of more and more frequent treatments has taken place in cotton fields in Peru, Egypt, Central America, and Texas (see Chapter 6). The cotton bollworm, *Helicoverpa (= Heliothis) zea* (Boddie), and the tobacco budworm, *Helicoverpa virescens* (Fabricius), for example, have developed multiple resistances to nearly all available insecticides (Chapter 10) (Adkisson, 1969). Some insects have changed from secondary pests, usually kept below damaging numbers by beneficial insects, into primary pests that have virtually destroyed cotton production in some areas. In efforts to control the resurgence of pests, growers have increased applications of such highly toxic materials as methyl parathion and parathion to 10, 20, and, in extreme cases, up to 60 applications during the growing season, with total applications of 30–40 lb or more of active ingredient per acre. Under these conditions the cost of pest control has made the production of cotton profitless, and the industry has collapsed in certain areas. In addition, such prodigious use of pesticides has had highly deleterious effects on the environmental quality and has posed serious hazards to the health of agricultural workers.

B. Patterns of Crop Protection

Smith (1969) has classified worldwide patterns of crop protection in the cotton agricultural ecosystem into the following five phases, which are also applicable to many other crops.

1. *Subsistence Phase* The crop, usually grown under nonirrigated conditions, is part of a subsistence agriculture. Normally the crop does not enter the world market and is consumed in the village or bartered in the marketplace. Yields are low. There is no organized program of crop protection. Whatever crop protection is available results from natural control, the inherent resistance of the cotton plant, handpicking, cultural practices, rare insecticide treatments, and luck.
2. *Exploitation Phase* Crop protection programs are developed to protect expanded new acreage, new varieties, or new markets. Growers have observed the spectacular kill of insects with the new synthetic insecticides, and in most instances the pest-control program is dependent solely on chemical pesticides. They are used intensively, often on fixed schedules, and often as prophylactic treatments whether or not the pest is present. At first these programs are successful, resulting in high yields of food and fiber, and chemical pesticides are exploited to the maximum.
3. *Crisis Phase* After a variable number of years in the exploitation phase and the heavy use of insecticides a series of events occurs. More frequent applications of pesticides and higher dosages are needed to obtain effective control. Insect populations often resurge rapidly after treatments, and the pest population gradually becomes tolerant to the pesticide. Another pesticide is substituted, and the pest population becomes tolerant to it too. At the same time, insects that never cause damage or that are only occasional feeders become serious primary pests. This combination of pesticide resistance, pest resurgence, and unleashed secondary pests causes greatly increased production costs.

4. *Disaster Phase* Pesticide usage increases production costs to the point where the crop can no longer be grown and marketed profitably. Pesticide residues in the soil may be at such high levels that other crops cannot be successfully grown and made to meet legal residue tolerances. Repeated applications of insecticides and often mixtures of two insecticides no longer produce a crop that is acceptable to processors or the fresh market. There is a collapse of the existing pest-control program.
5. *Integrated Control Phase* Insect-control programs are implemented that accept and utilize ecological factors and compatibility in control measures. The concept is one of optimizing control rather than maximizing it; it is pest management.

Not all pest-control programs fit neatly into the above phases, and some may exist side by side or circumvent some phases altogether. Currently most pest control is in the exploitation phase, and pest-management concepts should be quickly adopted to avoid the crisis and disaster phases. Developing countries that are implementing or revising crop protection schemes can profit from the mistakes of others and adopt sound pest-management concepts to avoid control problems that will almost certainly arise.

C. Environmental Contamination

The ubiquitous presence of pesticide residues in foods, feeds, and organisms occupying every part of the ecosystem has caused widespread concern among scientists and thoughtful citizens alike about contamination of the environment. The effects of DDT transfer and magnification in the environment are well known. A classic example is the Clear Lake, California, incident, in which DDD applied at 20 ppb to control the larvae of the Clear Lake gnat, *Chaoborus astictopus* Dyar and Shannon, accumulated to more than 2000 ppm in carnivorous fish and western grebes (Hunt, 1966). From such examples we have come to realize that the single-factor approach to insect control, involving sole reliance on insecticides, has the following limitations: (1) selection of resistance in pest populations, (2) destruction of beneficial species, (3) resurgence of treated populations, (4) outbreaks of secondary pests, (5) residues in feeds, foods, and water, and (6) hazards to humans and the environment.

It is unlikely that the many adverse events of the past four decades could have been prevented. There was and still is sincere effort on the part of many people and governments to use the miracle insecticides to the benefit of people and there are still many pest problems for which the use of chemicals provides the only acceptable solution. "Contrary to the thinking of some people, the use of pesticides for pest control is not an ecological sin. When their use is approached from the sound base of ecological principles, chemical pesticides provide dependable and valuable tools and such use is indispensable in modern society" (NAS, 1969). However, reliance on insecticides as the only control agent has created problems in insect control and the environment, and these in turn have strengthened the need for pest management. It is likely that most insect pest-management programs will utilize insecticides, but this use must be compatible with other controls and consistent with pest-management concepts.

Pesticides are needed in agriculture and they are essential tools in many pest-management programs, but economy and convenience should not override environmental considerations. The scope of pest problems and the need for pesticides dictate a broad-based approach to pest control. As such, pest management is the best and possibly the only route to environmentally acceptable pest control in agriculture.

III. CONCEPTS OF PEST MANAGEMENT

A. Understanding the Agricultural Ecosystem

Ecosystems are self-sufficient habitats where living organisms and the nonliving environment interact to exchange energy and matter in a continuing cycle (NAS, 1969). Ecosystems are entities, such as forests, ponds, and fields, and in general they are self-regulating. Ecosystems and the ecological aspects of insect pest management are discussed in more detail in Chapter 2.

Agricultural ecosystems (agroecosystems) contain a lesser diversity of animal and plant species than do natural ecosystems such as forests and prairies. Usually there are a few major species and numerous minor species and, in a pest outbreak, usually only one pest species at a time (often a major species) is present in large numbers. A typical agricultural unit may contain only 1 to 4 major crop species and 6 to 10 major pest species; yet one need only walk into a crop field to recognize that the diversity of plants and insects is not as limited as conditions suggest. Further, there are the effects of intercrop or interfield movement of pest populations (Barfield and Stimac, 1981; Kennedy and Margolies, 1985), and pest dispersal from weedy roadsides and grass waterways, and this knowledge must be considered in the design of arthropod management programs. Some good examples are European corn borer action sites in weedy area (see Chapter 12), the congregation of large numbers of silk-clipping corn rootworm beetles in late maturing corn fields, and the movement of caterpillars, stem borers, and spider mites into adjacent crop fields following the mowing of roadside vegetation.

The agroecosystem is intensively manipulated by humans and subject to sudden alterations such as plowing, mowing, and treatments with pesticides. Agronomic practices are critical in pest management, since the need for pest control or the intensity of a pest problem is often directly related to agronomic practices. The magnitude of the agroecosystem is illustrated by the fact that the earth's surface is about 25% land, 71% ocean, and 4% freshwater lakes. About 24% of the land is potentially arable; of this, about one-half is currently being cropped to support 5.4 billion people. Obviously, these cropped acres must be intensively managed.

Agroecosystems can be more susceptible to pest damage and catastrophic outbreaks because of the lack of diversity in species of plants and species of insects and the sudden alterations imposed by weather and people. However, the agroecosystem is a complex of food chains and food webs that interact together to produce a surprisingly stable unit. The diversity of species is frequently offset by the homogeneity of plant species and the uniformity of agronomic practices. Often an insect can attack, establish, and survive only during a short period of time, and uniformity in planting, plant development, and maturation can restrict the rapid increase of a pest. Furthermore, the lack of diversity of plant species in agroecosystems is often offset by density; an increased density of plants per acre can dilute pest attack or provide conditions unfavorable to pest increase, and plant species that are tolerant or resistant to insects are better able to withstand pest damage or suppress pest establishment and increase. Few of the multiple interactions that exist have ever been examined or explained, but it is important in pest management to recognize the existence of complex biological systems in the agroecosystem.

CASE HISTORY

Weires and Chiang (1973) provide an excellent example of the food web associated with cabbage plants in Minnesota. The web illustrated in Fig. 1.1 is composed of food meshes. A food mesh is defined by Allee et al. (1949) as "a taxonomic entity in a food web; for example, a species or subspecies at a particular stage in its life cycle." The larval stage of the cabbage looper, *Trichoplusia ni* (Hübner), is one mesh feeding on cabbage leaves; the adult feeding on nectar constitutes another mesh. Quiescent stages such as eggs and pupae are not feeding meshes, but they constitute a part of the total food web.

In Fig. 1.1 the herbivorous, saprophagous, and saccharophilous meshes occupy the web's inner circle. First-order carnivore, predator, and parasite meshes occupy the second circle. Second-order carnivores occupy the outer circle. The cabbage food web contains 1 plant species, 11 leaf feeders, 10 sap feeders, 4 root feeders, 21 saprobes, 79 saccharophiles, and 85 carnivores interacting in the community.

The food web illustrated in Table 1.1 is an example of the evolutionary process within which and over time emerges a group of organisms that are able to live and survive together. Agroecosystems are important arenas for evolutionary selection. Although some pest-management practices rely on cultural practices or various behaviors of the insect to protect crop plants, many are designed to reduce pest populations by increasing insect mortality or decreasing fecundity, that is, through the use of insecticides, biocontrol agents, and resistant plants. When pest populations harbor genetic variability for physiological or behavioral characters that circumvent control measures, the emergence of better adapted pests that are

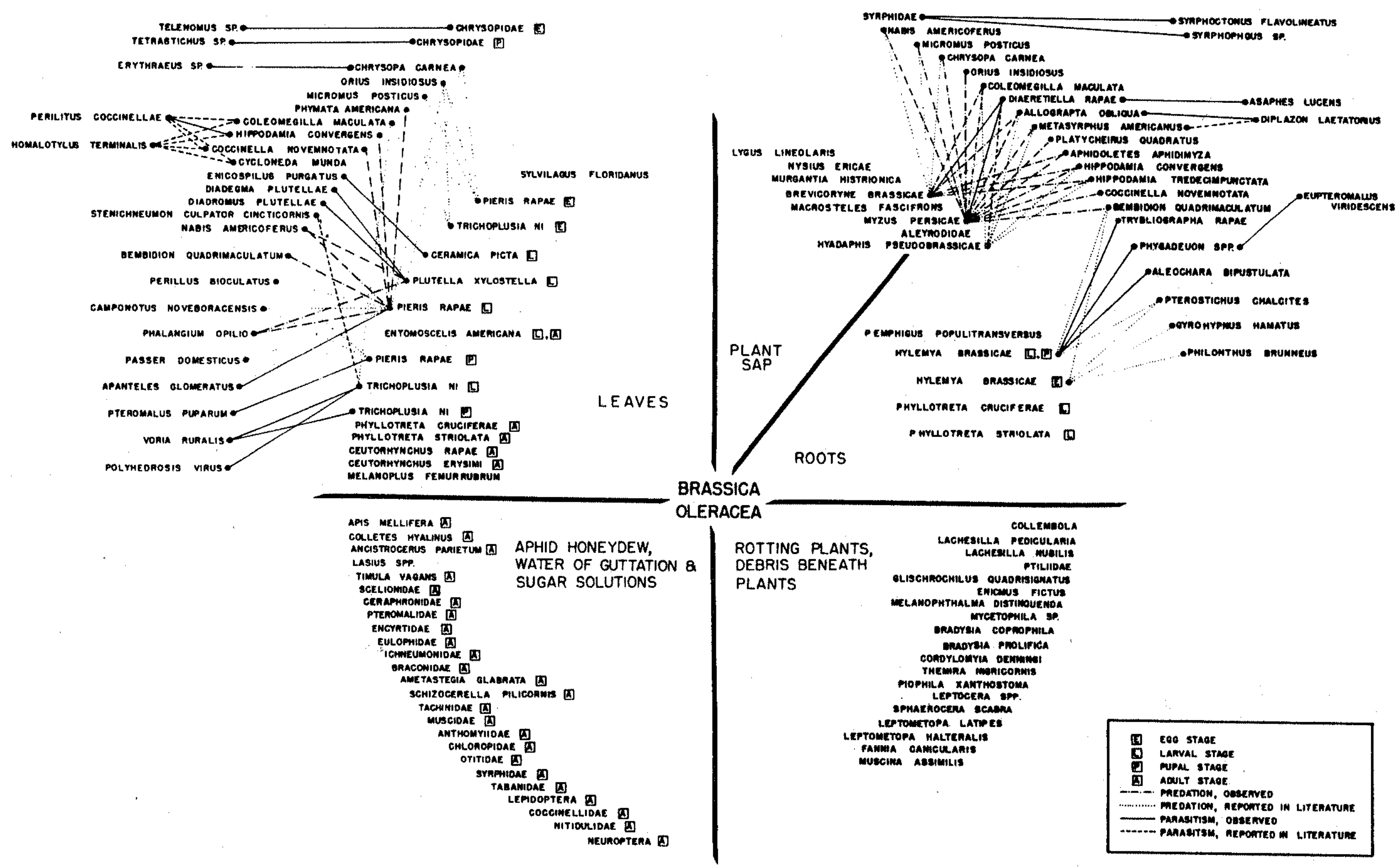

Figure 1.1 Food web associated with cabbage plants in Minnesota. (Weires and Chiang (1973). Courtesy of H. C. Chiang and the University of Minnesota Agricultural Experiment stations.)

Table 1.1 Effect of Crop Rotation of Corn on Insect Populations or Potential Damage

	Corn Rotation[a]		
	None	Soybeans	Pasture and Hay Crops
Seed corn beetles	0	0	+
Seed corn maggot	0	0	+
Wireworms	–	–	+
White grubs	–	+	+
Corn root aphid	–	–	+
Grape colaspis	–	–	+
Northern corn rootworm	+	–	–
Western corn rootworm	+	–	–
Southern corn rootworm	0	0	0
Black cutworm	0	+	0
Billbugs	–	–	+
Slugs	–	–	0
Thrips	0	?	+
Mites	0	0	0
European corn borer	0	0	0
Southwestern corn borer	0	0	0
Corn earworm	0	0	0
Fall armyworm	0	0	0
True armyworm	0	0	+
Chinch bug	0	0	+
Corn leaf aphid	0	0	0
Totals +	2	2	10
–	6	7	2
0	13	11	9
?	0	1	0

[a] + means the practice will increase the population or damage from that insect; – means it will reduce the population or damage; 0 means no effect; ? means effect unknown.

harder to control is virtually inevitable (Gould, 1983, 1988a,b; Hare, 1983; Via, 1990). The most obvious example of this is when insects develop resistance to insecticides (see Chapter 6) and become more difficult to control. Less obvious are behavioral changes (see Chapter 12), which can elevate a pest of minor or moderate importance to major pest status.

B. Planning the Agricultural Ecosystem

Much can be gained through the purposeful manipulation of crop varieties and production techniques to reduce pest problems. In insect pest management, applied agroecosystem planning should anticipate pest problems and ways to avoid them. For example, a crop variety should not be grown if it is