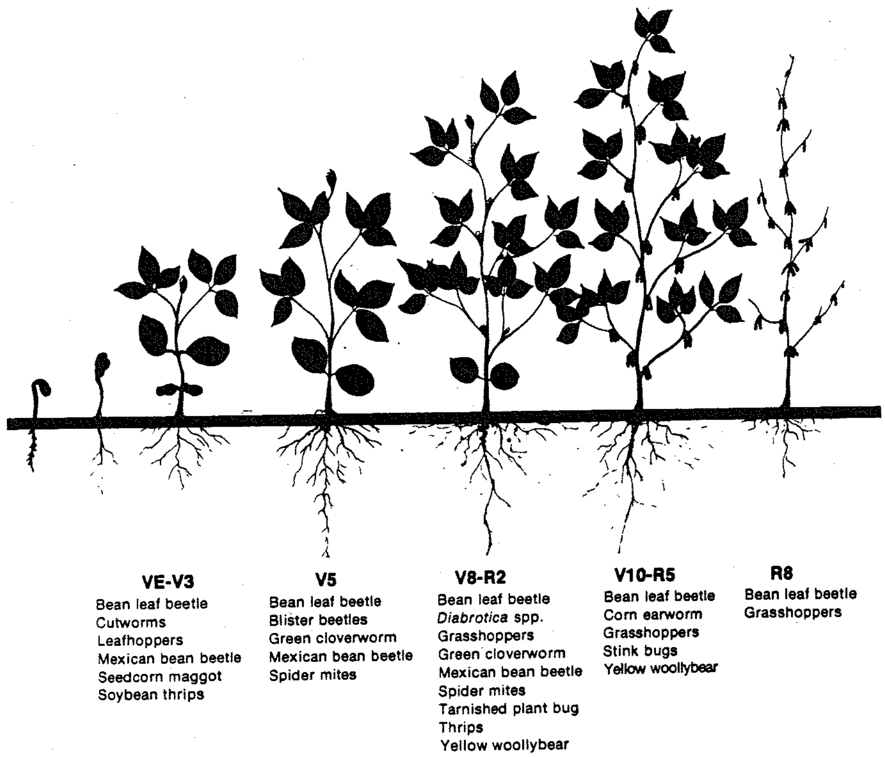

Figure 1.4 At each growth stage the crop is attacked by a different complex of insect pests. Stages of growth: VE–V3 = seedling; V5 = early vegetative growth; R2 = full bloom; R5 = beginning seed; R8 = full maturity.

susceptibility to injury varies and a numbering system has been devised to identify different stages of soybean plant growth (Table 1.4). Nodes are the points at which leaf petioles or branches are attached to the main stem. The number of nodes is used to describe the vegetative stages, which are designated by the letter V. The reproductive stages—bloom, pod set, and pod fill—are designated by the letter R. Emerging seedlings are at stage VE, and seedlings with open cotyledons are at stage VC. After the VC stage, the appearance of one unifoliolate node signals stage V1, followed by a second node with an open trifoliolate leaf at stage V2, a third node at V3, and so on. The reproductive stages go from R1 to R8, that is, from early flowering through pod maturity. In Fig. 1.4 a series of growth stages is identified according to the V-R system.

Soybean can tolerate considerable defoliation without yield reduction. Tolerance varies with the stage of plant growth, overall plant vigor, and the adequacy of growing conditions such as moisture, temperature, and soil fertility. The relationship between defoliation of four growth stages and the probable yield reduction is shown graphically in Fig. 1.5. While the plants are still growing and producing new leaves, and again after the seeds are completely filled, soybean can tolerate considerable defoliation without yield loss. But during the early part of the repro-

Table 1.4 Growth Stages of Soybean

Stages	Stage Name	Description
Vegetative		
VE	Emergence	Cotyledons above the soil surface
VC	Cotyledon	Unifoliolate leaves unrolled enough so that leaf edges are not touching
V1	First node	Fully developed leaves at unifoliolate nodes
V2	Second node	Fully developed trifoliolate leaf at node above unifoliolate nodes
V3	Third node	Three nodes on main stem with fully developed leaves beginning with unifoliolate nodes
V(*n*)	*n*th node	*n* number of nodes on main stem with fully developed leaves beginning with unifoliolate nodes; *n* can be any number, beginning with 1 for first-node stage (V1)
Reproductive[a]		
R1	Beginning bloom	One open flower at any node on main stem
R2	Full bloom	Open flower at one of two uppermost nodes on main stem with fully developed leaf
R3	Beginning pod	Pod 5 mm long at one of four uppermost nodes on main stem with fully developed leaf
R4	Full pod	Pod 2 cm long at one of four uppermost nodes on main stem with fully developed leaf
R5	Beginning seed	Seed 3 mm long in pod at one of four uppermost nodes on main stem with fully developed leaf
R6	Full seed	Pod containing a green seed that fills pod cavity at one of four uppermost nodes on main stem with fully developed leaf
R7	Beginning maturity	One normal pod with mature pod color on main stem
R8	Full maturity	Ninety-five percent of pods with mature pod color; 5–10 days of drying weather usually required after R8 before soybeans dry to less than 15% moisture

[a] The designation for a plant at a reproductive stage should include both the V and the R stages. For example, at full bloom a plant with 11 fully developed trifoliolates above the unifoliolate nodes would be at stage V12R2 because the unifoliolate nodes are counted as one.

Source: Adapted from Iowa Cooperative Extension Service Special Report No. 80 (1977).

ductive stage, the plants become increasingly sensitive to defoliation. They are most sensitive during the period of pod development. Even at this stage (R4 to R6), however, soybean plants can normally lose 20% of their leaf area before any effect on yield occurs.

Correct estimates of defoliation and the pest population responsible are essential to establishing the economic damage thresholds for foliage-feeding insects. Kogan

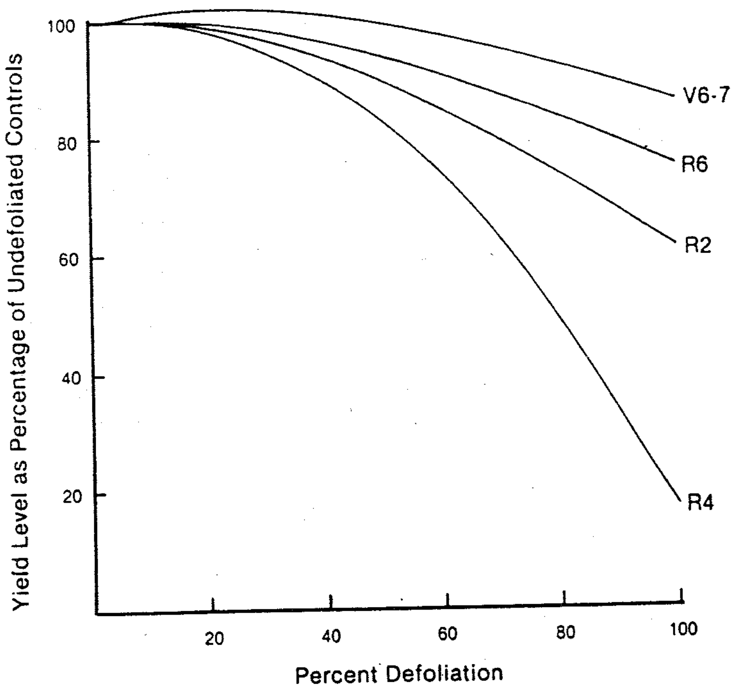

Figure 1.5 Relationship between defoliation and yield reduction at four stages of plant growth.

and Kuhlman (1982) show methods for estimating defoliation and measuring pest populations. Some thresholds currently available for soybean insect defoliators are shown in Table 1.5.

E. Leaving a Pest Residue

The ecological balances sought in pest-management programs necessitate the widespread encouragement of beneficial insects that are effective natural enemies of the pest species. These are often effectively removed by direct contact with broad-spectrum insecticides regularly applied to fields and orchards, and also destroyed by starvation when their prey is totally eliminated by chemical control. Therefore, an important concept of pest management is the necessity for leaving a permanent pest residue, below the economic threshold, in an area where control measures are conducted. The concept is to suppress a pest but not annihilate it. Needless to say, this idea is at variance with the general grower attitude and consumer insistence on unblemished fresh produce and canned products free of insect fragments.

The exceptions to this concept are (1) the complete absence of parasitoids, predators, or diseases of a pest, and (2) the practice of eradication where it is truly feasible within acceptable ecological parameters. Elimination of the screwworm from the southeastern United States by the sterile-male tech-

Table 1.5 Economic Damage Threshold for Defoliators with Chewing Mouthparts—Plants Within Pod-Set and Pod-Fill Stages (R3 to R6)

Species	Thresholds
Bean leaf beetle	16 beetles per foot of row, 20% defoliation
Green cloverworm	8–12 worms (more than ½ in. long) per foot of row, 20% defoliation
Grasshoppers	4–6 adults and large nymphs per foot of row, 20% defoliation

nique is a classic example of exception 2, and other equally sophisticated programs should be developed and implemented (Chapter 7). However, at best, most eradication programs have only retarded the spread of the pest and led to the generalization that a well-entrenched insect pest cannot be eradicated by massive applications of insecticides alone. Regrettably, insect pest control over the past 35 years has all too frequently diverged from the idea of economic thresholds and tolerable levels toward pest eradication in a field, orchard, state, or country.

CASE HISTORY

The European red mite, *Panonychus ulmi* (Koch), was only an occasional pest of apples and other deciduous fruits before the introduction of DDT into fruit orchards in 1946 for the control of the codling moth. DDT, however, adversely affects the predators that largely controlled the European red mite population, and this mite has become a limiting factor in deciduous fruit production. It feeds on foliage, causing loss of chlorophyll and leaf drop, weakening buds, and producing undersized fruit. Because of a very rapid life cycle, as short as 4 days from egg to adult at 77°F (25°C), the mite has a great capacity for the rapid development of races resistant to pesticides, and during the past 25 years orchardists have used in succession a large range of special acaricides and organophosphorus pesticides. Mite control on apple is complicated by the large numbers of other pests for which regular spray applications are made during the apple-growing season (Chapter 13). As a result of this complex of enemies and the complications of pest control, as many as 20 sprays are applied during a season in some apple orchards. Pest control in apple orchards has been largely a preventive chemical program, sprays being applied at regular intervals as insurance against possible attack (Glass and Hoyt, 1972).

Luckmann et al. (1971) and Meyer (1974) have demonstrated a unique management program for the control of phytophagous mites in apple orchards in Illinois (Fig. 1.6). Mite control was previously a difficult problem, requiring the application of six to seven sprays each season; the use of carbaryl, moreover, had completely eliminated predaceous mites from some orchards. In the mite program a single spray applied to the periphery of the tree suppresses the European red mite,

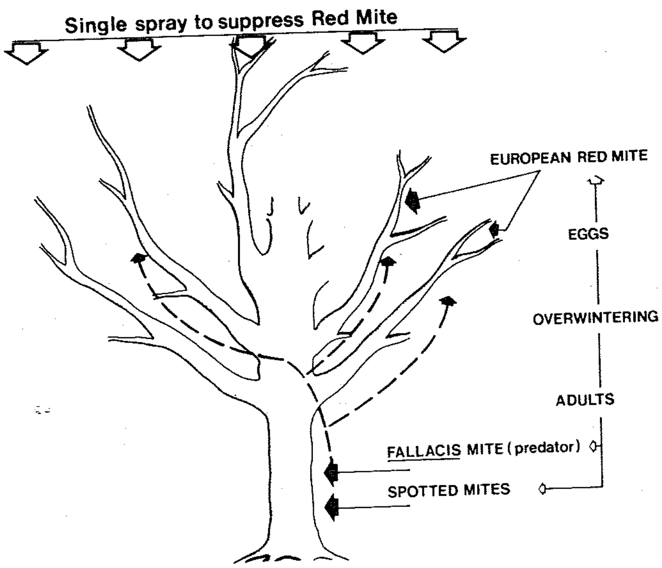

Figure 1.6 The salient ecological facts concerning life histories of mites on an orchard tree.

Panonychus ulmi (Koch), which overwinters and begins early-season increase on peripheral twigs and branches. The spray is applied 3–5 weeks after bloom. The predatory mite *Amblyseius fallacis* (Garman), which overwinters on the trunk and in the grass and debris at the base of the tree, is allowed to increase by preying on spotted mites, *Tetranychus* spp., which also overwinter at the base of the tree. The increasing population of the predator mite then spreads upward throughout the tree to control all phytophagous mites for the remainder of the season. The predatory mite is resistant to some insecticides, and these are used to control insect pests of apple such as the codling moth (see Chapters 4, 13).

Amblyseius fallacis has been reared in the laboratory and successfully released and established in orchards devoid of the predator (R. H. Meyer, personal communication). Orchardists are advised to avoid clean cultivation around the base of the tree, to leave some debris and ground cover (e.g., grass) to aid the predators in overwintering and increasing the following spring. Habitat management around the base of the tree is the key to this mite-management program.

F. Timing Treatments

A crucial problem in successful pest management is the proper timing of insecticide treatments. Virtually every group that has critically evaluated the need for pest management has commented forcefully on this. The President's Science Advisory Committee (1965) recommended the replacement of wasteful routine treatment schedules by treat-when-necessary schedules and commented that "substantial reduction in pesticide use, in specific cases as much as 50%, can be made by applying our present knowledge of pests and their control." The American Chemical Society (1969) recommendations on minimizing contamination of the environment with pesticides state, "Optimum methods of pest control will involve careful integration of chemical, biological, and cultural techniques—only in this way can the objective of economic control of pests in crops and animals be obtained with minimal environmental and ecological impact."

Treatment should be based on need, and a single spray properly timed can often prevent excessive spraying. More efficient use results from the careful timing of treatments based on improved techniques of monitoring pest populations and crop development. Examples of this are the use of pheromone traps for monitoring the appearance and intensity of the codling moth on apple and the black cutworm on corn (Chapters 6 and 12).

CASE HISTORY

Classifying crop susceptibility to the establishment, survival, and control of the European corn borer, *Ostrinia nubilalis* (Hübner), is a standard practice. Corn borer larvae do not survive on small corn because of the presence of the chemical DIMBOA (Chapters 3 and 12), so treatment is justified only on taller corn. But corn varieties differ in growth habits. Some mature in 70 days and some in 120 days; some are 4 ft tall at maturity, while others are 8 ft tall. A 36-in. plant of one variety might be highly susceptible to attack by the corn borer, while a 36-in. plant of another is still immune. The tassel ratio technique (Fig. 1.7) of Luckmann and Decker (1952) is an aid to insect scouts and growers in monitoring corn development, predicting potential for damage, and selecting timing of treatment for first-generation corn borers. The ratio compares the height of the developing tassel inside the plant to the extended height of the plant. If the extended height of the plant is 50 in. and the height of the tassel is 15 in., then the tassel ratio is 30:

$$\frac{\text{Tassel height}}{\text{Extended plant height}} \times 100 = \text{TR} \qquad \frac{15\text{ in.}}{50\text{ in.}} = 0.3 \times 100 = 30$$

Pretassel corn should receive a single treatment of insecticide between tassel ratio 40 and 60 if plants show evidence of fresh borer feeding on the whorl leaves. See annual recommendations of the State Cooperative Extension Service for directions on surveying for first generation European corn borer and need for treatment.

G. Public Understanding and Acceptance

Educating people about pest management is the most important way to deal with insect pest problems. No program is any more successful than the degree of commitment made by the people involved. Special efforts must be made by extension entomologists to educate growers and the public in the methodologies of pest management and the reasons for using them.

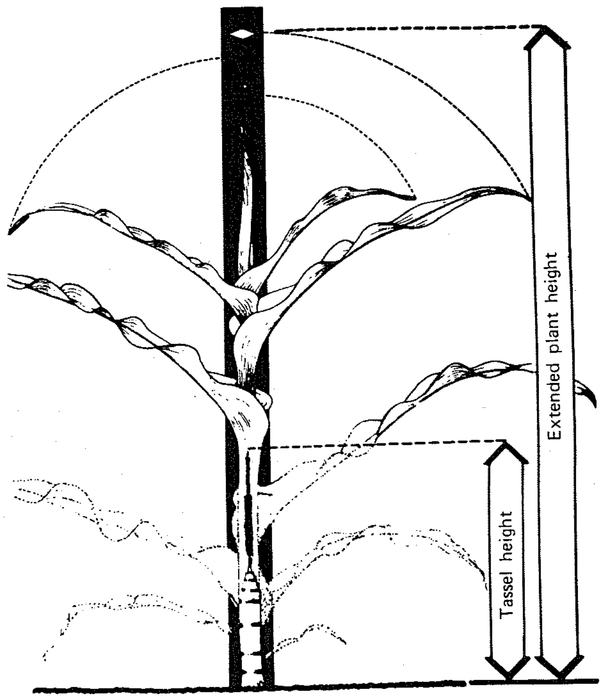

Figure 1.7 Measurements needed to obtain tassel ratio (TR):

$$\frac{\text{Tassel height}}{\text{Extended plant height}} \times 10 = \text{TR}$$

Effective communication and salesmanship are the key to successful public understanding, acceptance, and use of pest management.

Pest management, as Rabb (1972) points out, involves (1) a scientific judgment—How can insect control be achieved?—and (2) a social judgment—How should insect control be achieved? The answer to the second question involves both economic and social acceptance (Geier, 1966), but acceptance and even conviction that a pest can best be controlled via a pest-management program is useless unless put into action. Acceptance without action will undoubtedly be the greatest single impediment to pest management. Leadership in pest management is a critical factor.

It is safe to say that pest-management concepts and philosophy are not fully understood and appreciated by all key people who are in a position to make recommendations. One of the barriers is the erroneous assumption that a pest-management program must be complete, with all parameters known, before implementation can begin. This sort of thinking constitutes a serious waste of available knowledge and experience. A satisfactory program can be started on a single pest of a complex of 5 to 10 that attack a crop. It will be far easier to add components directed at other pests in the complex if some sort of program is already in operation and if growers already accept the pest-management philosophy.

Furthermore, it is not necessary to know everything about pest biology and the economic injury level of pest populations before beginning a pest-management program. From accumulated experience we can be confident that, if the economic injury level lies somewhere between 10 and 20 insects per plant or tree, a grower having a population of 25 to 30 or more insects per unit has a potential for high damage, while a grower with 0 to 5 insects per unit has a potential for little or no damage. Thus, the initial phase of a pest-management program could be directed only to situations with potentials for very high or very low damage, while researchers and students are in the process of defining more precise economic injury levels and are refining methods of sampling and procedures of survey. It is certain that pest damage will not occur if the pest is not present, and the communication and use of the "zero concept" (few or no pests present) will be meaningful to a large number of growers. Such limited pest-management guidelines, provided that they are accurate, can be the vehicle for the education and implementation of more inclusive guidelines and innovations in the future. Grieshop et al. (1988) reported that experience with previous pest management innovations was a factor in grower adoption of a University of California Tomato IPM Program that began in 1984. Successful previous experience, they found, leads to satisfied cooperators, who likely have the confidence necessary to use a new technique.

A substantial step in pest management was taken in 1972 with *Implementing Practical Pest-Management Strategies,* the proceedings of the National Extension Pest-Management Workshop (1972), and the subsequent Federal funding of extension pest-management programs in every state in the United States. There is still a wide divergence in philosophy between the specialist who seeks to promote pest-management practices and the specialist who in general seeks to promote the maximum application of pesticides. The bridging of these philosophies and the education of a vital third party, the producer of commodities and consumer of pesticides, is very important. Extension specialists rank education of clientele as the most important challenge in pest management, especially, according to Allen and Rajotte (1990), as socio-economic influences such as concerns about food safety, human pesticide exposure, and environmental contamination are amplified between now and the year 2000.

One strategy in pest management is the formation of a legal, quasi-legal, or voluntary cooperative district to implement pest-management strategies on an areawide basis. Two good examples are the Florida Citrus IPM Program and the Fillmore Citrus Protective District (FCPD), Ventura, California. The fact that members are predominately citrus growers permitted them to see their problems as a group and to recognize the long-term benefits to the citrus industry gained in dealing with pest problems as a group. The key to

FCPD success is credited to the manager who was a good entomologist, was willing to experiment, and had an understanding of people (Graebner et al., 1984). These districts offer many opportunities for public understanding, acceptance, and support. They may be empowered to provide support for the hiring of professional insect scouts and control personnel, and a district-wide program is valuable in enforcing public cooperation in desirable pest-management practices, such as removal of alternative hosts, drainage of standing water, or disposal of crop refuse. The district provides a visible symbol and focus for public educational programs and for cooperative work with land grant colleges and Federal extension programs. With continued strong emphasis, pest management will move further away from the public sector to the private sector, with pest management firms offering pest scouting and crop management for a fee.

CASE HISTORY

The green peach aphid, *Myzus persicae* (Sulzer), is the most important insect vector of plant diseases and is known to transmit more than 50 plant viruses, including aster yellows, cranberry false blossom, curly top of sugar beets, peach yellows, and potato leaf roll. It is chiefly responsible for the transmission of a complex group of potato viruses that may cause 60–95% losses in potato production. Virus transmission may occur with aphid feeding periods of only 10–15 seconds. The aphid overwinters as black, shiny eggs on the bark of peach, apricot, plum, and cherry trees, and the young aphids begin to hatch about bloom time. When full-grown, the wingless, parthenogenic females give birth to living young. These aphids remain on the peach for two to three generations, when most of the individuals acquire wings and migrate to potato, beet, or other summer host plants in the late spring. At the onset of cold weather in the fall, the female aphids produce true sexual females. These mate with males flying from summer host plants, and the fertilized females deposit the overwintering eggs on peach and apricot trees.

Idaho, the Potato State, initiated a multicounty campaign to minimize the transmission of potato virus diseases by *Myzus persicae*. (Sulzer). This novel program involves all residents in Idaho potato seed and potato production districts through a public information campaign highlighted by components such as the bumper sticker shown in Fig. 1.8. The bumper sticker plea "*A*pricots and *P*eaches *H*arbor *I*nsects *D*amaging to *S*puds" seeks to enlist public support in destroying or spraying all domestic and wild peach and apricot trees that provide essential overwintering hosts for the green peach aphid. As the program has progressed, grower cooperatives have been formed to hire pest scouts and to fund the cost of destroying or spraying with an ovicide all wild and cultivated apricot and peach trees in potato-growing districts. Education programs have been directed to the urban home gardener in seed and commercial potato production districts, emphasizing the need to plant certified virus-free seed potatoes to eliminate virus reservoirs in urban areas. Public understanding and cooperation through effective communication is a key tactic in the Idaho potato pest-management program.

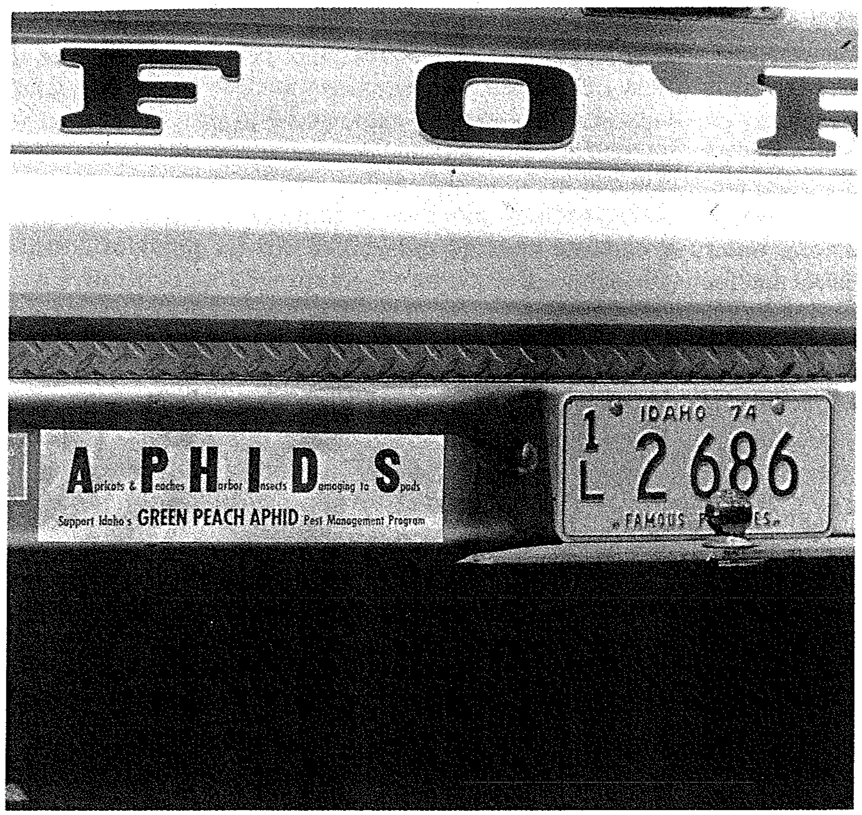

Figure 1.8 Idaho bumper sticker.

IV. TOOLS OF PEST MANAGEMENT

The more than 100 years of the formal existence of the Federal Bureau of Entomology, of the Agricultural Experiment Station system, and of the Cooperative State Extension Service has given the United States an unsurpassed background of knowledge and experience in pest control and a framework within which pest-management strategies can be applied. As emphasized repeatedly in this book, our present knowledge is adequate to support major beneficial changes in pest-control practices. The major innovations necessary for designing pest-management programs will relate to the concepts of pest management (Section III) and to their economic and social acceptance.

The available techniques for controlling individual insect pests are almost inexhaustible and involve a very wide range of applied science and technology. They are conveniently categorized, in increasing order of complexity, as cultural, mechanical, physical, biological, chemical, genetic, and regulatory