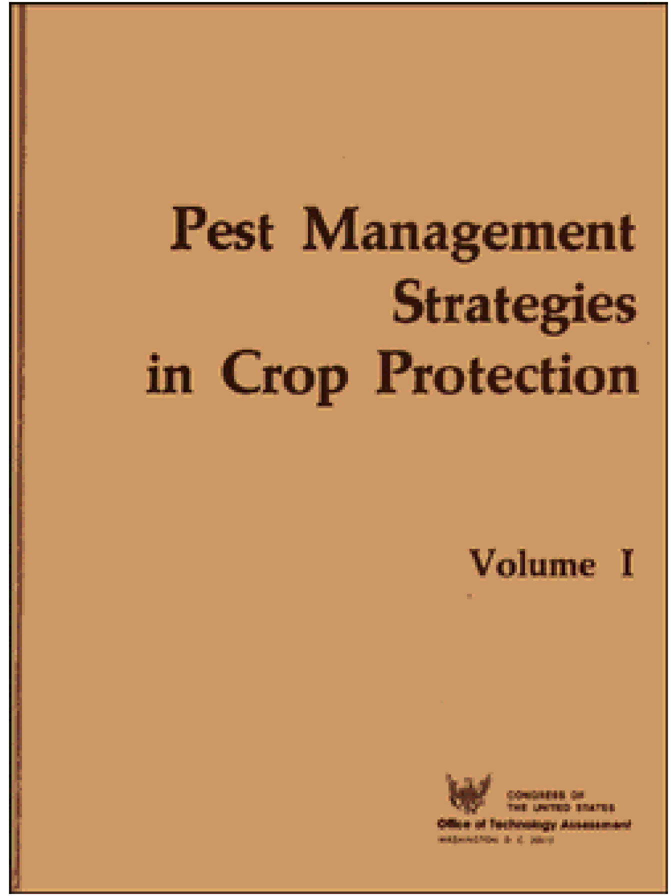
Pest Management Strategies in Crop Protection

October 1979

NTIS order #PB80-120017



Library of Congress Catalog Card Number **79-600176**

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 Stock No. 052-003-00708-8

FOREWORD

This report assesses the array of tactics used to control pests of agricultural crops in the United States.

The assessment was requested by Senator Herman E. Talmadge, Chairman of the Senate Committee on Agriculture, Nutrition, and Forestry.

The Office of Technology Assessment was assisted by an advisory panel of scientists, farmers, consumers, and representatives of industry and public interest groups, Nine working groups were commissioned to carry out the major objectives of the assessment. The work was supplemented by a 2-day public participation meeting in which the assessment panel members and the public exchanged views and concerns regarding present crop protection methods. In addition, critical reviews of the draft reports were provided by Federal officials, and a wide spectrum of interested individuals. To all of these people OTA offers sincere thanks.

This report is in two volumes. Volume I is the summary report and is based on the OTA-commissioned studies conducted by each of the nine working groups, panel discussions including the 2-day public meeting, extensive staff work, and outside reviewers' comments. Volume II is the collection of indepth studies from which volume I was prepared, and is intended to be used as background and reference material for those who need additional details. The transcript of the 2-day public meeting is also included in volume II.

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Executive Summary

Executive Summary

INTRODUCTION

In the United States, total losses from all pests are generally estimated to be one-third of total potential production before harvest, and nearly 10 percent after harvest. Losses are believed to be considerably greater in the tropics. Thus, at least one-third of the world's potential food harvest is lost to pests. The vulnerability of crops to pests makes pest control one of the major management components of the total crop production system. This vulnerability has become more prominent as the trend toward high productivity of only a few select crops has increased. This trend dominates U.S. agriculture. During the past century U.S. agriculture has changed from relatively small, labor-intensive, diversified units to large, highly specialized, and mechanized operations. Today, modern agriculture is a complex system in which a series of interlocking physical, biological, and management functions all interact to determine the yield and quality of a cultivated crop.

In the past three decades, U.S. agriculture has increasingly depended on chemical pesticides to control the pests that damage crops. Heightened concern over the environmental effects of pesticides, coupled with increased pest resistance and secondary pest outbreaks, severely limits the effective pesticides available to farmers. While these trends are most fully developed in the industrialized nations, especially in the United States, the problem is worldwide. If farmers are to meet the growing demand for food, new strategies for reducing pest damage must be found.

This pest management strategies assessment was requested by Senator Herman Talmadge, Chairman of the Senate Committee on Agriculture, Nutrition, and Forestry. Its primary focus is on agricultural crop protection. The study sought to:

1. assess crop protection problems, current and emerging control technologies, and projected future developments over the next 15 years for each of seven regional cropping systems in the United States,
2. evaluate Federal constraints to improved pest management in the United States, and
3. review the problems, potentials, and impacts of the transfer of North American crop protection technology to the developing world.

These objectives were addressed by nine study groups: one each for the seven cropping systems in 1 and one each for 2 and 3. The crops and regions selected were: wheat in the Great Plains States, corn in the Corn Belt, cotton and sorghum in Texas, deciduous tree-fruits (especially apple] in the northern half of the country, potatoes in the Northeastern States, soybean in the Southeastern sector, and selected vegetables in California. These crops are representative of more than 90 percent of U.S. agricultural production.

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DISCUSSION

Present Pest Control Tactics and Problems

Agricultural producers have coped with the changing nature of pest problems by using one or more of several control tactics. None of these practices is entirely satisfactory or universally applicable. Moreover, all practices used to control any one pest complex impact on nontarget organisms and can create other problems. Control tactics most commonly used on U.S. farms are:

- Chemical: herbicides, insecticides, fungicides, nematicides, etc.;
- Cultural: cultivation, crop rotation, strategic planting and harvesting dates, sanitation;
- Plant resistance: plant varieties genetically resistant or tolerant to pests; and
- Biological: predators, parasites, microbial.

Table 1 shows the principal control tactics used against major pests of the several crops in this report,

The major problems associated with present controls stem primarily from the extremely limited number of effective control tactics.

Table I.—Principal Control Tactics Used Against Major Pests of the Seven Regional Cropping Systems

	Major pests				
	Insects	Nematodes	Pathogens	Weeds	Vertebrates
Wheat (Great Plains)	2,1,3	2	3.2	1,2	2
Corn (Cornbelt)	1,2,3	–	3,2,1	1,2	–
Soybeans (Southeast)	1	1,3.2	1,2	1,2	–
Apples (North)	1	1 2	1,3,2	1,2	1,2
Potatoes (Northeast)	1,2	2,1,3	2,1	1.2	–
Cotton (Texas)	1,23	3	3,2,1	1,2	–
Melons (California).	1	1	2,3	1,2	4
Cole (California)	1	1	2	1,2	4
Lettuce (California)	1,2	1,3	2,1,3	1,2	4
Tomatoes (California)	1,2	1,3	3,2	1.2	4
Strawberries (California)	1	–	2	1	4

Control tactics
1 Chemical (insecticides nematicides fungicides herbicides)
2 Cultural (cultivation crop rotation planting dates sanitation)
3 Plant resistance (plant varieties genetically resistant to pests)
4 Biological predators parasites ml crobia!s I

These problems are expected to increase as pests, through evolutionary adaptation, become resistant to existing controls. For example, disease-resistant wheat eventually loses its effectiveness as strains of disease pathogens evolve that are capable of overcoming such resistance, late planting of a crop to avoid an insect pest becomes futile as other pest strains are encountered that are adapted to late planting, and the continual exposure of pests to chemical pesticides promotes the evolution of pests resistant to these chemicals. Moreover, some pest control measures have secondary effects that are often as serious as the problems for which the controls originally were used. For example, some chemical pesticides eliminate beneficial predators and parasites and other nontarget organisms along with the targeted pests and produce secondary pest outbreaks, In other cases the removal of a primary weed pest may result in secondary pest outbreaks, and tillage for pest control increases soil erosion and water loss. Moreover, it often takes years to understand fully the secondary consequences. In addition. a de-emphasis in research programs in genetic plant resistance to pests is one factor that has led to a reduction in the acreage of certain pest-resistant crops. In Kansas and Nebraska alone, the acreage of Hessian-fly-resistant wheats has decreased from about 66 percent in 1973 to about 42 percent in 1977. Finally, the health and safety of agricultural workers and bystanders are of widespread concern as many of the chemicals in use today pose known and unknown risks to humans.

These are major problems that are raising serious concerns about both the present and future availability of suitable control measures and alternative means of control.

Fifteen-Year Prelection for Crop Protection

No revolutionary new pest control tactics are expected to be implemented over the next

15 years. This projection assumes that such control technologies must already be in at least the early stages of development, Although the total use of pesticides is not expected to increase appreciably, the use of herbicides is expected to accelerate considerably. Several new tactics in crop protection, such as the use of hormones, antihormones, allelopathy, and molecular genetic manipulation will probably be of limited use during the next 15 years, although they have great potential for the future. One exception may be the use of pheromones (sex attractants) to control insects, a technique that could become widely adopted if technological problems can be solved.

However, there is a promising approach, integrated pest management (1PM), that is slowly evolving within U.S. agriculture, This approach offers promise of more stable crop protection and production with the least hazard to man and the environment. 1PM will be used more widely as efficient, economically sound systems become available. These should provide more stable management of many pests than now exists and should reduce pesticide use to the minimum effective level required to allow continued growth in agricultural production.

Integrated Pest Management

Because of the continually changing nature of pests, their environment, and the economic impact of pest combinations, coupled with a mounting public concern regarding human health and environmental problems associated with the use of chemical pesticides, a concerted effort is required to develop programs that contain pest damage while providing protection against hazards to humans, animals, plants, and the environment, 1PM views pest control within a whole-systems context of crop production and is defined as follows:

Integrated pest management (1PM) is the optimization of pest control in an economically and ecologically sound manner, accomplished by the coordinated use of multiple tactics to assure stable crop production and to maintain pest damage below the economic injury level while minimizing hazards to humans, animals, plants, and the environment.

In its broadest form, an 1PM program encompasses all significant components of the agroecosystem-soil, crops, water and air, insects, pathogens, weeds, nematodes, and other organisms—which interact among themselves and with other components of the system, Present 1PM programs, however, are most commonly limited to single-pest classes.

Present State of implementation of IPM

The full potential of IPM has not been realized in any of the seven cropping systems examined in this report. However, there are many situations in which multiple-control tactics are being used. Although these are relatively simple systems, they can be expanded in the future.

Where multiple tactics are used for any one crop, they are usually directed against specific pests or classes of pests rather than all pests. The tactics most commonly employed involve cultural controls and resistant plants combined with minimum effective rates of chemical pesticides. The combined use of herbicides and limited cultivation, to replace cultivation alone, for weed control has significantly reduced soil erosion, but has created other problems.

Short-term models developed from the data of some pest-monitoring programs are succeeding in predicting some pest outbreaks. These tools allow growers to apply pesticides only as needed or to substitute other appropriate tactics, Broad monitoring programs and predictive models are among the most promising components of 1PM, but are limited at present by a lack of organizational structure; a lack of adequate weather monitoring at the local, regional, and national levels; and insufficient bionomic data.

Transfer of IPM Technology to the Developing World

The concept of 1PM is widely accepted internationally and the transfer of its basic philosophy to the developing world through several national and international assistance programs has progressed. However, systems must be developed that are adapted to the agricultural conditions in the developing countries and are compatible with social customs, political structures, and economic systems as well,

Traditional subsistence agriculture of the developing tropical world must deal with an array of crops and associated pests generally not found in temperate countries. Pest management systems developed for the intensive high-energy agriculture of the temperate world are often inappropriate. Agromedical training, pest management workshops, adequate libraries, onsite demonstration projects, and crop protection research and extension under the title XII amendment to the Foreign Assistance Act and others will be required to develop the necessary knowledge bank and to implement vigorous, effective 1PM programs. It is estimated that 50 percent of the extremely high pest-caused losses in the developing world may be prevented through application of appropriate 1PM systems,

MAJOR FINDINGS AND CONCLUSIONS

1, The limited variety and effectiveness of present pest control tactics seriously limit farmers' ability to reduce current crop losses;
2. 1PM appears to be the most promising crop protection strategy for the next 15 years;
3, OTA estimates that 1PM programs for major U.S. crops can reduce pesticide use up to 75 percent, reduce preharvest pest-caused losses by 50 percent, and reduce total pest control costs by a significant amount;
4. International implementation of 1PM requires systems that are adapted to local agricultural conditions and are compatible with social customs, political structures, and economic systems;
5. Technological and administrative obstacles that-impede the development and implementation of 1PM must be removed to achieve a more effective crop protection system in the United States.

   The technological obstacles lie primarily in the areas of basic knowledge, delivery systems, and personnel. An inadequate base of knowledge in the basic biology, bionomics, and interactions of crop pests seriously limits the range of control tactics available for integrating pest management into a total crop production system.

   At the same time, the lack of an adequate delivery system impedes the dissemination of data necessary to support effective pest-management decisions. Along with this is a shortage of properly trained personnel to conduct needed research, to develop 1PM programs, and to provide information delivery systems. The extension pilot 1PM programs were initiated with Federal funding but did not provide adequate means to increase the knowledge and trained manpower base with which to support 1PM. A lack of practical, demonstrated interdisciplinary programs has resulted in grower skepticism and uncertainty regarding the economic benefits of 1PM.

   The administrative obstacles stem from the lack of cooperation and coordination between Federal and State agencies which impede programs of basic and applied research in 1PM. A clear focus of intent concerning future 1PM activities must be conveyed by the various agencies involved in the funding of research and extension activities, the regulation of pesticide use, and in the marketing of farm products.

6. Congressional action or inaction will affect the future form of U.S. crop protection strategy.

CONGRESSIONAL OPTI0NS

The basic option that Congress faces is whether to make a policy judgment to commit the additional resources required to accelerate the present slow evolutionary trend toward the adoption of 1PM crop protection systems, Thus, Congress faces a choice between: 1) the status quo for U.S. pest control methods, which, although including 1PM, continues to rely heavily on chemicals or 2) developing a strategy to accelerate the present slow evolutionary shift to 1PM as a whole-systems approach to U.S. crop protection.

Option 1: Status Quo

Pros: The control tactics presently available for crop protection are relatively simple, readily available, and economically attractive. They are used primarily in response to single-pest outbreaks. Their principal advantage is that their effects are known, they work, and they have gained the confidence of growers.

Cons: Chemical pesticides are the most frequently used tactic at present. Effects of some chemical control measures include the induction of secondary pest outbreaks, adverse effects on beneficial species and on nontarget organisms, development of pesticide-resistant pests, and environmental and health hazards. There is serious concern about the future availability of suitable control tactics, since the already-limited range of tactics will be reduced even further as more pests develop resistance to some chemical pesticides and as Government regulations remove other pesticides essential to pest control. Alternative control tactics are limited and often are not feasible to use or are not adequately effective. The evolutionary shift to 1PM is too slow to have a significant impact except in a few situations.

Option 2: Accelerate the Shift to Integrated Pest Management

Pros: Under IPM, pest management is accomplished through a whole-systems approach that considers all components of the agroecosystem that interact among themselves and with other components of the system. Problems posed by resistant pests, destruction of beneficial organisms, and secondary pest outbreaks would decline; greater management flexibility and ecosystem stability would be provided while greater precision in taking control action may reduce the need for pesticides which, in turn, could reduce the onset of pesticide resistance and health and environmental hazards.

Cons: A substantially greater investment of money, personnel, and time in research, education, and implementation will be needed to increase the speed of adoption of 1PM. Included is the high cost of educating growers, agents, consultants, and others as well as that of maintaining monitoring and delivery systems. Congress could provide either moderate or major support toward accelerating the adoption of 1PM.

A moderate increase in commitment would augment the present teaching, research, and extension programs. With this increased support, 1PM could eventually replace most unilateral pest control programs over the next 20 to 30 years.

A major effort over the next few years to remove the obstacles to the implementation of 1PM would enable much of the potential of 1PM to be realized within 15 years. Under 1PM U.S. agriculture could achieve an increased production while at the same time providing maximum protection to man, his crops, and the environment.

To remove the obstacles to 1PM, the following actions are all required:

- provide increased funds and longer time support for disciplinary and interdisciplinary research in the basic biology, bionomics, and interactions of crop pests:
- provide increased support for biological control and host-plant resistance efforts, along with increased flexibility in pesticide use and incentives for the development of low-sales-volume, selective pesticides;
- create a federally coordinated pest and weather-monitoring program, support public information delivery systems, offer incentives for the formation of private information delivery systems, and increase support for State plant health clinics;
- provide direct Federal support for pest management training programs and establish regional pest management study centers;
- provide the means to make available increased education, extension, and practical 1PM demonstration programs:
- review the relationship between existing food quality standards and pesticide use; and
- establish a clear focus of Federal intent and assign to the U.S. Department of Agriculture, the lead Agency, the responsibility, authority, and necessary funding to coordinate 1PM research programs and to implement an adequately staffed and coordinated information delivery system,

Chapter I

Historical Perspective on Crop Protection

Historical Perspective on Crop Protection

Since recorded history, the impact of pests on food crops has been important. Many practices of "traditional" and "modern" agriculture have evolved because of pest problems. Without doubt, pests of food crops influenced the course of civilizations-for example, the ancient Greeks and Remans knew of and used pesticides in the Mediterranean Basin. Crop losses from pests during those times were probably even more severe in the humid tropics, just as they are today.

Over the 10,000 or more years that man has cultivated crops, he gradually evolved production systems that ensured an adequate food supply for the family or tribal unit from one harvest until the next. Seeds were selected from plants that survived the rigors of weather and pest infestations; cultivation, planting time, and other production practices were adopted that ensured consistent rather than high but variable yields. At best, however, such ancient practices were based on trial and error without the benefit of modern genetics, chemistry, and cultural capabilities; they were only moderately effective and resulted in relatively low and unstable production levels. Furthermore, effective means did not exist to deal with disasters such as locust plagues and blight.

During the last century agriculture in industrial countries has changed from relatively small, labor-intensive, diversified family units to large, highly mechanized operations. As production became concentrated in favorable areas and as monoculture, high fertility, irrigation, and other components of modern agriculture were widely adopted, pest problems frequently became more severe. Insects, disease organisms, and nematode problems were magnified, particularly on fruits and vegetables, and weed problems became more acute as those species most suited for the new cropping systems proliferated. This situation was further exacerbated by the movement of pest species from one continent to another. Many of the most serious pests in the United States were introduced from other centinents.

As a result of the increasing need for methods to prevent losses due to pests, an impressive array of crop protection technologies has evolved. Included are pest-resistant plants, cultural controls, biological controls, pesticides, behavior-modifying substances, quarantine laws, and pest eradication programs. Some cultural controls are not adaptable to high-production agriculture: some pesticides have declined in effectiveness: other controls are used successfully to manage only a limited number of pests: none are entirely satisfactory or universally applicable, Recently, the increasing dependence on chemical pesticides has raised concern regarding risks to human health and the environment.

Pest-resistant plants were recognized in the 19th century, but only in the 20th century has breeding for pest resistance become an active area of research. Numerous cultivars (varieties) resistant to one or more diseases were developed, and varieties of apples, grapes, and wheat were known to be resistant to woolly aphid, phylloxera, and Hessian fly, respectively. During the last 30 years the development of cultivars resistant to major disease organisms and nematodes has accelerated. The development of insect-resistant crops has received less emphasis partly because of the easy availability of economical and effective insecticides. Breeding for weed resistance has focused on the ability to compete but otherwise has been given little attention. Recently, allelopathy (the ability of one plant to suppress another by producing toxic substances) has received attention as a weed control tactic.

Cultural control methods are as old as agriculture and are used primarily for weed, nematode, and disease control. These methods include sanitation, destruction of alternate hosts and volunteer plants, crop rotation, tillage, trap crops, time of planting, water and fertilizer management, and use of pest-free seed and planting stock. Although cultural methods alone are not likely to ensure adequate controls, they often can reduce pest population pressures and enhance other control tactics. The availability of economical herbicides, fungicides, and insecticides has reduced emphasis on cultural controls; the integrated pest management (1PM) approach to crop protection has brought renewed attention to these old cultural methods,

Biological control is the regulation of pest organisms by their natural enemies and is important in pest management. Primarily, insects and mites are controlled by this method, but it may play an important role in the regulation of some disease organisms, weeds, and vertebrates. Natural enemies are macrobial (vertebrates, insects, and mites) or microbial (fungi, bacteria, viruses), and may be indigenous or introduced from other areas.

The earliest known use of biological control was by the Chinese who used ants to control insect pests in citrus orchards. Other better known cases were the introduction of the Vedalia beetle into California citrus groves in 1890 to control the introduced cottony cushion scale and the control of prickly pear cactus in Australia through the introduction of a lepidopterous insect in 1925.

The importance of biological control was not realized for many situations until certain insecticides that affected a broad range of organisms were used on crops such as cotton and apple. This resulted in the removal of the natural enemies for some secondary or even previously unknown pests that then became major damaging pests, The earliest planned 1PM control efforts were made in 1940 on apples in Nova Scotia in an attempt to use insecticides and fungicides that would not interfere with biological control of insects and mites.

Pesticides have been used for more than 2,000 years but, until the last century, only to a limited extent. During the late 1800's and early 1900's, the first widespread use of insecticides was initiated, Arsenical were used on potatoes, cotton, apples, and a few other crops, Bordeaux mixture and liquid lime sulfur were used on grapes, potatoes, and fruits to prevent severe losses by disease organisms. By 1903 crude but practical gasoline-powered spraying and dusting equipment was in use: by 1915 the use of chemical insecticides and fungicides on most crops had become standard practice, The inorganic predominated until the 1940's when DDT, BHC, the dithiocarbamate fungicides, and 2,4-D became the forerunners of a revolutionary new class of chemicals, the synthetic organic compounds. During the last 30 years the total use of pesticides has increased twelvefold in the United States alone; increases in the developing countries have been much more gradual, The latest figures show the rate of increase slowing for fungicides and insecticides, while herbicide use continues to expand until now its use far exceeds that of any other group of pesticides. In 1977, 7 percent of pesticide sales in the United States were for fungicides, 35 percent were for insecticides, and 58 percent were for herbicides.

Although microbial pesticides have been explored, only one bacterium, Bacillus thuringiensis, is in extensive commercial use at present for control of agricultural pests. one insect virus is registered for full use and several others have experimental-use permits for field tests as the first step toward full registration. It is noteworthy that commercially produced Microbials are considered. by law, to be pesticides. but the regulation of pests by their ‘‘natural’” enemies, which include microbial agents, is biological control.

Behavior-modifying substances such as insect pheromones are a recent development and their ultimate role in crop protection is unknown. The pheromone Gossyplure is registered for control of the pink bollworm on cot ton. They, and other attractants, are now widely used to monitor insect activity.

Quarantine regulations originated in the late 19th and early 20th centuries. Germany instituted regulatory measures in 1873 to prohibit entry of products that might spread grape phylloxera. During the next 10 years various States enacted the first quarantine laws in the United States. In 1905 the Federal Insect Pest Act was enacted, and in 1912 the Federal Plant Quarantine Act was passed by Congress. These regulations were based on the concept that the spread of pests through human activity can be prevented, especially if a geographic barrier. such as an ocean or mountain range, exists between the place of origin and the area to be protected. Today. the extent and rate of world travel and trade has led to a reexamination of these procedures in an attempt to adapt to changing conditions. In 1974 Congress passed the Noxious Weed Act which was not funded until 1978. and then only modestly.

Eradication is the complete extermination of a pest from an area and is permanent unless the pest is reintroduced. It may be the ideal method of dealing with a newly introduced species. Eradication programs are politically attractive because of their visibility and because they offer short-term relief from attacks of the pest involved, but permanent success is difficult, if not impossible, to attain for most pests with present technology. Eradication of the screw worm in the Southeast and, on several occasions, of the Mediterranean fruit fly in Florida are successful examples, but attempts to eradicate the common barberry, field bindweed. witchweed, gypsy moth. golden nematode, and fire ant have failed. Also the potential hazards to human health and the environment must be considered. Much concern exists that funds and manpower so badly needed for other crop protection efforts will be wasted on futile eradication projects.

Integrated pest management (1PM) is a concept of crop production incorporating effective, stable, long-lasting crop protection components that minimize the negative side effects of current pest control actions. As mentioned above, none of the current control tactics are entirely satisfactory or universally applicable even though U.S. farmers have achieved a high degree of dominance over many plant pests during the last century.

organic pesticides were first acclaimed as the ultimate solution to crop protection problems, but experience over time has shown that, for all their advantages with respect to human heaIth and conservation of food and fiber, they have many limitations. On cotton and a few other crops in some areas, pest resistance to insecticides and secondary induced pests have resulted in disastrous losses. Biological, cultural, host-plant resistance, and other tactics are all effective against specific pests but have Iimitations that restrict their general usefulness in crop production. These developments have led to a general recognition over the past two decades of the need for improved crop protection systems. The 1PM concept developed in response to this need.

*’Integrated pest management”’ is a term that has different meanings to different people. Definition problems have plagued the 1PM effort since its inception. It is an all-inclusive concept that should be applicable to all pests (weeds, plant pathogens, nematodes, vertebrates, insects, etc.) However, terminology, control tactics, and strategies vary among disciplinary groups so that it is difficult to arrive at a definition completely appropriate to all interests. The term “inte-

grated pest management,*' as used throughout this report, is defined as follows:

Integrated pest management (1PM) is the optimization of pest control in an economically and ecologically sound manner, accomplished by the coordinated use of multiple tactics to assure stable crop production and to maintain pest damage below the economic injury level while minimizing hazards to humans, animals, plants, and the environment.

In the above definition, 1PM is synonymous with "'integrated pest control, " a term generally used outside the United States. "Integrated pest management" and "pest management" are used interchangeably in this report.

The current definitions of some common terms used in crop protection are:

Pest—Formerly restricted in common use to insects and certain rodents, now applies to all noxious and damaging organisms including insects. mites, nematodes, plant pathogens, weeds, and vertebrates.

Pesticides—Includes insecticides, miticides, nematicides, herbicides, fungicides, etc.

Strategies— Pest control strategies are the general approaches or systems used to manage a pest or pests. 1PM is the strategy of using applicable multiple tactics to prevent pest losses.

Tactics—These are the specific methods used to achieve pest control. These include pesticides, pest-resistant varieties, cultural practices, biological control, and others.

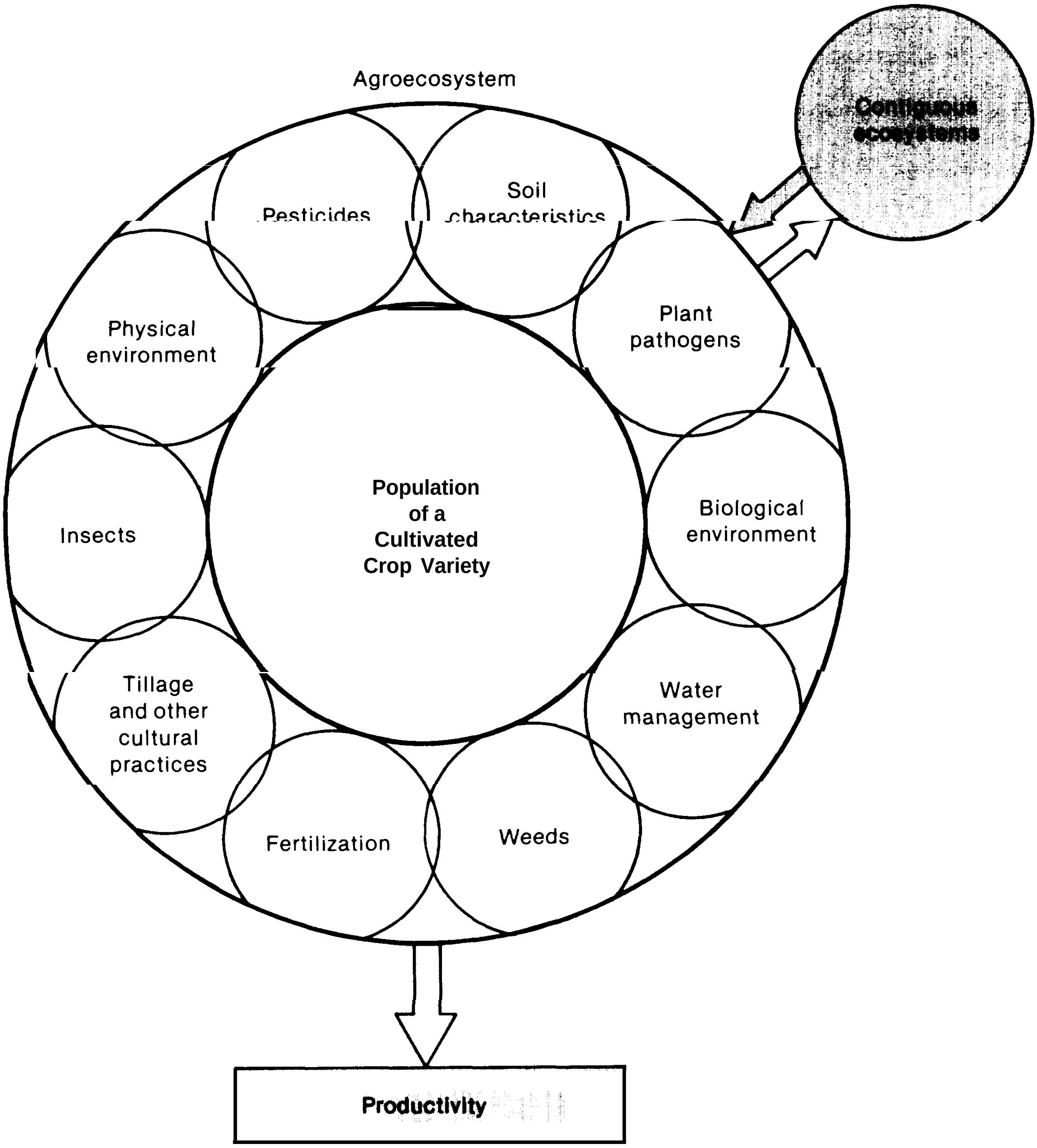
1PM in its broadest form considers all major pests in an agroecosystem and is integrated as one component of the total crop production system, However, integrated control tactics for individual or groups of similar pests can be implemented without waiting for the "perfect"' total program to be developed, These tactics can be modified, improved, and integrated with control tactics for other pests as new information becomes available,

Pest management is not a primary goal; rather, it is one component of the total crop production system which is a series of interlocking physical, biological, and management functions all interacting to determine the yield of a cultivated crop (see figure I). Crop pests are important elements of the system that interact among themselves and with other components of the system; they are managed not as a primary objective but only as they reduce productivity of the system by an amount greater than the cost of control.

As an organized, comprehensive approach to the management of crop pests, 1PM proceeds through a series of steps in planning pest management programs. These steps and their underlying principles, presented in the order of their priority in developing programs, are:

1. Identify the pests to be managed in the crop production system (agroecosystem). An organism should not be classed as a pest until it is proven to be so. A species may be a pest in some situations and not in others. Pest identification should be coupled with the establishment of economic thresholds. (See no, 4 below.)
2. Define the management unit—the agroecosystem. The limits of the agroecosystem should be determined by the characteristics of the local cropping system and the patterns of movement of the key pests involved. Multiple-species management requires a "best compromise" solution to the overall pest problems within the capabilities of the involved farmers.
3. Development of the pest management strategy. The fundamental strategy of pest management is the coordinated use of multiple control tactics in a single integrated system. The goal is to hold pest numbers and crop damage to tolerable levels. It is generally a containment strategy rather than an eradication strategy.
4 Establish economic injury thresholds. The economic injury threshold is the pest population level that causes a loss to the

Figure 1 .— Diagrammatic Concept of an Agroecosystem



SOURCE J L Apple Impact of Plant Disease on World Food Product Ion pp 39.49 In D Pimentel ed *World Food Pest Losses and the Environment* (Boulder Colo Westview Press 1978)

crop greater than the cost of carrying out a pest control action. Obviously, the economic threshold values (pest population levels) vary for a given crop depending on the value of the crop, the state of its development, and environmental conditions (both biological and physical).

5. Develop reliable monitoring techniques. Monitoring information on some pests provides the basis for decisions on immediate suppressive pest managment actions, whereas for other pests such information is useful only for management decisions concerning future cropping

seasons. This involves the measurement of pest populations (numbers of spores, insects, nematodes, weeds, etc.) or amount of disease.

6. Develop descriptive and predictive models. Modeling is a very useful tool in organizing research, in identifying knowledge gaps that must be filled to understand the system, and in predicting over time the behavior of the crop production system and its pest components. This is a desired goal in the development of sophisticated systems but is not an absolute requirement for all 1PM programs,

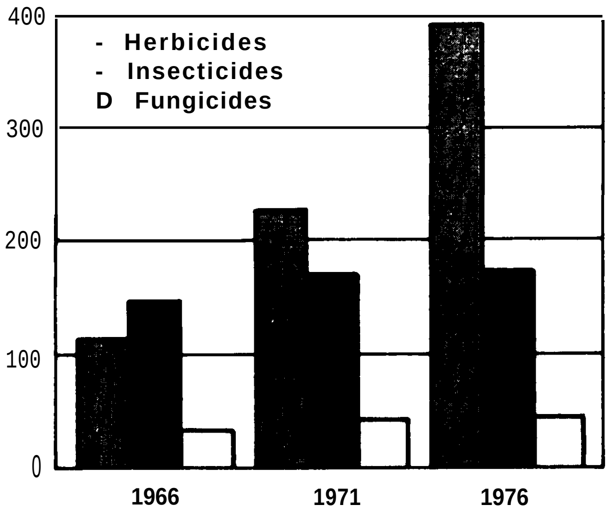
Chapter II

Present. Status of Crop Protection

Present Status of Crop Protection

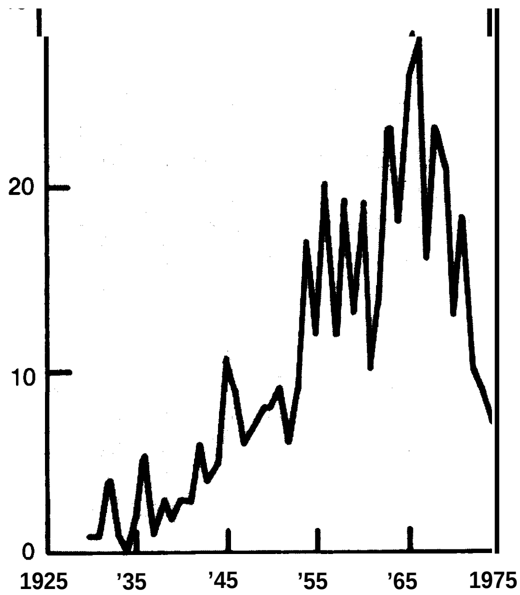
In 1966 U.S. farmers used approximately 300 million lbs of pesticides for crop protection; by 1976 pesticide use had doubled to more than 600 million lbs. This escalation reflects the dramatic increase in herbicide use over the 10-year period, while insecticide and fungicide use has increased only slightly (figure 2). In contrast, the number of new pesticides introduced each year has declined steadily from a high of about 30 in 1967 to less than 10 in 1975 (figure 3). Although there are more than 1,200 chemicals labeled for pesticide use and thousands of registered pesticide formulations, farmers currently use a relatively small number of major pesticides: 17 herbicides, 20 insecticides, and 6 fungicides account for more than 80 percent of all pesticides used.

Figure 2.—Volume of Pesticides Used on U.S. Farms



SOURCE Adapted from 1978 *Handbook of Agricultural Charts,* USDA Agriculture Handbook #551

Figure 3.—Number of Pesticides Introduced Each Year From 1930



SOURCE C A I Goring 1977 *The* Costs of *Commercializing Pesticides* pp 1 33 In D L Watson and A W A Brown (eds) *Pesticide Management and Insecticide Resistance* (New York Academic Press)

A recent review of crop protection methods indicates that pesticides are contributing to pest and environmental problems; other reviews focus on the millions of lives saved, increased crop productivity, and preservation of food and fiber afforded by proper use of modern pesticides. Some claim that, in general, pesticides are not necessary and that adequate alternative tactics for crop protection are available, while others believe that pesticides are essential in modern agriculture and that massive economic dislocations and further deterioration of an already precarious food balance would result from a loss of pesticides. What is the true situation?

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What would happen if effective pesticides were not available for use? What alternative control tactics and strategies are available? Could they prevent predicted severe disruptions and dislocations of food production? If alternative crop protection technology is available but unused, how can it be implemented? If there were to be adverse consequences, would the benefits derived justify the costs? What must be done to reduce pest-caused losses of food with a minimum of insult to the environment and without endangering human health? These are the questions addressed in this report.

Most broad discussions of the status of crop protection deal in generalities based on averaged data. To avoid this limitation the crop protection problems, technology, strategies, economics, obstacles to improvement, and needs were examined in detail for seven cropping systems in the United States. For each system, teams of crop protection scientists, economists, agronomists, farmers, environmentalists, and consumer representatives were commissioned to prepare reports on the following subjects: 1) general nature of the cropping system in their region, 2) major pest of the crop(s), 3) present control strategies and tactics, 4) present and predicted problems with current practices, 5) predictable changes in pest control over the next 10 to 15 years, 6) projected impacts of available approaches to pest control, 7) obstacles to implementation of pest management strategies and tactics, and 8) requirements for a viable, privately operated pest management delivery system.

The crops and regions selected were: wheat in the Great Plains States, corn in the Corn Belt, cotton and associated sorghum problems in Texas, deciduous tree-fruits (especially apple) in the northern half of the country, potatoes in the Northeastern States, soybeans in the Southeastern sector, and selected vegetables in California. These crops are representatives of more than 90 percent of agricultural production in the United States. They also span the range of economic returns per unit area, the quality standards as they relate to pest damage, and the amounts of pesticides used totally or on a per-acre basis. Pests associated with these crops include insects, diseases, weeds, nematodes, and vertebrates such as rodents and birds. Hence a study of crop protection on these seven cropping systems provides a realistic appraisal of the present status and short-term future prospects of crop pest management in the United States.

The complete detailed reports of each of the seven cropping systems are in volume II. This volume is based on those reports.

WHEAT IN THE GREAT PLAINS

Wheat, which originated in the Near East, was introduced in the United States in colonial times. It ranks as one of the most important food crops in the United States and the world. The Great Plains States (Colorado, Kansas, Montana, Nebraska, New Mexico, North Dakota, South Dakota, Oklahoma, Texas, and Wyoming) produce 54 percent of U.S. wheat on 64 percent (45 million acres) of the harvested wheat acreage. Production generally is on large farms where it is the major agricultural enterprise. Wheat farming is highly mechanized and one person can manage 1,500 to 2,000 acres annually in a wheat-fallow rotation.

Wheat production in the Great Plains is risky because of variability in moisture, weeds, diseases, insects, and hail. Moisture is the greatest limitation to consistent wheat production and a stable agriculture. Wheat production in the Great Plains has traditionally relied on a mix of pest control methods. In contrast to other U.S. agricultural regions, wheat producers have depended less on chemical control of pests because of the extensiveness of wheat production, the marginal economic return, and the effectiveness of some nonchemical control methods on pests.

pests of wheat

Wheat in the Great Plains is attacked by more than 30 arthropods, 20 plant pathogens, 16 vertebrates, and 20 weeds which cause total annual production losses of approximately 28 percent. Weeds are the major economic pest, while vertebrates are of minor importance. In addition to biological pests, there are environmental hazards of soil erosion, hail storms, and problems associated with the depletion of soil organic matter. The principal control tactics used against the top 10 pests in each of four categories are listed in table 2.

Chemical Pesticide Use

In 1971, approximately 47 percent of the wheat acreage was treated with pesticides with a total expenditure over $20 million. In 1977 pesticide costs for wheat were $1.23, $1.11, and $0.65 per acre in the southern, northern, and central Great Plains regions, respectively.

Insecticide use on wheat is low compared to other field crops. About 8 percent of the U.S. wheat acreage annually receives an insecticide application, most of which is used to control greenbug, cutworms, armyworms. and grasshoppers. Fourteen insecticides are registered for use on wheat; nine are organophosphates and five are organochlorines.

Because of uncertain economic benefits, less than 1 percent of the wheat acreage in the Great Plains is treated with fungicides for foliar disease control. Fungicidal seed treatment is increasing for the control of common bunt and seedling blight. No vertebrate species is considered a major nuisance in the Great Plains.

More than 90 percent of the pesticides used on wheat are herbicides. About 20 percent of the winter wheat acreage in 1977 was treated with herbicides, while 95 percent of the spring wheat acreage was treated. Such data emphasize the greater weed competitiveness of winter wheat compared with spring wheats. The six major herbicides used on wheat are 2,4-D, MCPA, dicamba, bromoxynil, triallate, and barban. Triallate is used preemergence and the others are used postemergence.

Cultural Pest Control

Cultural practices play a major role in reducing the incidence of many pest problems, but other pest problems may be aggravated by such practices. Delayed seeding of wheat may control certain insects and diseases, but later emerging pests then become a problem. Plowing, burning, or crop rotation destroys some diseases present on wheat residues, but plowing or burning exposes soil to moisture loss and erosion. Cultural control methods for vertebrates include time of planting to discourage migration, planting trap crops of preferred foods, and the use of mechanical scare devices. Production practices that stimulate growth of wheat plants are generally used to provide maximum competition to weeds. A few examples of this include selection of the wheat cultivar, seedbed preparation, method of seeding, seeding rates and dates, row spacing, fertilization, irrigation or water management, erosion control, managed grazing of wheat growth, and sanitation.

Plant Resistance

Plant resistance to insects is the most effective component of management for the Hessian fly and wheat stem sawfly, two of the major insects of wheat in the Great Plains. Greenbug-resistant wheat should be available to growers in 4 to 5 years.

The major approach in controlling wheat diseases is through the use of resistant varieties. For example, stem rust caused major losses in spring wheat from 1918 through 1955, but no significant loss has occurred since then when cultivars with stacked resistances to this disease came into widespread use. Cultivars with specific resist-

Table 2.—Control Tactics Now Employed Against Major Pests of Wheat in the Great Plains

Major pests	Introduced (1)	Pred & para..	Mlcro-blal	resist-	Samta-	natlng	Crop	Plantlng	Clean	Water	FertW		Chemical: Soil	Chemical: Seed	Chemical: Foliar	Other: Monitor-ing	Other: Predic-tive models
Weeds																	
Wild oats	I	1	1	1	2	1	2	2	2	1	2	2	2	1	2	1	2
Mustards	I	1	1	1	2	1	2	2	3	1	2	1	1	1	3	1	1
Winter annual bromes	I	1	1	1	2	1	2	2	2	1	2	3	1	1	1	1	1
Foxtail	I	1	1	1	2	1	2	2	2	1	2	3	1	1	1	1	1
Field bindweed	,1	1	1	1	2	1	2	2	2	1	2	2	2	1	3	1	1
Thistles	1	1	1	1	2	1	2	2	3	1	2	2	1	1	3	1	1
Wild buckwheat ... :	I	1	1	1	2	1	2	2	2	1	2	2	1	1	3	1	1
Quack grass .	I	1	1	1	2	1	2	2	2	1	2	2	2	1	1	1	1
Jointed goatgrass	I	1	1	1	2	1	2	2	2	1	2	2	1	1	1	1	1
Field penny cress. .,	I	1	1	1	2	1	2	2	3	1	2	2	1	1	3	1	1
Arthrop~ds																	
! essian fly	I	1	1	3	2	2	1	2	1	1	1	2	2	1	1	3	1
Greenbug.	I	1	1	1	1	2	1	1	1	1	2	1	1	1	3	2	1
Wheat stem sawfly	N	1	1	2	1	2	1	1	1	1	1	2	1	1	1	2	1
Army worms . .	N	1	1	1	1	1	1	1	1	1	1	1	1	1	3	2	2
Cutworms . . .	N	1	1	1	1	1	1	2	1	1	1	2	1	1	3	2	2
Aphids ., .,	N	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1
Grasshoppers	N	1	1	1	1	1	1	2	1	1	1	1	2	1	3	2	1
Wheat stem maggot	N	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1
False wireworm	N	1	1	1	1	1	2	1	1	1	1	2	2	1	1	2	1
True wireworm	N	1	1	1	1	1	2	1	1	1	1	2	2	1	1	2	1
Diseases																	
Stem rust	N	1	1	3		2	1	2	1	1	2	1	1	1	1	3	2
Leaf rust :	N	1	1	3		1	1	2	1	1	2	1	1	1	2	3	2
Tan spot	N	1	1	2		1	2	1	2	1	1	3	1	1	2	1	1
Septoria leaf blotch.	N	1	1	2		1	2	1	3	1	1	2	1	1	2	1	1
Root foot rots	N	1	1	2		1	2	3	2	2	2	2	1	2	1	1	1
Wheat streak mosaic	N	1	1	1		2	2	3	1	1	1	2	1	1	1	2	2
Barley yellow dwarf	N	1	1	2		1	1	2	1	1	1	1	1	1	2	2	2
Soll borne mosaic.	N	1	1	2		1	2	2	1	1	1	1	1	1	1	2	1
Powdery mildew	N	1	1	2		1	1	1	1	1	2	1	1	1	1	1	1
Bacterial leaf blight.	N	1	1	2		1	1	1	1	1	1	2	1	1	1	1	1
Vertebrates																	
13-llned ground squirrel	N	1	1	1	1	1	2	1	1	1	1	2	1	1	1	1	1
Franklin ground squirrel	N	1	1	1	1	1	2	1	1	1	1	2	1	1	1	1	1
Spotted ground squirrel	N	1	1	1	1	1	2	1	1	1	1	2	1	1	1	1	1
Richardson ground squirrel	N	1	1	1	1	1	2	1	1	1	1	2	1	1	1	1	1
Norway rat	I	1	1	1	2	1	2	1	1	1	1	1	1	1	1	1	1
House mouse	I	1	1	1	2	1	2	1	1	1	1	2	1	1	1	1	1
Deer mouse	I	1	1	1	1	1	2	1	1	1	1	2	1	1	1	1	1
Cotton rat	N	1	1	1	2	1	2	1	1	1	1	2	1	1	1	1	1
Meadow vole	N	1	1	1	1	1	2	1	1	1	1	2	1	1	1	1	1
Prairie vole	N	1	1	1	1	1	2	1	1	1	1	2	1	1	1	1	1

Key 1 = little or no use
2 = some use
3 = major use

ances are also used to control several other diseases.

Little directed effort has been made through breeding to improve the ability of wheat cultivars to compete with weeds. However, wheat breeders have selected large seed and fast-emerging, vigorous seedlings that have improved weed competitiveness. Use of short-stemmed wheats ‘that better resist lodging has increased weed control problems.

Biological Control

Efforts to develop or manipulate specific biological control methods for wheat pests have not succeeded. However, a number of natural enemies of wheat pests are operative and of some importance in the control of certain pests. Their natural manipulation would be possible if the necessary research personnel were available to develop specific tactics.

Organic Farming

Intensive organic farming methods are not practical for the extensive culture of wheat on low-value marginal land of the Great Plains.

Other Control Practices

Specific control methods of limited use on wheat pests include electrical discharge methods, ultrahigh radio waves, laser beams, pheromones, and various mechanical means of removing weeds remaining after other control methods have been used. Soil fumigants have possible application for the destruction of soil fungi and bacteria, nematodes, arthropods, and weed propagules.

Current Use of Pest Management Systems

Wheat growers in the Great Plains have practiced insect management for years. Because wheat is a relatively low-value crop, prevention of damage is emphasized rather than heavy reliance on insecticides after the crop is infested. Those cultural control methods and plant resistance that add little or no extra cost to growers are incorporated into wheat management practices to obtain integrated control of single insects or insect complexes. However, when no alternative methods to chemical control are available, proper timing and minimum rates of insecticides are recommended.

Wheat stem rust, a disease with great potential for widespread wheat destruction, is controlled in the United States by a combination of measures that comprise an integrated pest management (1PM) system. Measures employed are cultural practices, alternate host eradication, quarantine, resistant cultivars, and disease monitoring. Chemical control has no role in the current management program against stem rust. For the past 23 years this disease has not affected production in the highly vulnerable spring wheat area where susceptible cultivars in trap plots are severely infested in 2 out of 3 years.

Accurate short-term models exist for predicting the development of leaf and stem rust and would be useful for predicting outbreaks. These models are in limited use, however, because the required organizational structure is lacking for their application throughout the Great Plains.

Wheat farmers use weed pest management, knowingly or unknowingly, to protect their crops by cultural, mechanical, biological, chemical, and preventive control methods. The introduction of the ecofarming system of producing wheat is an example of weed management being introduced into the Great Plains. Ecofarming is a system of controlling weeds and managing plant residues throughout a cropping sequence with a minimum use of tillage. This system reduces soil erosion and crop production costs while increasing weed control, water infiltration, moisture conservation, and crop yields. Ecofarming was introduced in Nebraska in 1973 on 200 acres and by 1978 was used on nearly 100,000 acres.

Insects.—Government regulations that restrict or ban the use of certain insecticides have reduced their availability and have increased control costs for some wheat pests. For example, two organochlorines (endrin and toxaphene) are the only effective materials presently available for cutworm and armyworm control. Further restrictions on the use of organochlorines will leave wheat vulnerable to these and other soil insects.

Although insecticide resistance is not a major problem in wheat pests, there is evidence that the greenbug has developed tolerance to organophosphates, which are the only insecticides registered for use against greenbug on wheat. Thus there is a pressing need for new insecticides and alternate control methods for this pest.

Acreage of Hessian-fly-resistant wheats in Kansas and Nebraska has decreased from about 66 percent of the acreage in 1973 to about 42 percent of the acreage in 1977. Along with this decrease there has been a corresponding increase in Hessian fly infestations in the previously resistant acreage. Also, a serious outbreak of Hessian fly occurred on 50,000 acres of spring wheat in South Dakota in 1978. Both winter and spring wheats are becoming highly vulnerable to outbreaks of Hessian fly,

There is only limited effort to continue developing wheat-stem-sawfly-resistant cultivars. The U.S. Department of Agriculture's (USDA) Science and Education Administration (SEA) terminated research on wheat stem sawfly in 1972. In the absence of this research effort, the resistant cultivars presently grown are expected to be replaced with susceptible cultivars that have other improved agronomic characteristics. Thus, infestations of wheat stem sawfly are expected to increase.

An increase in ecofarming as a system for wheat production may result in the emergence of vertebrate pests. This system will provide suitable habitat for several mammalian and avian species that can affect stand establishment and grain production,

Diseases.—Zinc ion-maneb complex and zineb fungicides currently are undergoing rebuttable presumption against registration (RPAR) by the Environmental Protection Agency (EPA). If registration of these fungicides is not approved, no alternative broad spectrum fungicide of comparable effectiveness is available for control of foliar diseases in wheat.

Use of minimal tillage with continuous cropping in the eastern Great Plains has increased the potential threat from diseases that develop from pathogens surviving on infested debris. The extent of this threat will increase with the acceptance of ecofarming techniques.

Vulnerability of wheat to leaf rust in the Great Plains is high and the diversity of resistance to this disease is inadequate. Virulence exists in the leaf rust population of the United States for all useful resistant cultivars. Therefore, a major epidemic could occur any year.

Weeds.—Weeds infesting spring wheat are mostly early-maturing summer annuals. The winter wheats are infested most severely by winter annual weeds or weeds that germinate in early spring. Grass weeds are becoming an increasing problem because control methods are generally unavailable. Specific cultural methods such as stubble-mulch farming have controlled tap-rooted weeds while allowing shallow, fibrous-rooted weeds to increase. Field bindweed continues to be a severe problem especially in the western part of the Great Plains. Ecofarming and other minimum tillage wheat production systems decrease most annual weeds while perennial weeds increase.

Wild oat continues as the major summer annual weed in the spring wheat area. Also, it has recently become an increasing weed species acting as a winter annual in Texas and Oklahoma. The spread of this species should be stopped before it infests the entire winter wheat belt in the Great Plains.

Other weeds are spreading in both winter and spring wheat areas and are not adequately controlled.

Soil erosion by wind and water continues to be a problem when tillage is utilized. The main reason for tillage is weed control. If wheat residues are left on the soil surface, weed control is more difficult and requires additional cultivations that reduce residues needed to prevent soil erosion. Weeds are heavy users of moisture which is the limiting factor in crop production in the Great Plains. However, tillage reduces soil moisture by exposing soil to the air. Tillage controls weeds by burial of the weeds, desiccation of the weeds by cutting the roots, or drying out the surface soil sufficiently to prevent weed seed germination, Herbicide use could be a trade-off to tillage for weed control and would result in reduced soil erosion and moisture loss.

For a detailed report of crop protection on wheat in the Great Plains, see volume II.

CORN IN THE CORN BELT

The Corn Belt agroecosystem is one of the world's most intensive farming centers. It includes a lo-State geographical area in the North-Central United States characterized by near optimum environment, resources, and supporting services for corn production. It produces 83 percent of the Nation's corn, 68 percent of the soybeans, 30 percent of the wheat, and 30 percent of the grain sorghum. More than 46 percent of the cropped acreage of the United States is in the Corn Belt.

Corn and soybean are the major crops and the major cropping system in much of the Corn Belt. Wheat and grain sorghum are important rotational crops in some States, but double cropping of wheat followed by soybean in the same year is restricted to southern portions of the Corn Belt where the climate is favorable to this practice. Most Corn Belt farmers rotate the major crops, but monocropping is practiced in areas heavily committed to the production of livestock and where the climate restricts soybean harvest to a short period each fall. Irrigation has expanded the western boundary for corn production where rainfall or soil types were previously considered too dry; sorghum and winter wheat, rather than soybean, are the more common rota tional crops in these areas. Corn Belt farms are highly mechanized and efficient, and the cropping system must be considered when developing pest management programs for corn.

Pests of Corn

Of the 30 annual and perennial weeds, 30 species of insects, and 50 disease pathogens that are potential pests of corn in the region, only 19 weeds, 6 insects, 9 disease pathogens, and 8 nematodes are major and consistent pests. Another dozen or so are major but sporadic pests of corn. Although the severity of pest problems varies by area and season. catastrophic outbreaks have not occurred because of generally restrictive environmental conditions and reasonably effective control tactics. Realistic estimates of annual crop losses in yield and quality caused by pests are difficult to develop, but losses would be astronomical without pest control.

Major weeds include annual and perennial grasses as well as annual and perennial broad leaf species. Four weed species infest 70 to 100 percent of the area. The other species are not as ubiquitous but have the potential of reducing yields markedly on 10 to 40 percent of the acreage. Whether reproduced through seeds or by vegetative parts, the potential always exists for disastrous losses from weeds unless controlled. Many Corn Belt farmers consider weed control their most important production problem.

Soil-borne pathogens as a group inflict the greatest consistent losses from diseases in the Corn Belt. The root- and stalk-rot pathogens alone cause estimated crop losses of 10 to 14 percent annually; viral, bacterial, fungal, and other pathogens attack foliage, stalks, and grain causing severe loss when plants are stressed by environmental conditions, weed competition, or management practices. New diseases occur periodically through biotic changes in virulence or adaptability of the pathogen and through the introduction of exotic diseases. Changes in cultural practices, the genetic makeup of hybrids, and weather variations induce dramatic changes in pest species. Further, new problems have been identified, such as nematodes on corn; virtually every agricultural soil contains several genera of these plant parasitic organisms.

A variety of insects reduces yields every year in the Corn Belt and many are capable of causing catastrophic damage. Several insects annually infest millions of acres and significantly reduce yields. Major and consistent insect pests such as corn rootworm, European corn borer, fall armyworm, and the black cutworm generally monopolize the concern of growers. Major but sporadic pests such as the corn leaf aphid have the potential of causing widespread damage, although serious losses may not occur each year. Most of the major corn insect pests are widely distributed or dispersed throughout corn-growing areas. The rootworm complex is only damaging where corn follows corn in the rotation. The western corn rootworm is a relatively new pest in the central Corn Belt and is currently migrating throughout the Midwestern United States. The indirect damage caused by a weed as an alternate host for pathogens or insects, or by an insect or nematode as a vector of disease, may be greater than either pest inflicts independently, thus an integrated approach is required for effective pest control.

As new strains of pests develop or as new exotic pest imports increase in severity, management practices to control them are modified. These changes, in turn, may favor other pest problems. Emphasis on a specific control tactic for one pest may permit greater flexibility or impose greater problems in the control of other pests.

Pest control tactics are designed to disrupt the favorable combination of biotic and environmental factors necessary for pest development. Pest control is an essential part of the crop protection system. Generally, pest control strategies emphasize prevention whenever possible because many corn pests cannot be effectively controlled if they become established during the cropping season. A combination of tactics is available to reduce the variety of pest threats in the Corn Belt. The principal control tactics used against major pests are shown in table 3,

Chemical Pest Control

Pesticides are primarily applied to soil and seed to provide effective, dependable, and sometimes the only control for some pests or pest complexes. The largest quantities of pesticides used on corn in the Corn Belt are applied to the soil, pre- or post-emergence, for weed and insect control. In 1977, approximately 46 percent of the corn acreage received insecticides and 80 percent was treated with a small quantity of fungicide as a seed protestant. The greatest potential for disastrous yield losses from weeds is reflected in the use of herbicides on practically all corn acreage. Current control tactics are based principally on chemicals and cultural controls for weeds and insects and on cultural controls and genetically resistant plants for diseases.

A shift to reduced tillage for erosion control, moisture retention, and labor and energy efficiency has increased the need for and reliance on pesticides. Zero-tillage systems may also require fungicides, rodenticides, and higher dosages of pesticides because contemporary herbicides and insecticides are not as effective in controlling annual weeds or insects when large quantities of crop residue remain on the soil surface.

Cultural Pest Control

Cultural practices are an integral part of most pest control strategies and are most effective in combination with other pest control measures. Cultural practices are the only tactic available for many of the soil-borne diseases. Specific cultural practices used throughout the Corn Belt to reduce survival, germination, development, or spread of pests include the use of clean disease-free seed, adjusted planting or harvesting dates, tillage, drainage, crop sequence, crop rotation, plant nutrition (fertilization), and sanitation (table 3). Cultural practices are combined with herbicides for more effective weed control. Data collected over 10 years shows that one or two cultivations with an herbicide result in higher

Table 3.—Control Tactics Now Employed Against Major Pests of Corn in the Corn Belt

Major pests	Native (N) or Introduced (I)	Biological: Pred & para	Biological: Microbial	Host plant resistance	Cultural: Sanitation	Cultural: Eliminating hosts	Cultural: Crop rotation	Cultural: Planting date	Cultural: Clean seed	Cultural: Water mgmt	Cultural: Fertility mgmt	Cultural: Tillage	Chemical: Soil	Chemical: Seed	Chemical: Foliar	Monitoring	Predictive models
Weeds																	
Foxtail spp.	N	1	1	1	2	1	1	1	1	1	1	3	3	1	1	3	1
Pigweed	I	1	1	1	2	1	1	1	1	1	1	3	3	1	3	3	1
Quack grass	I	1	1	1	2	1	1	1	1	1	1	3	3	1	3	3	1
Lambsquarter	I	1	1	1	2	1	1	1	1	1	1	3	3	1	3	3	1
Velvet leaf		1	1	1	2	1	1	1	1	1	1	3	3	1	3	3	1
Fall panicum		1	1	1	2	1	1	1	1	1	1	3	3	1	1	3	1
Barnyard grass	I	1	1	1	2	1	1	1	1	1	1	3	3	1	1	3	1
Crabgrass		1	1	1	2	1	1	1	1	1	1	3	3	1	1	3	1
Yellow nutsedge	I	1	1	1	2	1	1	1	1	2	1	3	3	1	1	3	1
Smartweed		1	1	1	2	1	1	0	1	2	1	3	3	1	3	3	1
Arthropods																	
Corn rootworms		1	1	1	1	3	3	2	1	2	2	1	3	1	2	2	2
Cutworms		1	1	1	1	3	2	3	1	2	2	1	3	1	3	1	1
European cornborers	I	1	1	3	2	1	1	2	1	2	2	1	1	1	2	1	1
Army worms		1	1	1	2	1	1	1	1	2	2	1	2	0	3	1	1
Corn leaf aphid		1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1
Stored grain insects		1	1	1	3	1	1	1	1	1	1	1	1	3	1	1	1
Diseases																	
Seedling blight	N	1	1	3	2	1	2	2	3	3	1	1	1	3	1		
Stalk rots	N	1	1	3	2	1	3	2	1	3	3	2	1	1	1		
Anthracnose	N	1	1	2	3	1	3	1	1	2	2	3	1	1	1		
Leaf blights	N	1	1	3	2	1	1	1	1	2	2	1	1	1	1		
Bacterial wilt		1	1	3	3	1	2	2	1	1	1	1	1	1	1		
Smut	N	1	1	3	2	1	1	1	1	1	1	1	1	1	1		
Ear rot	N	1	1	3	2	1	2	1	1	1	2	1	1	1	1		
Viruses				3	2	3	2	3	1	1	1	3	1	1	1		

Key 1 = little or no use
2 = some use
3 = major use

yields of corn than do multiple cultivations without herbicides.

Seeding date disrupts the synchrony between a susceptible stage in crop development and the pest cycle. Full-season corn hybrids are generally higher yielding and more efficient than short-season hybrids, but seeding after a certain date greatly reduces the yield potential of full-season hybrids. Seeding in cold, wet soil generally increases weed competition, seedling diseases, and early insect damage, but it may reduce stress during grain formation and avoid severe losses from viruses, bacterial wilt, and serious stalk- and ear-damaging pests that may be more prevalent later in the season. Early-maturing varieties may escape disease and insect damage for the same reason. As a pest management device, seeding dates must be balanced against available moisture during the cropping season, the limited number of days available for the crop to develop and mature, overall pest problems, and other management decisions.

Tillage is a direct control measure for weeds and an indirect control for diseases and insects. Clean cultivation removes some alternate hosts of insects and pathogens, while incorporation of crop residues into the soil hastens their degradation and subjects pests to natural enemies or antagonists. Crop residue on the soil surface increases some pest problems by maintaining a high population of the pest where it is easily disseminated (diseases), stimulated to germinate (weeds), or protected from natural enemies (insects). Damage by rodents and birds increases with reduction in tillage in row crop agriculture.

Crop rotation is one of the oldest methods of control and it is still one of the most economically effective nonchemical means of decreasing most soil pests. The Corn Belt growers have **a** distinct advantage in choosing crop rotation as a control tactic, since the crop grown in rotation is usually one of high value (soybean, wheat, sorghum). Indeed, long-term crop rotation studies covering many decades show that the best way to produce corn in the Corn Belt is to grow it in rotation, especially with soybean and wheat, However, the generalization that greater crop diversity in the Corn Belt would result in fewer pests is not justified. The importance of using crop rotation for pest control depends on the seriousness of a specific pest, since other pest problems may be enhanced through crop rotation. Crop sequence determines the overall complex of pests present more than the length of rotation between crops.

Plant Resisitance

The effectiveness of plant resistance in combination with cultural controls accounts in large part for the very low use of pesticides for disease control in the Corn Belt. Pest-resistant plants provide a natural, economic, environmentally safe, self-generating system that is compatible with other control tactics, is readily accepted by farmers, and has been a primary control tactic for several decades. Twenty-two of the thirty-eight most damaging corn diseases are effectively controlled by genetic resistance. Resistance has also been identified for 11 others. Resistance is not exploited as effectively for control of corn insects because of the lack of a uniform natural infestation or a suitable method for rearing corn insects that are required to screen for resistance. Breeding plants for greater vigor, stiffer stalks, and tolerance to higher population densities that permit closer row spacing etc., also provides more competition against weeds,

The evolution and selection of pests resistant to specific control tactics or capable of overcoming plant resistance are natural phenomena. Thus, breeding plants for crop resistance is a continuing process because of the development of new pest biotypes, import of new pests, and changes in behavior of pests. Breeding higher yielding, better adapted, more energy-efficient, and more nutritious varieties are also continuing goals. Great untapped potential for pest-resistant corn cultivars exists both with presently available germ plasm and with germ plasm from other regions of the world. Techniques necessary to advance the field of genetic resistance are already proven. Further improvement through this avenue depends on long-term support and increased communication among geneticists, plant breeders, and crop protection scientists.

Biological Control

The regulation of pest organisms by their natural enemies is one reason why many pests seldom reach their full biotic potential in the Corn Belt. Indigenous parasitic or antagonistic biological control organisms are important agents for control of many soil-borne pests of corn, and some of these biological control agents can be manipulated by specific cultural practices such as crop sequence, tillage, and fertilization, Manipulation of these control organisms by habitat management has generally been as effective as the introduction and establishment of exotic organisms.

Organic Farming

The term “organic farming” is poorly defined and often used rather loosely. Organic farmers benefit from resistant crop varieties, areawide biological control programs, and reduction in certain insect and weed pests as more sophisticated control tactics are applied by neighbors. Only a very few farmers practice pure organic farming; an increase in organic farming in the Corn Belt would require major shifts in cropping practices, would reduce the yield and grain available for export, and would increase the risk of catastrophic outbreaks and loss from pests. Organic sources of nutrients such as animal waste are available only in limited quantities, and much of the grain produced on organic farms is used as feed for livestock on the farm.

Other Control Tactics

The combination of crop resistance and biological, cultural, and chemical control tactics used in the Corn Belt is constantly changing as new farming practices become available. For example, reduced tillage practices may greatly decrease losses from cornstalk rot and will decrease the movement of sediment and pesticides into water, but reduced tillage may increase the severity of some other pests. Pest scouting, by the farmer or by someone hired, is gaining importance in the Corn Belt as a viable pest management tactic to aid the judicious use of pesticides. Other new developments in pest management include sex pheromone traps that are used to detect the occurence and density of black cutworm moths early in the season, and the identification of karimones that, by providing the chemical communication needed for many insect predators and parasites to find their prey, make some biological control agents more effective.

Current Use of Pest Management Systems

Some 1PM practices are used in the Corn Belt, and there is an awareness of pest control advantages through an integrated approach to pest management. The interest in 1PM reflects a growing concern for stability in agricultural production by preventing crises in pest control. Recent innovations in pest monitoring provide a means of enhancing pest management through greatly improving the efficiency of chemical and cultural control tactics. In this way 1PM can play an important role in minimizing nontarget pollution by pesticides. 1PM is on the verge of greater acceptance and use by farmers in the Corn Belt.

Those proven practices that are ready for incorporation into programs on some crops and for some pest species are being adopted. Thus, the farm management system must include effective pest control practices integrated with those essential for optimum crop production.

Current adoption and use of pest management are largely limited by the lack of basic and applied research information on pest biology and by the lack of timely biological and weather data for incorporation into pest management systems. For most pest species, pest management lacks the data base for accurate pest detection, prediction of pest density, and relating pest density to crop loss. Until these data are obtained and field-tested and control tactics are improved, the prophylactic use of pesticides as “insurance” against pest problems will continue.

Pest management can integrate pest control into crop protection/crop production systems that will reduce the severity of pests, the frequency of pest problems, and pest resistance. For example, pest monitoring can reduce the need for prophylactic use of some pesticides through improved detection of pests, measurement of pest density, relating pest density to yield loss, and rapid delivery of this information to the user. Reduction in pesticide need and use is not the objective of pest management, though many of the pest control tactics such as resistant host plants, some cultural practices, pest scouting, and biological control may, over time, reduce the need for pesticides and the energy it requires to produce them. Improved pest management currently reduces the annual dependency on a given pesticide by using pest-tolerant crop varieties, crop rotation, timely harvesting of a crop, and by enhancing the effectiveness of predators, parasites, and antagonists. Pest management research is needed to develop improved application technology and formulations that will reduce drift and hazard to the user and the environment.

Present Problems and Concerns in Crop Protection on Corn

Problems in pest control are anticipated from: 1) limited basic knowledge on pest and pest/crop interactions, 2) rapid changes in cultural practices, S) decreased public effort in breeding for resistance, 4) decreased effectiveness of some insecticides and limited effort in product development in certain pest areas, 5) Government regulations against pesticides, and 6) introduced exotic pests.

Limited knowledge.—Serious knowledge gaps exist in both basic and applied information of disease and lifecycles; physiology of dormancy or virulence; mechanisms of biological control, resistance, or susceptibility; physiology of host-parasite interactions; the biology and behavior of pests indifferent environments: and threshold damage level. Present pest management practices will be difficult to improve without the generation of new research data.

Minimum tillage.—Minimum or reduced tillage practices increase the severity of certain insects and diseases previously controlled by cultural practices. Although these problems are not insurmountable, they will require much additional research and place an additional burden on a severely limited manpower pool for pest control.

Narrow germ plasm base.—Although the potential corn germplasm base is not limiting and the relatively narrow germ plasm present in any one year's commercial production is frequently cycled (approximately every 4 years) as improved inbreds are developed and released, there is a severely limited manpower resource for using the broad genetic base available for further improvement of pest resistance. After locating gene sources, 8 to 14 years are generally required to incorporate genetic resistance into high-yielding, environmentally adapted, high-quality varieties. Breeding programs have an impressive record for pest control through resistance, This effort is being diluted by esoteric studies that are only remotely applicable to practical problemsolving, Approaches to plant improvement (genetic engineering, tissue culture, etc.) with long lag periods before they can be applied to current problems have tended to detract from, and decrease emphasis on, the traditional breeding and crop improvement programs. Private companies still depend on public release of germ plasm materials for varietal improvement.

Evolution of resistant biotypes.—Pest resistance to pesticides should be considered a natural phenomenon in response to environmental pressure. Several major insects have developed resistance to the cyclodiene insecticides—aldrin, dieldrin, and heptachlor. There is also evidence of reduced efficacy of carbamate and organic phosphate insecticides for controlling corn rootworms. The potential lack of suitable effective soil insecticides for the future is cause for alarm. No weed resistance to herbicides or corn disease pathogens to fungicides are known, although weeds naturally resistant to herbicides may be selectively favored as competition is reduced. Genetic resistance to some foliar diseases is relatively unstable (4 to 8 years) while to other pathogens it is very stable (25 or more years). Much concern exists that effective, safe chemical pesticides will not be available when needed against those pests that result from shifts to minimum tillage or that may develop resistance to existing products.

Exotic pests.—Most commercial hybrids currently grown are susceptible to several exotic pests that could cause disastrous losses if introduced accidentally. Exclusion of these pests from the United States must be maintained as a priority strategy for pest control even though ongoing integrated research and extension programs eventually may be able to minimize their initial impact.

Economics of pest management systems.—Reluctance on the part of growers to change practices for pest control or to reduce pesticide use is frequently associated with previous loss experiences and uncertainty that the change will not result in lower yields or greater risk of pest problems and associated yield instability. Economics definitely influence the rate of adoption of new practices. The higher the potential return, the more rapid the adoption rate. It is difficult to promote a change if the practices are not economical.

Any improvement in technology that increases production potential, efficiency, incentive, and quality will, in turn, result in lower prices for consumer products. Greater advances in pest management are still needed to control present and potential pests that are capable of limiting the necessities of life for tomorrow's consumer.

For a detailed report of crop protection on corn in the Corn Belt, see volume II.

SOYBEAN IN THE SOUTHEAST

Soybean was a domesticated crop in China several thousands years B.C. but has been an important crop in the United States only during the last 40 years. More than 64 million acres of soybean, which is more than half of total world production, are now grown in the United States. Approximately $4 billion worth was exported from the 1977 crop.

Soybean production areas in the Southeastern United States are characterized by temperate to subtropical temperatures, generally humid conditions, and long growing seasons. The area considered in this report includes States ranging from Arkansas, Kentucky, and Virginia southward to Florida and the Texas gulf coast. Acreage tripled in the region from 1960 to 1973 with another 4 million added by 1979 to bring the total to 21 million acres or 37 percent of total national production. The major agroecosystems involve soybean/corn/forage, soybean/corn/cotton/small grain, soybean/grassland, soybean/rice, and soy bean/sugarcane. There is great diversity on many farms including tobacco, peanuts, and vegetable crops, plus hedgerows, forests, and swamps where numerous wild hosts of soybean pests may be found. Predictably, pest problems will change over time on this relatively new major crop.

Farming operations and availability of management options vary widely with farm size, which ranges from less than 100 to more than 100,000 acres. Sufficient flexibility must be built into pest management efforts to accommodate this wide range of farming operations.

Pests of Soybean

The pests of soybean that cause economic losses include weeds, insects, nematodes, and plant pathogens. The economic impact of these pests cannot be effectively fractionated into separate units such as individual weed species or even as a complex of weed species. The total effect of all pests (weeds, insects, nematodes, and plant pathogens) is what the soybean producer must consider. The presence of one pest may compound the adverse effects of another. Control procedures—i. e., chemical or cultural—taken against one group of pests may have a strong influence on the incidence of other pests. Therefore, the producer must integrate efforts among disciplines to control pests properly.

Weeds are the most important of these pests and are estimated to cause average annual losses of 15 to 20 percent of the potential value of the crop with present controls. In addition to competing directly with the crop for nutrients and space, they also interfere with the operation of equipment and harbor insects, pathogens, and nematodes. Costs of control practices, which include herbicides and tillage, are high.

The exodus of labor from southern farms during the last 20 years has been accompanied by a dramatic rise in the development and use of herbicides for weed control. Annual grasses were the major problem weeds during the early to mid-1960's. A very effective family of herbicides (dinitroanilines) was employed against these grasses. As use of these grass herbicides expanded, broadleaf weeds became more and more serious competitors with soybean plants for essential space, nutrients, light, and moisture. The early season and widespread control of grasses had basically provided niches into which the broadleaf weeds moved. Unfortunately, these types of weeds are more similar to soybean than were grasses, which makes development of effective controls of broadleaf weeds much more complicated.

Insects may cause yield losses by attacking roots and nodules, stems, foliage, and pods. The most common insect pests of economic importance on soybean are complexes that feed on foliage and pods (seed) in August and September. However, the economic importance of root-, nodule-, and stem-feeding insects is becoming more obvious as research efforts are intensified. Direct costs of insect pests are related primarily to crop losses and expenditures for insecticidal application. However, the occasional misuse of insecticides through unnecessary applications, use of the wrong insecticide, or use of unnecessarily high rates often has indirect consequences, such as killing of natural enemies and subsequent pest resurgences, which are extremely difficult to assess.

Nematodes associated with soybean are very small (almost microscopic), cylindrical, elongated soil-dwelling worms, and their adverse effects on production are difficult to assess. The effects may range from complete crop loss in some areas to very subtle effects that reduce yields. Some feed on decaying organic matter, others are predators, but those with which we are most concerned feed on roots and nodules of the soybean plant. Nematodes have a large number of crop and weed hosts in addition to soybean. Because of inadequate information many producers apply nematicides to all of their fields when only a few fields or portions of fields may need treatment.

Diseases of soybean in the Southeast can cause serious losses in production. Pathogens infest various plant parts but the principal diseases are foliar. Soil-borne diseases occur much more erratically. The Mississippi River Valley and Delta are frequently the sites of the most severe damage from such organisms because of their heavier soil types. In addition to the use of resistant plant varieties, recent control practices also involve two applications of a fungicide during pod development. In most States in the lower South, these applications have consistently increased yields, but in the upper South, yield responses have been erratic.

Disease-loss relationships are only partially developed but vary within the Southeast. Definitive data are not currently available, either on losses from individual diseases or on losses from disease complexes.

The major pests and principal control tactics of soybean in the Southeast are in table 4.

Chemical Pesticide Use

Chemical pesticides are vital in the control of each class of soybean pest. This is true even though weed control depends more on chemicals than does insect or nematode control. Plant disease control has generally depended less on chemicals, but use of foliar-applied fungicides currently is increasing yields and thus becoming more widely used.

Weed control in soybean production began changing markedly in the early 1960's with the introduction and use of more consistent, effective chemical herbicides. By 1969, approximately 50 percent of the soybean acreage was treated with an herbicide. Now almost all of the acreage is treated with some form of herbicide that is used in preplant, preemerge, or postemerge treatment. Basically, control of all of the major weeds depends on chemical herbicides that perform best when used in addition to good cultural practices rather than as the sole means of control. Evaluation of performance has developed from rating herbicides for overall weed control, to control of grasses and broadleaf weeds, and eventually to the control of specific weeds.

Current predictions indicate that herbicide use will level off, primarily because most

Table 4.—Control Tactics Now Employed Against Major Pests of Soybean in the Southeast

Major pesfs	Native (N) Introduced (I)	Biological: Pred & para	Biological: Microblal	Host plant resistance	Cultural: Sanltatlon	Cultural: Elimlnatlng hosts	Cultural: Crop rotation	Cultural: Plantlng date	Cultural: Clean seed	Cultural: Water mgmt	Cultural: Fertility mgmt	Cultural: Tlllagel	Chemical: Soll	Chemical: Seed	Chemical: Foliar	Other: Monitoring	Other: Predictive models
Weeds																	
Cocklebur	N	1	1	1	2	1	2	1	3	1	1	3	2	1	3	3	1
Slcklepod	I	1	1	1	2	1	2	1	3	1	1	3	3	1	3	3	1
Mornlngglory	I	1	1	1	2	1	2	1	3	1	1	3	2	1	3	3	1
Johnson grass	I	1	1	1	2	1	2	1	3	1	1	3	3	1	2	1	1
Plgweed	I	1	1	1	1	1	1	1	3	1	1	3	3	1	2	2	1
Crabgrass	N	1	1	1	1	1	1	1	3	1	1	2	3	1	1	1	1
Prickly slda	I	1	1	1	1	1	1	1	3	1	1	2	3	1	2	2	1
Hemp sesbanla	I	1	1	1	2	1	2	1	3	1	1	3	3	1	3	3	1
Florlda pusley	N	1	1	1	1	1	1	1	3	1	1	2	3	1	1	1	1
Nutsedges	I	1	1	1	2	1	2	1	3	1	1	3	2	1	2	2	1
Arthropods																	
Bean leaf beetle*	N	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1
Mexican bean beetle	I	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1
Corn earworm'	N	2	1	1	1	1	1	2	1	1	1	1	1	1	3	1	1
Soybean looper"'		2	2	1	1	1	1	1	1	1	1	1	1	1	3	1	1
Velvet bean caterpillar	;	2	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1
Southern green stink bug*	I	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1
Diseases																	
Anthracnose	N	1	1	1	1	1	2	1	2	1	1	1	1	2	3	1	3
Brown spot	I	1	1	1	1	1	1	1	2	1	1	1	1	2	3	1	3
Frogeye	I	1	1	2	1	1	1	1	2	1	1	1	1	1	3	1	2
Southern bllght	N	1	1	1	1	1	3	1	1	1	1	1	2	1	1	2	1
Pod and stem bllght		1	1	1	1	1	2	1	2	1	2	1	1	3	2	1	2
Bacterial bllght	N	1	1	1	1	1	1	1	2	1	1	1	1	2	1	1	2
Nematodes																	
Root knot	N	1	1	3	1	1	2	1	1	1	1	1	3	1	1	2	1
Soybean cyst	I	1	1	3	1	1	3	1	3	1	1	1	2	1	1	1	1
Lesion	N	1	1	1	1	1	2	1	1	1	1	1	3	1	1	1	1
Renlform	I	1	1	2	1	1	2	1	1	1	1	1	3	1	1	1	1
Lance	N	1	1	1	1	1	2	1	1	1	1	1	3	1	1	1	1
Ectoparasltes	N	1	1	1	1	1	2	1	1	1	1	1	3	1	1	1	1

"Trap crop control
''M!q~ale aqnua ly from central Amenc?n and C?rr!fwan

Kei 1 = hllle or no use
2 = some use
3 = major use

acreage is now treated. However, this leveling off may fail to materialize if no-till cultural practices are adopted more widely. No-till culture requires more broadcast applications of herbicides than do conventional tillage methods, more types of herbicides, and possibly slightly higher rates of application. Also, as herbicides become more weed-specific, the leveling-off trend may be delayed further.

Chemical insecticides provide soybean growers with a consistently effective and economical method of suppressing populations of insect pests that threaten crop yields. The only other control method is using a bacterium (or biological insecticide) against some lepidopterous larvae, such as the soybean looper and the velvetbean caterpillar. Selective dosage rates control the pest species but have the least adverse effect on natural enemies (particularly predators and insect pathogens). For example, low rates of carbaryl will control pests such as corn earworm but have little adverse impact on natural enemies. On the other hand, rates of methyl parathion that are sufficient to control the earworm cause high mortality among natural enemies. However, methyl parathion is effective, economical, and widely used for control of stink bugs late in the season when natural enemy disruption is relatively unimportant. Insecticides must be used judiciously.

Chemical control of nematodes has depended heavily on the use of DBCP against species for which there are no effective cultural techniques or resistant soybean varieties. Its use has been severely restricted recently and it will be ultimately lost because of health hazards to workers in plants that manufacture or formulate the chemical. DBCP was effective and fitted easily into the land-preparation planting operation because of its easy application. Further, its use had the apparent benefit of promoting colonization of roots by endomycorrhizae, beneficial fungi that promote phosphorus and water uptake. Chemicals that may replace DBCP are generally less effective, and some have adverse effects on insect predators. The loss of DBCP for control of major nematodes, and the scrutiny other chemicals are receiving from EPA in the RPAR (rebuttable presumption against registration) process, may seriously impair control of nematode pests of soybean.

Chemical control of soybean diseases has been practiced only on a limited basis using fungicides as seed treatments and, more recently, as foliar applications. Chemicals are currently applied to less than 10 percent of the acreage in the Southeast for control of foliage, stem, and pod diseases.

Cultural Pest Control

Cultural controls are used for all pest classes of soybean, are probably used less against insects than against other pests, but are generally less important than chemical control.

Mechanical tillage and hoeing or weeding by hand were the major weed control measures before development of effective herbicides. Hand labor is not used now because of extremely high costs and, moreover, is usually unavailable at any cost. However, producers rely heavily on mechanical tillage as an excellent means of controlling weeds in soybean. Even where herbicides are used, tillage is a valuable component of a Johnson grass control program.

Rotation of both crops and chemicals is another effective method to control weeds that plague soybean. Also, narrower row widths provide an earlier shading effect than wider rows and are often effective against certain weeds.

Although cultural controls are not widely used for insects, trap crop control procedures using limited plantings of early-maturing varieties are employed in some areas. Also, deep plowing is recommended as the only consistently effective method for control of the stem borer Dectes. Avoidance of severe damage from the corn earworm is accomplished in some areas through cultural practices including early planting of early-maturing varieties and narrower rows to hasten canopy closure.

Rotation of nonhost crops with soybean has reduced nematode damage. Rotations are not often used, however, because the rotation crop may have a low value, the nematodes to be controlled have a wide host range, and frequent rotation may build up other pathogenic species. Currently rotation in soybean production is effective against the soybean cyst nematode,

Cultural control of diseases in soybean include rotation, deep turning (plowing) for burial of crop litter, and harvesting as soon after senescence as possible to reduce seed diseases. Rotation and deep turning reduce the amount of disease inoculum present when the crop is planted. However, the use of rotation as well as deep plowing is declining because of increasing conversions to regional soybean monoculture and to no-till culture, respectively.

Plant Resistance

Pest-resistant varieties are vital to the control of certain nematodes and plant diseases. Although resistance to certain insects has been identified and resistant lines are in various stages of development, there currently are no insect-resistant varieties in commercial use. Certain varieties with different growth patterns may compete better with weeds, but this varies with particular growing conditions. Additionally, herbicide tolerance varies among existing soybean varieties.

Some nematodes are currently controlled with resistant varieties that allow the grower to produce high yields even when fields are heavily infested. Nematode-resistant varieties are not without disadvantage; however, they are only effective against a specific nematode and are usually susceptible to other nematodes within the same genus. On the plus side, use of resistant varieties avoids dependence on lengthy rotational schemes that may involve crops of low economic value, and reduces the need for costly and perhaps hazardous chemicals. Also, nematode populations are reduced more rapidly by this control method than through rotation practices.

Several important diseases of soybean are controlled through the use of resistant varieties. Several varieties are resistant to Phytophthora, and others have recognized tolerance to the frogeye leafspot pathogen. Most major varieties have moderate levels of resistance to target spot. Every major variety in the South has resistance to bacterial pustule and wildfire which have been observed at very high levels in susceptible lines in certain areas. These diseases would be very important if our current commercial varieties were susceptible.

Biological Control

In general, biological control methods for insects have been neither used by growers nor determined to be of significant importance by researchers. However, there are exceptions which include the control of a weed (northern joint vetch) with a disease organism, the regulation of insect populations by a large complex of natural enemies that serve to keep pest populations at subeconomic levels, and manipulation of cultural practices to enhance indigenous control of many soilborne pathogens. Biological control of the Mexican bean beetle through annual releases of a parasite from Asia appears promising.

In some areas of the Southeast, growers have quickly learned the benefits of natural insect enemies, and received maximum benefit from them by: 1) not applying insecticides until economic thresholds are reached, 2) using insecticides that are least destructive to the natural enemies, and 3) using insecticides at minimum effect rates for target pests.

Current Use of Pest Management Systems

Weed control recommendations are based on several factors such as soil type, percentage of soil organic matter, available method(s) of application, growth stage of crop, growth stage of weeds, costs of control methods, climatic and stress conditions, labeling restrictions, and specific weeds involved. Threshold levels have not been used because they are largely unavailable.

Most States in the region currently recommend prototype management programs for insect pests based primarily on: 1) scouting to determine economic damage thresholds that usually include an assessment of defoliation level, plant growth stage, and numbers of insects per unit area, and 2) using minimum effective rates of insecticides that have the least effect on natural enemies for control of target pests that exceed these economic thresholds. Some States combine the above with cultural controls for certain pests. Enthusiasm has been the characteristic response of growers who use these programs. Not only have such programs been adopted in areas of the southern United States but recent studies in Brazil have demonstrated the effectiveness and adaptability of these systems in areas where pest complexes and conditions differ.

The need for nematode control is most effectively determined by intensive sampling in the fall after maturation and harvest of the soybean crop. Most States provide services for annual soil sample analyses on which recommendations are based.

Foliar diseases of soybean are generally controlled with two applications of a fungicide. A system developed for predicting the probable occurrence of disease infection and the necessity of fungicidal applications is estimated to reduce the number of applica-

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tions by about 30 percent from an across-the-board recommendation.

Some Southeastern States have prototype soybean pest management scouting programs whereby fields are checked at weekly intervals for insects, diseases, and weeds. Currently, no State presents data from a pest-monitoring system in timely regional summaries or forecasts outbreaks. Although models have been used in research programs, they are not used currently for control strategy decisions in the field. Pest management systems are by no means universally employed by growers, Many times weed control chemicals are applied too late for greatest effectiveness, and preplant or aerially applied postemerge treatments are used when postemerge directed sprays would be more effective. Too often insecticides that are destructive to natural enemies are applied when no insecticide is necessary or when a less-destructive one would do a better job. Many growers treat all of their fields with a nematicide when only a few fields or portions of fields actually require treatment. Prescribed sampling for nematodes and insects frequently is not done because of limitations of the data obtained, thus “insurance” treatments are used. Too many fungicidal applications are made routinely even when conditions are dry and foliar diseases are not a problem.

Present Problems and Concerns in Crop Protection on Soybeans

Monoculture.—Producers are converting to regional monoculture without an adequate number of acres of crops with which to rotate. This is done mainly for economic reasons. After several years, fields planted to single crops may decline in productivity. Moreover, monoculture may increase the risk of some disease or nematode problems. Rotation is necessary for control of a number of weeds.

Exotic pests.—It is necessary to prevent the introduction of pests such as soybean rust from Puerto Rico and other areas, and the soybean pod-borer from the Orient.

Resistance of pesticides.—There are now serious levels of soybean looper resistance to methomyl and there is concern that disease organisms also will rapidly develop resistance to benomyl as its use increases, Cultivars must be developed to resist these pests so that effective control tactics can be available.

Resistance to resistant cultivars.—Certain races of the soybean cyst nematode cause serious losses on previously resistant varieties. Resistance-breeding biotypes are also encountered in the root-knot nematode.

Slowdown in development of pesticides.—This was identified as a serious problem for all pest classes, but particularly for nematodes (loss of DBCP) and plant diseases (benomyl on RPAR list) that have developed pesticide resistances.

Knowledge gaps.—There is need for increased disciplinary and truly interdisciplinary studies that are now lacking because of insufficient funding and newness of identified needs. Where information on current technology is available, staff to provide instruction on implementation is not adequate.

For a detailed report of crop protection on soybean in the Southeast, see volume II.

APPLE IN THE NORTH

The apple, a fruit native to Eurasia, was introduced to North America in early colonial times. Until the latter part of the 19th century, commercial apple production was scattered throughout the northern half of the country, but since then has been concentrated in restricted favorable areas of the humid Eastern and Midwestern States and in irrigated areas of the arid West. It also occurs in the wild throughout much of the country where it is an important food source for wildlife. Apple production in the United States usually exceeds 150 million bushels yearly, with an on-farm value of about $500 million. Apple agroecosystems and their pest complexes vary greatly from east to west.

Pests of Apple

Apple orchards harbor a variety of native and introduced pests such as arthropods, disease pathogens, nematodes, weeds, and vertebrates. In the humid East and Midwest, the number of economically important insect and mite species is greater than in the arid western portion of the United States, but the intensity of attack may be equally severe in all areas. About 20 insects and a similar number of diseases are potentially limiting factors nationally and require control measures on an annual basis. Plant-parasitic nem-a todes reduce productivity as root pathogens, predisposition agents, and virus vectors. When weed species are added, the number of pests that occur is increased by at least one order of magnitude. Vertebrates are serious pests of orchards in many sections.

If left unmanaged or uncontrolled, apples will sustain 80- to 100-percent damage from pests annually. A single blemish on the fruit caused by pests can either render it unmarketable or greatly reduced in value. Thus, pest control is a major production operation of apple growers,

Several control strategies are employed against these pests including biological, host-plant resistance, cultural, chemical, and others to ensure that damage at harvest is less than l-percent infested or infected fruit. This level of pest-free commodity is necessary for the dessert and cosmetic appeal of the fresh fruit. Freedom from internal insect fruit feeders is required for processed fruits,

The major pests of apple and principal control tactics are shown in table 5.

Chemical Pesticide Use

On a per-acre basis apples receive the highest amounts of pesticides, seasonally, of any major U.S. crop. Of the 12 million lbs of pesticides used in 1974 on apples, approximately 7 million were fungicides, 5 million were insecticides, and 100,000 were herbicides.

Insect pests of apple are controlled primarily by chemical means, although improved monitoring methods such as pheromone traps allow pest control personnel to appraise accurately the need to spray and thus minimize the use of insecticides, Models, when coupled with monitored events, improve the scheduling of insecticide use even more, which results in maximum insecticide effectiveness.

Nematodes are usually controlled chemically during preplant periods. Other techniques are useful after planting, but in cases of extreme nematode attack, postplant nematicides may be applied,

Diseases of apple are controlled primarily by fungicides and by host-plant resistant varieties. Apple scab, the most serious disease in humid areas east of the Mississippi, is controlled only by fungicide sprays. However, resistance to chemicals such as benomyi and dodine have greatly reduced the availability of chemicals for disease control. These compounds are applied on the basis of detailed monitoring of weather conditions favorable for disease development (e.g., wetting periods, temperature, ascospore levels). Models are available that integrate these factors and provide more detailed forecasts of scab infection periods by which growers can more precisely determine the need for spraying. Recently, in-field microprocessors have been developed that accomplish these same tasks.

Fireblight, a serious disease, can be readily monitored in orchards of the Western United States using a selective cultural media technique to determine the need to apply control sprays, (Application of this method alone in California pear orchards is estimated to save between $960,000 to $1,600,000 per season in spray costs.)

Mildew, rust, and virus diseases of apple and other deciduous tree fruits are primarily managed by chemicals and host-plant resist-

Table 5.—Control Tactics Now Employed Against Major Pests of Apple

Major pests	Native (N) / Introduced (I)	Biological: Pred & para	Biological: Micro-bial	Host plant resist-ance	Cultural: Sanita-tion	Cultural: Elimi-nating hosts	Cultural: Crop rotation	Cultural: Mechan ical ex-cluslon	Cultural: Clean stock	Cultural: Water mgmt	Cultural: Fertility mgmt	Cultural: Tillage & me-chanlcal	Chemical: Soll	Chemical: Seed	Chemical: Fohar	Other: Monitor-Ing	Other: Predlc-llve
Weeds																	
Quack grass . .	I	1	1	1	1	1	1	1	1	1	1	2	3	1	3	1	1
Poison ivy . .	N	1	1	1	1	1	1	1	1	1	1	2	1	1	3	1	1
Field bindweed	I	1	1	1	1	1	1	1	1	1	1	2	2	1	3	1	1
Common dandelion	I	1	1	1	1	1	1	1	1	1	1	2	3	1	3	1	1
Redroot pigweed	I	1	1	1	1	1	1	1	1	1	1	3	3	1	3	1	1
Lambsquarters	N,I	1	1	1	1	1	1	1	1	1	1	3	3	1	3	1	1
Large crabgrass	I	1	1	1	1	1	1	1	1	1	1	3	3	1	3	1	1
Arthropods																	
Codling moth	I	1	2	1	1	1	1	1	1	1	1	1	1	1	3	2	2
Apple maggot	N	1	1	1	1	1	1	1	1	1	1	1	1	1	3	2	1
Plum curcuho ...	N	1	1	1	1	1	1	1	1	1	1	1	1	1	3	2	1
Leaf rollers	N	2	2	1	1	2	1	1	1	1	1	1	1	1	2	2	2
San Jose scale	I	2	1	1	1	1	1	1	1	1	1	1	1	1	3	1	2
Aphids	N	3	1	2	1	1	1	1	1	1	2	1	1	1	3	2	2
Mites	IN	3	1	1	1	1	1	1	1	2	2	1	1	1	3	2	2
Diseases																	
Scab	I	1	1	2	1	1	1	1	1	1	2	1	1	1	3	2	3
Rusts	N	1	1	2	1	2	1	1	1	1	1	1	1	1	3	2	1
Fire blight	N	1	1	2	2	2	1	1	1	1	2	1	1	1	3	2	2
Powdery mildew	I	1	1	2	1	1	1	1	1	1	1	1	1	1	3	1	1
Viruses	N,I	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1
Nematodes																	
Root-lesion	?	1	1	1	3	1	2	1	2	2	1	1	3	1	2	2	2
Root-knot .,	7	1	1	1	2	2	2	1	2	2	1	1	2	1	2	2	1
Dagger	~	1	1	1	3	2	2	1	2	2	1	1	3	1	2	2	1
Ring	?	1	1	1	2	2	2	1	2	2	1	1	2	1	2	2	1
Needle	9	1	1	1	2	2	2	1	2	2	1	1	2	1	2	2	1
Vertebrates																	
Rodents	N	1	1	1	3	1	1	2	1	1	1	3	3	1	1	2	1
Birds*	N	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1
Deer*	N	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1

'Repellents = 3

Key 1 = little or no use
2 = some use
3 = major use

ance. Monitoring methods for predicting the potentials of these diseases are less well-developed than for apple scab.

Weeds in orchards are less intensively controlled than weeds in most annual crops, but in young orchards herbicides are used widely,

Soil and foliar applications of chemicals are used under conditions of intensive rodent populations, and chemical repellents are used to reduce damage by birds; no satisfactory methods are available for deer control.

Cultural Pest Control

Mowing is the major cultural method of pest control in orchards and is used widely to manage weeds in orchards maintained with a sod ground cover. Tillage controls weeds in orchards where sod is not the ground cover.

Plant Resistance

Resistant plants control pests most effectively when combined with chemical pesticides, as in the control of mildew and rust diseases. Plant resistance controls nematodes after trees are planted, but pests must be first chemically controlled during preplant periods to reduce their populations. Some disease-resistant varieties are available for planting in new orchards.

Biological Control

Indirect secondary pests such as mites and aphids can be controlled primarily by biological means if predators or parasites have not been killed by unselective chemicals applied against other pests. For these pests, management models are available for estimating biological control effectiveness; these tools enable pest managers to determine the need to readjust predator or parasite pest ratios based on field population counts. Possibilities for biological control of nematodes may be considerable but, generally, they have not been explored for fruit crops.

Other Control Tactics

Other control tactics include sanitation, fertility management, sterile insects, pheromone confusion, monitoring, and physical barriers. Sanitation measures for arthropod pest control most often involve destruction of infested fruit that harbors species such as the codling moth and apple maggot. Sanitation also helps to control nematodes and to reduce rodent populations; fertility management can affect aphid, leaf-roller, and mite population levels. Physical barriers such as fences and netting are possible but impractical exclusion methods for deer and birds.

Current Use of Pest Management Systems

Integrated pest control has long been associated with apple culture. There is evidence that it had some of its earliest significant beginnings on this crop in North America insofar as implementation is concerned. The first widespread and extensive program was in the 1940's-50's in Nova Scotia. Research in 1PM was greatly intensified during the 1960's, especially for mites and apple scab. A comparison between current practices (table 5) and those discussed below indicates the degree to which integrated pest control has been developed and used on apple.

During the 1970's efforts have expanded to provide improved monitoring tools and techniques for primary arthropod pests of orchards that feed directly in the fruit. In commercial practice the tolerance for such pests is essentially zero. Recent advances in monitoring technology with baited traps and careful orchard inspections have enabled growers to spray against such pests only as needed. Thorough inspections must be made throughout orchards on individual farms by well-trained pest management personnel to avoid the possibility of infestations and serious economic losses.

Programs of integrated mite control in the Pacific Northwest partly resulted from resistance development to pesticides among spider mites and a similar resistance development in the predators that attack these pests. Those successful programs of integrated mite control stimulated interest countrywide, and during the period 1965-75 similar programs were researched and implemented in virtually every major fruit-growing State in the United States. Computer models for several of the mite systems have been developed and when coupled with monitoring data, they provide the basis for more effective decisionmaking relative to chemical pest control. Implementation of these programs reduced the need for chemical control of mites by 50 to 90 percent which translates to a savings of $10 to $30 per acre where implementation has been most successful.

Beyond mite systems, 1PM programs for several other insect pests such as aphids and leafhoppers are in the initial stages of development. New nonchemical methods of insect control such as the sterile male technique for the codling moth and pheromone control via the confusion method for the codling moth, redbanded leaf roller, Oriental fruit moth, and grape berry moth are technologically feasible and show promise for the near future. A most recent advance is an early warning forecasting system for predicting apple pest phenology developed for use on a national scale as a result of the National Science Foundation (NSF)/EPA-sponsored Huffaker Project. To date, reasonably precise growth models for the apple tree and timing models for ascospore maturity of the apple scab disease and some more than 10 insect pests of apple are available. Further research and development of this program over the next 10 to 15 years will greatly improve timing control procedures for apple pests and certainly facilitate a more judicious use of pesticides.

In parallel with work on 1PM systems for mites, techniques for apple scab control have been developed to show that fungicides may be precisely timed relative to specific rain periods. With impetus from research supported by the NSF/EPA-sponsored Huffaker Project in the mid-1970's, additional refinements in disease management have been developed. Most significant advances have been in the measurement, monitoring, and prediction of inoculum of the scab fungus. Work on the design and construction of instruments to monitor weather at the orchard level has been significant. The computerization of several of these technologies has been accomplished, especially to forecast disease infections. Most of these developments have been implemented into 1PM programs in certain States. Although, to date, usually only relatively small reductions in fungicide use have been realized, fungicides are now much more effectively used,

Resistant varieties that control disease and insects have not yet significantly impacted 1PM for apples and other tree fruits. Most of the current apple varieties are highly susceptible to one or more diseases. Several new varieties are available that are highly resistant to apple scab and some other diseases, but none of these have been widely planted, Currently, an effort in breeding for resistance to several diseases and insects is underway. The possibility of utilizing tissue culture to speed up this slow process in apples is being examined.

1PM programs for nematodes and weed pests on apples are less developed than are those for insects and diseases primarily because these pests have not been considered major problems. In recent years, however, the effect of nematicides in improving stand and vigor of replanted apple orchards has been dramatically proven. It thus appears that the use of nematicides as preplant and, to some extent, postplant treatments for apples will become a standard practice and may result in a significant increase in chemical use for this purpose. To date, resistance to nematicides is minimal, and their ecological impacts are little understood. Because nematodes are primarily soil-borne, the opportunities for 1PM programs for these parasites are large. However, at present they are almost totally undeveloped. The manipulation of chemicals, weeds, cover crops, and rootstock cultivars offers a considerable promise for economic control of these pests without undesirable environmental effects.

In summary, proven 1PM technologies available for disease control in tree fruits are utilized to a high level. Thus, fungicide use is as efficient as possible within the current scenario of agronomic practice, pesticide availability, spray technology, and extension of information. Further improvement depends on the development and implementation of new 1PM technology. Although there are now several working prototype 1PM systems, especially for insect and disease pests, that significantly reduce pest resistance and pesticide usage, we are still only working with a small portion of the entire pest complex attacking apple. Implementation of these prototypes has proceeded in a rather piecemeal fashion and has been limited by many institutional and production-related constraints. Probably the greatest success in implementation to date has come from improved monitoring of apple pests and more effective use of pesticides.

Present Problems and Concerns in Crop Protection on Apple

Apple and other deciduous tree-fruit plantings present a crop protection situation quite different from most other agricultural crops. Planting an orchard is a long-term investment for 20 to 50 or more years. Fruit growing means monoculture for the life of the orchard. Orchards offer opportunities for encouraging biological control not possible on annual crops, but the system precludes the possibilities of using cultural controls such as crop destruction and makes the development of resistant cultivars an extremely lengthy procedure, Interestingly, however, many of the problems and concerns in crop protection are similar to those on other crops.

The evolution of resistant biotypes is a major concern for insect, mite, and disease organisms of apple, With apple, insect resistance was first documented in 1908 when the San Jose scale was found resistant to HCN. During the 1930's there was widespread resistance in the codling moth for lead arsenate, an insecticide then in general use against this insect. Growers in several areas were unable to prevent devastating losses. This same insect was able to evolve resistant strains to DDT after less than 10 years of exposure, and the red-banded leaf rollers developed resistance to TDE in about the same length of time. As a result, DDT and TDE were little used beyond 1960, long before the use of DDT was banned in the United States. Resistance to organophosphates and most miticides has developed generally among mites. Leafhoppers and, in some areas, leaf miners are resistant to all insecticides registered on apples except the carbamates. It is interesting to note that the long-term use of the organophosphate insecticides has resulted in the evolution of resistance among beneficial species of natural enemies of aphids, mites, and leafhoppers. In fact, such resistant natural enemies are the basis for the successful integrated mite and aphid control programs used in several States.

With fungicides the history of resistance has been variable. Sulfur fungicides have been used on apples for three quarters of a century without evidence of resistance among disease pathogens. Dithiocarbamates and captan have been used for three to four decades without resistance problems. Yet dodine- and benomyl-resistant strains of scab have been documented after relatively short periods of use.

To date the only success in coping with resistance problems has been to use chemicals with different modes of activity. This process may not be a practical long-term solution, and much greater research is needed to find more suitable solutions.

The slowdown in new pesticide development is of great concern because of the very rapid evolution of resistance to existing insecticides, miticides, nematicides, and fungicides and the potential loss of useful materials now on the RPAR list. The very existence of the apple industry rests on the availability of effective pesticides.

The lack of alternatives to chemical pesticides for control of several major diseases and insects is a major concern. A great need exists for development of practical alternative tactics and strategies.

Lack of information is the greatest overall constraint to the maintenance of present pest control capability. Progress in 1PM on apple has been possible in recent years with Federal and State support, but unless the knowledge gap in basic information is reduced, further progress will be severely limited.

For a detailed report of crop protection on apple in the North, see volume II.

POTATO IN THE NORTHEAST

Potato is a row crop that had its origin in South America where it was a staple crop of the Incas and many other people. It has since spread to most parts of the world and is now the sixth most important source of human food. This report is limited to Irish potato production in 10 Northeastern States (Maine, New Hamphshire, Vermont, Connecticut, Massachusetts, Rhode Island, New York, Pennsylvania, New Jersey, and Delaware). The most concentrated production is in Maine where approximately 110,000 acres are planted to potatoes. The total value of the Northeast crop fluctuates considerably; for example, in 1974 the value was $215.5 million and in 1975 it was $305 million. Average annual production for the period 1973-76 was 55 million cwt (hundredweight).

Potato is propagated vegetatively as tubers, a method that creates special problems regarding the transmission of diseases. Therefore, more vigorous control procedures are practiced to produce pest-free tubers for seed than for food uses. A large number of pests attack potato including the late-blight fungus, which caused the disastrous potato famine in Ireland during the 1840's, and the Colorado potato beetle, which caused great losses as it spread into the eastern half of the North American Continent during the 1860's and 1870's and later throughout Europe. These and other pests continue to affect potato production and practices.

Pests of Potato in the Northeast

The major pests of potato include nematodes, disease pathogens, weeds, and insects. Vertebrates are not a problem. The important pests found in the Northeast include 12 weed species, 5 insects, 9 pathogens, and 2 nematodes. Some pests such as weeds are a constant problem. Others, such as insects and plant pathogens, have a sporadic but explo sive destructive potential; in some seasons they may cause minor losses while in others they may cause complete crop failures. It is believed that potatoes could not be grown commercially in the Northeast without pesticides.

Annual broadleaf weeds and grasses and perennial weeds are problems in potato production. The broadleaf annuals grow rapidly when soil temperatures are relatively low, while the annual grasses grow best later in the season when soil temperatures rise. The perennial weeds reproduce primarily by underground roots and, once established, are difficult to control. These weeds can cause considerable yield and quality reductions as they not only compete with potatoes for nutrients and water but can also penetrate the potato tuber. A recent estimate of economic losses due to weeds in four of the Northeastern States (Maine, New York, Pennsylvania, New Jersey) totaled $6.6 million, which includes costs of herbicides as well as yield and quality losses.

Insect pests, while not as predictable as weeds in their patterns of destruction, consistently cause crop losses. Of the more than 100 insects known to damage potatoes in the United States, only 5 are serious pests in the Northeast; these are primarily aphids and beetles. Many produce several generations during a growing season and can reach economically important proportions very rapidly.

Nematode problems in Northeast potatoes usually are associated with crops grown in monoculture. Where potatoes are grown in sandy soils, root damage and yield reduction can be considerable; losses as high as 25 percent have been reported. Although a program of integrated control can significantly reduce population densities of the golden nematode, the cost of this program is high.

Disease pathogens of potatoes are primarily fungal, viral, and bacterial and infect foliage and tubers. Some can result in disastrous field losses if rigid control measures are not followed; others cause major losses in storage and transit. Insects and weeds spread several diseases and often infect potatoes in combination.

The major pests of Northeast potatoes and principal control tactics are shown in table 6.

Chemical Pesticide Use

Pesticides are widely used on potatoes throughout the United States but especially in the Northeastern areas. In 1971, fungicides, herbicides, and insecticides were applied to almost all potato acreage in the Northeast. Most growers follow a treatment schedule of regular intervals throughout most of the growing season to control diseases. Systemic insecticides may be applied to the soil at planting to control early insect pests with the least possible disturbance to beneficial species. Later, insecticides are applied to the foliage as required to control aphids, beetles, and leafhoppers. Most potato growers apply an herbicide before the crop emerges. All growers use some mechanical tillage. In addition, potato fields are sprayed just prior to harvest with a vine killer to hasten ripening and to make harvesting more efficient. These materials also kill any weeds that may be present. In areas where the golden nematode is present, some soil treatments are made with nematicides but the number of acres treated is very small.

Table 6.—Control Tactics Now Employed Against Major Pests of Potatoes in the Northeast

Malor pests	Native (N) Introduced (1)	Blologlcal		Host plant resistance	Cultural							Chemical			Other	
		Pred & para	Mlcro-Dial		Sanitation	Eliminating hosts	Crop rotation	Planting date (early harvest)	Clean seed	Water mgmt	Fertility mgmt	Tillage	Soil	Seed	Follar	Monitoring	Predictive models
Weeds																	
Nutsedge	N			2	2		2					3	3		2		
Smartweed	N			2	2		2					3	3		2		
Ragweed	N			2	2		2					3	3		2		
Fall panlcum	N			2	2		2					3	3		2		
Quack grass	I			2	2		2					3	3		2		
Redroot plgweed	I			2	2		2					3	3		2		
Lambsquarters	I			2	2		2					3	3		2		
Mustard	I			2	2		2					3	3		2		
Barnyard grass	I			2	2		2					3	3		2		
Foxtail–yellow	I			2	2		2					3	3		2		
Foxtail–green	I			2	2		2					3	3		2		
Large crabgrass	I			2	2		2					3	3		2		
Arthropods																	
Green peach aphid	I	1	1	1	2	1	1	2	1	1	1		1	2	3	1	1
Colorado potato beetle	N	1	1	1	1	1	1	1	1	1	1		1	2	3	1	1
Leafhopper	N	1	1	1	1	1	1	1	1	1	t		1	2	3	1	1
Flea beetle	N	1	1	1	1	1	1	1	1	1	1		1	2	3	1	1
Potato aphid	N	1	1	1	1	1	1	1	1	1	1		1	2	3	1	1
Diseases																	
P tnfestans	I	1	1	2	3	1	1	1	1	1	1		1	1	3	1	1
A solani	"?	1	1	1	2	1	2	1	1	1	2		1	1	3	1	1
Pvx, Pvy	1	1	1	1	3	1	1	2(2)	3	1	1		2	1	3	1	1
Leaf roll	1	1	1	1	3	2	1	2 (2)	3	1	1		2	1	3	1	1
Bacterial rots	N	1	1	1	3	1	2	3	3	2	1		1	1	1	1	1
Fusorlum	N	1	1	1	3	1	2	2	3	2	1		1	2	1	1	1
Vertlcllllum	N	1	1	2	3	1	2	1	3	2	1		1	2	1	1	1
Rhlzoctonla	N	1	1	1	3	1	2	2	1	1	1		1	2	1	1	1
Streptomyces	N	1	1	2	2	1	1	1	1	1	3		1	1	1	1	1
Nematodes																	
G rostochlensls	1	1	1	2	3	1	2	I(I)	3	1	1		3	1	1	2	1
P penetrans	N	1	1	1	1	1	1	I(I)	1	1	1		2	1	1	1	1

Key 1 = Illtle or no use
2 = some use
3 = majo(use

Cultural Pest Control

Cultural practices are used intensively to control potato diseases. One of the most important practices is to plant pathogen-free seed tubers that are produced by specialized growers using strict sanitation and rigorous disease controls. Diseases not controlled by this practice can cause yield losses of 50 to 75 percent. Destruction of infected plants and cull potatoes reduces the chance of blight and aids in the control of several other diseases. One of the most widely applied cultural disease controls is the maintenance of soils at low pH levels primarily to prevent potato scab. Rotation and monoculture control some disease, but these practices tend to increase other problems. Mechanical tillage in combination with herbicides is used universally for weed control.

In a pilot program in Maine, attempts have been made to control the green peach aphid by eliminating its overwintering host (Canada Plum) and by preventing its introduction on bedding plants, vegetables, or ornamental transplants,

Plant Resistance

At present, highly effective late-blight-resistant potatoes are not available for commercial use. Cultivars with single gene resistance to late blight were not successful because of the ability of the blight pathogen to overcome such plant resistance, There is a serious need for cultivars resistant to several diseases. Golden-nematode-resistant cultivars are used in infested soils,

Potato cultivars do vary in their competitiveness with weeds, but growers choose varieties based on other qualities. No potatoes with resistance to insects are available commercially in the Northeast. However, there are varieties known to have insect resistance, and research is underway to incorporate them into commercial lines.

Biological Control

Currently, no strategies used on potatoes involve the conscious manipulation of biological control agents for insect, pathogen, nematode, or weed pests. However, a number of naturally occurring parasites and predators do regulate insect pest populations. Entomophthora fungi cause spectacular reductions in aphid populations, but, unfortunately, fungicides applied to control late blight and other diseases also destroy populations of the Entomophthora. A lady beetle predator of aphids has been established recently in the Northeast in a few locations but its usefulness is not yet determined.

Organic Farming

Organic farming practices for pest control are not adequate for commercial potato production.

Other Control Practices

Eradication and quarantine efforts against the golden nematode have only helped to delay the spread of this pest. Other control tactics such as the use of pheromones, repellents, allelopathy, etc., have not been developed for management of potato pests.

Current Use of Pest Management Systems

Several components of the 1PM approach are now used in potato production. However, attempts to develop and implement them have been piecemeal and uncoordinated. Late-blight forecasting schemes based on the weather (e. g., "Blightcast") have been developed and make possible much more efficient use of fungicides against this disease. In practice, however, it is not popular among growers because savings are small and available fungicides are relatively cheap. Also, effective use of the forecast requires timely treatments when infections occur. Many Northeast potato farmers are not adequately equipped to treat their entire planting within the required time. Others depend on aerial application by commercial operators who must schedule their operations, Thus potato growers must continue to use protective sprays on a calendar schedule.

Additional techniques help manage several other diseases. These techniques include: early harvest to avoid virus infection of either seed or table stock potatoes: application of oils to prevent transmission of certain viruses; rotation, which is practiced by a large proportion of potato producers to prevent dramatic increases in soil-borne pathogen populations; and isolation of certified seed-potato production from other types of potato production, which permits production of higher quality seed.

Currently, weed control blends mechanical and chemical means and functions fairly well. It is not formally labeled as a pest management program. A more specialized 1PM program for weeds cannot be developed until a wider range of cultivars that are competitive with weeds and a group of postemergence selective herbicides become available. Neither of these is likely to become a reality in the near future,

While insect control on potatoes is based largely on the use of insecticides, some efforts are made to use selective insecticides or broad-spectrum materials in such a manner that they cause the least possible destruction of beneficial. Various techniques are being developed to predict or identify when aphids might become a problem. In Maine, a north-south trap line more than 250 miles long is used to determine when aphids begin to migrate into the area. Timing insecticide applications or making a decision for early harvesting of the crop can be based on such information.

Present Problems and Concerns in Crop Protection on Potatoes

Several concerns about the present and near future of crop protection on potatoes seem to center around pesticides because these are the primary tools used for control of potato pests. The basic problem, however, seems to rest on a lack of information on pests, the crop, the environment, and their interactions. Specific problems and concerns are:

Development of resistance to pesticides has created a difficult problem in some areas, particularly on Long Island. The Colorado potato beetle has developed resistance to all except the newest insecticides. Aphids have also developed resistance to some insecticides, but the situation is not yet critical.

The slowing rate of introduction of new pesticides to replace those lost to resistance and regulation is a concern. Also there is a need for new herbicides which can be used postemergence on potatoes.

Lack of effective alternative management to offset problems with pesticides, especially insecticides, suggests there may be serious pest-caused losses in future years.

Lack of support and manpower to develop pest management tactics and strategies is critical. Some pest-resistant germ plasm is known, but incorporating resistance into useful commercial cultivars requires much effort and time. With present resources, the procedure will be lengthy. There is also a need for new resistant germ plasm for use in breeding, Other areas such as determining economic thresholds, developing more comprehensive predictive models, economic analysis of pest control methods, practical demonstrations of new technologies, etc., are also needed.

For a detailed report of crop protection on potatoes in the Northeast, see volume II.

CALIFORNIA VEGETABLES

California is by far the most important vegetable-producing State, producing about half of the total national supply of fresh-market and processing vegetables and accounting for virtually all of the commercial supply of some vegetables and vegetable seed. Vegetables are produced in California in several districts in the coastal and interior valleys and usually are produced as part of year-round cropping systems. The coastal plains and valleys have a cool oceanic climate suited to the year-round production of vegetable crops but particularly the summer production of cool-season crops. Here, vegetables follow vegetables on a double- or triple-crop annual cycle, with no attempt at rotation. The interior desert valleys are suited to winter and spring production but are too hot for summer and fall vegetables. In these areas most vegetables are grown in rotation with one another and with a variety of field crops including small grains, alfalfa, and sugar beets. Rotations serve a variety of purposes, often to utilize an off season not suited to the main crop and to reduce buildup of insects and diseases.

Vegetable production usually occupies high-quality land that is precisely leveled and served by advanced irrigation systems and other backup systems including nearby packing and shipment facilities.

This assessment of vegetable pest management in California reviews practices in lettuce, melons, potatoes, strawberries, tomatoes, and cole crops. These crops account for about three-fourths of the 860,000 acres and $1.7 billion farm value of California vegetables and provide a representative sample of crop protection problems and practices in irrigated vegetable production.

Pests of California Vegetables

Pests that attack vegetables include disease pathogens (viruses, bacteria, fungi), nematodes, insects, mites, slugs, birds, rodents, and weeds. The principal crop losses are due to weeds, disease pathogens, and insects.

Vegetables are intensive crops, and all aspects of their production including protection from pests are pursued intensively and uncompromisingly. Growers spend upwards of $100 per acre per season for pest protection in the best situations, but many spend as much as $1,000 per acre in the case of strawberries, where cost of fumigants, insecticides, and other pesticides alone may exceed $600 per acre.

The general level of crop protection achieved in practice is excellent. Aggregate losses from insects, diseases, and other pests including weed competition are probably no more than 20 percent of the value of the assessment crops and rarely more than 10 percent to any one of the main categories of pests. An important benefit has been to stabilize production and reduce the large price gyrations that have accompanied insect and disease epidemics which have caused much distress to both producer and consumer.

Weeds rarely attack the crop directly but reduce production by competing with the crop for water, sunlight, and plant nutrients. Some weeds carry disease organisms and insects that attack the crop. Others are seed plants that are parasitic on crops. Vegetable crops generally compete poorly with weeds and require a high level of weed control for economical vegetable production. It is ordinarily not feasible to grow vegetables in fields heavily infested with perennial weeds unless major reclamation measures are undertaken beforehand.

Insects and other arthropods that affect vegetables often are present in the field at the time of planting. Some of the insects attack all common vegetables as well as other crops and weeds. In addition to feeding, insects contaminate crops with fecal material, sometimes inject toxins into plants, and spread plant diseases. Some insects are beneficial either as enemies of other pests or as pollinators.

Usually plant diseases occur sporadically but losses may be severe locally. For the most part the disease organisms are specific for each host and closely related weed species, but a few, such as soft-rot bacteria and root-knot nematodes, can attack several crops and many noncrop plants.

Because of the dry summers California vegetables are largely free of the many plant diseases that propagate on moist foliage.

Thus, many wet-weather diseases that require chemical control in the East and Midwest do not occur in California or appear only briefly during spring and fall. In contrast, the soil-borne fungi causing vascular wilts and root rots are favored by the year-round cropping as are viruses harbored by weeds and viruses spread by insects that withstand the mild winters.

Thus, California conditions, while providing relief from foliar diseases, favor insect-borne viruses and soil-borne fungi, disease pathogens that are relatively unresponsive to chemical controls. This has caused research efforts to be directed toward intensive breeding for resistance and systematic attention to a broad range of cultural and biological techniques.

The current strategy in vegetable production is for the farmer to control every production variable that can be profitably controlled. Economics dictate the ecological strategy in pest management as in other production practices. Tables 7 through 12 show the control tactics currently used against major pests of California vegetables.

Chemical Pesticide Use

Insect control in California vegetables is heavily dependent on insecticides. Although crop rotation, field sanitation, quarantine, and a variety of cultural and managerial methods are employed, they do not control insects and mites adequately. Generally, the short crop cycle, the high value of the crop, and the high market standards for freedom from insect parts, blemishes, and filth place great pressure on the grower to use insecticides intensively. Unlike orchards and vineyards, little time is available to establish natural balances that could reduce the need for pesticides. Insecticide treatments are often, if not typically, by routine schedule or rule of thumb rather than on the basis of assessment of pest populations.

Herbicides, used in combination with cultivation and hand weeding, adequately control the weeds of most crops. Herbicides are inexpensive and are effective against most weeds; however, some weeds, particularly those closely related to the crop, are resistant to available herbicides and must be removed initially by hand at high cost. Herbicides are

Table 7.—Control Tactics Now Employed Against Major Pests of Lettuce in California

	Biological			Cultural								Chemical			Other	
Major pests — Native (N), Introduced (I)	Pred. & para.	Microbial	Host plant resistance	Sanitation	Eliminating hosts	Crop rotation	Planting date	Clean seed	Water mgmt.	Fertility mgmt.	Tillage	Soil	Seed	Foliar	Monitoring	Predictive models
Weeds																
All	1	1	1	1	1	2	1	2	1	1	3	3	1	1	2	1
Arthropods																
Loopers and other worms	1	1	1	1	1	1	2	1	1	1	1	1	1	3	1	1
Aphids	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1
Leaf miners	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1
Diseases																
Big vein	1	1	2	1	1	3	2	1	1	1	1	2	1	1	2	1
Downy mildew	1	1	1	1	1	1	2	1	1	1	1	1	1	2	1	1
Sclerotinia	1	1	1	1	1	2	2	1	3	1	2	1	1	2	1	1
Nematodes																
Root knot and stubby root	1	1	3	2	2	2	2	1	1	1	1	3	1	1	2	1
Vertebrates																
All	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Key: 1 = little or no use
2 = some use
3 = major use

Table 8.—Control Tactics Now Employed Against Major Pests of Melons in California

	Host plant resistance	Sanitation	Eliminating hosts	Crop rotation	Planting date	Clean seed	Water mgmt	Fertility mgmt	Tillage	Soil	Seed	Foliar		
				Cultural										
	1	1	1	2	1	2	1	1	3	3	1	1	2	1
	1	1	1	1	1	1	1	1	1	1	1	3	1	1
	1	1	1	1	1	1	1	1	1	1	1	3	1	1
	1	1	1	1	1	1	1	1	1	1	1	3	1	1
	2	1	1	2	1	1	1	1	1	1	1	1	1	1
	2	1	1	2	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	2	2	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	3	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Key 1 = little or no use
2 = some use
3 = major use

Table 9.—Control Tactics Now Employed Against Major Pests of Potatoes in California

Major pests	Native (N) / Introduced (I)	Biological: Pred & para	Biological: Microbial	Cultural: Host plant resistance	Cultural: Sanitation	Cultural: Eliminating hosts	Cultural: Crop rotation	Cultural: Planting date	Cultural: Clean seed	Cultural: Water mgmt	Cultural: Fertility mgmt	Cultural: Tillage	Cultural: Soil	Chemical: Seed	Chemical: Foliar	Other: Monitoring	Other: Predictive models
Weeds																	
All		1	1	1	1	1	2	1	1	1	1	2	3	1	2	2	1
Arthropods																	
Tuber moth		1	1	1	3	2	1	2	1	1	1	3	1	1	2	1	1
Peach aphid		1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1
Leafhopper		1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1
Diseases																	
Ring rot		1	1	1	3	1	1	1	3	1	1	1	1	1	1	1	1
Scab		1	1	1	2	1	3	1	2	1	1	1	1	1	1	1	1
Late blight.		1	1	2	1	1	1	2	1	1	1	1	1	1	2	1	1
Viruses		1	1	2	1	1	1	1	3	1	1	1	1	1	2	1	1
Nematodes																	
Root knot		1	1	1	1	1	2	1	1	1	1	1	3	1	1	1	1
Vertebrates																	
All		2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Key 1 = little or no use
2 = some use
3 = major use

Table 10.—Control Tactics Now Employed Against Major pests of Strawberries in California

Native (N) / Introduced (I)	Blolog[cal		Host plant resls[ance	Cultural								Chemlcdl			Other	
Major pests	'red & para	Micro - bial		Samta flon	Ellm[-natlng hosts	Crop rotahon	Planhng date	Clean seed	Water mgmt	Fertlllty mgmf	TIllaqe	Soil	Seed	Follar	Monitor lnq	Predlc tlve models
Weeds																
All	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1
Arthropods																
Mites	1	1	1-2	2	1	1	1	1	1	1	1	1	1	3	1	1
Aphfds	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1
Diseases																
Vertlcilllum wilt	1	1	1	3	1	1	1	3	1	1	1	1	1	1	1	1
Virus	1	1	1	2	1	1	1	3	1	1	1	1	1	1	1	1
Gray mold	1	1	1	3	1	1	1	1	2	1	1	1	1	2	1	1
Vertebrates																
All	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Key 1 = little or no usP
?= some use
3 = IT ,IIOC use

Table 11 .—Control Tactics Now Employed Against Major Pests of Tomatoes in California

Native (N) / Introduced (I)	Bloloqlcal		Host plant reslsl ance	Cultural								Chemical			Other	
Major pests	Pred & para	Micro blal		Samta hon	Elm-latlnq hosts	CroD rolatlon	Plantlnq dale	Clean seed	Water mqmi	Fertlllty mgmt	rlllage	soil	Seed	Fohar	Mon!tor lnq	Predtc tlve models
Weeds																
All	1	1	1	1	1	2	1	2	1	1	3	3	1	1	2	1
Arthropods																
Fruit worms	1	1	1	1	1	1	2	1	1	1	1	1	1	3	1	1
Pln worms	1	1	1	1	1	1	2	1	1	1	1	1	1	3	1	1
Mites	1	1	1	1	1	1	2	1	1	1	1	1	1	3	1	1
Potato aphid	1	1	2	1	1	1	2	1	1	1	1	1	1	3	1	1
Diseases																
Vertlcllllum wilt	1	1	3	1	1	2	1	1	1	1	1	1	1	1	1	1
Fusarlum wilt	1	1	3	1	1	2	1	1	1	1	1	1	1	1	1	1
Black mold	1	1	1	1	1	1	3	1	1	1	1	1	1	2	1	1
Nematodes																
Root knot	1	1	3	1	1	1	1	1	1	1	1	3	1	1	1	1
Vertebrates																
All	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Key 1 = hrlle or no use
2 = some use
3 = major ufe

the principal controls of weeds of Califorina potatoes at all stages of their growth and, thus, hand weeding is rarely necessary. Land used for strawberry production is fumigated for control of a wide variety of pests prior to planting. The fumigant destroys most of the weed seeds in the strawberry crops, but supplemental hand weeding is still necessary, particularly if the crop is grown a second consecutive year, The fumigant is broadly effective in control of nematodes, general plant diseases, and soil-borne insects.

Cultural Pest Control

Disease prevention usually results from a combination of measures such as crop rotation, production of disease-free seed and vegetative propagation stock, destruction of crop residues, proper irrigation, use of seed

Table 12.—Control Tactics Now Employed Against Major Pests of Cole Crops in California

Major pests	Biologlcal: Nahve (N) Introduced (1)	Biologlcal: Pred & para	Biologlcal: Mlcro-blal	Host plant resist ance	Cultural: SanNa-hon	Cultural: Ellml-natlng hosts	Cultural: Crop rotation	Cultural: Planting date	Cultural: Clean seed	Cultural: mgmt	Cultural: . :	~ C l w m c a l: K Y Y I z U I I V I				Other: Monitor-Ing	Other: Predlc-twe models
Weeds																	
All	. . . . .	1	1	1	1	1	2	1	2	1	1	3	3	1	1	2	1
Atihropods																	
Worms	1		1	1	1	1	1	1	1	1	1	1	1	1	3	1	1
Cabbage aphids		1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1
Maggots	: : :	1	1	1	1	1	1	2	1	1	1	1	1	1	3	1	1
Diseases																	
Clubroot	1		1	1	1	1	2	1	1	1	1	1	2	1	1	1	1
Nematodes																	
Root knot.		1	1	1	2	1	2	1	1	1	1	1	3	1	1	1	1
Vertebrates																	
All	2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Key 1 = hllle or no use
2 = some use
3 = major use

protestants, timing of planting, preplanning soil fumigation, and, particularly, the use of resistant varieties. Despite all efforts, available methods sometimes fail and substantial disease losses occur. Nevertheless, protection of vegetable crops from plant diseases is currently far more effective than at any time in the past.

Crop rotation, timing of planting or transplanting, control of weed and other hosts, general sanitation, and other cultural procedures are important and well-recognized means of controlling insects and mites in vegetable production. These methods adequately control many potential pests, thus reducing the need for insecticides.

Weed control is currently accomplished about half by cultural and managerial methods and half by herbicides. Once crops are well-established and weed-free as a result of a combination of chemical, mechanical, and manual methods they may be maintained for the rest of the growing season essentially weed-free by chemicals at very low cost.

Plant Resistance

Resistant plant varieties combined with cultural and chemical control tactics, are employed in disease prevention. Recently, much progress has been made in breeding varieties resistant to diseases that cause severe losses. Breeding for resistance to insects has received less attention, while resistance to weeds is largely a matter of breeding for crop vigor. Breeding for resistance to pests and diseases as a primary means of pest control has never received the recognition and funding that it deserves.

Biological Control

There is some release of natural enemies of vegetable pests, but major biological control programs that could be manipulated by growers are not available, nor are they likely to become available soon.

The national and international work force in biological control has not been sufficient to make a major impact on pest control practices, and there is little evidence that the deficiency will be corrected.

Organic Farming

Organic farming is highly labor-intensive and is most suited to hoe gardens and to small-market gardens for local consumption. However, there are no “organic” solutions to many crop protection problems in plant culture, and for this and other reasons the method is not competitive nor sufficiently productive in large-scale vegetable production in California.

Other Control Tactics

Pest management is greatly handicapped by the lack of sufficient knowledge of the basic biology of agricultural pests. There is great need for thorough study of the lifecycles and means of survival of agricultural pests. Such studies afford the only rational approach to the discovery and development of entirely new control procedures.

Current Use of Pest Management Systems

Insect, weed, and disease controls are based on a complex balance of cultural and chemical methods. The use of resistant varieties is an additional method in disease control and of particular importance in a preventive strategy. However, there is nothing inherent in integrated systems that ensures reduced pesticide use and an increase in the use of alternative cultural and other methods. A close analysis of all existing factors indicates that the Dresent trend in California toward a chemically intensive, highly integrated system is likely to accelerate.

Present Problems and Concerns in Crop Protection on California vegetables

Current practices provide more efficient crop protection than has been available at any time in the past, yet the technology is still inefficient, hazardous, expensive, and often offensive to the consumer. The potential for improvement lies in the direction of further research to find technology as free as possible from the defects of present methods. The need is for intensified research leading to more resistant varieties and improved chemicals, cultural methods, and biological controls.

There is concern that if the present reliable pesticides were no longer available, less efficient pesticides would be substituted which would result in both increased costs and quantities used.

For a detailed report of crop protection on California vegetables, see volume II.

COTTON AND SORGHUM IN TEXAS

During the past decade in Texas, cotton has contributed approximately $800 million in cash receipts annually; sorghum has followed with an average of approximately $700 million. The two crops represent approximately 50 percent of the total cash receipts from all crops and are produced on about 50 percent of the total cropland acreage in the State.

Since 1880 Texas has produced 31 percent of the Nation's cotton of which approximately 63 percent is exported annually. Sorghum is currently the State's second leading export commodity with 50 percent of the annual production exported. The two crops have become important complementary crops in most geographic areas of the State. They provide the Texas producer with an alternative economic crop choice which enables a response to market conditions. Additionally, the two crops are excellent in a rotation program that significantly contributes to improved soil conditioning, weed control, plant disease suppression, and diversity in the crop ecosystem.

Pests of Cotton and Sorghum

Cotton: Of the most prevalent pests of cotton only four insects, six pathogens. two nematodes, and seven weeds are considered of major importance annually. Present pest losses in cotton are estimated at 35 percent of potential production, which represents an estimated annual loss of nearly 1.2 million bales and a dollar loss to producers in excess of $250 million.

Of the insect species considered major pests, only the cotton fleahopper and boll weevil are viewed as "key*' pests that require direct annual action by the producer to avoid

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economic losses. The bollworm and tobacco budworm most often cause economic damage following disruption of the delicate balance between the pests and their natural control factors. The other insect pests of cotton are typically occasional pests, causing only sporadic economic losses in limited production areas,

Losses due to disease organisms and nematodes are influenced dramatically by weather, cultural practices, soil type, date of planting, seed quality, variety, and a combination of these factors. The producer's ability to recognize specific disease and nematode problems, and assess their importance, is critical in permitting him to wisely design a management strategy utilizing available alternative tactics.

Pigweed is the most serious weed pest of cotton in Texas. It accounts for about 52 percent of the losses to weeds in Texas cotton and infests nearly 85 percent of the cotton acreage. Johnson grass is the second most important weed, infesting over 36 percent of the cotton acreage and accounting for about 17 percent of the losses to weeds in cotton.

Sorghum.—Of the pests of sorghum in Texas, 2 insects, 15 pathogens, and 6 weeds are of major importance, Losses in sorghum due to all pests are estimated at 30 percent of potential yield. This loss estimate exceeds 144 million bushels with an average value in excess of $218 million annually over the last decade,

The sorghum midge and greenbug are the key insect pests that together account for over 80 percent of the estimated losses attributed to arthropod pests. The remaining arthropod pests are secondary or occasional pests.

The diseases of sorghum are numerous and their importance in any given year is influenced extensively by weather conditions. The predominant diseases contributing to reduced yields are downy mildew, head smut, maize dwarf mosaic, charcoal rot, and red rot.

Most producers consider weeds to be their major pest problem, Controlling the grassy weed species is particularly difficult in this crop. Effective weed control requires an intelligent combination of tillage, herbicides, fallow, and/or rotation with a broadleafed crop, such as cotton or soybeans.

Tables 13 and 14 show the control tactics currently used against major pests of cotton and sorghum.

Chemical Pesticide Use

Dramatic changes have occurred in the control of cotton pests during the last 10 to 15 years. Following World War II cotton breeders used the "insecticide umbrella" to develop cotton varieties with superior yield and fiber qualities which were produced with phenomenal success under the same insecticide umbrella. Reflecting the success of the breeding effort and effectiveness of insecticides, average yields on a decade basis exceeded 200 lbs per acre statewide for the first time in this century in the 1950-59 period. With the development of insecticide resistance in the mid-1960's, the insecticide umbrella ruptured, and the entire production system began to change.

Cotton acreage, average yields, and pesticide use patterns from 1945 to the present reflect the transition of the cotton industry in Texas through the exploitation, crisis, disaster, and early recovery phases of cotton production. Insecticide use on cotton in Texas peaked at nearly 20 million lbs in 1964, was over 11.5 million lbs in 1966, declined to 9.6 million lbs in 1971, and was just under 2.5 million lbs in 1976. This reduction reflects, in part, a shift from high-dosage type insecticides, such as DDT, to low-dosage materials. The base acreage treated has only been reduced from an estimated 45 percent of the cotton acreage in 1964 to 32 percent in 1976. The major change in the insecticide use pattern has been in the number of applications used and the rate of insecticide (active ingredient) used per application,

Table 13. —Control Tactics Now Employed Against Major Pests of Cotton in Texas

Major pesls	Native (N) Introduced (I)	B!oloqlcal: Red & oara	B!oloqlcal: Micro-b[al	Host plant reslst ance	Cultural: Sanlla tlon	Cultural: Eliml natlrrq host;	Cultural: Crop rotallon	Cultural: Plantlnq da!e	Cultural: Clean seea	Cultural: Water mgmt	Cultural: Fertll!ty mgmt	Cultural: T[llage	Chern,cal: Soll	Chern,cal: Seed	Chern,cal: Follar	Othel: Momtor Inq	Othel: Pred(c tlve models
Weeds																	
Plgweed		1			1		1	1		1		2	3		1		
Mornlngglory		1			1		2	1		1		2	3		2		
Cocklebur		1			2		2	1		1		2	3		2		
Field bindweed		1			2		3	1		1		3	1		1		
Silver nightshade		2			2		3	1		1		3	1		1		
Jungle rice		1			1		1	1		1		2	3		1		
Barnyard grass		1			1		1	1		1		2	3		1		
Panlcums		1			1		1	1		1		2	3		1		
Bermuda grass		1			2		1	1		1		3	1		3		
Johnson grass		1			2		1	1		1		3	3		3		
Arthropods																	
Boll weevil	1	2	2	1	2	3	1	3	1	1	1	1	1	1	3	3	1
Fleahopper	N	Z	1	1	1	2	1	1	1	1	1	1	2	1	2	3	1
Bollworm	N	3	3	2	1	1	1	1	1	2	2	1	1	1	2	3	2
Tob budworm	N	3	3	2	1	1	1	1	1	2	2	1	1	1	2	3	2
Cabbage looper	N	3	2	1	1	1	1	1	1	1	1	1	1	1	2	3	1
Spider mites	N	2	2	1	1	1	1	1	1	1	1	1	1	1	2	3	1
Pink bollworm	1	2	2	1	2	3	1	2	1	1	1	2	1	1	2	3	1
Lygus bugs	N	2	1	1	1	2	1	1	1	1	1	1	1	1	2	3	1
Thrlps	N	2	1	1	1	1	1	1	1	1	1	1	2	2	3	3	1
Aphids	N	3	2	1	1	1	1	1	1	1	1	1	2	2	2	3	1
Diseases																	
Bacterial bllght				3	2		1	1	2	1		1	1	2	1		
Seedling diseases				2	2		2	2	2	1		1	2	2	1		
Fusarlum wilt				3	1		3	1	1	1		1	2	1	1		
Vertlclll[um wilt				3	1		3	1	1	1		1	1	1	1		
P root rot				1	1		3	2	1	1		1	1	1	1		
Boll rots				2	2		1	2	1	1		1	1	1	1		
S W cotton rust				3	1		1	1	1	1		1	1	1	3		
Fungal leaf spots				2	2		2	1	1	1		1	1	1	1		
Viruses				1	1		1	1	1	1		1	1	1	1		
Nematodes																	
Root knot and renlform				3	1		3	1	1	1		1	2	1	1		

Key 1 = lhlfle 0, no use
? = some use
3 = major use

Cotton insect control in Texas still depends on the availability of effective insecticides. This is particularly true for the control of the two key pests: cotton fleahopper and boll weevil. Fleahopper control is achieved by using carefully timed applications at significantly reduced rates; boll weevil control often has been aided by shifting application timing to reduce the risk of other pest outbreaks. Far less dependence is placed on insecticides in controlling bollworm and tobacco budworm.

Control of insects on sorghum relies heavily on insecticides and planting date for the major pests. In 1966, insecticide use was limited **to** no more than 2 percent of the harvested acreage; by 1976 ‘insecticides were being used on almost 60 percent of the State’s sorghum acreage, The major use of insecticides on sorghum is for control of greenbug. Minimum effective insecticide rates combined with naturally occurring predators, parasites, and economic thresholds are effective tactics used to minimize greenbug losses. Insecticide use in midge control is limited in most production areas to late-planted fields.

Pesticides are not used for disease control in cotton except in the treatment of seed and in-furrow fungicide applications for seedling diseases, and on rare occasions as an emer-

Table 14.—Control Tactics Now Employed Against Major Pests of Sorghum in Texas

Major pests	Native (N) Introduced (I)	Biological: Pred & para	Biological: Microbial	Host plant resistance	Cultural: Sanitation	Cultural: Eliminating hosts	Cultural: Crop rotation	Cultural: Planting date	Cultural: Clean seed	Cultural: Water mgmt	Cultural: Fertility mgmt	Cultural: Tillage	Chemical: Soil	Chemical: Seed	Chemical: Foliar	Other: Monitoring	Other: Predictive models
Weeds																	
Brown panicum		1			2		2	1		1		2	3		1		
Jungle rice		1			2		3	1		1		2	3		1		
Johnson grass		1			2		3	1		1		3	1		3		
Bermuda grass		1			3		3	1		1		2	1		3		
Nutsedges		1			1		3	1		1		2	1		3		
Pigweed		1			1		1	1		1		2	3		2		
Morningglory		1			2		1	1		1		2	3		3		
Cocklebur		1			2		2	1		1		2	3		3		
Field bindweed		1			3		1	1		1		2	1		3		
Texas blueweed		1			2		1	1		1		2	1		3		
Arthropods																	
White grub		1	1	1	2	2	2	2	1	1	1	1	3	1	1	1	1
Wireworms		1	1	1	2	2	3	2	1	1	1	1	2	3	1	1	1
Greenbug aphid	I	2	1	3	1	1	1	2	1	1	1	1	1	1	3	2	1
Fall army worm	I	1	1	1	1	1	1	3	1	1	1	1	1	1	2	1	1
Beet army worm	I	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1
S. W. corn borer	I	1	1	1	3	1	2	2	1	1	1	1	1	1	1	1	1
Sugarcane borer		1	1	1	3	1	2	3	1	1	1	1	1	1	1	1	1
Chinch bug		1	1	2	1	2	1	2	1	1	1	1	1	1	2	1	1
Sorghum midge	I	1	1	1	1	1	1	3	1	1	1	1	1	1	3	1	1
Sorghum webworm		1	1	1	1	1	1	3	1	1	1	1	1	1	3	1	1
Diseases																	
Leaf blight				3	1		2	2	1	1		2	1	1	1		
Anthracnose				3	2		2	2	2	1		2	1	1	1		
Grey leaf spot				2	2		3	1	1	1		1	1	1	1		
Zonate leaf spot				2	1		2	1	1	1		1	1	1	1		
Bact leaf stripe				3	2		2	1	1	1		1	1	1	1		
Head smut				3	1		2	2	1	1		2	1	1	1		
Loose smut				2	1		1	1	1	1		1	1	3	1		
Covered smut				2	1		1	1	1	1		1	1	3	1		
Rust				3	1		1	2	1	1		1	1	1	1		
Sorghum d mildew				3	1		3	3	1	1		1	1	3	1		

Key 1 = little or no use
2 = some use
3 = major use

gency treatment to control Southwestern cotton rust. The use of pesticides for disease control in sorghum is limited primarily to seed treatment.

Weed control in cotton witnessed a rapid transition from a combination of cultivation and hand-hoeing in the 1950's to a combination of tillage and herbicides in the 1970's. Herbicides use more than doubled from 1966 to 1976. Approximately 70 to 75 percent of Texas cotton acreage is presently treated with one or more herbicide applications. Weed control in sorghum depends on cultivation, rotation, and herbicide use. Although herbicides are considered by many to be the basis of a good weed control program, they are not effective unless integrated with cultural practices. Herbicides become much more important in conservation or minimum tillage production systems.

Nematicides, in combination with varietal resistance, control nematodes in Texas cotton. Approximately 200,000 acres are treated annually with nematicides.

Cultural Pest Control

Cultural controls that are of major importance on cotton and sorghum are crop rotation, tillage, planting and harvesting dates, and sanitation. Other cultural methods, such as the use of clean seed, eliminating pest hosts, nutrition, and water and fertility management, are employed but to a lesser extent.

Although insecticides are a major control tactic in avoiding or reducing losses on cotton due to the boll weevil, the use of rapidly fruiting cotton varieties and short production management are equally important tactics in a successful pest control strategy. Sorghum losses from midge damage are reduced by using an early, uniform planting practice within each of the production areas. This practice limits the length of the "effective" midge buildup period to no more than one or two generations and has proved to be an extremely important tactic.

Disease control in cotton primarily depends on crop residue management and crop rotation in combination with varietal resistance and seed treatment. Burial of crop residues that incite biological activity in soil reduces the survival of soil-inhabiting pathogens. Early planting, rapidly maturing varieties, and short-season management practices reduce losses resulting from boll rot, Verticillimn wilt, and Phymatotrichum root rot. In sorghum, disease control relies principally on crop rotation, host resistance, and seed treatment.

A cotton/sorghum crop rotation is extremely important in controlling certain weeds in cotton. Timely cultivations are reliable in removing rhizomatous weed roots and stems, and effectively reduce competition during early cotton growth stages. In sorghum, weed control depends extensively on cultivation, crop rotation, and herbicides. Effective control requires rotation with cotton, soybeans, etc., and frequent fall tillage or the application of glyphosate for rhizome control. Although herbicides are effectively used against some weeds, cultural practices are the foundation of any weed management program.

Plant Resistance

Beginning in the mid-1960's the cotton-breeding programs in Texas stressed the development of genetic lines with multiple insect and disease resistance—primarily tolerance and escape resistance mechanisms. This breeding practice reflected a significant and, in retrospect, important change in basic breeding philosophy. Most of these varieties displayed high seedling vigor and rapid fruiting characteristics. These so-called "short season'" varieties were selected under harsh, pest-competitive, natural conditions and were found to produce well in the field when in competition with disease pathogens and insect pests. Varietal resistance is extensively relied on in reducing losses associated with bacterial blight, Verticillium wilt, the Fusarium wilt root-knot nematode complex, nematodes, and seedling disease—the major diseases of cotton.

With the development of hybrids in the 1950's, sorghum breeders until recently selected hybrids for grain quality and high yields with limited attention to insect resistance. In the absence of effective fungicides, genetic resistance to sorghum diseases has received major attention in breeding programs. Greenbug-resistant lines were released to commercial breeders and subsequently made available to producers on a limited basis in 1975. Greenbug-resistant varieties are currently being planted on over 50 percent of the Texas acreage, but sorghum producers have not learned to fully utilize these resistant varieties.

Biological Control

Farmers, producers, consultants, research entomologists, and extension specialists are sensitive to the important role of naturally occurring beneficial species in suppressing damaging insect populations. This is particularity true of the secondary pest species, Naturally occurring predators and parasites are the principal controls of most insect pests of cotton.

Other Control Tactics

Greater emphasis is presently being placed on careful field monitoring and the use of economic thresholds to establish clearly the potential for economic loss and the need for direct action by the the producer.

Current Use of Pest Management Systems

Although virtually all of the pest problems associated with cotton and sorghum production are controlled by a combination of tactics, the management program employed in weed control most closely resembles a truly integrated pest management strategy. The use of cultivation, crop rotation, hand-hoeing, and crop residue burial in combination with herbicides is a strategy designed specifically to address the weed problems encountered in a given field or production area.

Present Problems and Concerns in Crop Protection on Cotton and Sorghum in Texas

Based on the pesticide use experience in controlling cotton insect pests, there is concern developing among weed scientists that additional weed control tactics need to be developed to broaden the available control alternatives. To develop this technology, however, additional weed scientists and supporting resources will be absolutely essential.

The importance of naturally occurring parasites and predators in regulating insect pests of cotton has been established, However, the ability to optimize the use of this tactic is greatly limited by a lack of knowledge concerning the manipulation of these natural control factors.

For a detailed report of crop protection on cotton and sorghum in Texas, see volume II.

Chapter III

Fifteen-Year Prelection of Agricultural Pest Control in the United States

Fifteen-Year Projection of Agricultural Pest Control in the United States

Each of the seven regional work groups was asked to project crop protection for their crops based on three assumptions: 1) continuation of current crop protection tactics, 2) no pesticide use, and 3) full implementation of integrated pest management (1PM). An overriding assumption was that any significant new technology that will take place in the field during the next 15 years is in the early developmental stages at this time. For example, the developmental period for a new pesticide is 8 to 10 years before initial registration which is then followed by an additional period of time before it is generally adopted by users. A similar or longer time span is involved in developing and introducing pest-resistant cultivars. Radically new procedures are likely to require even longer periods to be fully validated, demonstrated, and adopted.

The scenarios for the several crops are shown in figures 4 to 16. It must be emphasized that these projections are schematic trends and, because actual trends are not known, they are not quantitatively accurate; rather, they are intended to illustrate our best qualitative estimates of what may occur in the next one and one-half decades.

From these figures it is obvious that great variation exists in the dependence on pesticides to produce each of the crops. Crop losses for wheat, corn, and soybeans would increase significantly without pesticides but could be reduced to a reasonable level after several years by substitution of other tactics. Current yield potential of corn and soybeans would not be maintained, but alternate tactics could reduce pest losses. On the other hand, production of apples, lettuce, cole crops, strawberries, and Northeast potatoes would be disastrously reduced to the level at which commercial production would become impossible. Obviously one cannot generalize on the role of pesticides in production across agricultural crops.

The principal impact of the adoption of 1PM over the present mix of tactics would be a trend towards reduced pesticide use accompanied by more stable control of insects and diseases. Considerable fluctuations in crop losses are anticipated when the use of certain existing chemicals is discontinued because of pest resistance, regulations, economics, or combinations thereof when no effective substitutes are immediately available, For most crops, losses would be consistently less with greater implementation of 1PM than with current practices.

As stated elsewhere, a significant percentage of crop production is lost prior to harvest because of pest activity. This occurs in spite of the extensive use of pesticides. This implies that pesticides are not efficient or effectively used; actually they are reasonably efficient and cost-effective for farmers in most situations. The extensive crop losses that do

Figure 4.—Schematic Projections for Three Crop Protection Scenarios for Wheat in the Great Plains

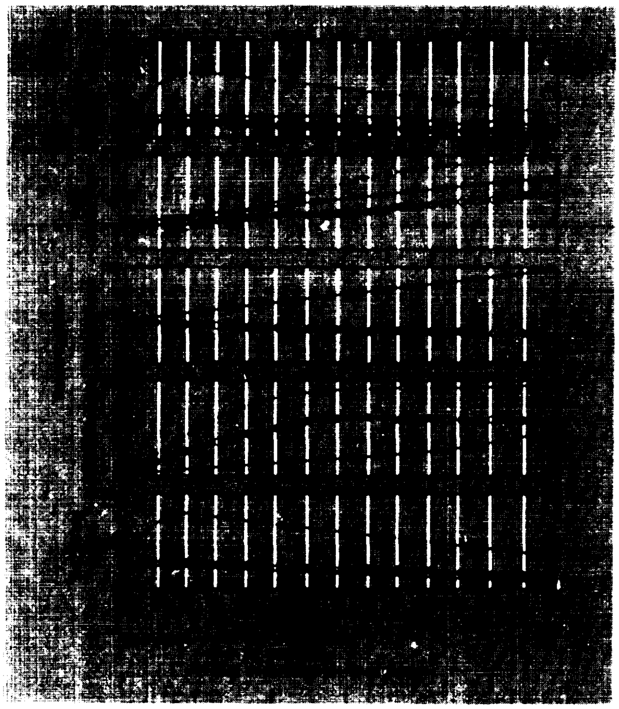


Figure 5.—Schematic Projections for Three Crop Protection Scenarios for Corn in the Corn Belt

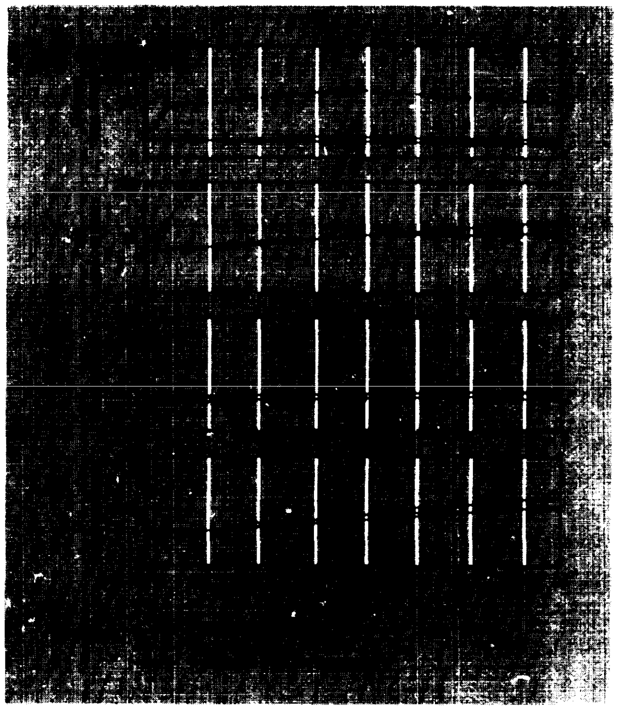


Figure 6.—Schematic Projections for Three Crop Protection Scenarios for Soybeans in the Southeast

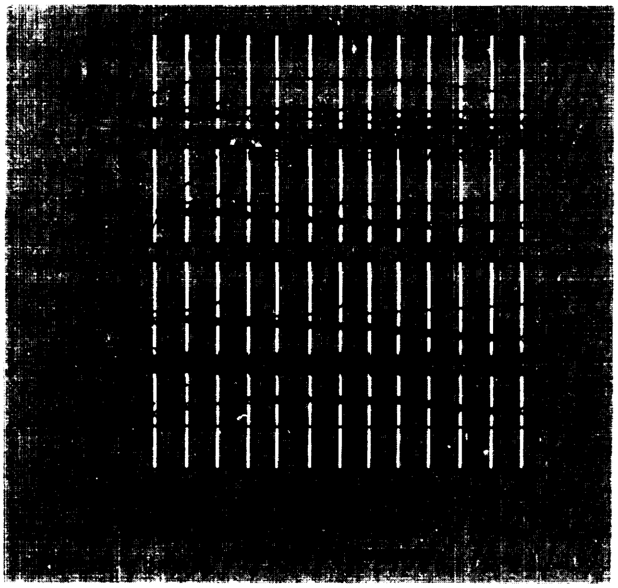


Figure 7.—Schematic Projections for Three Crop Protection Scenarios for Apples in the North

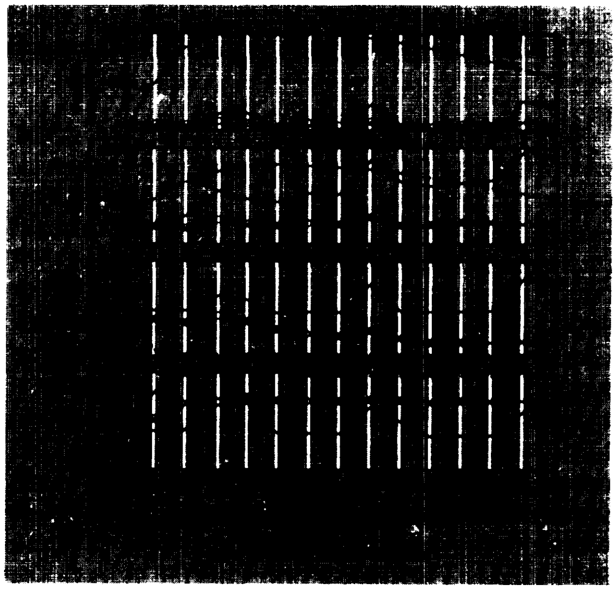


Figure 8.—Schematic Projections for Three Crop Protection Scenarios for Potatoes in the Northeast

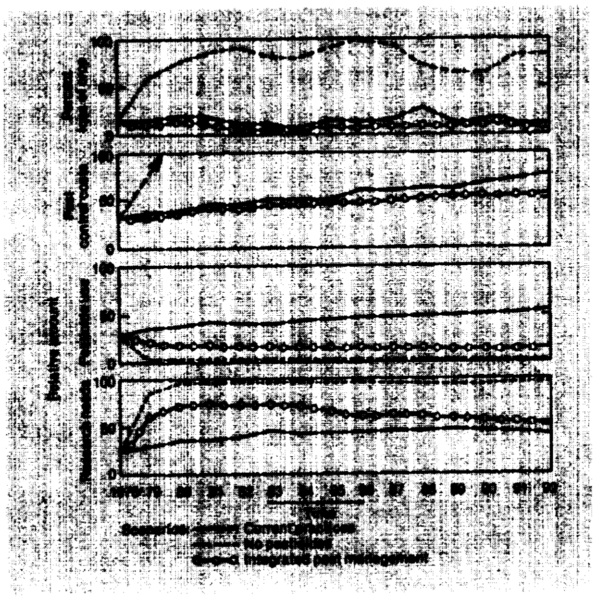


Figure 9.—Schematic Projections for Three Crop Protection Scenarios for Lettuce in California

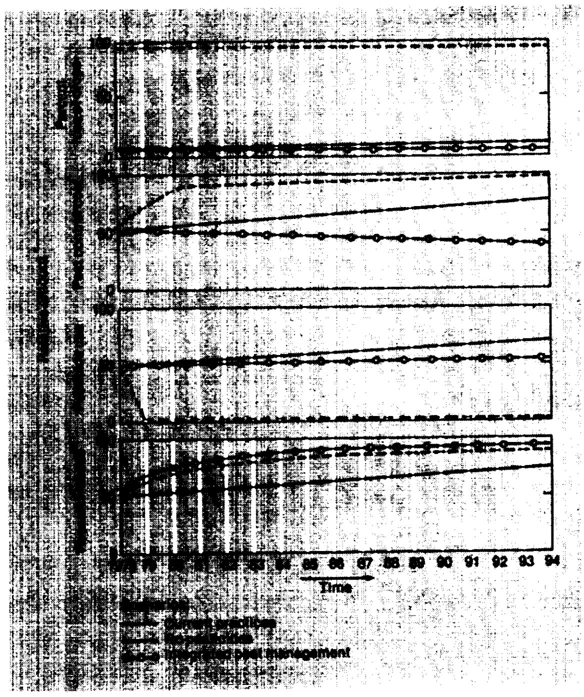


Figure 10.—Schematic Projections for Three Crop Protection Scenarios for Melons in California

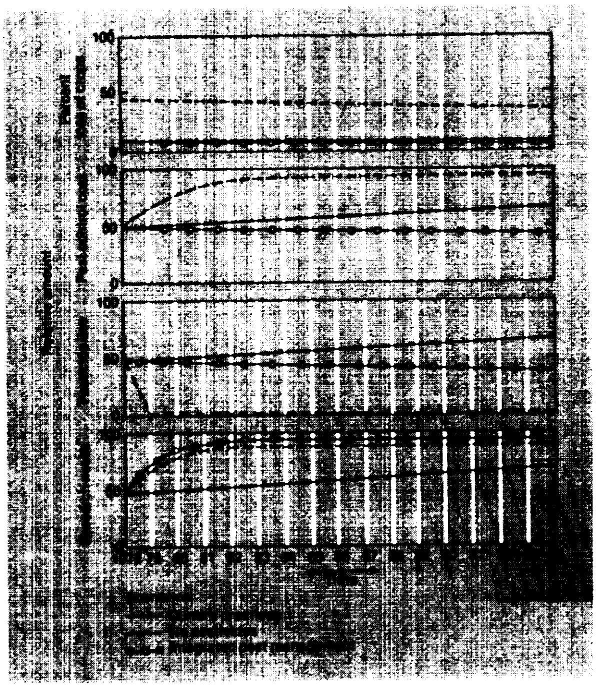


Figure 11 .—Schematic Projections for Three Crop Protection Scenarios for Potatoes in California

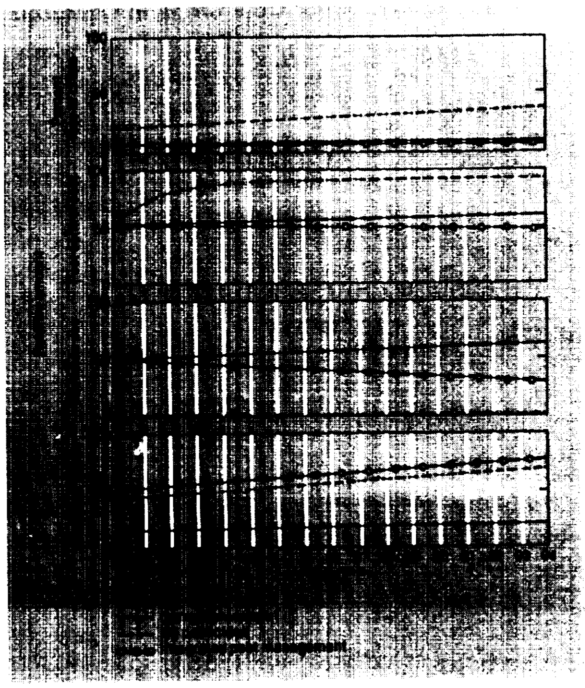


Figure 12.—Schematic Projections for Three Crop Protection Scenarios for Strawberries in California

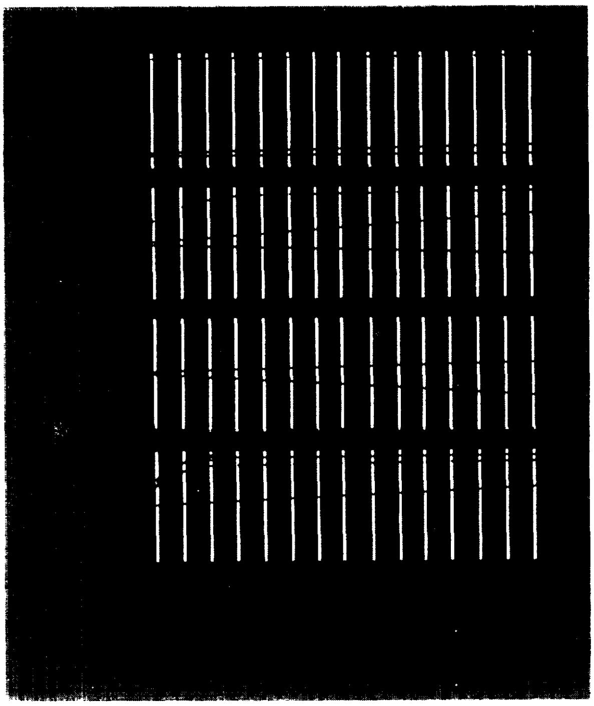


Figure 13.—Schematic Projections for Three Crop Protection Scenarios for Tomatoes in California

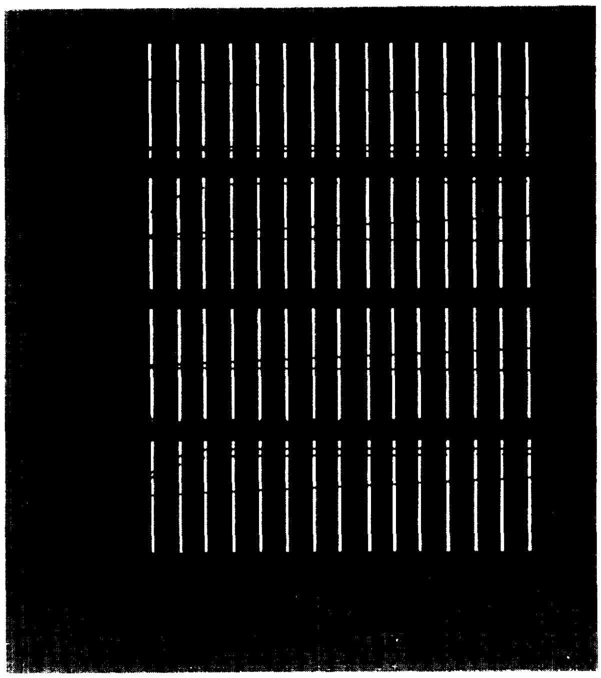


Figure 14.—Schematic Projections for Three Crop Protection Scenarios for Cole Crops in California

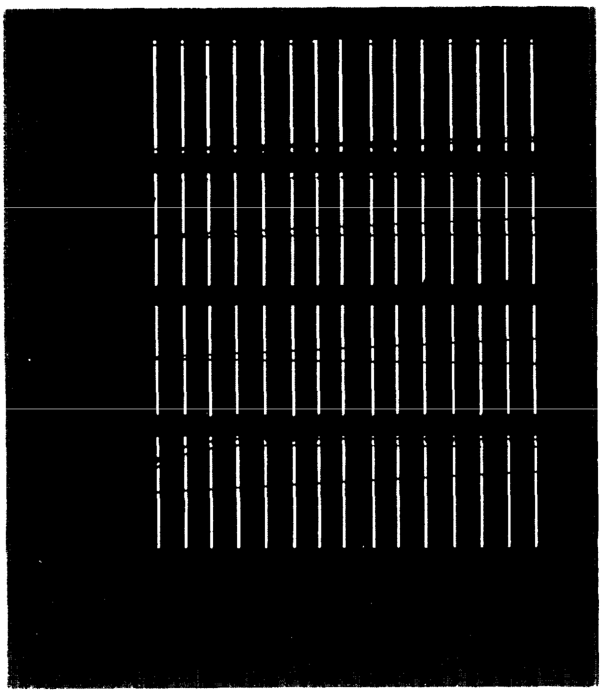


Figure 15.—Schematic Projections for Three Crop Protection Scenarios for Cotton in Texas

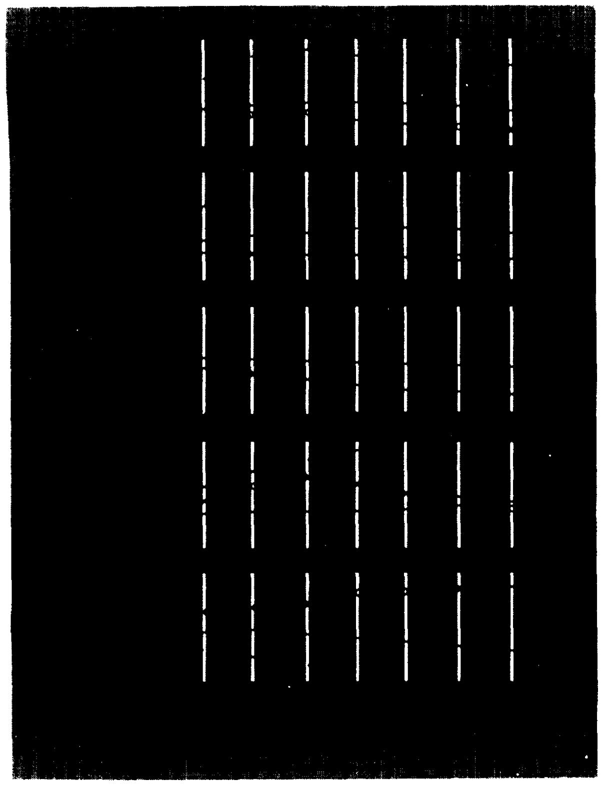
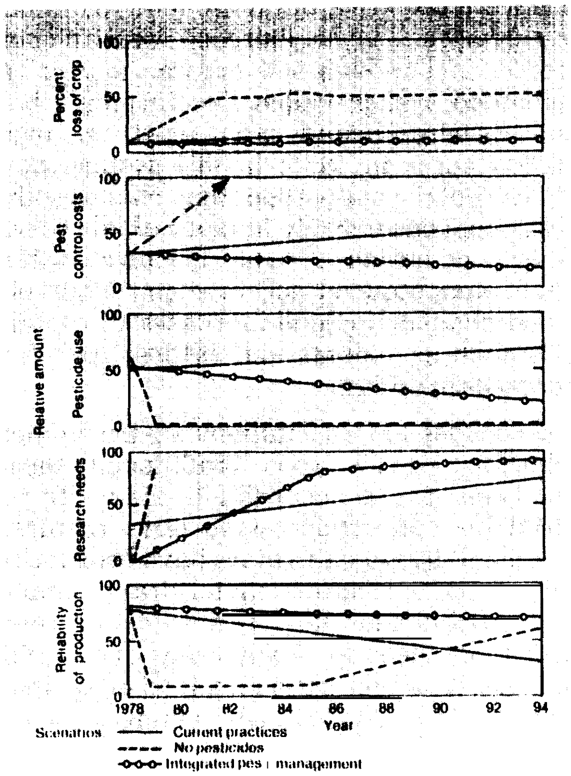


Figure 16.—Schematic Projections for Three Crop Protection Scenarios for Sorghum in Texas



occur are caused by pests against which pesticides are not generally used and for which there are no other known feasible control tactics. The development of other control tactics, such as host resistance, cultural controls, and biological controls and their implementation in 1PM systems will significantly reduce pest losses. It has been estimated that current losses can be reduced up to 50 percent or more on a number of crops.

Production costs for pest control on most crops are expected to be much higher without pesticides than with either current practices or 1PM. The need for increased cultivation, hand weeding, and insect picking would add greatly to production costs. 1PM is expected over time to reduce production costs somewhat, but the reduction will probably be minimal even on high pesticide use crops such as cotton and apple. The reliability of crop production is much improved on many crops by the use of pesticides and is further improved by the use of 1PM programs.

With increased IPM, pesticide use is projected to decrease on all the crops considered; however, the amount of reduction is speculative and may not be as significant as is often assumed by some persons. It is more certain that the pesticides that are applied will be used more efficiently and effectively.

One final projection observed in figures 4 through **16** is the amount of research required for the three scenarios. If pesticides were not available, much additional research would be needed to improve crop protection by other tactics and strategies. Even with an all-out effort, the results obtained for most crops are not expected to be equal to the judicious use of pesticides during the next 15 years. Also evident is the estimate that more research effort is required to develop and implement pest management strategies than to continue with the present mix of tactics. This reflects the greater complexity of the 1PM approach over the use of single tactics and the time and effort required to develop and implement such methods.

A review of the seven regional reports, as well as other reports and the literature, provides little evidence that there will be any revolutionary new technological developments in insect, mite, disease, nematode, and vertebrate control over the next 10 to 15 years. The new synthetic pyrethroids and certain other insecticides are most promising but are likely to be used in place of. and in a manner similar to, existing products. The same situation exists for fungicides, nematicides, rodenticides, and avicides. On the other hand, projections for the use of existing and new herbicides indicate that their use will increase dramatically over the next 10 to 15 years. In fact these materials are creating a revolution in the production of certain agricultural crops in the United States, particularly in wheat and corn, as discussed later in this chapter.

In spite of the great need for improved pesticide application technology. there are few new developments underway that promise to have significant impacts on pesticide use during the next 15 years. Recent research at the University of Georgia has produced a breakthrough in the use of electrostatically charged dusts and sprays. Evidence shows that application rates can be halved using this method without loss of insect control on row crops. Several prototype sprayers are being evaluated on row crops, and research is planned to adapt the principle to tree crops. This development can significantly improve the efficiency of pesticide applications and reduce the quantities used. Another development, resulting from joint research efforts of weed scientists and engineers, is the recirculating sprayer. It can be used effectively for weed control in some situations with greatly reduced rates of herbicide application and lower costs to farmers, The full potential and impact of these and other new developments have yet to be determined. A need still remains for much greater efficiency in aerial application to improve the target-to-draft ratio.

Much of past and even present agricultural production practice has been dictated by disease, insect, nematode, and, especially, weed problems. The development and use of an array of herbicides with various combinations of selectivity, short- and long-residual action in the soil, systemic and contact activity, etc., now provide farmers with the capability of controlling weeds without the usual plowing, fitting, transplanting, and frequent cultivations that have been required for thousands of years. The practice of no-till corn is being widely adopted, particularly in rolling land where soil erosion is severe. Here, weeds are killed by a contact herbicide and seed sown in unplowed soil. The dead surface vegetation remains in place where it prevents erosion by as much as 50 percent depending on slope, rainfall, and soil type.

A similar development is underway in the dry-land Great Plains wheat production area where herbicides are also replacing plowing and cultivation. To conserve moisture, the land is left fallow (not cropped) for varying periods of time. Because weeds remove moisture from the soil during fallow they must be controlled. Until recently frequent cultivations were required, but these tend to dry out the surface soil layer, increase wind and soil erosion, and reduce soil organic matter. A production system called "ecofarming" has been developed and was used on over 100,000 acres in 1978. In this system, herbicides replace cultivation, thus changing the ecosystem considerably in favor of increased soil organic matter, greater moisture conservation, and reduced soil erosion. Other observed changes include increases in certain pests such as rodents and rattlesnakes, but decreases in others.

Herbicides are also influencing production technology for row crops. Traditionally these have been spaced according to the width required for cultivation—wide rows required for animal-drawn cultivators have been modified to accommodate tractor-drawn implements. Herbicides now can eliminate most cultivation needs for many crops and permit spacings based on considerations other than weed control, Again, such changes in the microenvironment favor some pest organisms and reduce others.

The ultimate potential for changes in agricultural production methods created by herbicides has yet to be determined. Similarly, the secondary impacts on crop protection problems are not fully known or understood. Obviously, much more interdisciplinary crop protection research is required.

A similar but unknown potential for changing cultural production systems exist in tropical agroecosystems, even rather primitive forms (see chapter VII).

A trend observed in California toward strawberry production in nearly sterile soil is likely to continue and may expand to other high-value crops. For example, California farmers are finding that yields of other crops are significantly higher when planted in land fumigated the preceding year for strawberry production. For many years fruit growers have had replant problems caused by nematodes and other pests that are now controlled by soil fumigation. Some form of soil fumigation is routine practice in greenhouses. The use of sterilized soil is possible only if a satisfactory soil fumigant or other method of accomplishing the same end is available. Because the current cost of such treatments is high [$450 to $!500 per acre for strawberries), the cost/benefit ratio is favorable only for high-value crops. If an inexpensive safe material or method were available, soil sterilization would expand and spread widely. No such material or method is now available, and all commonly used liquid soil fumigants are on the current RPAR (rebuttable presumption against registration) or pre-RPAR lists (April 1979). Research data on microwave soil sterilization shows that this method can be used to kill weed seed and some microorganisms but is not yet proven technologically nor is it considered to be feasible economically.

Chemical pest control includes the use of hormones for control of insects and weeds. Insect juvenile hormones or mimics do not appear promising except for control of certain species such as mosquitoes and house flies, which are a problem as adults but can be controlled as immatures. The recently discovered anti juvenile hormones appear much more promising, but none are available yet with a satisfactory spectrum of activity. A hormone that either inhibits or induces seed germination would have a potential use in weed control, but such chemicals are not yet available for practical use. As promising as these approaches appear to be, widespread success seems unlikely in the next 10 to 15 years.

Projecting the use of other control tactics is more difficult than for pesticides. We have already commented on changes in cultivation procedures now taking place and mentioned their potential impact on pest populations. Cultural controls including plowing and cultivation have been recommended and used for generations for the suppression of pests other than weeds. Some of these are being reexamined and may have potential in 1PM systems. Modern equipment permits the timely, efficient execution of operations that were once difficult or even impossible. Certain changes no doubt will be made for pest suppression purposes; however, no radical changes are likely. The use of rotations, time of planting, trap crops, and habitat diversification are based on economic and managerial considerations. These practices are not expected to change appreciably within the next 10 to 15 years. With the potential for increased costs of irrigation water and fertilizers during the projection period, increased manipulation of these tactics for managing pests is unlikely; in fact, decreased use of water and fertilizer for control will become less attractive economically.

Although biological control is of only limited use in the control of agricultural pests; insects, mites, and many minor arthropod pests would be major problems in the absence of the biological control provided by parasites, predators, and pathogens. The sudden elevation of secondary insect and mite pests to major importance following applications of certain insecticides provides ample evidence of the role of biological agents. Other major weed, plant pathogen, vertebrate, and nematode pests are controlled less effectively by biological agents.

It is entirely possible that at least some currently important arthropod pests will be effectively controlled biologically during the next few years. An excellent example is the use of a small wasp parasite from India that has effectively provided season-long control of the Mexican bean beetle when released early in the season.

Based on experience over the past few years, the projection for the increased use of host-plant resistance is not encouraging. Much of the breeding work to incorporate resistance into commercially available cultivars has been discontinued in State experiment stations and Federal laboratories on the basis that this work is more appropriately done by commercial seed firms. The latter have not been effective in recent years either because of a lack of incentive or a lack of suitable resistant germ plasm and the genetic information required to combine resistance with desirable agronomic qualities. Experience indicates that the use of resistant cultivars is likely to decrease rather than increase over the next decade unless strong publicly supported efforts in host-plant resistance programs are implemented.

Autocidal (sterile male release) control of insects has been effective against certain species, especially the screwworm and the fruit flies, and has been demonstrated to be effective against low populations of codling moth and onion maggots but is not now economically competitive with other control methods, The autocidal method has not been effective or practical against moderate-to-high insect populations or where heavy migration is common. Technical problems and the expense of mass rearing and sterilization have limited the range of uses for this innovative and ecologically sound method of insect control. No large increases in its use are anticipated over the next 15 years except possibly in conjunction with eradication projects where costs are not the prime consideration.

The use of insect pheromones for control has been demonstrated successfully using two approaches. The use of pheromone-baited traps to control insects by eliminating males and reducing mating is subject to the same limitations as the sterile male release method. Although the use of these pheromones for control by "male confusion'" has been successful (Gossyplure H,F. is registered and being used by some cotton farmers in Arizona and California), there have been enough failures in experimental testing to suggest that there are still some unsolved problems. However, it is expected that these materials will be used commercially for direct control of some insects within the next few years.

Eradication of pest organisms is perhaps the ideal solution for introduced species if it can be accomplished without incurring unacceptable costs and risks to human health and the environment, Experience indicates that eradication is not feasible for established species, For example, the barberry eradication program is being terminated in 1979 after 61 years of unsuccessful effort. The reduction in numbers of barberry, the alternate host of stem rust of wheat in the Great Plains area, may have helped to reduce the threat of this severe disease, but the goal of eradication is now deemed unattainable by any acceptable means. The fire ant eradication program has also failed. Success seems attainable only with newly introduced species before the infestations become widespread and well-established. Some organisms such as nematodes simply cannot be eradicated. Any proposed eradication program must be carefully examined in terms of probability of meeting objectives, Political pressures for eradication are considerable but must be tempered by the reality of experience. A second experiment to evaluate the feasibility of boll weevil eradication is now underway. Many knowledgeable people are convinced that eradication of this pest is not feasible with present technology at any reasonable cost and risk to the environment. Certainly eradication will not be an important part of agricultural pest control except where new pests may be introduced.

Quarantine efforts to prevent the introduction of new pests are partially successful and judged to be cost-effective but are inadequate with present transportation facilities and practices for people, animals, and goods. Modifications and improvements are needed to adapt outdated quarantine methods to today's conditions.

Organic farming, as defined in this report, is crop production without using synthetic fertilizers, pesticides, antibiotics, and other agricultural chemicals. In considering organic farming as it affects crop protection against pests, we assume that acceptable pesticides are only those derived from plants, such as rotenone, nicotine, and pyrethrum. However, others suggest that organic farming can involve a minimum, or minor, use of synthetic pesticides, If that were the case, the distinction between organic and conventional farming is obscured and organic farming approaches the 1PM concept regarding pesticide use. Unfortunately, most of the arguments for and against organic farming are qualitative in nature; there are scant quantitative comparative data on the value of organic versus conventional farming for crop protection.

The opportunities for successful use of organic farming methods vary greatly with crop susceptibility to pests, climate, availability of labor, season, and regulations regarding undamaged produce in the marketplace. Certain fruit and vegetable crops are almost completely destroyed by a variety of pests if not properly protected with appropriate pesticides. In other cases, the amount of hand labor involved in weeding is prohibitive for large-scale commercial agriculture. However, some crops that are less severely attacked and for which nonpesticidal controls are known can be produced successfully on a commercial scale without the use of synthetic pesticides, although yields may be lower than with conventional methods. These include several field and forage crops such as alfalfa and field corn. At present, very few commercial farmers within the seven cropping regions of this report are using organic methods of crop production. The estimated 10,000 to 15,000 organic farms in the United States are relatively small operations for which organic farming is most applicable.

Because of the considerable interest in organic farming and the increasing demand for organically grown foods, research is needed in this area. At present, those interested in producing organic foods cannot obtain from county agents or agricultural experiment stations much, if any, information on how to manage pests without pesticides. Research is needed to evaluate the value of methods now being proposed, such as companion plantings, and to develop new' techniques, Much of present research on developing 1PM systems involves approaches that may be useful to organic producers. The tactics of genetic host-plant resistance, encouraging biological control organisms, and cultural controls, along with other tactics, must be improved and incorporated into demonstrated production systems to make this approach more widely attractive in commercial agriculture.

A careful study of pest control in the seven regions indicates that there is now' much more 1PM being practiced than is generally recognized. This is particularly true for wheat in the Great Plains States where extensive use has been made of cultural, host-plant resistance, and chemical controls for weeds, insects, diseases, and vertebrates, and where extensive disease-monitoring systems are used. Pest management systems have been integrated into wheat production practices with due consideration of environmental factors. The impetus for 1PM development and implementation has been economics (wheat is a low-value crop) and the lack of appropriate single-control tactics. The present level of 1PM, however, is still far from its potential on this crop. Various levels of 1PM are used on the other crops.

We project that the implementation of 1PM in crop production in the United States will proceed slowly over the next 15 years unless much greater inputs are made at the National and State levels. The major obstacle to faster adoption is lack of demonstrated feasible 1PM systems. This is due to a number of factors, but lack of information on the basic biology of pests and crops, lack of established economic thresholds, cost/benefit analyses of 1PM programs, and the primitive state of predictive modeling and agroecosystems analyses are the most important.

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Chapter IV

Present Problems, Concerns, and Most Promising Approaches

Present Problems, Concerns, and Most Promising Approaches

In chapter II the crop protection problems and concerns for each of the seven regional systems are described. In this chapter these problems and concerns are grouped according to type of control tactic and strategy and are presented along with others generally recognized for pest control, which are followed by several areas of general concern. Finally, several approaches are presented that appear to be most promising.

SPECIFIC AREAS OF CROP PROTECTION

Cultural Controls

Crop rotations developed in the first half of the 20th century were practiced. in part. to centrol certain pests including weeds. For economic and other reasons many of these old rotations were replaced by' monoculture; (planting the same crop on the same land each year) or by rotation with different crops (e.g., the rotation of soybeans instead of oats with corn in the Corn Belt States). Such changes in the agroecosystem often have impacts on the incidence of pests, The studies of the seven regional systems clearly show that such impacts may be both negative and positive depending on the nature of the specific pests. They also show that the changes are not predictable and that a very serious knowledge gap exists in understanding the basic interactions between pests and their physical and biological environments. Until this information is available, pest management by habitat modification through cultural means can only be developed on a trial-and-error basis. When several pests are involved, as on most crops, this process is time-consuming and expensive.

Because of the rapid acceptance of new technologies by American farmers. there is concern that new cultural practices could c; ıuse excessive pest-caused losses over wide areas. The rapid adoption of no-till corn is an excellant example. By 1977 minimum t ill age (no-till) methods were used on over 300,000 acres of corn in Maryland, and many of these acres were show'ing enough insect and slug damage by these formerly very minor pests to warrant pesticicle applications. The only avaiable effective insecticide properly registerd for use in this situation was on the RPAR (rebuttable presumption against registration) list. Similar concerns exist for no-till corn in other areas and for other crops involved in major changes in production technology.

Such cultural changes may or may not be totally sound economically, environmentally. or socially. only time with further research and experience will provide the answer. However, the need to adapt pest management practices to new production methods must be considered early and given adequate attention. Crop cultivars resistant to new pa thogens, nematodes, and insects may be the longterm answer. but for the short term, appropriate pesticides must be used if available. If pest problems become a limiting factor, even the most promising new cultural practices may have to be abandoned.

Host-Plant Resistance

Concern over the present and future use of pest-resistant cultivars lies in two areas: 1) the effective use of known resistant germ plasm and 2) the identification and preservation of new sources of resistance.

The uses of pest-resistant wheat and corn cultivars on a large scale for both diseases and insects are classic success stories of host-plant resistance. However, recent trends in the Great Plains Wheat Belt are disturbing. The acreage of Hessian-fly-resistant wheats in Kansas and Nebraska has decreased from about 66 percent in 1973 to about 42 percent in 1977. Hessian fly infestations have increased where susceptible cultivars have been planted. In South Dakota in 1978, in an area not normally heavily infested, an estimated 1.25 million acres of spring wheat were infested resulting in losses of $25 million to $50 million, An even greater decrease in resistant-wheat acreage is expected in the next 2 to 5 years as a result of recent releases of cultivars that have improved agronomic traits and disease resistance but which are susceptible to Hessian fly, Insect resistance has not been a significant component of commercial breeding programs, and none of the new commercial wheats have resistance to Hessian fly, In 1972, U.S. Department of Agriculture (USDA) research on wheat stem sawfly was terminated. The resistant cultivars presently grown are expected to be replaced with susceptible cultivars, and infestations of this pest are also expected to increase.

A similar trend towards the use of corn hybrids more susceptible to corn borer is reported in parts of the Corn Belt with concomitant increases in infestations and insecticide use, The reduced use of resistant crops does not extend to all areas and all crops. For example, greater use is now being made of resistant cotton.

The reasons for the reduced use of known germ-plasm resistance for such important insects as the Hessian fly, wheat stem sawfly, and the corn borer are complicated. Because resistant cultivars have been effective in reducing damage and pest populations for many years, there is little recent evidence of the potential destructiveness of these insects. As a result. new generations of farmers do not demand resistant cultivars, This trend has been abetted by the deemphasis of breeding programs in many State experiment stations and USDA laboratories. The latter development was based in part on the assumption that commercial seed companies could do the necessary work to maintain and increase pest resistance. Experience indicates that this was not a correct assumption. The trend away from plant resistance-breeding research in publicly supported institutions has been abetted by the erosion in Federal support for agricultural research and the concept among administrators and researchers that plant-breeding research of this nature is less prestigious than basic studies. Lacking demand by growers and the stimulus and information from Federal and State experiment stations, commercial seed companies have also deemphasized efforts to incorporate insect and even some disease and nematode resistance into new cultivars, The result of this trend could have disastrous consequences not unlike the southern corn leaf blight epidemic of 1970. Although the corn blight epidemic required only 1 year to correct (the problem was one of cytoplasmic susceptibility), insect, disease, and nematode epidemics brought on by the use of susceptible cultivars could take several years to correct.

Development of pest-resistant crops with good agronomic characters is a lengthy and expensive procedure, However, the cost/benefit ratio, especially the cost in terms of use by growers, is very small. And perhaps of more importance, resistant cultivars can be used by small as well as large growers and even by gardeners. Adequate funding of public research to ensure continued development of resistant crop cultivars appears to be not only desirable but imperative for long-range effective pest management and the public good.

Germ plasm resistant to many diseases, nematodes, insects. and mites is not available for a number of crops. This is most pronounced for crops that originated outside centinental North America. Areas where plants and their pest coevolved are good sources of resistant germ plasm. In some cases, wild progenitors of our cultivated crops in which resistance may be found are being lost. In order to find and preserve these sources, search and conservation projects are needed. These efforts should include vegetables and fruits as well as major crops such as wheat, corn, and soybeans. A new opportunity exists with respect to soybean as improved relations with China afford considerable promise in developing programs to locate pest-resistant germ plasm where soybean originated,

Present USDA/State plant introduction programs do not adequately meet the need for developing pest-resistant crops. Recent efforts to increase introductions and establish germ-plasm banks have been underfunded and developed slowly. Programs such as the one for rice at the International Rice Research Institute in the Philippines where thousands of genetic lines are maintained and evaluated for resistance to pests are needed. Such projects could be cooperative with other countries with similar interests. The costs of these programs are high but the almost certain potential benefits are much, much greater.

Biological Controls

Just as the major emphasis on breeding for host-plant resistance in the past has been for disease control, the greatest effort in biological control has been on insects and mites. Recently however, more attention is being given to biological control of pathogens, weeds, and vertebrates.

A few spectacular successes in biological weed control have occurred—i. e., the control of prickly pear cactus in Australia through the introduction of insects that feed on this plant and that are indigenous to the area from which the weed originated. Another example is the control of alligator weed in irrigation canals and ponds in the Southeastern United States through the introduction of a leaf- and stem-feeding flea beetle from South America. Biological control works best when only one weed species is the problem, as opposed to having several species involved. Good examples are lantana and the prickly pear cactus, which are primary weeds that take over certain habitats. Control of these by any specific means including biological is satisfactory. However, the use of specific controls for single species in agricultural crops is not satisfactory because other weeds quickly take over niches left by the controlled species.

Biological control of plant pathogens and nematodes may be more promising than was thought earlier. A recent breakthrough is the use of one bacterial species (Agrobacterium radiobacter) to control crown gall on apple and other crops caused by another bacterial species in the same genus IAgrobacterium tume~aciens). The lack of knowledge of the basic interactions among species of micro-organisms limits judging the potential of this approach for control of these pests.

Vertebrate pests are normally held in check by predators, parasites, and disease. Attempts to use specific biological control measures have had few successes and many failures. The introduction of the ferret predator into Puerto Rico failed to control rats and actually added a new pest to the island. The introduction of' myxomytosis disease to Australia to control rabbits succeeded initially, but over several years strains of rabbit evolved that were resistant to the disease, The rabbit is still a pest but is not as serious a problem as formerly.

As mentioned earlier, the greatest effort in biological control has been against insects and mites. So-called "classical" biological centrol—i. e,, the introduction of agents to control exotic or native pests—has produced the most spectacular results. The control of the cottony cushion scale on citrus in California through the introduction of the Vedalia beetle in 1899 is perhaps the best known example, There are recent successful examples such as the control of the alfalfa weevil and citrus blackfly with introduced parasites. The other phase of biological control is to increase naturally occurring agents through manipulating the environment or by artificially propagating and distributing them. Spores of the bacterium causing milky disease of Japanese beetle larvae have been used for many years to reduce populations of this introduced pest. Currently efforts are underway to propagate and disseminate virus diseases of certain insects and tiny wasp parasites of the eggs of several insect pest species.

A substantial number of the major insect pests of agricultural crops in the United States are introduced, and there is good reason to believe that they can be effectively controlled by biological agents introduced from their points of origin. The major obstacle to greater success is the low level of support available for facilities, personnel, and operational funds to identify, investigate, introduce, and establish these beneficial organisms. The USDA 1979 budget for classical biological control is $2 million. With the exception of California and Hawaii, the States do not have strong programs, Also, according to some experts, the effort within USDA could be improved by a vertical rather than a primarily horizontal approach—i.e., having the same scientist or team conduct the total effort from discovery through establishment rather than different groups being responsible for each operational stage. In view of the potential benefits to be derived from the successful introduction of biological control agents, the low levels of Federal and State efforts seriously limit the progress of this important program. An evaluation of past efforts indicates that the benefit/cost ratio has been 30 to 1 In addition to the direct dollar benefit, there has been a reduction in both crop losses and the use of insecticides. While biological controls are not permanent or uniform each year, they tend to be more permanent than most other tactics and require little or no further expense once established.

Quarantine

A study of tables 2 to 14 shows clearly that many of our major weed, insect, mite, pathogen, nematode, and vertebrate pests are introduced. Some are serious in the United States but are of little importance in their native habitat. Lack of biological control agents, the presence of more susceptible hosts, more favorable environmental conditions, and other reasons are cited as causes for this phenomenon. But regardless of the reasons, the potential for serious and even disastrous crop losses that result from the introduction of additional new pests is very real. There are many identified potential pests and undoubtedly many others of unknown potential.

The rapid movement of people, food, fiber, and other goods about the globe makes effective quarantine a difficult task. As a consequence, present efforts and methods are not considered to be as effective as formerly. There is a need to develop and implement improved technologies for preventing the introduction of undesirable organisms into the United States. Also a need exists to improve survey and identification capabilities for exotic pests in order to find new introductions before they become too widespread and well-established to be eradicated,

Eradication

Large sums of money have been, and still are being, spent in attempts to eradicate insect and weed pests. Successes have been limited to a few situations such as elimination of the Mediterranean fruit fly from Florida and California and the screwworm from the Southeastern States. In all these instances, newness or restricted winter survival area (screwworm survived winter only in southern Florida) limited the infestations. Eradication efforts against barberry and the imported fire ant failed. Large sums of money and much manpower are now being utilized in a second boll weevil eradication experiment. With present technology, many knowledgeable scientists consider the probability of successful eradication of this widespread, well-established insect pest of cotton to be extremely remote.

Eradication is attractive because success offers a permanent solution to a pest problem, at least until the next introduction. Eradication programs are politically attractive because of their visibility and because, while in progress, they offer short-term relief from attacks of the pests involved, but permanent success is difficult, if not impossible, to attain for most pests using present technology. Also, the potential hazards to human health and the environment must be considered. There is much concern that funds and manpower so badly needed for other crop protection efforts will be wasted on technically unsound eradication projects that are doomed to failure from the beginning.

pesticides

Present problems and concerns for pesticides for agricultural crops focus on health hazards, environmental hazards, and availability and effectiveness. While this report has concentrated on crop protection technologies and strategies, concerns about human and environmental hazards associated with the manufacture, distribution, and use of pesticides have been expressed by assessment panel members, by participants in a public meeting, and by the public media.

Health problems associated with pesticides involve acute (or subacute) and chronic low-level effects. In the United States, where medical services are readily available and poison control centers have been established, acute effects are relatively clear-cut and can be identified correctly. There are concerns, however, that some effects, particularly the subacute, are not identified and reported. Also some concern exists that some illnesses are incorrectly ascribed to pesticide intoxication.

The safe use of pesticides has received great emphasis in the United States over the past 25 years. The effort has succeeded despite the vast increase in the availability and use of pesticides during this period; the incidence of fatal poisonings directly attributed to pesticides has dropped continually—from 152 in 1956 to 31 in 1976—while total population and total accidental poisoning deaths have more than doubled. The meager data that are available from developing countries indicate much higher death rates, even though pesticides are not used as extensively as in the United States. Although acute toxicity episodes can be minimized through education, they remain a continuing hazard, especially where educational and medical facilities are minimal.

The phenomenon of delayed neurotoxicity for a few pesticides has received considerable attention in recent years following the discovery that permanent weakness, ataxia, and paralysis can be induced by a single sublethal exposure to leptophos, an organophosphate insecticide. EPN, also in the same chemical group, has caused similar effects in test animals. Fortunately, most organophosphate pesticides do not cause these delayed problems.

The long-term exposure of humans to comparatively low levels of many pesticides in the environment and in the body is of great concern because of known and suspected potential harmful effects. These effects are many and may include eye irritation, neurological and reproductive impairment, teratogenic effects, cancer, and others.

Real human hazards that result from long-term pesticide exposure are extremely difficult to assess. For example, the induction period for cancer may be in the range of 20 to 30 years with complications resulting from exposure to other synthetic and natural potential carcinogenic agents. Thus, human epidemiological studies are difficult to conduct and produce inconclusive results. In spite of the fact that chlorinated hydrocarbon insecticides, particularly DDT, have been in the environment and present in human tissue for more than 30 years, and certain inorganic pesticides for nearly a century, no detectable effects on the human population have been proven. However, this does not prove that no effects have occurred or that none will occur.

The organochlorine insecticides (DDT, aldrin, dieldrin, endrin, heptachlor, and chlordane) are persistent chemicals and have been commonly found in human foods and human tissues. Since most uses for these products have been discontinued in the United States, a steady decline has occurred in the concentration of these materials or their metabolizes in human adipose tissue. Extensive toxicological studies on several experimental species including mammals, birds, and fish must be conducted before pesticides can be registered for use, Currently there is much concern and controversy about extrapolating from animals to humans, particularly regarding carcinogenicity.

With the exception of the inorganic and organochlorines, pesticides or harmful metabolizes are relatively short-lived in the environment. A few herbicides persist in the soil up to 12 to 18 months but most disappear in considerably less time. Less is known about residues in air that serve as a global transport medium for pesticides. Water pollution by pesticides exists in most surface waters in the United States at very low levels, Organochlorine insecticide residue levels reached a peak in 1966 and declined in succeeding years as the use of these products was reduced,

Pesticide residues are also found in plants and animals. The phenomenon of "bioaccumulation' '—i. e., the process in which low levels of a chemical in organisms, such as algae, at the bottom of the food chain accumulate through the food chain until extremely high levels occur in animals such as fish or birds at the top of the chain—has resulted in serious losses of some wildlife species.

Until the 1960's detailed evaluations of the impacts of pesticides on the environment had not been done. Because of this and because the world ecosystem is large and complex, only limited knowledge is available on the subject except in the area of acute toxicity. Generally, acute toxicity problems for wildlife are known and managed at acceptable levels except for accidents or misuse.

On the other hand, much concern exists about known and unknown chronic effects on wildlife from low levels of exposure to pesticides. These can be subtle effects such as the eggshell thinning in the bald eagle, the peregrine falcon, and the brown pelican which seriously reduced the reproductive potential of these species. A comparable reproductive problem developed in a variety of fish and food-chain-dependent mammals. These reproductive disorders have declined with the elimination of DDT and most other organochlorine pesticides from agricultural and forest uses. Concerns have been expressed for other chronic effects such as growth inhibition, acute nervous stress, oncogenesis, and others. Indirect effects of pesticides on wildlife are also thought to be significant. Suppression of food, obviously, is a potentially harmful effect,

Capabilities for detecting and measuring pesticide residues in the physical and biological environment now extend to parts per billion or less. Unfortunately, little is known of possible hazards of such low residues. Risks must be weighed against benefits to determine whether or not specific chemicals should be approved for use in agriculture. Thus, their use should be limited to essential needs where risk/benefit ratios are favorable and where other control tactics are insufficient.

There are serious concerns about the future availability and effectiveness of pesticides. For all the crops included in this report on which pesticides are used extensively, there was concern that effective materials are lost because of regulations, resistance, economics, or combinations thereof more rapidly than replacements are found, developed, and introduced. This situation is most critical for insecticides and miticides, is potentially very critical if present RPAR's fungicides are lost, and is least critical for herbicides. The lack of safe and effective rodenticides and avicides is also a problem. For short periods during the past few years, no effective insecticides were available to control insect complexes on cotton in parts of Texas and Mexico, and no miticides were available for control of mites on apples in Washington. Several emergency registrations of new insecticides on fruit, vegetables, and cotton were necessary because existing materials were no longer effective or registered.

The number of registrations of new molecular structures for pest control for agricultural crops has dropped sharply during the past 10 years. With the continuing loss of effectiveness of current products due to resistance, and losses due to regulations and economic factors, the situation is likely to worsen, especially on minor crops.

To date the problem of acquired Weed resistance—i. e., the evolution of weed strains resistant to an herbicide—is not serious in weed control even though examples exist. The major resistance problem in chemical weed control occurs when naturally resistant weed species survive, thrive, and soon take over without competition from other weeds. Such problems are managed by using combinations of herbicides, changing herbicides, and crop rotations. The loss of inexpensive selective herbicides, such as the phenoxv materials **2,4-I)** and **2,4,5-T'**, would create a difficult problem for a number of agricultural and nonagricultural users.

A major overall concern about pesticides is the lack of availability of compounds possessing the required range of activity against pests. This is particularly the case in developing pest management systems that involve the use of pesticides. For some situations, an insect icicle or miticide with a verv narrow range or short residual toxicitv is required to reduce a pest species without disrupting biological control agents. In other cases, pesticides may be required that control a broad range of weeds, pathogens, or insects. Sometimes short residual contact materials are required while for others, as for control of soil insects or season-long weed control. residual effectiveness may be required for several months. When no pesticide with appropriate activities is available, substitutes often have to be used at higher rates with repeated applications and sometimes with harmful effects on beneficial species. A limited range of pesticides restricts the potential for pest management on many crops.

The inefficiency of pesticide application technology is another concern. In some applications as little as 25 percent of the toxicants reach the target. This inefficiency is not only wasteful but can cause secondary health and environmental problems outside the target area,

The difficulty in obtaining registrations of pesticides for minor crops and minor uses is another serious problem that the 1979 Amendment to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) is designed to alleviate. A further concern is the problem of developing and registering new and novel types of control agents such as insect pheromones and hormones or antihorrnones, allelopathic materials, and microbial pesticides.

GENERAL PROBLEMS AND CONCERNS

Pest-Caused Losses

The amount of land now cultivated is 50 percent greater than would be required if there were no pest-induced losses. The amounts of fertilizers, energy requirements, labor, capital, and other inputs are also correspondingly greater. The total direct cost to this Nation is enormous. Secondary costs may, in the long run, be even greater. For example, soil erosion losses that result from cultivation of marginal, sloping lands and tillage for weeds and other pest controls represent significant costs to society while the costs of pesticide use in terms of health and the environment have only recently been addressed.

The economic impacts of increased losses that would occur if no pesticides were used on grains and soybeans have been estimated based on economic models (see Volume 11—Corn). Food grain, feed grain, and oilmeal prices would increase 60 percent, 200 percent, and 171 percent, respectively. Consumer welfare would decrease by over $38 billion annually, but farm income would increase by $27 billion with a net economic efficiency loss of about $11 billion annually. These estimates were made on a short-term basis; the long-term impacts are not known.

Although estimates were not made of the impacts of reduced pest-caused production losses as a result of the use of alternative pest management strategies, improved pest control can be expected to favor consumer welfare and eventually the entire community, For example, if pest-induced losses could be reduced by one-half, current production could be maintained with a 30-percent reduction in agricultural land use.

A major problem with the above type of estimating and generalizing is that crop losses are not uniform across crops nor are the methods of control. As stated earlier, pesticides are the primary control tactic for specific pests on some crops while host resistance, cultural, or biological control may be basic for others. Also, direct measurable losses for some crops are thought to be minimal, while for others there are appreciable known losses against which no economically feasible controls are available.

Instability of Pests and Pest Control Tactics

Without doubt the overriding problem and concern in crop protection on agricultural crops is the ephemeral nature of most control tactics. This is due in large measure to the evolutionary process by which organisms adapt to their environments. The process has been going on as long as life itself, but in agriculture, evolution of pest species is accelerated by intense selection pressures either for resistant strains or resistant species. The practices of plowing and cultivating soon result in the elimination of perennials and great increases in high seed-producing annual weeds. The use of stem-rust-resistant wheat cultivars eventually results in rust strains capable of overcoming such resistance. Continual exposure of pests to disease or other biological control agents can lead to resistant pests as in the case of rabbits to myxomytosis in Australia, The rapid evolution of pesticide-resistant insects and mites is documented by the long list of species with acquired resistance. A similar pattern is developing for some plant pathogens. Some rodents are now resistant to anticoagulant control agents. Many pesticides, especially insecticides and miticides, have been short-lived relative to long-term crop protection.

In addition, there are the problems of the spread of pests into new areas, of the introduction of exotic pests, of the adaptation of indigenous species to cultivated crops and changes in agricultural practices, crops, and cropping systems that impact on the nature and intensity of pest problems. Weather, too, can drastically change pest problems from year to year and even within the same year.

Thus, pest problems and solutions are continually changing and evolving and always will. The great concern is whether adequate control tactics and strategies can be made available to avoid serious or catastrophic losses. The present national effort, both public and private, may not be adequate to maintain present levels of crop protection, let alone reduce losses caused by pests.

Inadequate information to Develop and Implement Effective Pest Management Systems

Another general problem and concern in crop protection that emerged from the original crop studies is a lack of knowledge that must be available as a basis for developing effective, economical pest management systems for agricultural crops. The identified knowledge gaps are:

- basic biology of pest organisms;
- interactions between pests and hosts;

- interactions between pests and their bio logical environment;
- pest detection and monitoring capabilities;
- prediction capabilities;
- economic thresholds, particularly for multiple-pest complexes;
- impact of crop rotation, tillage, pesticide use, and other production practices on pest problems; and
- prevention or delay of pest resistance to control tactics, especially pesticides.

Not all of the above information is needed to initiate pest management; relatively simple systems can be put in practice with moderate levels of information. However, further advances will occur largely on the basis of new knowledge in these areas.

Lack of Manpower

All the regional study teams reported that there is not enough available scientific manpower to significantly increase the rate at which pest management is now being developed. Estimates of the number of additional scientific man-years required to fill the knowledge gaps in a reasonable length of time and to make significant gains in crop protection indicate that appreciable increases are needed for all the cropping regions considered.

Another manpower problem is the number of persons needed for integrated pest management (IPM) implementation to perform scouting, consulting, and other components of pest management on agricultural crops. The USDA/Science and Education Administration/Extension Service estimates there will be over 3,600 private farm advisors (consultants) and 63,000 seasonal scouts needed by 1986. The Extension Committee on Organization & Policy (ECOP) Pest Management Planning Committee estimated 5,000 advisors and up to 70,000 seasonal scouts. Recently the National Agricultural Chemicals 1PM Committee estimated a need for 7,600 to 10,600 supervisory personnel and 61,300 to 82,600 scouts to fully implement 1PM on cotton, corn, sorghum, soybean, alfalfa hay, peanut, rice, commercial vegetables, fruits and planted nuts, and tobacco. The three estimates are remarkably close. The assumption is made that most scouts and advisors or consultants will be in the private sector and supported by the primary beneficiaries, the producers.

The above estimates of personnel requirements may not be very accurate, but even if the demand should be only 50 percent of these, a sizable number of persons must be trained and paid. The added manpower will replace "insurance applied" pesticides and other tactics used to ensure that unacceptable crop losses will be avoided. In other words, manpower is to be substituted for unneeded pesticide use, tillage, etc., and to ensure maximum effectiveness of all tactics. The eventual level of substitution will depend on economics and the value to the producers of the crop protection service provided by the private sector.

The lack of manpower required for teaching and training personnel needed to develop and implement improved crop protection tactics and 1PM systems is also a problem and concern for those institutions responsible for such activities.

Lack of Alternatives to Chemical Pesticides

There are enough known and potential problems with the use of most pesticides to indicate that research efforts must be increased to develop alternative control tactics. The regional studies illustrate that there are many insect, disease, nematode, and weed problems for which there are no alternative control techniques to pesticides. Without the use of pesticides, diseases and insect pests of apple and potato, boll weevil on cotton, strawberry diseases, insects and weeds, all classes of pests on vegetables, and weeds in wheat, corn, and soybean would take intolerable tolls in production of these crops. The lack of alternatives is not only a concern but creates the potential for a major dislocation in food production should critical pesticides become unavailable for use. Potential alternatives, as indicated in earlier sections, may take years to develop.

MOST PROMISING APPROACHES

It is not practical to concentrate on any one control tactic to the exclusion of others. If crop losses in the United States and elsewhere are to be reduced, efforts must be made on all fronts. The availability of a suitable array of control tactics is essential for the future of crop protection and pest management programs.

The primary responsibility for developing, implementing, and maintaining these tactics lies in the public sector, in the private sector, or in both sectors. Those depending on public sector teaching, research, and extension efforts are host-plant resistance, cultural controls, biological controls, monitoring, modeling, and prediction technology. Industry often interacts to enhance these, especially in designing and producing equipment, Quarantine and eradication programs are almost entirely publicly supported.

The private sector has primarily developed and introduced traditional pesticides, while the public sector has greatly influenced and controlled the use and regulation of these materials. Application technology efforts have been supported by both.

The development and use of microbial pesticides, hormones, antihormones, pheromones, and allelopathic agents have resulted from the efforts of Federal, State, and industry scientists.

The need for an integrated approach to crop protection is becoming more and more evident as the problems of unilateral controls are being discovered. Therefore, a basic requirement for maintaining present levels of crop protection and reducing present losses is the availability of feasible pest management programs for all of our crops. These will require multidisciplinary efforts by scientists in the crop protection, crop production, economics, and related disciplines as well as the cooperation of private industry.

An essential component of any system to ensure reduced crop losses due to pests is an appropriate and adequate farmer advisory capability. This must involve the cooperative extension system, weather service, private consultants, scouts, and the pesticide industry.

And the final essential element to improve crop protection is a teaching capability adequate for the task. Appropriate instruction and information are needed for all persons including farmers, county agents, extension specialists, industry personnel, consultants, scouts, and crop protection researchers.

A study of the seven regional reports suggests that the development of pest-resistant cultivars offers significant promise of reducing losses on a long-term basis from diseases, nematodes, insects, and perhaps mites. The results obtained on several crops when realistic efforts have been made are impressive: examples from this assessment are found on cotton, wheat, corn, vegetables, and potato. Useful resistance has been bred into tobacco, rice, and many ornamental. Tolerance of attack by pest organisms can be useful in reducing losses. It has been demonstrated experimentally and in actual practical use that control tactics, such as pesticides and time of planting, are more effective on plants with even a modest degree of resistance than they are on susceptible plants grown under similar conditions.

The classical biological control approach on insects and mites, especially exotic species, is one that should be stressed to reduce losses by these arthropods. The augmentation of existing natural enemies is another underdeveloped area that offers much promise for reducing insect and mite losses. This can be accomplished by propagating and releasing parasites and predators, creating favorable environments, and using pesticides in a manner least harmful to beneficial organisms. Biological control is particularly adapted to those pest organisms that can be tolerated in low numbers on crops, Less success has been obtained against direct feeders such as the codling moth, cabbage worms, cabbage looper, and European corn borer. The ultimate role of biological control of plant pathogens and nematodes is unclear, but enough successes have been obtained to suggest that considerable effort should be made in this area.

By singling out host-plan resistance and biological control as those ta ctics offering the greatest potential in pest management strategies, we are not suggesting that other tactics are unimportant or do not warrant further research and development. Rather, we emphasize that their potential justifies a greater degree of effort than in the past and that excellent gains toward improved pest management are possible through increased efforts.

Chapter V

Obstacles to the Development and Adoption of Improved Pest Control Tactics and Pest Management Strategies

Obstacles to the Development and Adoption of Improved Pest Control Tactics and Pest Management Strategies

Great advances have been made in crop protection in the United States over the past century, but there are many difficult problems and concerns about present and future capabilities to protect our agriculture from the ravages of pests. A clear need exists for new and improved crop protection tactics and new pest management strategies. There are also serious concerns about the negative impacts of tactics used in crop protection, especially as they affect human health, the environment, and agricultural productivity.

This chapter addresses the obstacles to the development and adoption of new and improved pest control strategies and tactics, and problems of the Federal, land-grant, and private enterprise systems that undergird agricultural pest management in the United States. The impression should not be drawn that all is wrong but rather that a reasonably good system has faults that should be modified to meet present and future needs.

The several constraints that are identified in this report form the basis of two dominant but related classes of obstacles to the implementation of integrated pest management (1PM): technological and administrative. Technological obstacles are: 1) inadequate knowledge base for full 1PM development in both basic and applied aspects of crop protection, z) narrow range of available control tactics, 3) inadequate delivery systems, 4) lack of environmental monitoring systems, 5) lack of adequate pest management training programs and trained manpower, and 6) grower skepticism. Administrative obstacles are: 1) lack of cooperation and coordination and 2) cosmetic (esthetic] standards. There is no general agreement among experts regarding the relative importance of each of these, but certainly the inadequate scientific knowledge base for full 1PM development is at the top of the list. Also, lack of cooperation and coordination within the Federal agencies and between them and the States is of prime importance.

TECHNOLOGICAL OBSTACLES

Inadequate Knowledge Base

An inadequate knowledge base is a major obstacle to future advances in crop protection. The rate at which new advances in pest management are made will depend largely on the rate of development of new knowledge in both basic and applied crop protection and related sciences. It is generally recognized that few sophisticated 1PM systems are operational. Of the programs in operation, most are already as sophisticated as they can be with existing information. Further information has not been developed on the basic biology of pests, biosystematics, interactions within pest complexes and between them and their host plants, economic thresholds, and the economics of pest management. Only research can provide this information.

A major gap impeding implementation of improved pest management is definitive knowledge of the interactions of pest complexes that attack the farm production unit. Growers are increasingly aware of the need to consider entire complexes of pests of all their crops in the total farm management system. They want information on the total impact of pest complexes rather than on individual pest species, and they need to know how actions taken against one pest or group of pests on one crop may affect other pest populations on that or other crops.

Data to support crop loss estimates due to most pests is lacking. Figures that are widely quoted on pest losses are little more than educated guesses. Accurate data on crop yield, quality, and the effect of pest populations on these factors are essential to establish economic thresholds, to make control recommendations, and to evaluate the success of pest management programs.

Adequate information in these crucial areas is not available. The broadly interdisciplinary research, which cuts across departmental, agency, and institutional lines and which is necessary to address these questions, has not been adequately supported. At present, a major portion of the public sector funds for crop protection is in basic and components research, but very little is spent putting the pieces together. Much of the fault for this lies in the necessity for a strong disciplinary base before interdisciplinary research can be effective. Funding and incentives simply have not been there to foster the kind of effort needed.

Pest management implementation programs also depend on the use of accurate economic thresholds to make decisions on when and how to act against a pest population. Thresholds are difficult to quantify; many are based on "rule-of-thumb" estimates of the tradeoff between costs of control and crop losses. If the number of implemented pest management programs is to increase, substantially greater effort must be expended on the development of economic thresholds and other short-term research needed primarily for implementation programs.

One other area, the economics of pest management programs, has not been adequately investigated. Economic benefits are the key to the rapid adoption of a pest management program by growers. Economic research is necessary to determine the costs and benefits of different control tactics, develop sophisticated economic threshold levels, and present growers with specific examples of the increases in economic return that can be obtained in a pest management program. Part of the problem is the lack of money available for such research. Much of the problem is due to the lack of awareness of the subfield of pest control by professional economists. Efforts to make more economists aware of the issues and opportunities in pest management should be encouraged.

Narrow Range of Control Tactics

A wide array of cultural, biological, and chemical control tactics is necessary to design and implement effective pest management programs. Unfortunately, a broad choice of tactics is not available for use on most crops. Some tactics are in their early stages of development; others are being slowly reemphasized and updated. For some conventional broad-spectrum pesticides, there are serious questions regarding their safety and applicability in pest management programs. Further, the effectiveness of some pesticides is being eroded as resistance to them becomes more and more widespread.

Efforts should be made to improve the efficiency of pesticide use. A considerable potential for greater precision in the accuracy and uniformity of pesticide applications now exists. Improved equipment, such as electrostatically charged dusts and sprays, variable-rate sprayers, recirculating sprayers, and microwave soil sterilizers, is now being evaluated. Such equipment may have potential for use in pest control if it can be developed for practical uses. The efficiency of certain pesticides can be improved by formulation changes that can provide extended periods of pesticide activity with lower rates of application. Also, certain broad-spectrum chemicals may be timed and properly applied to afford selective activity.

It is important that agricultural and chemical engineers be included in both the research and implementation phases of pest management. Their expertise can help to broaden the range of available tactics, add precision to current practices, and develop new control tactics. It is clear that a concerted effort has to be made to present the grower with a broad assortment of safe and effective control measures from which to design a practical pest managment program.

Control tactics regulated by the Federal Government include the pesticides as regulated by the Environmental Protection Agency (EPA), under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), and to a much smaller degree the biological control programs of the U.S. Department of Agriculture (USDA) and the States, EPA responsibility for pesticide regulations affects both the development and use of pesticides in pest management programs. This includes not only conventional broad-spectrum pesticides but selective conventional pesticides—pheromones, hormones, viruses, and bacteria as well.

A new set of amendments to FIFRA has been passed by Congress to deal with the problems created by EPA's registration protocols. Developed after lengthy hearings and debate, they are designed to speed up the registration process without sacrificing environmental quality and safety. Because these issues are widely discussed elsewhere, they are not addressed here. One point that does deserve mention, however, is the lack of a uniform national policy for making regulatory decisions on potential carcinogens. There are concerns in two areas. One is a genuine disagreement over the accuracy of the various guidelines for determining carcinogenicity that are now used by regulatory agencies. The other is the effect that this lack of uniformity of standards has had on the predictability and stability of the regulatory process. EPA has developed one policy on interpreting data on the potential carcinogenicity of a chemical; the Occupational Safety and Health Administration, the Food and Drug Administration (FDA), and the Consumer Product Safety Commission have developed others. Industry is faced with a situation where the same chemical may be classed as a carcinogen by one agency and not by another simply on the basis of a different end use. This lack of uniformity and the resulting unpredictability of the regulatory process has affected the use of chemical pesticides as part of a pest control program. Current congressional and executive branch interest in developing a uniform policy for making regulatory decisions on carcinogenicity should be given strong support.

EPA's authority to regulate pesticides under FIFRA extends to their use in the field. Under FIFRA, legal use of a pesticide is governed by label restrictions and directions for use. The Agency took the stance that application of a pesticide to a crop named on the label but against an unnamed pest or at less than the recommended dosage was an illegal action. The inflexibility created by this situation made it difficult to design programs using less than label dosages or prescribed methods of application. The passage of the 1978 FIFRA Amendment should largely eliminate this problem by allowing pest management programs to be developed using pesticides against unnamed pests, at lower than labeled dosage rates, and applied by novel means unless prohibited by the label.

An unintended side effect of the amendment, however, increases the potential liability of pest management advisors. Under the present situation of strictly enforced label recommendations, liability lies primarily with the manufacturer for harm due to foreseeable use. If a pest management advisor makes a recommendation to use a pesticide at less than label rate, against an unnamed pest, or using a novel method, and damage or poor control results, liability may shift from the pesticide manufacturer to the consultant. Liability problems may inhibit the formation of private pest management consulting firms and advisory organizations.

Some items falling under EPA's definition of pesticides have come under increasing public attention as potentially effective tools while presenting minimal health and environmental dangers. Included are narrowly selective conventional pesticides, the so called third-generation insecticides—pheromones, hormones, viruses, fungi, bacteria, and protozoa. The development and commercialization of these items have been exceedingly slow, much slower than the public interest in them would warrant.

Part of the difficulty is a question of quantity. One desirable feature shared by the above pesticides is their narrow spectrum of activity. By affecting only a particular pest genus or family, these pesticides, especially the insecticides and miticides, can allow beneficial predators and parasites to survive in a treated field. The narrow spectrum of their activity also means that in most cases relatively small quantities will be sold. This small market potential, coupled with the fact that the quantity of data required to register them is the same or more than that necessary for a broad-spectrum pesticide, has made their development an unattractive investment, and industry has opted for the more profitable broad-spectrum high-volume pesticides. Where profitable markets for certain narrow-spectrum pesticides do exist—for example, in situations where key pests are involved such as the boll weevil on cotton and the codling moth on apple—industry needs to redirect its development efforts and take advantage of these markets for narrow-spectrum pesticides. In addition, the Government could use all appropriate means to expand the research aimed at discovering new molecular models of selective pesticidal activity.

The third-generation pesticides and microbial face a qualitative as well as quantitative problem. They are qualitatively different from conventional pesticides; they act by to tally different mechanisms, and they raise different questions as to potential hazards to the environment. At present, EPA's registration requirements for these compounds are extremely unclear. Past decisions appear to have been based on the same tests required for chemical pesticides. The added delays due both to uncertainty over tests required and to conducting inappropriate tests have decreased their attractiveness to industry.

One explanation for this is that EPA has not made adequate use of the mechanisms available which would allow it to tailor reregistration requirements directly to the different classes of chemicals. Because broad-spectrum pesticides are the most important, the tests designed to answer questions about their potential dangers were developed first. EPA is applying the same tests to almost all compounds, and industry assumes they will continue to do so. While EPA intends to put together differential guidelines for the registration of pheromones, hormones, and microbes, guidelines for broad-spectrum chemicals have to be revised first. This will continue the confusion and delays in attempting to register third-generation pesticides.

Another obstacle facing the commercial development of pheromones and microbial is the uncertain status of patent and proprietary rights. Pheromones are naturally occurring chemicals and cannot be patented, but the process by which they are manufactured is patentable, as are any novel chemical analogues of them. Until recently, micro-organisms were also considered unpatentable. Two recent decisions[1] of the U.S. Court of Customs and Patent Appeals have opened the possibility that these organisms may be patentable.

With respect to "classical" biological control—i. e., the importation of natural

[1]Bergy, 197 USPQ, 78: Chakrabarty, 197 USPQ, 72.

enemies as opposed to the augmentation of existing forms or the use of autocidal methods—it is apparent that a major increase in support of Federal and State importation programs is long overdue. Classical biological control has proven potential, particularly for insect and mite pests, but programs to expand it have been understaffed and uncoordinated. Existing USDA and State programs for natural enemy exploration and importation have neither the funds nor the organizational network to adequately explore and take advantage of the possibilities for major breakthroughs. The need for more effective coordination of these efforts is now being recognized by the States and USDA.

Success in increasing the number of in-field biological control organisms has been very slow. Much of the problem has been the low level of funding that biological control has received. Another part of the problem has been the lack of a formally designated action agency to ensure that once established, an introduced natural enemy is distributed within a large geographical area.

A related constraint is the inadequacy of international programs created to discover new germ plasm. Over 95 percent of crops grown in the United States have their origin, centers of genetic diversity, and pest centers outside the United States. Success of efforts to expand the use of host resistance as well as biological control requires work in parts of the world where these crops are indigenous. It is in these areas that, through thousands of years, balanced cropping systems, natural resistance, and biological control agents have evolved. Unfortunately, detailed information about the patterns of crop variability in centers of crop diversity is lacking for most crops. As a consequence, even less is known about ancient cropping systems, the basic biology of pests, and the distribution patterns of natural resistance and biological controls.

Seed and other breeding materials collected in centers of crop diversity are the best proven sources for developing natural resistance. Furthermore, these traditional materials will be needed even if the dreams of genetic engineers become a reality. For nearly a decade and a half, the United Nations' Food and Agriculture Organization has led in planning international efforts to collect and conserve crop variability. USDA's Agricultural Research (AR) has had a similar plan to minimize genetic vulnerability of the Nation's crops through germ plasm collection and conservation. If diverse genetic materials are not available to plant breeders, the long-term potentials of developing pest-resistant and tolerant varieties cannot be realized. The corollary task of understanding the basic mechanisms and genetics of resistance for each crop also depends on the availability of such germ plasm.

Lack of Adequate Delivery Systems

The lack of adequate pest management delivery systems also constrains improved crop protection. These systems must include the mechanisms and personnel required to Col lect and disseminate the information necessary to operate effective pest management programs. Delivery methods are in the early stages of development, and many different systems are being tried in various regions of the country. It is unlikely that any one single system will work successfully in all regions.

The organizations currently used to deliver pest management services to individual growers can be broadly categorized as follows: a) public service entities, b) private commercial entities, and c) grower-owned entities (commercial, cooperative, and nonprofit).

Public service entities include Federal agencies and the land-grant universities with their research and cooperative extension services. The USDA/Extension Service-sponsored pest management pilot projects have been the major effort to implement pest management programs by the public sector. These programs have been extremely important in making people aware of pest management and creating a market for private pest management services. Care must be exercised in determining the most useful extent to which the publicly supported programs should be developed—i.e., the point at which public programs stop creating a market for private firms and become competitive with services that could be provided by the private sector.

Private commercial entities will be a vital factor in the long-term success of pest management programs nationwide. Well-trained pest management consultants can offer farmers more individualized services than those in public programs, Private consultants are likely to have the most success in concentrated farming areas and where net farm income allows efficient manpower and equipment utilization.

A major problem facing private pest management consultants is the danger of unqualified persons identifying themselves as experts in the field of pest management. Most States do not have regulatory standards to determine the competence of a pest management consultant. Growers are faced with a situation in which enterprising individuals can sell themselves as pest management specialists on the basis of superficial field-checking skills while totally lacking the ability to translate field data into sound pest management recommendations. A few such individuals in a particular region could severely harm the emerging consultant industry in that area.

Another area of concern is the liability of pest management consultants for crop damage due to pests or control measures. If a grower changes his pest control practice on the basis of a consultant's advice and his crop suffers pest damage, the consultant can be sued for malpractice. Just as in many other professions, today's soaring malpractice insurance costs could present a severe financial obstacle to the formation of new consulting services.

Grower-owned entitites that are operated as business organizations that sell their services have to meet the same natural business constraints as private consultants and are faced by many of the same problems. Grower-owned pest management cooperatives also encounter the same governmental and natural constraints faced by regular commercial entities. The seasonal nature of pest management activities can create difficulties for ventures that are limited only to pest management services. This often can be overcome by providing pest management services in conjunction with other sales and service activities. For existing cooperatives, it may be possible to expand into pest management services. Both of these methods have been successfully employed by a small number of cooperatives around the country.

Organizing a cooperative specifically for the purpose of providing pest management services can often present an insurmountable financial barrier in areas where pest management is practiced only through an extension service pilot program. There are several constraints that apply here: 1) the number of farmers involved in the extension pilot program may be too small to assume the financial risk involved in capitalizing a full-service pest management co-op, 2) there is a natural reluctance to "sever the umbilical" to extension service pilot programs where they are in effect, and 3) the lack of qualified sales and service personnel to handle day-to-day operations makes formation of the cooperative difficult, even if otherwise possible.

Nonprofit grower-owned entities can be a means of avoiding these problems. They are functionally different from all other approaches to developing the pest management concept at the grower level. This is because: 1) they exist as a data-gathering base for joint land-grant university/Federal pest management programs; 2) they perform no sales or service functions such as consultation, pesticide sales, or pesticide application; and 3) the only direct benefit to member farmers is the receipt of a copy of pest identification and population data from the land-grant university. The farmer may use this information to make his own decision or furnish it to a consultant for recommendation. The direct benefit to the farmer is incidental to the overall benefit to farmers in general as a result of the data collected and analyzed.

These organizations can help growers move from extension pilot programs into self-supporting, grower-owned activities. They can be either registered as tax-exempt organizations or brought under the tax-exempt umbrella by becoming a county chapter of a university-sponsored State pest management association.

Obstacles to their widespread use include the unwillingness of growers to pay directly for pest management services and the complexities of registering with the Internal Revenue Service (IRS) for tax-exempt status. The paperwork surrounding the formation of these associations (even in an unincorporated form) may be a severe disincentive for farmers of low-to-moderate income and education. Farmers who need most to be involved in pest management programs are the ones most likely to be put off by endless correspondence and forms.

The role of pesticide company fieldmen and pesticide applicators in pest management programs has not been adequately defined. To date, these individuals have been the most readily available sources of information on pest control methods to farmers. Chemical company fieldmen are located in all areas of the country and are active in disseminating pest control information. Questions have arisen regarding the ability or willingness of these local company field representatives to embrace pest management at the farm level. Although a few are enthusiastic, their general approach to ongoing pest management projects has ranged from indifference to outright hostility. Industry spokesmen maintain that they recognize the benefits of the pest management approach and are willing to become involved. Some outside of industry express doubt that a person whose job is tied directly or indirectly to the sale or application of chemical pesticides can offer impartial advice on a program that uses multiple-control techniques. They view pesticides as comparable to human drugs and ask if physicians should be allowed to both prescribe and sell them to their patients.

This problem is complicated by the fact that many fieldmen are upstanding members of the local community. Their advice is respected and their friendship valued. Some way of including them in the move to 1PM should be found. One key will be to involve them without limiting the choice of controI tactics available in a program.

Lack of an Environmental Monitoring System

In addition to information relating to an individual grower's field, areawide information on pest populations and weather is necessary. For most agricultural pests, information from individual fields does not provide the clues needed to predict long-term or areawide changes in pest populations. Since many pests move, either actively or passively, and all are affected by weather patterns, data on weather, crop mix and growth, and pest populations are necessary for the development of predictive techniques and the use of these techniques in pest management programs.

A national environmental monitoring system does not exist, and useful information in existing research or implementation programs is slowly communicated to others. This results in duplication and information gaps that are both costly and unnecessary.

A national agroecosystem monitoring program using existing computer and electronic-sensing technology is necessary to provide the predictive capabilities essential to pest management systems. Such a program would provide benefits in two major areas: 1) extension specialists, agricultural agents, and private pest management consultants would have access to accurate and timely crop, weather, and pest population forecasts for use in existing pest management programs; and 2) researchers who cannot now afford to gather the areawide weather and crop information necessary to understand their relationship to pest populations would have available the information necessary to predict potential pest outbreaks.

Two major impediments to attempting to design such a system on a project-by-project or State-by-State system are: 1) the costs of data acquisition are too great to be borne by individual projects or farmers, and 2) many projects do not have the expertise to choose, install, operate, and service the specialized instruments required.

An interlocking network of State, regional, and national systems should provide the best possible service.

Lack of Pest Management Training Programs and Trained Manpower

The lack of trained manpower and programs in many institutions to train personnel limits the research, education, and implementation efforts in pest management and results in part from the incomplete acceptance of the concept within the university community. To date, most administrators, professional researchers, teachers, extension specialists, and paraprofessionals have been educated along strict disciplinary lines. This incomplete acceptance, coupled with decreasing Federal financial support for teaching, research, and extension in the food and agricultural sciences, has inhibited the development of multidisciplinary training programs in pest management. In a 1977 survey, only 34 of the 49 responding land-grant universities reported having undergraduate programs in pest management. These were aimed mainly at technical positions. At the graduate level, the number of M. S., Ph. D., and professional re-education programs is much smaller. These are the programs that will supply the individuals for teaching, research, and extension efforts so critical to the future of pest management.

A major constraint in establishing pest management training programs as well as academic teaching, research, and implementation programs has been the lack of adequate financial and facility support. The limited financial support for pest management that has been provided has come from the Federal Government through special grant or pilot program funds. This "soft money" does not attract highly trained faculty or provide motivation to develop programs that require an expansion of classroom or laboratory space at a university. There is little incentive to attach a high priority to programs that would, in effect, increase mission responsibility with an inadequate provision for increased staff and facility needs. Further, a "soft money" approach does not provide sufficient security incentives to attract the best practitioners available. In many universities there is a budgetary inability to pick up and continue programs at the expiration of grant or pilot program funds.

Along with a sound scientific foundation, pest management personnel must have training with a strong applied component. People with experience in field diagnosis and in making control recommendations are essential to the successful design of future pest management research and education programs, as well as the implementation of pest management programs. Field experience through internships must be a central component of any pest management training curriculum.

There are some unique difficulties in the training of private pest management advisors. A major one is the need for broad specialization in several areas. Scouts, scout supervisors, and pest management advisors such as county extension agents and private consultants are all needed to ensure effective coverage of a farmer's pest management needs.

Recruitment and training of scouts face some unique problems because of the seasonal nature of the work. Scouts must be trained to identify accurately at least the major pests in a grower's field and to assess pest damage to crops. The type and duration of their employment make it difficult to establish a permanent pool of trained scouts from which to hire each year. Efforts to locate individuals willing to work in the fields are concentrated on vacationing college students, farmers' spouses, and undergraduate students in pest management. Effective short-term training programs are needed to ensure the competence of the scouts.

Pest management practitioners are responsible for reviewing the data collected by the scouts and making control recommendations to the farmer. They should have a solid background in fundamental science as well as experience in field problems and farm management. They must be able to recognize and deal with all aspects of a farmer's pest problems, including weeds, diseases, nematodes, and insects. Specifically trained pest management practitioners are rare. Lack of personnel to provide the total production management schedule on a farm is a major limiting factor in pest management implementation. Traditional university departmental lines and the difficulty with which adequate applied components are introduced into a training program have made their establishment difficult. The lack of support for practical internships is a large obstacle.

Some have suggested that an entirely new program is needed leading to a professional degree in pest management, such as a doctor of plant health. Such a program would be similar to present programs in veterinary medicine and would involve a broad practical interdisciplinary education with an intensive clinical experience component. It would more adequately prepare an individual to address the special problems encountered when implementing a practical pest management program.

Grower Skepticism

Grower skepticism is often cited as an obstacle to the adoption of pest management systems. Reluctance by growers can be ascribed to such factors as confidence in their present pest control practices, hesitancy to spend money for the uncertain services offered in a pest management program, lack of serious threat from pests with currently used systems, and lack of demonstrated economic benefits from employing a pest management program.

These are less a reflection of growers' attitudes than of the present state of the art of pest management. Many growers have enthusiastically adopted a pest management program when a program was well-developed and presented. In some instances, the pest management approach has been the only solution to growers' pest problems and has saved their operations from financial disaster. The lack of availability of demonstrated economically sound pest management systems is the overriding obstacle to farmer adoption of 1PM.

Being businessmen, growers are the first to adopt new ways to solve their problems and cut their costs. People working in pest management must design programs that can be understood by growers, are practical in terms of growers' total farm management, and that offer them real economic benefits.

ADMINISTRATIVE OBSTACLES

Lack of Cooperation and Coordination

The preceding obstacles to improved crop protection and to the pest management approach refer to specific control tactics or strategies. Lack of cooperation and coordination are general constraints that are pervasive throughout crop protection and particularly for 1PM.

In 1971, concern over the environmental and health problems of pesticides resulted in the passage of the Federal Environmental Pesticide Control Act of 1972 (FEPCA) and an intensified search for more effective and desirable methods of pest control. The immediate product of the latter was the 1972 report of the Council on Environmental Quality (CEQ) entitled "Integrated Pest Managemerit. " Pest management was hailed as a way to couple environmental protection with the practical concerns of agricultural production. Unfortunately, this combination has become the center of a policy struggle.

The main agencies involved in the issue at the Federal level are CEQ, USDA, EPA, the National Science Foundation, and, to a lesser extent, FDA, and the Departments of State, Defense, and the Interior.

Before detailing this obstacle a brief introduction to the roles and responsibilities of these agencies is presented.

Council on Environmental Quality: CEQ's role is that of a catalyst. By performing broad policy oversight, participating in the budgetary process, and making recommendations to the President, it plans to "help the agencies develop a comprehensive approach to 1PM. " While CEQ recognizes the importance of production economies to the future of pest management, the main focus of its approach is to protect the quality of the environment. Its goal, as recently stated by Charles Warren, former chairman of the Council, is to "reduce the excessive use of such chemical pesticides and to use natural biological and environmental measures to achieve pest control whenever practical. "

U.S. Department of Agriculture: While CEQ has been given broad policy responsibility, the lead Agency for pest management research, education, and demonstration is USDA. Working with the associated system of land-grant universities, State agricultural experiment stations, and cooperative extension services, USDA aims to promote efficient, productive agriculture. These cooperating public institutions are the biggest factor in the development and introduction of new technologies for U.S. agriculture.

As the lead Agency for agriculture in the Federal Government, USDA is concerned with the ability of farmers to produce adequate supplies of food and fiber at a reasonable cost. Its many programs are designed to make U.S. agriculture more efficient, more productive, and economically sound. While vitally concerned with the environment, USDA's top priority in pest management is to ensure that the programs offer farmers adequate protection against pest damage at a reasonable expense.

Six major agencies of USDA are directly involved in efforts on pest management: Agricultural Research (AR); Cooperative Research (CR); Extension Service (ES); Economics, Statistics, and Cooperatives Service (ESCS); Animal and Plant Health Inspection Service (APHIS); and the Forest Service (FS). To coordinate the efforts of these different agencies, the Department created an interagency work group on pest management chaired by the Deputy Assistant Secretary for Conservation, Research, and Education. Its role is one of making suggestions and recommendations; it has no program direction or managerial responsibilities. In addition, the newly organized Science and Education Administration (SEA), home of AR, CR, and ES, recently formed an SEA-wide coordinating team for pest management. Composed of technical experts from the three agencies listed above and chaired by a pest management specialist, it makes recommendations on methods to integrate the programs of the involved agencies.

Environmental Protection **Agency:** EPA's involvement in pest management stems from its overall responsibility to protect the quality of the environment by regulating environmental and public health hazards. This duty is very different from the USDA's responsibility to promote agricultural production. These different roles are reflected very clearly in their approaches to pest management.

EPA's approach to 1PM represents a commitment to the production of food and fiber in the most environmentally protective way that is also economically sound. The responsibility is clearly to protect the environment by minimizing the application of pesticides to cropland. This affects pest management in two different ways. One involves the general effect of its registration procedures on the availability of pesticides for use in pest management programs. The second area includes plans by EPA to directly employ pest management in its regulatory programs. In a decision on registering a pesticide, ways to minimize the risks from the use of that pesticide are a central consideration. EPA views pest management as one method for reducing these risks.

EPA is also moving into the area of gathering and disseminating information about and encouraging the implementation of pest management programs. EPA has also funded research in pest management, including the Huffaker Project (see NSF).

National Science Foundation (NSF): NSF has been involved in pest management research and education. As part of its responsibility for supporting basic research, NSF was the lead Agency on the Huffaker Pest Management Project. This was the most ambitious pest management research project ever undertaken. It pioneered the use of systems analysis in looking at plant/pest interactions within a crop ecosystem and helped to bring pest management to the attention of all the land-grant universities. Together with EPA, NSF funneled $12.5 million into the project over a 7-year period.

NSF has also sponsored several undergraduate pest management training programs. As part of its science education effort, NSF helps develop programs to prepare scientists to work on important national problems. Demonstration pest management education programs have been started at Michigan State University, Cornell University, Kansas State University, University of California at Fresno, and Alabama A&M. The objective of these programs is to develop practical pest management curricula that can be used across the country.

In addition to these four agencies, several others have program responsibilities that affect pest management.

Food and Drug Administration: FDA is responsible for monitoring contaminants in food and feed under amendments to the Federal Food, Drug, and Cosmetic Act of 1938. The Act requires that EPA set maximum pesticide residue tolerances in food and feed. FDA is responsible for monitoring residue levels and enforcing the tolerance levels. Also under this Act, FDA has responsibility for monitoring processed foods for the presence of filth or foreign objects. This latter responsibility has involved FDA in the debate over the effect of cosmetic standards on pest management programs.

State Department: The State Department's Agency for International Development (AID) supports several activities that relate directly to pest control in developing countries. These programs are in the broad categories of training and education, country development projects, and direct emergency assistance. AID provides funds for the training of foreign nationals in many fields, including pest management. The Agency also supports pest management projects in developing countries through loans for equipment, supplies, and training. In addition, AID furnishes technical consultants and pesticides to countries where pest outbreaks have created disastrous crop-loss emergencies.

Since 1972, AID has supported the "University of California/AID Pest Management and Related Environmental Problems" project. The project has involved extensive surveys of pest problems in developing countries and workshops on pest and pesticide management. Project members have served as short-term consultants on pest problems and advised AID on matters relating to pests and pesticides.

Interior Department: Interior has responsibility for managing vast tracts of public lands. At present, the Department relies mainly on pesticides to protect these lands, while conducting some research into alternative methods of pest control. Wildlife and Fishery Divisions also conduct experiments on the impact of pest control techniques on nontarget species.

Defense Department: The Defense Department carries on a limited pest control research program that focuses on organisms that interfere with the Nation's military capability.

In the public sector, three areas in which the lack of cooperation is especially critical are identified within the Federal Government, between the Federal Government and the States, and within the land-grant university complexes. Lack of cooperation and coordination are frequently cited obstacles to the development of any program but the degree to which they affect pest management is unusually high.

Within the Federal Government

Although there has been considerable interest in pest management by Congress and the President, the lack of a well-defined set of objectives, with clearly outlined goals and responsibilities, has severely hampered efforts in this area. One result has been that agencies are competing for jurisdiction over pest management.

Each of the four main agencies involved in pest management (CEQ, USDA, EPA, and NSF) has its own particular organizational structure and set of priorities. The absence of a comprehensive set of goals leaves each of these agencies to pursue its own ends in pest management. CEQ's efforts to promote pest management have little impact without active Presidential support. USDA's leadership in pest management has been cautious. EPA took the initiative in 1972 with the new pesticides legislation to become an active promoter of pest management. NSF, following its basic mission, became involved in pest management by funding basic research and new educational programs. The result of this uneven Federal effort is a patchwork design of conflicting goals and overlapping efforts.

This is particularly true between USDA and EPA. USDA is faced with the difficulties associated with reorienting a complex Federal/State system, which has operated mainly under the philosophy of unilateral approaches to pest control, to a philosophy that actively seeks to include a large variety of control techniques. There is uncertainty within USDA over how the Department's existing programs can fit into the new research and education thrusts.

EPA stepped into what it sees as a void left by USDA and has become the main proponent of pest management at the Federal level. While it does not have a major responsibility for research and education or possess research and extension networks, EPA is becoming more and more active in these areas. The Agency provided a major part of the funding for the Huffaker Project and obtained authorization for $2.5 million to aid in the funding of the Adkisson project. It is also devoting some effort to developing information systems and incentives to promote the adoption of pest management. EPA's involvement in these areas of traditional USDA responsibility has increased the jurisdictional problem between the agencies.

As EPA expands the use of pest management in its regulatory programs, philosophical conflicts between the agencies arise as well. USDA feels that the best way to promote pest management is through education, not regulation. EPA's responsibility is to reduce the environmental hazards posed by pesticides. If they can employ pest management in a regulatory scheme to accomplish this goal, they will attempt to do so.

Without a firm commitment to bring agency programs together and to develop mutual goals and objectives, these jurisdictional and philosophical conflicts can only increase. The recent interagency agreement between EPA and USDA should eliminate much of the past confusion and conflict.

Between the Federal Government and the States

The federally funded extension pest management pilot projects have become a successful program of coordinated State and Federal action. On the other hand, the communication and cooperation in planning programs between the two arms of the public agricultural research effort—USDA's Agricultural Research and the State Agricultural Experiment Stations—have been much less successful.

This lack of cooperation in joint planning has been recognized as a serious problem by both USDA and the State Agricultural Experiment Stations, but progress has been very slow in the past. The Department's creation of SEA was aimed at increasing the cooperation among AR, the State research institutions associated with CR, USDA/ES, and the Cooperative Extension Service. The SEA-wide coordination team on pest management is currently examining ways to improve the coordination of Federal and State research efforts.

Within the Land-Grant Universities

Cooperation and coordination in teaching, research, and extension efforts have been slowed because of the universities' disciplinary and professional departmentalization. This departmentalization, which evolved over the past 100 years to meet the needs of students and to best conduct research and extension programs, serves the disciplinary needs of the universities but causes some obstacles for interdisciplinary approaches. These obstacles include lack of promotion and financial rewards for academic staff and inadequate funding for interdisciplinary programs, In addition, the pest management concept has not been accepted universally by researchers and extension specialists in the plant protection disciplines.

Cosmetic (Esthetic) Standards

The term "cosmetic standards" presents a problem itself. It has come to include a wide variety of different quality guidelines all relating to pest damage or contamination of foods. These guidelines include the "defect action levels" (DALs) for pest parts in food enforced by FDA, the State-set quality standards for produce, as well as the local co-op and processor standards for surface blemishes and appearance, All of these guidelines set acceptable levels for produce. Some aim at pest contamination; others aim at pest damage and produce appearance. Responsibility for setting them ranges from FDA to local marketing co-ops. Produce that does not meet these standards is kept off the market or sold at a lower grade and price.

Cosmetic standards in pest management mainly have impacts on fruits and vegetables grown for human consumption. Under strict standards, the economic threshold for pest damage on these crops is almost zero. This means that the farmer can tolerate almost no surface blemishes on the produce or pests or pest parts in the harvested crop. It means that pests in the field, especially insects, must be eliminated as completely as possible. This severely limits the use of biological control and other management techniques which depend on the presence of some pests in the field.

While widely discussed in articles on the future of pest management, "cosmetic standards" (some prefer the term "esthetic") do not appear to be a major obstacle to the adoption of pest management programs. What really is at issue is the tradeoff between the hazards associated with the use of pesticides and the hazards and willingness of the public to accept pest-damaged and contaminated food. With existing technology, achieving near-zero pest damage is possible only in a system based mainly on the use of chemical pesticides. If the cosmetic standards were relaxed, with a resulting increase in the economic threshold, the type of applicable pest management program could change considerably. Greater use could be made of natural control factors and other tactics that allow higher levels of some pests in the field. In either case, a pest management approach can be taken, but unless consumers become willing to trade less pesticide use for more pest-damaged food, programs on these crops will remain limited in the scope of control tactics employed.

Chapter VI

Actions Needed to Improve Crop Protection in the United States

Actions Needed to Improve Crop Protection in the United States

In view of the facts that pests collectively deprive the world of nearly one-half of the food mall attempts to produce, that many present control strategies are in trouble that some pesticides have raduced effectiveness against many pests that support for the development of pest resistance is declining for some craps, and that there are still undetermined risks involved in pesticide use both to health and the environment, it is imperative that Congress examine its commitment to improve crop protection capabilities and reduce risks. Statistics recently compiled by the U.S. Department of Agriculture(USDA) indicate that, in spite of the substantial funding and science years [SYs) spent on crop protection the effort directed toward integrated pest management (IPM) is relatively small. The total USDA expenditure for crop protection in 1977 was million of this total $81.3 million for USDA Agricultural Research [AR), and $110.3 million was for State research. The USDA **breakdown of the total is: basic research, 41 percent; control component research, 52 percent;** 1PM systems research—control tactics and management 6.4 percent ,

Thus, it is evident that the major present effort in both Federal-and State crop protection is devoted to basic and component research and very little to the integration of control tactics into management programs as part of total crop production systems. Under the existing mode of operation, it is the farmers who integrate the control tactics into, their production system and they must do this mostly by trial and error without the benefit of carefully conducted research to show -tie positive and negative interactions that may occur.

The simple solution of transferring significant proportions of present efforts from basic and control components research to 1PM systems research is not a viable option based on the results of the seven regional cropping systems studied. The development of 1PM systems requires additional basic knowledge about pests and crops as well as an extensive array of suitable management tactics. The situation has been compounded during the past decade by reduced funding (in terms of 1969 dollars). The traditional compartmentalization of crop protection programs according to disciplines has been very effective for basic and control component efforts but poses difficulties for developing interdisciplinary teaching, research, and extension programs. When additional funding for such efforts is minimal, temporary, or nonexistent, it is most difficult to mount new programs without jeopardizing essential ongoing efforts. An infusion of new funding is essential for success.

The basic policy judgment that Congress faces is whether to commit the resources required to increase the speed of adoption of 1PM systems. The specific options chosen will indicate the level of commitment to this approach. The degree to which the needed actions are carried out will affect the time frame within which 1PM achieves its full potential:

1, At the present level of commitment, the status of crop protection would be maintained as primarily therapeutic responses to single-pest outbreaks for the immediate future. The already-limited range of available control tactics would be reduced even further as regulations regarding the use of chemical pesticides and resistance to them remove essential control tactics without replacement. The evolutionary shift to 1PM is too slow to have a significant impact except in a few situations.

2. A moderate increase in commitment would augment the present teaching, research, and extension programs to the extent that 1PM could eventually replace most unilateral pest control programs over the next two or more decades.

3. A major thrust over the next few years to remove the obstacles to the implementation of 1PM would enable much of the potential of 1PM to be realized within 15 years. An unparalleled portion of U.S. agricultural potential production could be achieved under 1PM while providing maximum protection to man and the environment.

The technological and administrative obstacles to the implementation of 1PM are detailed in chapter V. Among the actions considered in this report for the removal of those obstacles, two emerge as indispensible at any level of commitment to 1PM. These are to:

1. Provide means to expand the knowledge base and the range of control tactics through basic research and to increase the pool of skilled manpower through expanded training programs.

2. Establish a clear focus of Federal intent and assign to USDA, the lead agency, the responsibility, authority, and necessary funding to coordinate research programs and to implement an adequately staffed and coordinated information delivery system.

The details of these actions are presented below and, although they correspond to the specific constraints identified in chapter V, they must be considered collectively to be effective. More complete discussions are in volume 11 (National Constraints).

EXPAND THE KNOWLEDGE BASE FOR PEST MANAGEMENT

Federal support of agricultural research in terms of real ‘dollars has declined over the past 38 years. During this period the States have been hard pressed to meet the land grant universities’ needs for facilities and staff required to accommodate an increased student load. This has resulted in reduced research efforts, including those on basic and applied crop protection. At present there are no significant opportunities to reallocate research funds and personnel from other activities to pest management programs. The USDA’s AR is in a similar situation because of recent personnel ceilings and budgetary problems.

1PM research must of necessity involve considerable disciplinary and interdisciplinary efforts. These require extra time, effort, and resources. A favorable climate and incentives for such efforts must be present to ensure adequate cooperation among scientists.

Funds for Disciplinary and Interdisciplinary Research

Congress could increase the basic knowledge of pest and pest complexes by designating certain research funds specifically for disciplinary and interdisciplinary studies in the four major protection disciplines (entomology, weed science, plant pathology, and hematology) and for other studies such as vertebrate pests. Funds are also needed to support work in other disciplines such as economics, agronomy, and agricultural engineering which can make significant contributions to pest management programs.

To promote interdisciplinary efforts, it is essential that the continuing needs for basic new knowledge within disciplines should not be ignored. Such knowledge will form the basis for future advances in pest management. Adequate funding in the USDA competitive grants program for the area of plant stress can ensure that new and imaginative basic research will be undertaken.

Attention should be paid to the distinction between designating existing funds and allocating funds for specific projects. If existing funds are designated for interdisciplinary research, it may be necessary to terminate ongoing vital disciplinary research. Additional funds are necessary to allow the initiation of new projects by new researchers not tied to existing programs.

Long-Term Support for Pest Management Research

If pest management is to have top priority nationally, it must be given long-term continuing support. This need is highlighted by the continuing and changing nature of crop protection problems and available control tactics that require continual study and updating.

To help solve this problem, Federal funds for pest management research should be made available on a more long-term basis for facilities and tenured staff. This would provide pest management with the solid base necessary to its future success. The mechanism to achieve this is to assign funding for pest managment research in the budget of USDA's Science and Education Administration (SEA)/AR, and SEA/Cooperative Research (CR). Increased support through Hatch Act funding of SEA/CR with the specific intent of Congress will provide the most productive returns per dollar invested not only because of the efficiency of this partnership program but because in this funding mechanism no overhead is charged and each Federal dollar is matched with 3 to 4 State dollars. Research areas most in need of support and scientific manpower requirements are discussed in chapter IV.

Reallocation of Funds From Unfeasible Eradication Programs

Certain eradication programs are not considered to be feasible. After a careful review of the merits of these programs on a case-by-case basis by an impartial review body, Congress could discontinue those judged to be unworthy on the basis of cost/benefit ratios and probabilities for success. The funds could be reallocated to projects considered to be more productive in terms of preventing pest-induced crop losses. An obvious exception is the Plant Quarantine Act, which actually needs greater financial and professional support.

Peer Recognition

The rewards currently given a scientist who makes a major breakthrough are usually meager. Congress could help advance technical development in pest management tactics and systems through a program that would recognize scientists and groups responsible for major breakthroughs. By instituting such a program, Federal and State researchers would be provided with an extra incentive to pursue new and innovative directions in pest management research.

INCREASE THE RANGE OF AVAILABLE CONTROL TACTICS

Integrated pest management is an ecological approach to crop protection that involves the coordinated use of two or more tactics to prevent pests from causing intolerable losses. Sometirnes management can be obtained by simply changing some cultural operation and using a selective pesticide. More often, however, an array of tactics is needed including pest-resistant crops, modified cultural practices, biological control, and pesticides with certain ranges of activity. A suitable array of tactics is essential for the formulation and implementation of pest management systems.

Increased Support for and Reorganization of Biological Control Efforts

"Classical" biological control (importation and establishment of exotic control agents such as parasites, predators, antagonistic micro-organisms, and other microbial) is an important tactic in pest management. The potential benefits apply more to insects and mites than other pests, but there are excellent examples of biological control of vertebrate pests, weeds, and plant pathogens. The payoff for success can be tremendous. The means for increasing the effectiveness of Federal and State biological control efforts are both quantitative and qualitative. Increased funding, with adequate consideration for the devalued dollar overseas, will enable needed increments in biological control exploration, importation, and distribution programs for beneficial species. The potential benefits of increased funding are about 30 to 1 based on past experience. The major negative aspect appears to be the cost, which is small compared to expected benefits. As part of this, adequate funding should be included to ensure that introduced beneficial are environmentally safe and effectively distributed by State and Federal agencies. Other means of enhancing biological control efforts relate to possible changes in the approaches used in Federal and State programs. The present Federal horizontal structure could be modified to a centrally organized, vertically structured unit. Instead of foreign field laboratories with a staff involved only in exploration, a field biologist would be intimately involved in all phases [exploration, importation, distribution) of the program. The advantage of this approach is that one person would be familiar with all aspects and requirements of the operation and would most likely succeed in finding and establishing biological control agents. Also, a national biological control planning body with more even representation among AR, CR, the Extension Service (ES), the Animal and Plant Health Inspection Service (APHIS), the Forest Service (FS), and the States than exists on the current AR working group should be established to plan and evaluate programs, set priorities for project activities and support, and coordinate State and Federal efforts.

The emphasis placed here on the "classical" approach is not intended to imply that other approaches to biological control, such as parasite and predator augmentation, are not important; these need continued support.

Increased Support for Host-Plati Resistance

The incorporation of pest resistance into agricultural crops **was** identified as a vast promising approach to reduce both losses caused by pests and dependence on pesticides. One of the major reasons for serious pest problems is that many of our crop cultivars have been selected primarily for improved agronomic and esthetic characteristics without adequate regard to incorporating resistance to pest attack. One of the advantages of pest-resistant crops is that they are inexpensive for the producer, whether large or small, as well as for the home gardener. The cost of the lengthy process of finding genetic sources of resistance and moving them through to the end product of agronomically acceptable crop cultivars is high. As noted earlier, the private sector has not always been effective in this area, and public sector support is necessary. The cost/benefit ratio in terms of direct economics as well as in terms of human health and environmental considerations is judged to be favorable. The long-term benefits provided by pest-resistant varieties should far outweigh costs involved. (In the case of Hessian fly, wheat stem sawfly, European corn borer, and spotted alfalfa aphid, the net return for each dollar invested was $30 per year or $300 over a 10-year period in reduced crop losses alone.)

Increased Flexibility in Pesticide Use

The need to tailor pest management programs to local conditions requires the flexible use of tactics in putting a program together. Until the passage of the 1978 Amendments to the Federal Insecticide, Fungicide, and Rodenticide Act, flexibility of pesticide use was limited by labeling—not only on maximum but also on minimum usage. Now pesticides can be used against unamed pests, at lower than label dosages, and in novel ways on crops for which registrations exist. Flexibility would be increased further by reducing the turnaround time for applications to amend pesticide labels, or by allowing the States flexibility under section 24(c) to permit labeling to be accepted, printed, and used in the States if it does not vary appreciably from the original label.

incentives for the Development of Low-Sales=Volume, selective Pesticides

General agreement exists among crop protectionists that narrow-spectrum, or selective, pesticides are essential to the development of fully integrated pest management programs. Such pesticides include the so-called "third-generation pesticides' '—pheromones, hormones, bacteria, and viruses. The barriers to the development and commercialization of these compounds are formidable. They include their generally small market size, Environmental Protection Agency (EPA) registration requirements, unknown health and environmental interactions, and in some cases lack of patent protection. Several different options available to Congress to remove many of these barriers fall into the categories of removing existing disincentives or providing incentives.

One disincentive-reducing means that is currently available would be for Congress to direct EPA to devote more time and manpower to adjusting the requirements for registration for these compounds. These adjustments could be based on findings regarding the amounts that would be used, relative safety of the compounds, and mode of action. An example of this would be the formulation of a narrow policy to cover the registration of pheromones. Such a policy could require that a material have a very low use rate, that it be a naturally occurring substance, and that it be in the most stringent toxicology category for registration under the narrow requirements. EPA is expressing intentions to move in this direction. The effectiveness of their efforts is being hampered by the internal desire to finish the registration guidelines for conventional pesticides. If Congress were to make the necessary manpower available to EPA specifically tied to directions to accelerate the adjustment of registration requirements to reflect more accurately the dangers from narrow-spectrum pesticides, this situation would be relieved considerably. If EPA had the incentive to tailor registration requirements to the expected level of danger, the number of tests required to register a selective compound would, in many cases, decrease. 1f industry had fewer data to collect, it would be more willing to develop the narrow-spectrum pesticides.

Two other means would be aimed at items that do not offer proprietary protection, such as U.S. proprietaries on micro-organisms. One would be to offer an extended exclusive license for the development and commercialization of a U.S. proprietary. The present limited period of license for private productions of U.S. proprietaries is generally too brief to warrant facilities, manpower, and monetary commitments from private industry. An extension of this exclusive license period to 10 years after market entry might work as an incentive to introduce materials into the market that are not economically feasible on a shorter time basis. Another would be for Congress to extend patent protection to include micro-organisms. Existing patent laws do not allow for the patenting of micro-organisms. Besides the proprietary protection that could be offered under options in the previous section, Congress could consider passing legislation to allow the patenting of certain micro-organisms. Precedents for such legislation can be found in the Plant Patent Act of 1970. Since the passage of the Plant Variety Protection Act, there has been a marked increase in the level of commercial breeding of new plant cultivars.

Finally, the Federal Government could offer support for the costs of developing narrow-spectrum pesticides. On top of the costs of registration, the potential market size for many selective compounds is too small to provide an adequate return. Interest in these compounds is due mainly to social and environtal, rather than economic, considerations. If their development is to be a high-priority item, Congress should consider subsidizing companies involved in the production of narrow-spectrum pesticides. Some form of subsidization would encourage the commercialization of certain materials that might otherwise not be economically feasible for development.

Several different mechanisms for providing such a subsidy are available. They include:

- **A Government loan program.** This would involve making funds available on a loan basis **to** carry selective chemicals to the point of market entry after the material has shown initial promise and market potential. Such a loan would be canceled in the event the item was never marketed. Repayment (in whole or in part) would be determined on a sliding scale geared to gross revenues received from the product less pro rata recovery of R&D cost. (This loan system was originally proposed by Carl Djerassi in 1974.)

  Such a program would not have to be funded by direct loan. In fact, the program might work best in the environment of percentage Government guaranteed loans from private institutions. Thus the Government cost is reduced over direct loans, the private enterprise money market is stimulated, and the developer, by assuming a percentage of the financial risk, operates at a disincentive to utilize Government funds to solve cash flow problems.
- **Government R&D Contracts.** Where an identified need exists for an item that cannot be economically developed, there is historical precedent for use of the R&D contract. Governmental costs could be reduced by letting the contract on two different basis: 1) a pure R&D contract that compensates only the R&D efforts of the research and developer or 2) a Government cost subsidy R&D contract that is tied to a lo-year exclusive license to produce the material developed.
- **Tax Credits.** Tax credits could be the lowest cost approach to developing materials which, while socioenvironmentally desirable, might be only marginally feasible from an economic standpoint. Allowance of direct credit against income taxes for a percentage of R&D costs of specified materials (or classes of materials) serves at least two ends. It makes real costs of the Government incentive negligible and keeps competition working in the free enterprise framework by not limiting R&D work to one company.

  Unfortunately, tax credits may also be one of the most complex and difficult approaches to administer, with enormous complications regarding whether or not the research should be subsidized by the Government.
- **Competitive Grant.** This approach to funding can be patterned after other endeavors where the Federal grant has been used as a stimulus to R&D efforts.

Development of a Uniform National Cancer Policy

The lack of uniformity in the cancer guidelines is a problem connected to the development, regulation, handling, and use of pesticides. The development of a uniform national policy is an important task that impinges on pest management as well as on many other important activities. Congress should use its oversight and legislative powers to ensure a uniform policy as soon as possible.

DEVELOP EFFICIENT PEST MANAGEMENT DELIVERY SYSTEMS

USDA-sponsored extension pilot programs will be operational in all 50 States in 1979. A framework is being set up in all States on which to build a public system for supporting pest management implementation programs. Congress must decide how rapidly 1PM should be adopted in the United States and to what extent delivery systems should be supported by Federal funds.

Support of Public Delivery Systems

As acceptance of pest management programs increases, an important role of extension will be to provide information and technical support to ongoing private programs. Such support programs will demand stable, long-term support and should include the flexibility to use the funds for facilities for extension pest management programs.

A pest management coordinating team is needed at the Federal level in USDA to provide adequate leadership for an expanded pest management program. USDA should reorder its priorities to create the needed capability to review, coordinate, and administer expanded support programs for pest management implementation.

To expedite implementation, each State should have a State pest management coordinator to head a team of specialists that would include at least one specialist from each of the major pest control disciplines. The team of State specialists will be essential to provide classroom, laboratory, and field training for consultants and scouts to assure successful establishment of pest management in their State.

Foster Private Sector Delivery Systems

If pest management is to be widely adopted, it will be because of the development of a large private sector involvement. Growers should be willing to pay for pest management services, and organizations must exist to offer such services on an economical basis. Means of increasing the private sector involvement in pest management can be provided by the Extension Service. Other assistance will come through federally sponsored education and research programs. Additional aid could be provided in some of the following manners:

Support for grower-owned cooperatives could be based on the elimination of some of the financial constraints to their formation. This could involve the subsidization of pest management trainees. It could also involve the banks for cooperatives. A congressional mandate could be given to the Center Bank and the District Bank for Cooperatives to publicize the availability of funds for financing cooperative pest management services. The Farm Credit Administration could also be directed to approve a favorable interest rate for loans made by the district banks for expansion of existing cooperatives or for formation of new pest management cooperatives. For fledgling nonprofit pest management cooperatives, a bill specifically exempting nonprofit pest management associations from taxation would ease the way for their formation.

Setting minimum certification standards for pest management specialists could also help private pest management consulting services. In most States, nothing restricts an individual from calling himself a pest management specialist. Congress could act to see that standards are established that prohibit such individuals from operating in an unrestricted manner. Details of ways to accomplish this are provided in volume II (National Constraints).

Congress could encourage the development of private pest management consultants through some form of support for their potential liability burdens as outlined in chapter V. One approach would be the development of a federally sponsored liability insurance program for consultants. An analogy for such a program exists in a bill in the pharmaceutical area, H.R. 1247. The bill, which was not reported out of committee, would have provided for the establishment of a tax-exempt trust for payment of liability claims. The decision that must be made is whether the gains outweigh the costs to the Government in increased time, costs, and opportunities for fraud. Another option is to offer low-interest loans for the establishment of private consuiting firms through the Small Business Administration or the Farmers Home Administration. Such loans could have the added effect of increasing the opportunity for apprenticeships and applied training for potential pest management personnel.

DEVELOP A NATIONALLY COORDINATED MONITORING PROGRAM

A welldesigned monitoring system for weather and biological factors can provide the necessary input for the design and use of predictive capabilities in a pest management program. Such a national environmental monitoring system does not exist now. Useful information in research or implementation programs is rarely communicated to others on a timely basis. A national system taking advantage of existing computer and electronic-sensing technology could be designed to meet the needs of pest management.

The National Weather Service's agricultural weather reports are not precise enough and do not have a rapid enough input/output cycle to be truly useful in pest management programs. Agricultural weather is relatively low on the Commerce Department's scale of priorities. Little effort has been made to get more accurate short- and long-range weather predictions on a local level.

Congress could direct the Commerce Department to work with USDA to develop a more precise agricultural weather system. The benefits of such a system would include increased precision in the prediction of pest outbreaks (with resulting savings in control and scouting costs to the grower) as well as a better base from which to plan general farm and rural operations. The cost of such a program could be kept at a reasonable level by making use of existing facilities and technology.

Several land-grant universities are now developing their own computer facilities for biological monitoring and prediction capabilities. These local efforts could be turned into a national biological monitoring system, where appropriate, by linking them to a national computer. This would be similar to current activities of the National Weather Service. It would create a network for the national accumulation of data from each of these State facilities. Congress could accomplish this by specifying appropriations for the establishment of a national facility for the collection and coordination of State information. The data accumulated could be used to trace migratory insect movements as well as to describe the status of other pests. Such information would also help to limit scouting and control costs to a specific period of time around the expected danger period. By using this information, significant savings can accrue to the farmer through decreased pesticide use and decreased scouting costs.

An expanded national effort is needed for the early detection of introduced pest species. Examples of new pests that have entered the country undetected and remained so for several years include the cereal leaf beetle, the citrus blackfly, and witchweed. Many of the major pests of our crops are introduced pests. If the eradication of introduced pests is to occur, early detection is absolutely essential. A review of the present Noxious Weed Act and adequate funding to allow inspection of shipments to the United States for exotic weed species should also be accomplished.

Pesticide use surveys could also be coordinated by USDA. Each State now has a cooperative crop-reporting service that can efficiently and effectively conduct such surveys.

USDA could provide national leadership and coordination so that State survey information can be readily assembled on a regional or national basis, Questions have been raised regarding the need and utility of an extensive use survey system. USDA already collects pesticide data. These data are extremely important in giving an overall picture of trends in pesticide use.

One means that would be extremely useful not only for training programs but also for implementation efforts and pest monitoring would be for Congress to support existing plant health clinics as well as help form new ones in the States. Animal health clinics are widely developed. There is a need to develop such services and teaching centers for plants. The clinics could serve as the focal point for pest management implementation efforts. They would include diagnostic as well as information capabilities; the accurate diagnosis of plant pest problems would eliminate much of the misuse and waste of pesticides and other control agents. The clinics could also provide staffing and facilities for clinical programs in pest management. With adequate support, they could be the backbone of the practical component of pest management degree programs. The volume and range of pest problems brought to the clinics would automatically monitor pest activities for each State. The clinics would also greatly increase the likelihood of detecting introduced pests in time to institute eradication or other indicated activities. Unfortunately, very few adequately sized and staffed clinics now exist.

Cost-effective support for the formation or improvement of plant clinics could be given by offering matching funds to those States willing to join in their development. Funds should include provisions for facilities as well as for staffing the clinics. Additionally, funds should be provided for interdisciplinary faculty participation in the clinics, for both diagnosis and training.

PROVIDE TRAINED MANPOWER AND TRAIN~N6 PR0GRAMS

Lack of trained manpower at several educational levels is an obstacle to the development and implementation or improvement of pest management systems. Increased funding earmarked for educational programs in pest management at all levels is needed to provide an impetus for more rapid increases in utilization of the pest management approach.

Support for Pest Management Training Programs

Only university administrators can act on many of the items outlined in this section. The prime vehicle for congressional action in pest management education would be to provide funds to support university programs. They are needed for the following levels:

- self and mutual retraining and reorientation of administrators, professional researchers, teachers, extension personnel, and leaders of State and Federal agencies;
- nondegree or certificate training programs or special short-course sessions for paraprofessionals (scout supervisors and scouts);
- integrated, high-quality baccalaureate degree programs to prepare students for graduate study in traditional disciplines as well as technical positions in industry, agribusiness, and farm, home, forest, and urban pest management;
- establish or improve pest management programs at the master of science level consisting of nonthesis terminal degrees for students preparing to be practicing professionals and a thesis degree for those aspiring to the Ph. D. level with a pest management emphasis or a professional doctorate in pest management; and
- a Ph. D. in traditional crop production or protection discipline with a minor in pest

management or minors in two related areas for preparing teachers and researchers for pest management.

A further possibility recommended only for consideration at select institutions, perhaps as a consortia basis, is a professional degree in pest management for training practitioners with the diagnostic and clinical skills to operate the pest management programs required to preserve the future health of our crops.

Support is also necessary to initiate and support medium-term postdoctoral fellowships for research for highly qualified new Ph.D.'s who would need additional experience. Such a program would provide incentives for outstanding young scientists to enter the field and, at the same time, make opportunities for creative developments in the field of pest management.

Adequate clinical components are a critical need in any of these pest management training programs. Universities should be encouraged to require a pest management internship. This would require the development of a strong certification program and a commitment on the part of certified practitioners as well as university administrators and faculty.

Congress could help by providing support to the universities for administering the internship program, to the certified practitioners, and to the students during field internship. Advantage should be taken of the opportunities offered by the USDA-sponsored pest management pilot programs. Pilot project funds could be used to provide training and subsistence for the pest management degree candidate. It could be required that every Extension Service action program include an internship component. The net result of this approach is a self-renewing supply of qualified scout supervisors and experienced pest managers available to public and private pest management organizations and the pesticide industry.

The Federal Government could also provide funds to support degree candidates for internships with private consultants, grower co-ops, and other organizations. These funds could serve as an indirect subsidy to fledgling organizations as well as provide opportunities for field experience.

Competitive Study Leave Grants

The need for updating professional skills for working scientists in rapidly proliferating fields such as pest management can be met by a system of study leave grants. These would provide an additional way to take advantage of the areas of technical expertise already forming at certain land-grant universities. Such a system would allow a specialist in pest management at one university or Federal unit to spend 6 months to 1 year at another university with a different set of problems and expertise in pest management.

Reducing Manpower Requirements

Another approach to the problem of lack of appropriately trained manpower is to reduce the labor required for pest management programs. The major portion of man-hours invested is in scouting and monitoring pest populations, crop development, and ecological factors that influence pest problems. Two approaches to reduce labor intensity have been identified:

- Areawide pest monitoring and population prediction on the basis of computer models will allow scouts to cut their time in the fields to the critical days of pest activity. Scouts could then cover a larger area.
- Develop and use automatic mechanical devices for monitoring pests and ecological factors influencing them. Most of the technology exists to design remote sensors tuned to different pheromones and sound frequencies to monitor for insect pests and provide rough estimates of population levels. Monitoring devices for vertebrate pests are also possible. Some devices are available for monitoring temperature, humidity, rainfall, and length of leaf wetness periods. These can be connected to minicomputers that

can signal dangers of plant disease infections. The development and techniques for use of such monitoring equipment involve research by both the private and public sector. Many segments of private industry, from the manufacturers who build them to the growers who save on their own time and scouting costs by using them, are interested in such monitoring systems. Congressional interest in pursuing this approach will depend on the level of private sector support and the desire to use pest management as a means to provide jobs to rural Americans.

Establish Regional Pest Management Study Centers

The establishment of regional pest management study centers is discussed in detail in the section "Improve Cooperation and Coordination. Regional centers could help train and update crop protection personnel in the latest developments in the field. Regional centers would be appropriate for workshops and training for professional pest management personnel but not for scouts or scout supervisors.

OVERCOME GROWER SKEPTICISM

Growers are the key to the adoption of pest management programs. Three approaches to obtain increased grower involvement have been identified: through education, by providing incentives, and by regulation.

Education

Education has been the traditional method of bringing new developments and technology to growers. This approach to grower involvement in pest management has the advantage of grower acceptance and an existing cooperative extension system to teach growers. The only missing element for many situations is the availability of feasible, economically sound validated pest management programs. Congress will play a critical role in determining the rate at which such programs are developed.

Providing Incentives

Providing incentives to increase grower participation in pest management is another option. Low-cost Federal crop insurance is one way to cover losses to pests and help overcome skepticism. There are major problems involved in establishing and operating such a program. Also, well-conceived and validated pest management programs should not be riskier than other control approaches.

Regulating Grower Involvement

Regulating grower involvement is a sensitive area because of current attitudes toward Federal regulatory efforts. Restrictions imposed on a national level would be met with strong opposition by growers. There is some interest in the use of locally enacted pest management districts to regulate grower participation. These districts can be established by a State enabling law and then confirmed by local grower referenda. In Texas, enabling legislation has been passed but no districts have yet been established.

IMPROVE COOPERATION AND COORDINATION

Problems in cooperation and coordination as a constraint to pest management exist within the Federal Government, between the Federal Government and the States, and with the State and land-grant university complexes. The problems and options to reduce the problems are outlined below.

Mechanisms to Coordinate Efforts of Federal Agencies

Legislation exists that is designed to correct any problems among Federal departments and agencies in the amendment to section 401(h) of the National Science and Technology Policy, Organization, and Priority Act of 1976 (90 Stat, 471, 42 U.S.C. 6651(h) provialed by section 1406 of Public Law 95-113, 91 Stat. 986). Nevertheless, we address here specifically the problem as related to pest management. The problem of unclear and sometimes conflicting goals being pursued by different agencies has severely hampered the Federal effort in pest management. Lack of a mandated responsibility for pest management support activities or a plan on which to organize agency programs is at the heart of this problem.

Two basic premises should be included in any deliberations on a Federal pest management strategy: 1) that USDA, with its extensive research and extension network, should have the primary responsibility for pest management programs, and 2) that EPA, with its responsibility for protecting the environment, has a valuable role in supporting the development of innovative tactics for and approaches to pest management. Other agencies, such as the National Science Foundation (NSF) and the Food and Drug Administration (FDA), also interact with 1PM development and implementation. These roles and interactions are taken into account in the following discussion.

Four different mechanisms to ensure better cooperation and coordination in the Federal pest management program are outlined. While they are presented separately, they would have the strongest effect if combined.

- A representative group from outside the Federal Government could be established as an oversight group for pest management. Such a group would be composed of individuals involved in pest management from the Federal, State, and private sectors. They would know the grassroots needs for pest management and could bring that perspective to bear while reviewing the Federal efforts. With no control over budgets and staffing, only strong executive support could make such a group an effective agent for coordinating Federal efforts. It could be most useful in an advisory capacity.
- To ensure that groups with program responsibility become involved, an interagency review group on pest management could be formed. To be an effective policymaking body, it would have to consist of individuals at the assistant secretary level from agencies with programs related to pest management. It would examine the current structure of Federal initiatives in pest management and suggest means to streamline them. It would also serve as a forum for the development of a national pest management plan, including program goals and agency responsibilities. The drawback here is that such groups are often ineffective. Starting with the intentions of making policy, they frequently evolve into forums for technical exchange, rather than for policy discussions.
- Congress could intervene and clarify the roles and responsibilities of the agencies involved in pest management. The aim would be to start with the functions of USDA and EPA outlined at the beginning of the discussion, include FDA, the Council on Environmental Quality (CEQ), and the Department of Defense (DOD), and other appropriate agencies, and assign specific program responsibilities and areas of interagency cooperation within pest management. The effect would not be to consolidate responsibility in **one** agency but to provide support and direction for intra-agency and interagency efforts. Existing areas of interagency cooperation could be given formal recognition, and other areas for future coopera-

tion could be outlined. If combined with the formation of an interagency review group charged with overseeing the success of the cooperation, the effect of any congressional effort could be greatly enhanced. The major drawback to this approach would be the interest required in Congress to undertake such a task.

- A Federal unit without present or future funding interests could be given a coordinating role for the national effort in 1PM, CEQ has already been acting to some extent in this role. To be effective, its coordinating and oversight role must be clearly delineated and adequate staffing provided. The staff should be supplemented by an outside advisory group as outlined previously. The advantages of this option would be to place a noncompetitive Federal unit with ready access to the executive branch and all Federal agencies involved in 1PM in a position to monitor and develop policy for the Federal effort. This option cannot function effectively without a clear mandate, a modest staff knowledgeable in the subject matter, and an appropriate advisory group.

Cooperation and Coordination Between Federal and State Agencies

Of primary concern is the relationship between USDA and the land-grant universities with teaching, research, and extension responsibilities. The main problems are in the areas of program development, priorities establishment, and budget development. Development of the planning and coordination mechanisms called for in title XIV of Public Law 95-I33 and the subsequent reorganization within USDA to form the Science and Education Administration and the organization of Interregional Project 6 should make coordination and cooperation easier. However, it must be encouraged at every level. Congress can contribute by ensuring that the intent of Public Law 95-113 is fully implemented and funded.

Several potential problems face the regional and national planning approach that is being put in place. One is the potential difficulty of fitting AR programs of national focus into the regional priorities. A second problem is adopting the State organization of the extension services to a regional structure. Related to this is the fact that States will be wary of another layer of administrators apparently prepared to dictate regional priorities in extension to them. A final problem is that by assigning priorities on both a national and regional basis even less funds will be going to work on critical local needs.

Coordination and Cooperation Within the Land-Grant Universities

Traditionally, pest management teaching, research, and extension have been approached from separate disciplines. 1PM requires consideration of more than one discipline and their interactions. This necessitates, as previously mentioned, not only even stronger discipline teaching and research but interdisciplinary and multidisciplinary teaching, research, and extension considerations. Present funding is simply not adequate to even approach this job.

Providing additional funding at the Federal level is essential for the development of new initiatives in 1PM in teaching and research just as it has been in the extension pilot programs. Congress can contribute the most to improved cooperation and coordination among the disciplines, especially in research, by providing significant additional funding. This additional funding will be more productive and effective if provided to States through the regular funding under the Hatch and Regional Research Acts by USDA's SEA/CR. This provides stable funding that enables the development of scientists in a tenure track of teaching and research. It also allows priorities to be set at the local level to develop programs that address the major 1PM problems in the local producer areas,

Establish Regional Pest Management Study Centers

A major limiting factor in the advancement of pest management is a space/time problem. The study, comprehension, and application of the pest management concept has been done largely on a personal or institutional basis. Until recently, few institutions had even a formal course or seminar in pest management. The few pest management specialists that exist are scattered over the country and the world, with inadequate opportunity in time, facility, or support for mutual discussion of ideas and strategies.

One option suggested to reduce this limiting factor is to establish regional pest management study centers. Such centers would have facilities for students, professors, researchers, extension specialists, and others to work, study, and train in pest management. They would combine a "think-tank" atmosphere with research, education, and implementation programs and would provide a place for the different groups in crop protection to discuss and attempt to unify approaches to pest management.

This approach would use the centers of technical strength in pest management that are developing across the country. At several land-grant universities advanced work is already being done in pest management. The base existing in these universities could be used to form a network of regional centers for pest management, education, research, and implementation. These centers could combine the think-tank atmosphere with work directed toward the needs of pest management programs in their regions.

Careful consideration should go into the design of each of the regional centers in terms of location, facilities, administration, funding, missions, and philosophy. The centers should be located at land-grant universities that have evolved as leaders in pest management and where facilities already exist or can be constructed. Congress could authorize and fund establishment of the centers. Funds could be allocated to the respective institutions to include hiring directors and permanent support personnel.

While the option of creating regional study centers promises to improve cooperation and coordination as well as to assist in training personnel, there are potential problems that must be considered. The problems and lack of success experienced with regional centers in other fields suggest that the concept may not be as useful in practice as in theory. The precise role of the centers in accomplishing their goals must be carefully evaluated to determine the probability of success. Administrative costs could become excessive and detract from the programs. In addition, linking the centers to institutions identified as leaders could increase the gap and the jealousies between the have and the have-nets in pest management. Such an occurrence could make regional cooperation extremely difficult.

Competitive Study Leave Grants

This option **was** presented under the training section. In addition to its merits for training, this option would help improve cooperation and coordination among Federal agencies, between the Federal agencies and the States, and among the States. The interchange of personnel on study leaves would improve communication, understanding, and the flow of information. Properly administered, this option could be a very positive force in furthering pest management.

REVIEW IMPACTS OF COSMETIC [ESTHETIC) STANDARDS

If Congress decides that reducing the use of chemical pesticides whenever possible is one of the goals of Federal pest management efforts, existing food quality standards should be evaluated. As noted in chapter V, the high-quality standards for certain fruits and vegetable crops necessitate the extensive use of chemical pesticides. The safety or nutritional value of the produce may or may not be improved by these quality standards and must be judged on a case-by-case evaluation.

Congressional efforts in this area could have two approaches. One would be aimed at the standards it has under direct control, such as the defect action levels (DALs) administered by FDA. An assessment of the effect of DALs on pesticide use, pesticide residues, human health, and market value similar to an environmental impact statement should be conducted. Such an analysis would compare the benefits from present DALs and those that would accrue from less-strict levels, It would allow a responsible decision to be made on the proper levels of defects allowed while protecting human health.

The second part of the congressional effort would be aimed at the broader issue of consumer and processor acceptance of damaged produce. Studies should be conducted on market elasticity and consumer willingness to accept blemished but safe food in order to reduce pesticide use, Chapter VII

Transfer of North American Crop Protection Technology to the Developing World

Transfer of North American Crop Protection Technology to the Developing World

The combination of control tactics in an ecologically oriented integrated system, known in the United States as "integrated pest management" (1PM), is being applied in the development of i&proved stable crop protection systems for U.S. agriculture and is widely accepted internationally; the term "integrated pest control" is used in most other countries for this holistic approach to pest control. The two terms are often used synonymously.

Considerable progress has been made in transferring the basic philosophy of 1PM to the developing world. This has been fostered by the Food and Agriculture Organization (FAO), World Health Organization (WHO), and certain bilateral assistance programs (especially those of Canada, France, the United Kingdom, and the United States). The Organization for Economic Cooperation and Development (OECD), the United Nations Environment Program, the World Bank, and the International Agriculture Research and Training Network of the Consultative Group for International Agricultural Research (CGIAR) have become involved in recent years.

The problem of actually implementing pest management systems in the developing world is not simply the transfer of the total 1PM concept, although certain components of the system have great potential for transfer. Much adaptive research on the potential component tactics of pest management and the development of entirely new systems adapted to local socioeconomic and ecological conditions will be required. Each candidate component to be considered for possible transfer will need to be evaluated separately in terms of its potential for use under the conditions that will be encountered. It must be compatible with and become part of the entire crop production process. Because production practices and environmental conditions vary widely within and between countries, the transfer of crop protection technology is most complicated. By applying the concept and the scientific methods by which crop protection technology is developed, in-country crop protectionists can produce a pest control procedure that is well-adapted ecologically to the local agroecosystem and is socially and economically acceptable as well.

PRESENT LEVEL OF PEST CONTROL TECHNOLOGY IN THE DEVELOPING WORLD

Pest **control technologies are used uneven**ly in the developing world. Within any one area the ecological environment, social customs, political events, and economic milieu all interact to set the magnitude of a particular pest problem and further to constrain feasible solutions. Therefore, every situation must be evaluated and developed on a case-by-case basis.

In a similar way, the level of dependence on pesticides varies from country to country. In general, the more developed the country, the greater the use of pesticides, but there are often large differences between crops in the same country. Surveys by FAO a few years ago indicated that the entire developing world used only about 7 percent of the global consumption of pesticides. Lack of financial resources to purchase pesticides is only one reason for this low use of pesticides. The agricultural infrastructure taken for granted in developed countries may be only partially developed or entirely lacking in developing countries. The present marketing system stresses certain crops in certain countries and, thus, produces an uneven supply situation. In times of serious pest problems, pesticides often are not available, are in the wrong place, or arrive in the right place at the wrong time. Furthermore, an inadequate transportation network in many countries does not provide a way for pesticides to move from the capital city to the rural areas where they are needed. Finally, few developing countries have adequate equipment to apply pesticides, and even fewer have a pest-monitoring system to detect pest infestations while they are still at manageable levels.

In developing countries, the large estate crops such as rubber, cotton, and sugar cane tend to get a heavier use of pesticides than do the plots of small farmers. In many cotton-producing countries in the developing world, two-thirds or more of pesticide use is on this single crop. In some developing countries, use of insecticides to protect stored products is also of considerable importance. Overall, there is a slight trend for increased use of pesticides in these countries, but the percentage of the world's total use is not increasing.

In the developed world, insecticides have declined in relative position among pesticides from being the dominant class of pesticide before 1960 to representing currently only about one-third of total pesticide use. This change primarily resulted from the rapid growth in the use of herbicides, which now represent the major portion of pesticides used on a global basis. 1n the developing world, insecticides remain the dominant class of pesticides used, and their use is increasing at a rate that would appear to maintain their dominant position for some time. Herbicides use, however, is increasing as appropriate and economically feasible uses are found.

OBSTACLES TO PEST MANAGEMENT SYSTEMS IN DEVELOPING COUNTRIES

1PM systems are developed through the careful ecological analysis of pest problems that exist in the growing crops. Research programs for 1PM systems must relate to the entire pest problem and the full complexity of the field situation. No amount of sophisticated laboratory research will produce an 1PM system. It is important to realize that research on field problems can be extremely complicated as it must deal with establishing the complex relationships that exist in the agroecosystem, such as those between the pest and the crop, among certain pests and noncrop plants, between the pest and its natural enemies and plant diversity, and among all of these considered together with other crops and the climate and economic and political aspects. These are often overwhelmingly complex problems facing the isolated crop-protection specialist in a developing country, and the obstacles to their solutions seem insurmountable. Furthermore, there is often a lack of extension personnel or other paraprofessionals to train and encourage farmers to adopt new practices, The specialist may also find that farmers are often incapable of or unwilling to adopt a new practice because they lack the financial resources or proper motivation. The specialist may also have difficulties communicating with the farmer because of language barriers or illiteracy or even reaching the farmer because of inadequate roads or transport,

It is not surprising, then, that the isolated and frustrated pest control specialist may recommend an easy short-term solution such as the use of some pesticide. The recommendation may be made with little or no opportunity for consideration of the complications of undesirable side effects on people, important natural enemies, and the general environment, and the long-term effects of pesticide use.

In spite of the difficult odds, sound 1PM systems have been developed under such circumstances. Indeed, every operational 1PM system in developing countries has had a relatively simple beginning. The first step in these programs was to develop an ecological perspective and then to design the best possible action based on available knowledge. This design, at best, approximated an ideal system which was then tested in the field. Where difficulties were encountered they were posed as questions for parallel solution-seeking research. In this way, even where resources may be limited, an effective 1PM system can often be developed and adapted to the local situation. This has been accomplished in Peru, Nicaragua, Malaysia, and certain other countries with modest financial inputs for the development of the programs.

PROBLEMS ASSOCIATED WITH TECHNOLOGY TRANSFER TO DEVELOPING COUNTRIES

Pest management systems developed for the temperate part of the world, as stressed earlier in this discussion, may be completely inappropriate to tropical and subtropical conditions of the developing world. This is because of not only the greatly contrasting physical and biotic conditions but also the contrasting problems of modern intensive high-energy agriculture and those of traditional subsistence agriculture involving multiple cropping and mixed cropping.

In the absence of adequate crop protection programs in many developing nations, there is an over-reliance on the reactive use of pesticides for pest control. There are numerous well-documented examples of the inadequacy of this approach in both developed and developing countries. Unless pest management or integrated pest control programs are initiated, additional "pesticide abuse" situations will occur. Complete dependence on pesticides over a period of time not only fails to control the pests in question but may actually aggravate pest problems and endanger human health and environmental quality. Pesticides misuse also imposes an additional cost on production.

The developing world must deal with an array of crops and pests that is not generally grown in temperate countries. These crops include avocados, bananas, breadfruit, cacao, cassava, coconuts, coffee, guava, mango, papaya, pineapple, plantains, sugarcane, tare, and yams. Many of these crops are of great importance in world commerce and contribute much to the world's food supply. Because a bank of technological knowledge on their culture and the management of their pests is not available in temperate countries, it must be developed in-place in the tropical developing world. Nevertheless, some component tactics from temperate 1PM systems can be adapted to these tropical and subtropical crops.

In any attempt to transfer the latest developments in pest control technology to the developing world it will be important to reach the decisionmakers in these countries, many of whom received their technological training prior to the resurrection of the ecological approach to pest control. As a result, considerable reeducation will be necessary and new approaches to communicate with the decisionmakers will be required to achieve satisfactory results. In addition, different social and economic values placed on the importance of food, environment, human life, individual rights, etc., in developing countries require considerable adaptations of pest management systems to accommodate these values.

POTENTIAL IMPACT OF PEST CONTROL TECHNOLOGY TRANSFER

The losses of food crops to pests in the developing world are enormous. Although detailed documentation is lacking, estimates of losses run between 25 and 50 percent of the food produced. Conservative estimates indicate that at least 50 percent of the losses can be recovered, At the same time, the need for enhanced protection from crop pests is further emphasized by the fact that other methods of crop improvement that result in an increased production of food will require additional pest protection for the high yields to be fully realized. For example, new, low-growing wheats and rice require considerably more weed control than long-stemmed varieties to prevent intolerable economic production losses.

However, it is difficult to translate the savings in crop yields that would result from improved pest control into economic terms that reflect the probable distribution of that savings to the population of the country. If the supply of a particular commodity is increased in an area as the result of the adoption of improved pest control practices, the price of that commodity may fall, and the effect of the lower price on small farmers may be severe. For example, nonadopters and late adopters of improved practices are particularly vulnerable because their production costs and yields will remain the same while the price they receive for their produce will decline. Unless additional concomitant measures are taken, the incomes and nutritional status of such farmers are likely to deteriorate over the short term. This prospect puts a special premium on selecting methods that are suited for adoption by small farmers. Over the long term, however, the economy of the country as a whole and the general welfare of the people will be improved.

Increases in yield are important, but increased production stability from year to year with improved pest control practices can be equally important. Without a sense of stability, investments in agriculture are not likely to be made that require more than one growing season for amortization.

The differential effects of successful innovation in pest control on different economic classes of agricultural people are the most difficult and yet perhaps the most important to analyze, New pesticides are likely to be adopted only by the wealthier and more progressive farmers because they have better access to credit for purchasing the necessary materials and machinery. If the new practices require more labor to be successful, wealthy, capitalized farmers may be at a disadvantage compared to poorer farmers using labor-intensive methods. On the other hand, if the new practices require the purchase of new machinery or the acquisition of new skills, the wealthier farmers may be at a relative advantage. Biological control, the breeding of resistant varieties, and other genetic methods of control usually will be operations performed with a high degree of public sector effort, and each will require the farmer to contribute little in purchases above and beyond that which is normal for the crop he is raising. Hence these technologies, which depend on enlightened levels of government support, have less chance of favoring one class of farmer over another.

When any proposed new technology is assessed, a crucial question is its effect on the labor requirements for agriculture. This is particularly important in the nonindustrialized market economies in which unemployment and underemployment are frequently endemic and in which no alternative industrial employment possibilities exist.

The emergence of resistance to insecticides dramatizes the point that new technologies are not necessarily permanent additions to options in crop protection. There are no theoretical reasons why resistance will not emerge eventually for any control practices directed against any pest or any crop. Thus, a high premium should be given to improved technologies that offer the potential of longer use before resistance develops.

Innovations in biological control, breeding for resistant varieties, and other genetic controls are not likely to create any direct adverse environmental impacts. Elimination of a pest like the tsetse fly from Central Africa might create indirect environmental effects by opening up areas to crop agriculture or to grazing that until now have been unused.

Cultural control will, in general, have little adverse effect on the environment unless the particular practices involve cultivation. In such cases, soil may be lost through wind or water erosion. Substituting herbicides for tillage may markedly reduce soil losses during crop production. In Kenya, herbicides may allow continued crop production in areas where “slash and burn, ” followed by abandonment after several years, is the traditional agricultural practice on small plots in the jungle.

Herbicides can be used not only to replace cultivation for weed removal but also to replace plowing for crops such as corn. In addition to savings in labor and energy, the “no-till” practice reduces erosion and increases soil organic matter, The technology of “no-till” agriculture may be widely applicable in the developing world where problems of erosion are severe.

The use of certain pesticides has had an adverse effect on the environment when the pesticides have entered the food chains of ecosystems or when they had direct toxic effects on nontarget organisms—e.g., birds and fish. Integrated pest control, because it depends on chemical pesticides only as a supplement to other means of control, is likely to have smaller adverse effects on the environment.

The developing world is on the threshold of a large increase in the use of pesticides. If these pesticide inputs are made unwisely, pest problems can be greatly exacerbated and there can be adverse effects on the environment and on agricultural workers. Properly developed pest management systems using pesticides as only one component of many can help avoid these problems.

Agromedical teams can play an important role in encouraging the safe and efficient use of pesticides. Timely education on safe handling of pesticides, monitoring of worker and environmental safety, and the training of medical personnel in developing countries to cope with pesticide-related health problems can greatly reduce the adverse impacts of pesticides.

STRATEGIES IN THE ADAPTION OF IMPROVED PEST MANAGEMENT PROGRAMS IN THE DEVELOPING WORLD

Education and training must be a core element in any program to develop improved pest management in developing countries. Fundamental training will be required in all aspects of pest management and at all levels to create and strengthen an adequate infrastructure to receive and adapt pest management technology. This should involve the decisionmaking administrators as well as the lower level technicians. Research, training, and extension, particularly adaptive research and on-the-farm demonstration, will be required at a significant level to develop the required knowledge base and to implement pest management systems successfully in the developing world.

A large number of agencies and institutions are involved in developing improved pest management in the developing world. These involve multilateral international agencies such as FAO, WHO, OECD, bilateral development assistance programs of many nations, and a number of other institutions. At times there has been an unfortunate lack of coordination and collaboration among these bodies. Recently steps have been taken by FAO and OECD to assure more coordination, and this should be reinforced and encouraged.

U.S. PROGRAMS

The U.S. Agency for International Development (AID), or its predecessors, have over the years had extensive and varied programs aimed at strengthening plant protection programs in developing countries. Many of these programs are developed in cooperation with U.S. universities, experiment stations, the U.S. Department of Agriculture (USDA), and other U.S. institutions. Most of these programs are directed toward individual countries and are supported directly by the local U.S. AID missions. AID also provides more than 25 percent of the funding for the CGIAR Agricultural Research and Training Network, whose programs contain considerable plant protection research.

Since 1971 AID has had a contract with the University of California (UC) for a global project in pest management and related environmental protection. This is a general technical services contract intended to develop improved pest management in the developing countries. The objectives of the project are:

- to provide research and technical assistance in AID's involvement with pesticides,
- to improve less developed countries' (LDC) regulation and pesticide-monitoring capabilities,
- to develop country- and international-based 1PM and environmental protection systems,
- to train competent LDC personnel to develop scientific skills and pest management expertise,
- to assist AID in developing networks of institutions relating to pest management expertise, and
- to assist in the development of a series of coordinated pest management research projects.

In this project, the University of California is cooperating with Oregon State University, University of Hawaii, Texas A&M University, University of Florida, University of Miami, Cornell University, University of Minnesota, and North Carolina State University to provide these services.

Oregon State University has had a research project on weed control in developing countries supported by AID since 1966. Much of their research has been carried out in developing countries of Latin America, with backup research in Oregon and Hawaii. They have done outstanding work in producing and disseminating information of value not only to weed scientists but also to other pest control disciplines.

The 1975 title XII amendment to the Foreign Assistance Act established a Board for International Food and Agricultural Development (BIFAD). One of the basic objectives of

BIFAD was to involve the U.S. universities with AID in sound long-term programs. Recently the Joint Research Committee of BIFAD identified "crop protection" as a priority area for a planning grant to develop plans for a collaborative research support program.

In the past 3 or 4 years a large number of documents have been developed by the U.S. National Academy of Sciences, U.S. AID, OECD, and others which give valuable background information on the subjects discussed in this report.

OPTIONS FOR CONGRESS TO IMPROVE CROP PROTECTION IN THE DEVELOPING WORLD

Support Education and Training of LDC Crop Protection Scientists

U.S. experience over the past 35 years in international efforts to increase food production in LDCs clearly indicates that short-term technical assistance is not productive. The key to success in agriculture is to support advanced education to those who will return to staff the universities, research institutes, and agricultural ministries in their own countries. Without such in-country scientists and specialists, few long-term improvements can be achieved.

To maintain trained staffs in universities and research institutions in LDCs, continuing efforts are required because of the attrition to administration, industry, and international organizations. Because advanced-degree training in LDCs is variable and tends towards inbreeding, it is important that overseas advanced educational programs be continued.

Congress should ensure that AID in cooperation with USDA and the land-grant universities supports a program of graduate training adequate to meet the needs of developing countries. This program should be coordinated with those of other nations and institutions to provide optimum results with available resources.

In addition to degree training, middle-career scientists need opportunities to have updating educational or work experience at an institution where advanced work in pest management is underway. Congress could ensure that there are adequate fellowships to fulfill these needs.

The two most serious problems encountered in educating and training foreign personnel are: 1) the reluctance of some people to return home and 2) learning to do research in sophisticated, well-equipped laboratories. Both of these problems are alleviated when scientists are permitted to carry out their thesis research at home or in a comparable situation under the direction of appropriate faculty advisors. This procedure has the advantage of training under realistic conditions, helping to solve local problems, and starting scientists on research that can be continued after completion of their advanced degree.

Agromedical Training for In-Country Personnel

Pesticides, especially insecticides, can be very hazardous to man, animals, and the environment. Some very unfortunate experiences have occurred in some LDCs as a result of misuse of pesticides. There is need for education in pesticide management, including their proper use, monitoring for residues in food and the environment, and the recognition and treatment of pesticide poisoning. The UC/AID pest management project has sponsored some successful pesticide management workshops in several parts of the developing world. This is an effective approach to reducing the hazards of pesticide use in LDCs.

Integrated Pest Management Workshop

In addition to the education and training of top-level scientists in the philosophy and methodology of pest management, there is a great need to provide practical short-term training for agriculturalists who are working directly with farmers in an advisory capacity. Six- to eight-week training workshops sponsored jointly by in-country institutions and AID with instruction by both local and foreign experts have proven to be very effective.

Provide the Less-Developed Countries With Pest Management Information

An almost universal problem for crop protection scientists in LDCs is lack of adequate libraries and up-to-date information. One solution may be to provide foreign literature or to subsidize the preparation and publication of books and bulletins by local scientists.

Establish Research Projects and Develop Pest Management Systems

The United States has the option of establishing appropriate research projects designed to develop practical pest management systems for local and regional situations. These projects could involve local scientists with cooperative inputs from U.S. scientists. Some projects might be designed for a local problem; others could involve scientists on a regional or even global basis, Care must be exercised to ensure that such projects are complementary with ongoing research in crop protection.

Provide Support for Crop Protection in the Title XII Program

A most important option is to develop a vigorous effective program in crop protection under the title XII amendment to the Foreign Assistance Act. The reduction of pest-induced losses provides one of the most promising approaches to increasing the world’s food supply.

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U. S. GOVERNMENT PRINTING OFFICE : 1979 0 - 5 1- 788