Chapter II

Present. Status of Crop Protection

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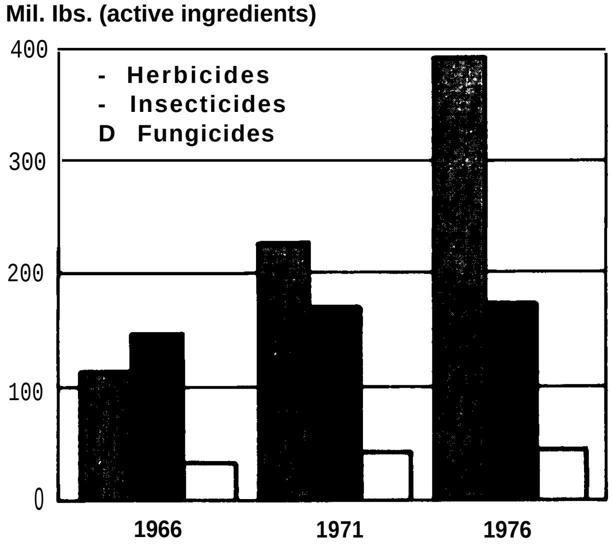
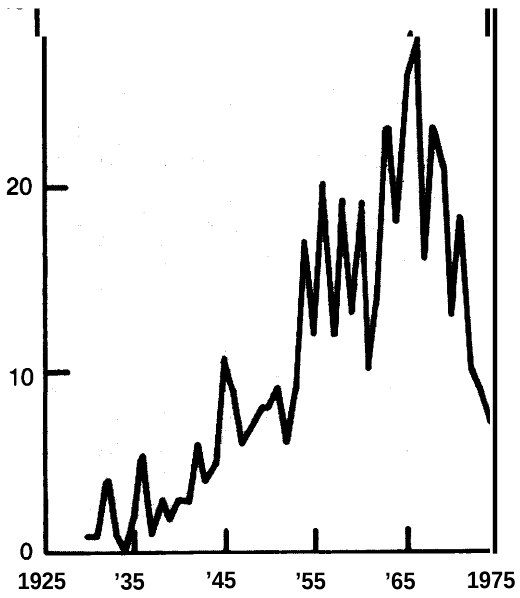
In 1966 U.S. farmers used approximately 300 million lbs of pesticides for crop protection; by 1976 pesticide use had doubled to more than 600 million lbs. This escalation reflects the dramatic increase in herbicide use over the 10-year period, while insecticide and fungicide use has increased only slightly (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..	Microbial	resist-	Samta-	natlng	Crop	Plantlng	Clean	Water	FertW		Chemical: Soil	Chemical: Seed	Chemical: Foliar	Other: Monitoring	Other: Predictive 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 tradeoff 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)	Pred & para	Microbial	Host plant resistance	Cultural: Sanitation	Eliminating hosts	Crop rotation	Planting date	Clean seed	Water mgmt	Fertility mgmt	Tillage	Soil	Seed	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
Velvetleaf		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
Armyworms		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 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																	
Cocklebur	N	1	1	1	2	1	2	1	3	1	1	3	2	1	3	3	1
Sicklepod	I	1	1	1	2	1	2	1	3	1	1	3	3	1	3	3	1
Morningglory	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
Pigweed	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 sida	I	1	1	1	1	1	1	1	3	1	1	2	3	1	2	2	1
Hemp sesbania	I	1	1	1	2	1	2	1	3	1	1	3	3	1	3	3	1
Florida 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 blight	N	1	1	1	1	1	3	1	1	1	1	1	2	1	1	2	1
Pod and stem blight		1	1	1	1	1	2	1	2	1	2	1	1	3	2	1	2
Bacterial blight	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
Reniform	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
Ectoparasites	N	1	1	1	1	1	2	1	1	1	1	1	3	1	1	1	1

*Trap crop control
"Migrate annually from central America and Caribbean

Key: 1 = little 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 meth-od(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 nema 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-Ilve
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 Hampshire, 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

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 (early harvest)	Cultural: Clean seed	Cultural: Water mgmt	Cultural: Fertility mgmt	Cultural: Tillage	Chemical: Soil	Chemical: Seed	Chemical: Foliar	Other: Monitoring	Other: 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 panicum	N			2	2		2					3	3		2		
Quack grass	I			2	2		2					3	3		2		
Redroot pigweed	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. infestans	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
Fusarium	N	1	1	1	3	1	2	2	3	2	1		1	2	1	1	1
Verticillium	N	1	1	2	3	1	2	1	3	2	1		1	2	1	1	1
Rhizoctonia	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. rostochiensis	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 = little or no use
2 = some use
3 = major 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

Native (N) Introduced (I)	Biological		Host	Cultural								Chemical			Other	
Major pests	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
Aph[ds	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																
Blg 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	i
Sclerotlnla	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 = hftle or no use
2 = some use
3 = malor 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	[illegible]	[illegible]
	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

Major pests — Native (N) / Introduced (I)	Blolog[cal: 'red & para	Blolog[cal: Micro-bial	Host plant resls[ance	Cultural: Samta flon	Cultural: Ellm[-natlng hosts	Cultural: Crop rotahon	Cultural: Planhng date	Cultural: Clean seed	Cultural: Water mgmt	Cultural: Fertlllty mgmf	Cultural: TIllaqe	Chemlcdl: Soil	Chemlcdl: Seed	Chemlcdl: Follar	Other: Monitor lnq	Other: 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 ,lIOC use

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

Major pests — Native (N) / Introduced (I)	Bloloqlcal: Pred & para	Bloloqlcal: Micro blal	Host plant reslsl ance	Cultural: Samta hon	Cultural: Elm-latlnq hosts	Cultural: CroD rolatlon	Cultural: Plantlnq dale	Cultural: Clean seed	Cultural: Water mqmi	Cultural: Fertlllty mgmt	Cultural: rlllage	Chemical: soil	Chemical: Seed	Chemical: Fohar	Other: Mon!tor lnq	Other: 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																
Vertlclllum 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

	Biologlcal				Cultural							~ C l w m c a l				Other	
Major pests	Nahve (N) Introduced (1)	Pred & para	Mlcro-blal	Host plant resistance	SanNa-hon	Ellml-natlng hosts	Crop rotation	Planting date	Clean seed	mgmt	. :	K Y	Y I	z U	I I V I	Monitor-Ing	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 pests	Native (N) Introduced (I)	Biological: Pred & para	Biological: Microbial	Host plant resistance	Sanitation	Elimination host	Crop rotation	Planting date	Clean seed	Water mgmt	Fertility mgmt	Tillage	Chemical: Soil	Chemical: Seed	Chemical: Foliar	Other: Monitoring	Other: Predictive models
Weeds																	
Pigweed		1			1		1	1		1		2	3		1		
Morningglory		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		
Panicums		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	I	2	2	1	2	3	1	3	1	1	1	1	1	1	3	3	1
Fleahopper	N	2	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	I	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
Thrips	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 blight				3	2		1	1	2	1		1	1	2	1		
Seedling diseases				2	2		2	2	2	1		1	2	2	1		
Fusarium wilt				3	1		3	1	1	1		1	2	1	1		
Verticillium 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 reniform				3	1		3	1	1	1		1	2	1	1		

Key: 1 = little or no use
2 = 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	Natwe (N) Introduced (I)	Biologlcal: Pred & para	Biologlcal: Mlcro-blal	Host plant resistance	Cultural: Sanlta-tlon	Cultural: Elm-natlng hosts	Cultural: Crop rotation	Cultural: Planlng date	Cultural: Clean seed	Cultural: Waler mgml	Cultural: Fertlllty mgmt	Cultural: Tlllage	Chemical: Soil	Chemical: Seed	Chemical: Follar	Other: Monitor-Ing	Other: Predlc-tlve models
Weeds																	
Brown panlcum		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		
Plgweed		1			1		1	1		1		2	3		2		
Mornmgglory		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 = mafor 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.