PROCEEDINGS OF A SYMPOSIUM
WASHINGTON, D. C., APRIL 27-29, 1970

ECONOMIC RESEARCH ON PESTICIDES FOR POLICY DECISIONMAKING

PROTECT

Use Pesticides Safely
FOLLOW THE LABEL
U.S. DEPARTMENT OF AGRICULTURE

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ECONOMIC RESEARCH SERVICE

FOREWORD

Concern about pesticides first came to a focus through the efforts of Rachel Carson and others who called attention to their effects on the environment. For a long time little thought was given to measuring the economic consequences of pesticide use. The issues seemed beyond the pale of economics in the realm of incommensurable social benefits and losses. Some saw pesticides as essential in preventing food shortages, while others were impressed with the harm done to the environment. More recently we have come to realize that economic measurement and appraisal can help solve the pesticide problem.

This symposium reviewed the present status of economic research on pesticides and identified new areas to meet future needs for policy decisions. It was planned by the Economic Research Service (ERS) and directed by Velmar W. Davis, Chief of the Production Resources Branch. At the opening session, ERS Administrator M.L. Upchurch welcomed the participants, outlined some of the major issues, congratulated those present for tackling them, and wished them well.

Ronald L. Mighell

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Complete titles and agency affiliations are given in the list of speakers, page 171.
The views expressed by the speakers are not necessarily those of the U.S. Department of Agriculture.

HIGHLIGHTS OF PAPERS

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In the opening paper, Byerly discussed the roles of the many agencies of Government that deal with pesticide matters. In recognition of these complex and interrelated roles, coordinating mechanisms have been established such as the Pesticide Subcommittee of the Cabinet Committee on Environmental Quality. Government agencies are responsible to the public and they must be responsive to public concern about pesticides. Byerly emphasized that the overriding factor in considering the use of pesticides is the protection of human health and welfare. But implicit in this top priority is the assurance of a continuing supply of high quality food and fiber as well as the need to minimize hazards to man from exposure to pesticides and their residues.

Ennis outlined the economic as well as other factors that should be considered in evaluating the restriction of herbicides. He identified alternatives that should be considered when a herbicide is restricted--other herbicides, cultivation, and other inputs, for example. Ennis stressed that available basic data on current losses and costs due to weeds are not adequate to make sound evaluation of the consequences of banning a particular herbicide or restricting certain uses. Even less adequate is our ability to characterize the effects of second-round problems and the interaction resulting from the loss of an important component of systems required for effective and efficient weed control.

Hoffmann reviewed the early and current methods of pest control and pointed out that the Entomology Research Division began reorienting its research in 1955. Presently, only 16 percent of the research is on conventional insecticides, 51 percent on biological and specific chemical control methods, and 33 percent on basic and fundamental research. He expressed concern about the acute toxicity of the organophosphates and carbamates and the immediate effect on people, predators, and parasites, and on bees needed for pollination. He emphasized the need to consider use of large-scale approaches to eradicate insect populations such as the boll weevil.

Both Ennis and Hoffmann expressed concern that major chemical companies might withdraw from research and development of new pesticides because of pending restrictions on the use of pesticides. Such actions could place the burden of research and development of future pest control methods almost entirely on the Government.

Clement singled out DDT for a complete ban, stating that DDT should be banned on principle even before we can quantify its full impact. He would also ban other organochlorine insecticides such as aldrin, dieldrin, benzene hexachloride, and heptachlor--not because of their persistence, but because of their biological magnification. The costs of farm production affected by banning the use of pesticides, according to Clement, are subject to substitution whereas the loss of a species is not only nonquantifiable but irreversible. He pointed out that there are no pests per se, only pest status which is a function of population level as a rule. The task, therefore, is not one of pest control, but of regulating damage and keeping it at some minimum level. The prevention of economic damage from the use of pesticides must become a fully internalized cost of production.

Fox presented the theoretical, physical, and economic concepts involved in evaluating a pesticide ban. These include production functions, cost functions associated with production, and supply and demand functions. He briefly described the economic effects on farmers, the pesticide industry, and consumers of restricting or banning the use of pesticides. He pointed out that farm programs are an important consideration in banning pesticides and that they could be altered to maintain farm income and shift the cost of banning pesticides to the taxpayer. Fox recognized that regional shifts in production, as well as practices, would be likely to result from banning or restricting pesticides. He stressed the need for input-output data associated with control of pests on farm crops. Also needed is information on cost functions covering a wide range of production. Price data for the commonly used pesticides would be useful. Although he implied concern for the economic evaluations of pesticides which would consider costs and benefits to total society, his discussion was primarily directed to the farm sector.

Ennis and Hoffmann generally favored restriction on the use of pesticides rather than a ban but warned of possible second-round consequences from alternative pesticides. Fox, in an economic context, would favor restrictions on certain pesticides in contrast to a complete ban as suggested by Clement.

Andrilenas discussed the assumptions used in evaluating the economic consequences of restricting the use of organochlorine insecticides on specific crops, banning the domestic use of 2, 4, 5-T, and banning the farm use of all phenoxy herbicides. He summarized the results of an ERS study evaluating the economic costs of restricting the use of the organochlorines on cotton, corn, peanuts, and tobacco. Andrilenas also examined four alternatives in restricting phenoxys in the production of wheat. For example, annual costs of producing wheat would increase $101 million if farmers were asked to maintain current production. These additional costs are primarily due to bringing additional acres into production and the loss of diverted-acre payments. If we assumed that acreage would be maintained rather than production, and that production would be permitted to decline and prices to increase, farmers' net income would increase by about $143 million rather than decline. Thus, Andrilenas pointed out that the burden of restricting pesticides could be shifted to either the farmer, the taxpayer, or the consumer, depending on policy.

Edwards described the welfare model he used to estimate costs and benefits from the use of insecticides in Dade County, Fla. The model recognized both internal and external costs and benefits, and was used to evaluate alternative policies in the use of insecticides.

Langham considered the development of an aggregative welfare model like that used in Dade County, Fla., by Edwards. He concluded that it would be possible to develop such a model for the United States but was not too optimistic about it becoming operational. Obtaining information on the externalities for a U.S. model would be difficult. One needs definitive information regarding substitution relationships among types of pesticides and among pesticides and other inputs. This information is required to synthesize possible shifts in the supply functions of farm commodities because of the adoption of a particular policy. Problems created by the time dimension are paramount and do more to negate the value of a national effort than perhaps any of the other difficulties. Although few data are available to support such an effort, there are probably more available at the U.S. level than at a small area level. The expertise and knowledge gained by those involved in such a project would be a valuable resource for policymakers. Langham would favor spending net new resources to obtain time series data on all forms of pollutants going into environment and on census and other demographic data on certain representative forms of life in the environment. He concluded that net new money should be involved in getting teams of entomologists, agronomists, economists, and ecologists to studying some of the substitution relationships and ecological consequences of alternative pesticide programs at farm levels.

Headley reported the results of his research in estimating productivity of pesticides and the elasticity of substitution of other inputs of pesticides. He believes that as the undesirable effects of pesticides become more recognized, knowledge of their productivity will be needed to justify their use and to formulate pesticide policies which assure maximum net benefits to society. His research shows that all types of pesticides generally returned more to farmers than they cost. On the average, $1 spent for pesticides generated $4 of additional sales. Southern cotton areas showed the lowest marginal contribution from pesticides--Corn Belt areas the highest. This indicates that modest reductions in pesticide use in the Southern cotton areas might not affect production significantly while restrictions in the corn areas could greatly reduce output. Headley also found that insecticide use can be reduced by more than 6 percent for each 1-percent increase in land use. This implies that to reduce pesticide use one policy alternative would be to return to use land held out of production by Government programs. This would increase the cropland base about 12 percent and would permit insecticide use to be reduced as much as 80 percent without affecting aggregate output, although more machinery and other inputs might be required to farm the additional acres.

Carlson pointed out that in detecting and controlling of pests, we need to include decisions involving timing of applications and use of chemical controls only when necessary. He concluded that pesticide use decision theory based on subjective expected utility maximization (Bayesian analysis) appears to be applicable when disease control costs are high relative to product prices, when the intensity of damage is highly variable from year to year, and when outbreaks can be predicted with some reliability. With this procedure, the major source of uncertainty that influences quantities of pesticides used is the magnitude of pest infestations and the associated crop losses. Carlson considered the Bayesian model particularly applicable for evaluating the use of fungicides to control brown rot in California peaches and other stone fruit. This fungus occurs infrequently but causes large losses when it develops.

Jenkins suggested that because of the wide range and complex nature of pesticide effects, a systems approach would be appropriate to evaluate alternative pesticide policies. Such an approach could consist of any of six increasingly complex levels beginning with a simple chemical control system for a single crop and pest species, and going up through a systematic study of the entire ecological system including all factors affecting infestation and control of pests. To fully understand the effects of national policy alternatives, the entire ecological system must be considered, both as it affects and is affected by pesticide use. One useful feature of this model is that optimum levels of pesticide use could be determined concurrently with optimum levels of other inputs to provide maximum net social benefits from a fixed level of resource use. To begin an analysis of the ecological system, several subsectors can be outlined. These subsectors relate pesticides to human, government, agricultural, commercial, international, and environmental considerations. Each of them affects or is affected by the type and intensity of pest control methodology used.

Eichers discussed data sources now available and pinpointed the areas where additional data are needed. He said that we will soon have fairly good information on how much of which pesticide products farmers use on what crops in different sections of the country. In addition we will have data on formulation types, whether materials are custom applied, banded, or broadcast, and the number of applications. But there is little information on nonfarm pesticide use and this is nearly half of the total. Also there is little general information on yield effects, or infestation levels associated with pesticide use. There is even less general statistical data available on the detrimental effects of pesticide use. There are volumes of research data on the effects of pesticide use. However, these projects are largely isolated studies aimed at identifying only a small segment of the total problem.

Cooke estimated the impact of restricting the use of insecticides in the production of cotton. He determined this impact by defining a representative large commercial cotton farm in the Mississippi Delta. Two different management situations were considered in the analysis. A comparison of insect control costs for high-use and low-use cotton producers indicated that the loss of chlorinated hydrocarbons would increase the cost of producing cotton for almost every producer in the Mississippi Delta. Also, these increases in costs would be proportionately greater for the low-use producer than for the high-use one. Because of an increase in insect resistance, it is doubtful whether cotton yields could be maintained after several years of dependence on methyl parathion, the leading alternative for bollworm and budworm control.

Berry focused his discussion on the use of pesticides on corn and soybeans. Significant quantities of pesticides are used on these crops including more than 25 percent of all organochlorine insecticides and phenoxy herbicides used on crops. Berry concluded that banning the use of phenoxy herbicides on corn would result in some additional use of dicamba and also atrizine or propachlor. The additional cost of these alternatives ranges from $1 per acre for dicamba to as much as $8 for the other materials. Cultivation can also replace some herbicide use but late season weed infestations might lower production. Restrictions on the use of organochlorine insecticides would probably have little effect on Illinois corn producers since they have already shifted to alternative insecticides. A ban on the use of all pesticides would be likely to reduce corn production, while favoring production of more soybeans because of the need for increased crop rotation to control soil insects in corn.

Delvo's case study approach showed how a pesticide restriction would affect commercial wheat farms in the Great Plains. Two case farms were chosen--one in southwestern Nebraska and the other in north-central South Dakota. Partial budget analysis was used to estimate the change in farm income, if the use of herbicides were restricted. A comparison of income losses for the two farms showed that inability to use herbicides reduced income from the South Dakota farm by $3.90 per cropland acre. This is three times the $1.31 loss in income per acre of cropland from the Nebraska farm.

Coulston described his experiences with an International Technical Assistance Research Program in developing approaches to determine the most economic rates of herbicide use and the best alternative weed control practices. Agronomists and economists are working jointly in planning and conducting experiments, not so much to determine research results, but to demonstrate the type and magnitude of information that could be developed jointly by their two disciplines. In one experiment, 19 application rates were included for different herbicides along with combinations of herbicides. These data were used to estimate production functions related to herbicide use. Results showed that lower rates than those recommended could often be used economically.

ECONOMIC RESEARCH ON PESTICIDES
FOR POLICY DECISIONMAKING

Proceedings of a 3-day Symposium
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OPENING REMARKS

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Francis Bacon, an English statesman, philosopher, and writer, was also interested in experimental agriculture. He once wrote: "Reading maketh a full man; conference a ready man; and writing an exact man. And therefore, if a man write little, he had need to have great memory; if he confer little, he had need to have a present wit; and if he read little, he had need to have much cunning."

These words still ring true today and a well-planned symposium should serve all three purposes. The preparation of papers for a symposium, such as this one, forces the speakers to organize and state their thoughts more exactly. The presentation of the papers and the interplay of discussion sharpen the wit of speakers and participants alike. And following the symposium, the reading of the proceedings increases the cunning and knowledge of participants and others interested in economics and pesticides.

In the current controversy over the use of pesticides, one research responsibility of the economist is to explore the consequences of alternative policy decisions. Thus, the overall objective of the symposium was to develop a research program that focuses on relevant and significant policy questions. More specifically, the following subobjectives provided the themes for the three sessions held during the symposium:

(1) To examine the question of restricting pesticides as viewed by different disciplines.

(2) To review current economic research and data collection on pesticides.

(3) To identify and specify new areas of research on the economics of pesticide use to meet future needs for policy decisionmaking.

A fourth subobjective, and an important one, was to improve communication and coordination of pesticide research among economists and those in other disciplines. Pesticide use is an area of research where the economist, if he is to be effective, cannot walk alone.

Progress in improving communication was made by having representatives of other disciplines and agencies in the Department of Agriculture and elsewhere join agricultural economists in actively discussing the use of pesticides. The first three objectives are ably accomplished as shown by the papers and summaries in the following sections, each representing an integral part of the symposium:

(1) The Pesticide Controversy

(2) Economic Research on Pesticides

(3) Future Research.

ROLE OF THE GOVERNMENT IN THE PESTICIDE CONTROVERSY

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The title is too simple. I shall discuss, albeit superficially, the many roles of many agencies of government--national, State, and local--and international and intergovernmental, too. In recognition of these complex, important, and interrelated roles, there are several coordinating agencies.

At the highest level in the executive branch, there is the Pesticide Subcommittee of the Cabinet Committee on Environmental Quality. The Pesticide Subcommittee is chaired by Secretary Hardin. Other members are the Secretaries of HEW and Interior. The Departments of Defense, Transportation, and State, including the Agency for International Development, have observer status.

Public Law 91-190, the National Environmental Policy Act of 1969, established a Council on Environmental Quality within the Executive Office of the President. Among the duties of the Council are: "To appraise programs and activities of the Federal Government in the light of the policy set forth in title I of this Act; to be conscious of and responsive to the scientific, economic, social, esthetic, and cultural needs and interests of the Nation; and to formulate and recommend national policies to promote the improvement of the quality of the environment."

The Council provides staff services to the Cabinet Committee on the Quality of the Environment. The Council is responsible for evaluation and recommendations to the President on programs and policies affecting the environment, including pesticides.

The Pesticide Subcommittee of the Cabinet Committee has a Working Group which acts through frequent meetings of its agency members and through subcommittees as in interagency mechanism to facilitate day-by-day coordination, review, and evaluation. The Working Group reports its principal findings and recommendations to the parent Pesticide Subcommittee.

Agency members of the Working Group represent the Departments of Agriculture, Defense, HEW, Interior, Transportation, and State. The Office of Science and Technology, the Bureau of the Budget, the Council on Environmental Quality, and the Office of Intergovernmental Relations have observers on the Working Group. The current chairman is George L. Hutton, Department of Defense. William S. Murray, HEW, serves as executive secretary of the Working Group. Current subcommittees are: Safety, Program Review, Information, Monitoring, Research. Other subcommittees will be established as needed.

The Working Group is concerned with all pesticide matters. However, specific responsibility for coordinating pesticide registration lies with designated departmental representatives under the January 28, 1970, interagency agreement signed by the Secretaries of Agriculture, HEW, and Interior. These representatives are responsible for identifying and resolving differences among the signatory agencies on questions of pesticide registration. Should departmental representatives fail to reach agreement after exhausting all procedures designed to facilitate and expedite resolution of differences, the disput would be referred to the Pesticide Subcommittee of the Cabinet Committee on the Environment. The Pesticide Subcommittee would advise its chairman, the Secretary of Agriculture, on solution of the dispute. Final responsibility on pesticide registration matters rests with the Secretary of Agriculture.

We must also recognize responsibilities of the legislative and judicial branches, of international agencies, and of State and local governments.

Now for some of the specific responsibilities of the several government agencies concerned with pesticides. Each agency has responsibilities related to its mission. Several have housekeeping responsibilities for pest control in installations under their control. Some have regulatory, research, information, and monitoring program responsibilities.

USDA has mission responsibility for assembling, producing, and disseminating information needed to protect rural people, communities, consumers, crops, forests, livestock, and the environment against arthropod pests, plant diseases, weeds, and nematodes. This mission must be accomplished with minimal hazard to man, nontarget organisms, and the environment.

USDA policy is stated in Secretary's Memorandum 1666.

USDA POLICY ON PESTICIDES

"It is the policy of the Department of Agriculture to practice and encourage the use of those means of effective pest control which provide the least potential hazard to man, his animals, wildlife, and the other components of the natural environment.

"For the foreseeable future, pesticides will be necessary tools for the protection of the nation's food and fiber supplies, people, and their homes.

"Where chemicals are required for pest control, patterns of use, methods of application and formulations which will most effectively limit the impact of the chemicals to the target organisms shall be used and recommended. In the use of these chemicals, the Department has a continuing concern for human health and well-being and for the protection of fish and wildlife, soil, air, and water from pesticide contamination.

"In keeping with this concern, persistent pesticides will not be used in Department pest control programs when an effective, nonresidual method of control is available. When persistent pesticides are necessary to combat pests, they will be used in minimal effective amounts, applied precisely to the infested area, and at minimal effective frequencies.

"Nonchemical methods of pest control, biological or cultural, will be used and recommended whenever such methods are available for the effective control or elimination of target pests. Integrated control systems utilizing both chemical and nonchemical techniques will be used and recommended in the interest of maximum effectiveness and safety.

"In carrying out its responsibilities, the Department will continue to:

-- Conduct and support cooperative research to find new, effective biological, cultural, and integrated pest control materials and methods;

-- Seek effective, specific, nonpersistent pesticides and methods of application least hazardous to man and his environment;

-- Require pesticide product labels which adequately inform all users of the composition and the proper and permitted use of each formulation;

-- Review and update all pesticide registrations, eliminating any uses not in conformity with current criteria of safety and efficacy;

-- Cooperate with other public and private organizations and industry in the development and evaluation of pest control materials and methods, assessment of benefits and potential hazards in control operations, monitoring for pesticide residues, and dissemination of pesticide safety information.

"All users of pesticides, whether in the home, garden, field, forest, or aquatic area or for public health and sanitary purposes, are strongly urged to heed label directions and exercise constant care in pesticide application, storage, and disposal for the protection of people, animals, and our total environment.

"The Department commends this policy to all who use, recommend, or regulate pesticides."

USDA is the principal research agency with respect to control of arthropod pests, plant diseases, weeds, and nematodes. USDA and the cooperating State agricultural experiment stations on the one hand, and industry on the other, produce most of the research information on which chemical, biological, physical, cultural, and integrated control rests.

Ecological control is a very valuable concept. In the future we will use the concept in developing agroecosystems which include not only the cotton field, but its neighboring turn ends, ditchbanks, roadsides, woods, and homesteads. Because these sites serve as harbors and habitats for commensals, pests, predators, and parasites with individual and aggregative impact on cotton, all of them are affected by pest controls used in the cotton field.

Here is a conflict of means--and of history. How can the scientists at Patuxent and their fellow researchers on wildlife catch up on the needed information for the thousands of diverse species while agriculture adds to its impressive mass of information relevant to pests of a few crops, livestock and forest species and the pests of man and his habitat?

USDA has responsibility for:

(1) Registration of pesticides under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA).

(2) Enforcement of FIFRA.

(3) Programs for protection against pests including:

(a) Inspection and quarantine with respect to interstate and international trade in plant, animal, and biological materials, and of transportation, equipment, and related loading and unloading points.

(b) Pest control programs in cooperation with the States, and protection of the National Forests against pests.

(c) Information and education and training programs in cooperation with States, especially through extension services.

(d) Research in Department laboratories in cooperation with State and other research institutions through payments to States with State agricultural experiment stations.

USDA has final responsibility for the registration of pesticide chemicals. This responsibility USDA has agreed to exercise subject to consultations as stated under the Interdepartmental Agreement, after consultation with the other signatory Departments.

Registration of pesticide chemicals for uses likely to result in a residue in foods is also conditioned upon establishment of a tolerance by the Food and Drug Administration (FDA). USDA will ask for an evaluation of health-related aspects of all pesticide registrations by the Department of Health, Education, and Welfare. USDA will in each case give full consideration to the information and opinion provided by DHEW.

REGISTRATION

To be accepted for registration, a pesticide formulation must be useful and safe when used according to the directions printed on the label. The applicant for registration must supply data on toxicity of the compound, its efficacy for the control of the target pest, and the chemical nature of the compound. Each application, when ready for action, is referred to USDI and DHEW for comment. Information supplied by these agencies is fully considered in the registration decision. Evidence of hazard to human health under intended use is given priority over efficacy. Possible hazard to the environment, harm to useful insects, fish, birds, and other wildlife, and probability of persistence in the environment are all taken into account. If the pesticide formulation is to be used on a food crop, the applicant must file a petition for a tolerance with FDA.

Once registered, the registered use of a formulation may be canceled (1) if it is found to be ineffective for the registered use; e.g., because of development of resistance to it by the target pest, or (2) because the registered use is determined to be hazardous not only to human health and welfare but also to wildlife and the environment. A registered formulation may be suspended if its use is found to constitute an imminent hazard. Imminent hazard is construed to be a hazard, especially to human health, threatening to occur immediately. It is this factor of immediacy of hazard that is essential to suspension, for suspended formulations must cease to move in interstate commerce immediately upon receipt of notification by the registrant of such suspension. The registrant may, of course, appeal the suspension, but during action on the appeal the suspended product must not move in interstate commerce. Cancellation, on the other hand, becomes effective 30 days after notification of the registrant. Should he appeal the cancellation, his canceled products may continue in interstate commerce during the appeal.

The Department of Health, Education, and Welfare is responsible for the establishment and enforcement of pesticide tolerances on or in foods and feeds moving in interstate commerce. It is also responsible for occupational health protection, which would include health of workers in pesticide chemical factories, and protection of applicators and other people exposed to pesticides. DHEW has responsibility for the human environment and its effects on man.

From the research standpoint, DHEW is the principal Federal agency concerned with toxicology of pesticide chemicals, with recent and continuing emphasis on carcinogenicity, teratogenicity, and mutagenicity. DHEW is concerned with the aerial dispersion of pesticide chemicals as a parameter of air quality and with the establishment of standards of air quality and drinking water.

DHEW is concerned with control of rats, especially in cities. The fleas rats carry are sometimes vectors of human disease, even of plague in the United States.

USDI is generally responsible for the control of vertebrate pests, and of all pests on public lands which it administers. The list of vertebrate pests is fairly long--starlings, prairie dogs, rattlesnakes, coyotes, lampreys, trash fish, and others.

USDI mission responsibilities include water quality, fish and wildlife, commercial fisheries, national parks, wilderness areas, and the natural environment alike. They are concerned with protecting all of these against both pests and hazards resulting from pesticide use.

STATE AND MUNICIPAL ROLES IN PESTICIDE CONTROL

State governments, through their departments of agriculture, public health, water, fish, game, conservation, and other agencies, may develop and apply State statutory and regulatory provisions. These are in addition to those affecting interstate commerce which are required by Federal agencies. Local governments, e.g., mosquito control districts and municipal public health departments, also have essential roles affecting pesticide use.

Some States have laws requiring the licensing of professional pesticide applicators and State registration of pesticides. Some States further restrict the usage of certain pesticides registered under FIFRA.

Further legislation and regulation by State and local authorities on sale and use of pesticides and on disposal of pesticide remnants, containers, and residues of some treated materials is urgently needed. Of particular concern is provision of safe procedures and places for disposal. Recycling for substantial quantities may be feasible but not for the small remnants and containers in the hands of householders and other small-scale users. For them we need incinerators which will reduce residues to harmless compounds, or sanitary landfills which will prevent escape of buried pesticide residues into the environment.

State and local governments have police authority which Federal agencies do not, and should not, have. Thus, aerial applicators must register with the Federal Aviation Administration, show evidence of competency in aerial application, and agree to follow label directions for use of pesticides. But only local authority can assure application under permissible weather and other conditions and compliance, in fact, with appropriate speed, altitude, and area limitations.

If we are to retain the use of effective pesticides, their precise application to the target area and their retention or degradation in the target site are conditions which must be met. Voluntary compliance, based on adequate information, is the chief assurance for use according to the conditions for which each pesticide formulation is registered. State and local regulations and surveillance are needed to assure compliance by those who cannot or will not comply voluntarily.

State and local regulations of application of pesticides by professional applicators can help us keep effective pesticides in safe usage for controlling pests in home and garden, in public food preparation and serving establishments, and on other premises where control of rats, roaches, and other vermin is a problem. Informed professional applicators may exterminate many pests by using pesticides that are too hazardous to the applicator to warrant application by the householder himself.

A major issue to be resolved in some States is the commercial farmer's use of highly toxic pesticides on his own premises. The Model State Law exempts farmers from its licensing provisions in operations on their own farms.

Our international concern over pesticides rests on several grounds in addition to our real concern for human health and welfare and the quality of the environment. These concerns include acceptance of our export products by other countries and our acceptance of products offered for import into the United States.

We are concerned with preventing the importation of arthropod pests, pest vertebrates, plant diseases, and nematodes into this country. We maintain inspection barriers at our ports of entry. In some cases, we cooperate with other countries in treating plant materials at point of origin or port of embarkation. Planes from some countries are disinfested with pesticide. Out international airports are treated--especially near loading sites--with persistent pesticides, including a very limited use of dieldrin in carefully supervised soil application.

We are concerned with pesticide residues in imported foods. Generally, sampled imported foods show about the same residues as our own, but about 3 percent of them show residues in excess of legal tolerance. We, with most other industrialized countries, adhere to the Codex Alimentarius which operates under WHO-FAO sponsorship. Committees consider pesticide use and food tolerance case by case, agreeing on the tolerances one by one.

Tolerances established by our FDA are based on a wide margin of safety. Whenever possible, allowances are made under this doctrine for amounts needed for control of heavy infestations or control under unfavorable weather conditions. Some European countries set tolerances for minimum residues expected under average to good agricultural practice. Since we are bound to accept agreed tolerances under the Codex, there is some concern lest tolerances may be set too low to permit effective pest control in some cases.

Tobacco presents an interesting case. Because it is a nonfood, no tolerance has been established for the formerly used DDT and TDE. Substantial residues occurred. Our foreign customers objected. USDA not only canceled uses of these pesticides (for which satisfactory alternates for control of tobacco insects exist) but also decided to refuse tobacco treated with these pesticides for loan under its support programs.

We have another potential problem concerned with international trade. If we increase production costs by eliminating cheap, effective pesticides because they constitute a hazard to the environment while other countries retain their use, may not our producers of the commodities affected suffer competitive disadvantage in the markets of the world, including our own?

Our concern for the world's health, including our own, is reflected through our participation in the World Health Organization. On January 27, 1970, the Executive Board of WHO was warned by its chief of vector biology and control that a major disaster would result from any action limiting use of DDT for control of malaria in developing countries. He told the Board that a major effort is aimed at finding insecticides that could replace DDT and not persist in the environment; 1,300 have been tested so far. 1/

DOMESTIC PROBLEMS

Are there problems among the three Departments? Of course, there are. And there is an effective mechanism for settling those requiring action, through the Working Group, the Interdepartmental Agreement, the Pesticide Subcommittee of the Cabinet Committee, and through daily contacts among people in the three agencies working on common problems.

Problems arise from insufficient, apparently conflicting empirical information; from differing priorities assigned to diverse values and goals; from conflict in theory; from conflict in law; from personality.

Nowhere is conflict in theory and in law more acute than in the field of carcinogenicity. The Food, Drug, and Cosmetic Act, through Sec. 409 (Delaney Amendment), interdicts any chemical additive to our food that has been shown to produce cancer in test animals. Yet, as the Secretary of HEW stated in his speech to the Pharmaceutical Association in Miami on April 10, selenium is both an essential nutrient and a carcinogen.

The Report of the Secretary's Commission on Pesticides and Their Relationship to Environmental Health (USDHEW, December 1969) produced by a panel of distinguished scientists, stated: "Recommendation 5: Minimize human exposure to those pesticides considered to present a potential health hazard to man."

In discussing this recommendation the report further states:

"In recent screening studies in animals employing high dosage levels, several compounds have been judged to be positive for tumor induction. In similar screening studies, other pesticides have been judged to be teratogenic. The evidence does not prove that these are injurious to man, but does indicate: (1) A need to reexamine the registered uses of the materials and other relevant data in order to institute prudent steps to minimize human exposure to these chemicals; and (2) to undertake additional appropriate evaluatory research on representative samples of these substances in order to guide future decisions. It is further important to have detailed knowledge of sample composition and purity. These materials are: aldrin; amitrol; aramite; ayadex; bis (2-chloroethyl) ether; chlorobenzilate; p,p'-DDT; dieldrin; heptachlor (epoxide); mirex; n-(2-Hydroxyethyl)-hydrazine; strobane; captan; carbaryl; the butyl, isopropyl, and isooctyl esters of 2,4-D; folpet; mercurials; PCNB, and 2,4,5-T.

"The imposition of restrictions on exposure, particularly from pesticide residues in food and water, should be accompanied by periodic review and adjustment of pesticide residue tolerances. Indiscriminate imposition of zero

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1/ 1970. WHO Press Release. WHO/6.

tolerances may well have disastrous consequences upon the supply of essential food and threaten the welfare of the entire Nation. Stepwise lowering of pesticide tolerance may in some cases be an effective and flexible instrument with which to execute policy."

Some of these compounds have been reported to cause cancer in test animals. The theory underlying the Delaney Amendment is that chemical carcinogens and radiation are cumulative so that accumulation of small dosages is roughly equal in effect to single large dosages. Thus, according to this theory, there is no "no effect" or threshold dose for carcinogens.

Scientists are sharply divided on this issue. Research during the past 20 years has established as fact that there are repair mechanisms which eliminate cells damaged by radiation. From a pragmatic point of view, carcinogens occur naturally in many foods and are produced by cooking in others. Thus, we may limit but are unlikely to eliminate carcinogens from our diet.

The Delaney clause was sharply emphasized in the Secretary's Commission on Pesticides (Mrak Commission) report to the Secretary of HEW. This arose from research information that certain pesticides may be carcinogens. The evidence for this finding persuaded a majority of the carcinogen panel but there was a minority report.

May I emphasize that this problem is not in conflict between USDA and DHEW. The conflict is among scientists and the conflict is institutionalized in the Delaney Amendment. Teratogenicity and mutagenicity are not synonymous with carcinogenicity but are joined in the same conflict of threshold--no threshold.

Value Differences

Differences in values are inherent in the missions of the three agencies. These differences are generally quantitative rather than qualitative. Wheat-growers generally like pheasants--ducks, too. Do they like them enough to suffer the inconvenience and cost of maintaining habitat--safe nesting sites for pheasants, wetlands for the ducks?

While pheasants seem to tolerate substantial amounts of DDT and its metabolites, ducks are reportedly less able to do so. There are several reports of mercury accumulation in pheasants from eating seed grain treated with mercurial fungicide. And most hunters expect that the pheasants they shoot will be eaten.

But the mercury problem is far broader than pesticide use. Apparently much mercurial pollution occurs when factories using mercury to manufacture alkalies discharge effluent into water.

Policy Differences

There are differences in policy with respect to lands administered by the various Departments. Recent action on 2, 4, 5-T illustrates this point. The Department of Defense has temporarily stopped the use of 2, 4, 5-T, including use in military establishments in the United States. Several months ago, the Department of the Interior stopped such use on public lands which it administers. The Department of Agriculture continues some use of 2, 4, 5-T in its direct and assisted programs.

Another problem currently under study is the use of mirex in the fire ant program. Preliminary investigations indicate that mirex may be hazardous to certain aquatic organisms. A 60, 000-acre area near Charleston, S.C., is under current study by USDI and USDA to determine whether or not such a hazard exists. Such questions as whether or not mirex poses a hazard, and what, if any, measures for control of fire ants or any other pests may be imposed on areas administered by USDI, USDA, or other Executive Departments continue to be dealt with by the Program Review Panel of the Working Group. Although pesticide registration is a basic consideration, such problems go considerably beyond the terms of the interdepartmental agreement.

Another and far more important area of potential conflict is that of standards of water quality with respect to pesticide residues. It is clearly within the responsibility of the Federal Water Quality Administration to work with the States in developing and enforcing such standards.

Conflict is one aspect of cooperation. The kid with a chip on his shoulder generally wants to get acquainted--to belong. Very few people--and scientists are people--want to be isolated by their dissent.

CONCLUSIONS

USDA and all other government agencies--Federal, State, local, and international--with missions including protection against pests and against pesticide residues--must pay special attention to their missions. But none may disregard the mission interests of other agencies. Coordinating mechanisms have been established and are in use.

All government agencies are responsible to and must be responsive to public concern. The public includes users, vendors, applicators, and other special interest groups. It includes all of us.

Special interests are important to those affected. Cockroach eradication is important to the householder with an infested kitchen and to a restaurateur with sanitary standards to meet. Cotton is important to the grower whose livelihood depends on it.

But there are priorities for all of us. The top priority concerning pesticides is the protection of human health--by using pesticides to control arthropod vectors of human disease and assure a continuing supply of abundant, high-quality food, and by regulating pesticides and pesticide use so that hazards to man through exposure to pesticides and their residues are minimized.

The public must finally decide the role of Government--in the marketplace, at the ballot box, in all the public forums, and through the mass media of public information.

All of us who are professionally concerned have a special obligation to make sure that the public is fully informed. In the words of Henry Miller, formerly in charge of the Fair Trade Practices Division, Federal Trade Commission, "It is not enough to tell the truth; it must be told in a fully disclosing and non-misleading manner."

RESTRICTING THE USE OF HERBICIDES--WHAT ARE THE ALTERNATIVES?

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Within the last few months, the registered uses of many pesticides have been suspended, canceled, or restricted. Some of them represented extensive usages and ones that had become well accepted in pest control programs on farms and in other areas. Among the pesticides affected were the herbicides--the most notable and recent was the herbicide 2,4,5-T. The following questions and answers discuss what are the alternatives to a use restriction on herbicides.

What are the main items to be considered in restricting the use of pesticides previously widely used agriculturally or nonagriculturally?

Probably the most important is recognition of possible hazards to the health or well-being of man, domestic animals, fish, wildlife, or other values in man's environment. Frequently, there is a conflict of interest because of differing opinions on the relative advantages of continuing to use the pesticide as compared to abandoning it and seeking an alternative way of dealing with the pest control problem. The conflicts may involve scientific, ecological, economic, legal, emotional, and political considerations. All of these are important ingredients in policy decisions on whether or not to restrict the use of a pesticide. I want to commend Chairman Davis and his colleagues for arranging this conference to formulate methodology to assess the many economic and noneconomic parameters involved in making policy decisions on pesticides.

What is involved in making a decision on restricting the use of herbicides?

Currently, one of the most important and first considerations is to assess the ecological consequences and other effects of the herbicides in the environment. What are the effects of the herbicide to be restricted as compared with its substitute?

Also, it is important to determine what losses and costs accrue because of the weeds that are controlled by the herbicide to be restricted. Our ability to quantify and describe the direct economic losses in quantity and quality of crop yields due to particular weeds is inadequate. We need to develop more adequate baseline data on losses and costs presently sustained because of weeds before we can do an effective job of estimating the economic impact of restricting the use of a given herbicide. I hope this conference will lead to efforts by economists, working with biologists, to obtain definitive economic data on:

(1) Suppressed growth and reduced crop production from the competitive effects of particular weeds and groups of weeds that compete for water, mineral nutrients, light, and possibly CO_2.

(2) Lowered harvested yields due to increased harvest losses caused by particular weeds.

(3) Lowered quality of harvested crops caused by contamination with weed seed and weed debris, increased moisture caused by weeds, and nonuniformity in maturity of the crop due to weed infestation.

(4) Lowered yield and quality of crops caused indirectly by weeds that increase the effects of other pests such as insects, nematodes, and plant diseases through action as alternate hosts and attractants, and by interfering with operations to control these other pests.

(5) Effects of herbicidal and nonherbicidal control measures on yield and quality of crops.

(6) Costs and efficiency of alternative methods of weed control.

The types of damage outlined above can be measured and expressed economically. More definitive data are needed also on cost-benefits of using herbicides to improve grazing for livestock; to increase efficiency of water management for irrigation, drainage, transportation, wildlife, fish production, and recreation; to improve forestry production; to maintain rights-of-way; and to control weeds in parks, lawns, and other noncrop areas.

Are there other factors, not usually recognized, that must be given consideration when formulating a decision or policy on restricting the use of herbicides?

The answer to this question is yes. Some of these are difficult to quantify economically, yet they represent important costs due to weeds. Among the items are:

(1) Cultivations and increased horsepower requirements

(2) Costs of applying herbicides or flame

(3) Wastage of irrigation water in ditches and fields

(4) Flooding due to clogging of drainage systems by aquatic weeds

(5) Damaged crops caused by herbicide residues in soil

(6) Damaged adjacent crops due to herbicide drift

(7) Cost of public agency research to develop new control measures

(8) Cost to government of regulating chemical uses

(9) Damage to environment by:

(a) erosion and soil compaction losses associated with excessive cultivations

(b) pollution caused by herbicides

(c) pollution caused by tractor fumes and dust from cultivators

(d) pollution caused by burning weeds

(10) Increased requirements for water

(11) Increased requirements for fertilizer

(12) Esthetic values

(13) Human health ailments caused by poisonous and allergenic weeds

(14) Cost of administering and regulating preventive and quarantine programs

(15) Future costs caused by ineffective weed control measures today

(16) Cost of providing fringe benefits to farm laborers such as housing, food, and medical care

(17) Increased labor requirements

(18) Reduction in acreages per operator that can be farmed.

I have outlined the complexity and some of the many economic interrelationships involved when weed control practices are changed. Depending on which herbicide or use is to be banned or restricted, some or all of the above factors must be considered.

The intangible attributes of herbicidal weed control must also be considered, for "man does not live by bread alone." Modern herbicides reduce the drudgery and great demands on man's time to produce adequate food, feed, and fiber, with the result that he has the time and energy to enjoy the arts, education, and recreation opportunities. Through use of pesticides, man's health has been improved. What weight should be given to these values if restricting the use of a pesticide has an important effect on one of these important benefits?

<u>What are the alternatives when the use of a herbicide is to be restricted?</u>

The answer will depend on what herbicide is involved. Generally, the answer to this question is:

(1) Use other herbicides

(2) Cultivate with mechanical devices

(3) Use flame cultivation

(4) Use hand labor

(5) Use biological or preventive control measures

(6) Use a combination of two or more of the above

(7) Use more land, water, fertilizer, and other resources to offset losses

(8) Accept the losses and drop the standard of living accordingly.

The decisionmaking process involved might be brought into focus by citing three analogies:

a. If we want to go from the East Coast to the West Coast, three kinds of transportation could be used: an oxcart, a bus, or a jet plane. Two of these are used regularly. The third could be brought back into usage.

b. If we want to analyze a large amount of data we can use a pencil and paper, a desk calculator, or an electronic computer. All methods are still used.

c. If we want to control weeds we can pull them by hand, cultivate them, use herbicides, or use a combination of methods. All of these are used today.

A decision on a method for transportation, for calculating data, and for controlling weeds depends on what we want in terms of speed, reliability, effectiveness, safety, and economy.

Although an alternate herbicide may be available, practicality, effectiveness, and economy may be overriding considerations. For example, we can control some of the same weeds with atrazine + oil as we can with 2, 4, -D. However, the former cannot be used for as many crops and situations as 2, 4-D. Atrazine + oil will not control some weeds that 2, 4-D will kill. Atrazine may persist in the soil and damage crops grown in rotation. And the mixture requires more critical timing of application than 2, 4-D.

<u>What second-round problems must be considered when alternatives to a herbicide are being selected</u>?

Many of these considerations have been listed above. Other problems that may be encountered when a herbicide practice is dropped include:

(a) Increases or shifts in weed populations

(b) Increased demands on labor and capital resources

(c) Increased risk to applicators

(d) Injury to crops from an alternative herbicide

(e) Requirement to alter rotations

(f) Reduced supplies of food, feed, fiber, and water

(g) Effect on economy of developing nations whose welfare depends on effective pest control

(h) Effect on local businesses that service users of pesticides.

<u>What are the effects of restricting use of a herbicide on integrated production practices</u>?

Systems of weed control are frequently complex and delicately balanced. Thus, restricting or banning the use of a production or management tool that has become an integral part of farm production practices can set off a series of chainlike effects or changes--all of which have an economic impact. The ability to control weeds in a given crop is affected. These effects can be illustrated by experimental data from two studies--one involving cotton (table 1) and the other soybeans (table 2).

In table 1 the four weed-control situations represent varying intensities of weed infestations due to site and rainfall pattern. Under two situations the use of conventional cultivation and hoeing plus either a preemergence treatment with a herbicide or cross-plowing gave the same results. A third component, flame, in combination with the conventional practice was not as effective. Under other situations a combination of three, or even four, weed control components was desirable. The loss of one weed control component can necessitate use of a large amount of hand labor as illustrated in table 1.

Table 1.--Impact of removal of weed control components from production practices 1/

Weed control treatment	Hours of hoe labor under four weed situations 2/			
	1	2	3	4
Cultivation + hoeing (A)	14	23	48	53
A + herbicide (B)	7	9	21	35
A + flame (C)	13	20	37	42
A + cross-plowing (D)	6	9	29	28
A + B + D	3	3	16	18
A + B + C + D	2	2	10	2

1/ Holstun, J.T., Jr., and others. Weeds 8: 232-243, 1960.
2/ Numbers represent increasing degrees of weed infestation.

Johnsongrass is a serious weed on many of our most productive soils. To prevent intolerable losses from this weed, weed control pressure must be applied during the growing of all crops in a rotation. Loss of ability to utilize all improved methods can mean the difference between successful crop production and failure. Note in table 2 that a combination of cultural practices and a herbicide was much more effective than either alone. Loss of the herbicide in this case would reduce the soybean yield by 10 bushels per acre.

Other effects on integrated pest control of restricting use of a herbicide is the ability to control diseases, nematodes, and insects in the crop normally treated with the herbicide as well as such pests in the total farm program. For example, weeds harbor viruses and other diseases that are transmitted to crop plants by insects. Nematodes such as the soybean cyst and rootknot species will reproduce on weeds and spread to crop plants. When the weeds are poorly controlled the other pest control problems intensify.

Many production practices are geared to the use of effective weed control measures. For example, close spacing of such row crops as soybeans and corn requires reliable herbicides to control weeds. Herbicides help reduce the

Table 2.--Effects of different weed controls for Johnsongrass on soybean yields 1/

Weed control practice	Johnsongrass control		Soybean yield
	July 5	November 2	
	Percent		Lbs. per acre
Conventional practice...	0	0	1080
10 diskings............	76	84	1980
Herbicide..............	62	70	1800
7 diskings + herbicide..	80	86	2580

1/ McWhorter, C.G. and Hartwig, E.E. Agronomy Journal 57:385-389, 1965.

need for frequent tillage and thus help conserve soil moisture--particularly in mulch and minimum tillage operations in the Corn Belt and Great Plains. Placement of fertilizer, choice of a crop variety, time of planting, time and method of harvest, and irrigation requirements are all partly determined by the kind and effectiveness of weed control measures available. If the restricted herbicide cannot be replaced by an equally effective herbicide or other measure, then a series of complex and interacting forces come into play.

What is our ability to anticipate effects of restricting the use of one herbicide on the use of substitute chemicals?

The answer to this question depends primarily on three factors: class or specific compound involved, type of restriction, and nature and extent of current usage patterns.

If farm use of TCA was restricted the impact would not be as serious as if 2,4-D was restricted. This is primarily because there are several effective alternate herbicides for TCA, but none for 2,4-D. Similarly, a ban on nonfarm uses of sodium chlorate would not be as serious as one on nonfarm uses of 2,4-D. A number of effective soil-sterilant herbicides can be used in place of sodium chlorate. But safe, substitute herbicides for 2,4,5-T to control brush are not available.

Anticipated effects of a restriction on herbicide usage are not limited to farm operation. Federal and State programs to control noxious weeds are affected. Likewise, quarantine and preventive weed-control measures may be hampered, e.g., the Federal program on control of witchweed and regulations on noxious weed seed content in farm seeds. Difficult to assess, but present nonetheless, is the reduced industrial effort in finding new herbicides and developing them in a climate of restrictions and bans.

The type of restriction and usage pattern of the herbicide involved in a restriction are important in anticipating the extent to which alternate herbicides may be used. For example, a total ban would have greater impact than a lesser one. A restriction on use of a herbicide on certain food crops, or in certain areas, or at certain times of the year would have much less effect than a ban on all uses. Additionally, the nature and extent of the usage are important. Is a large number of crops involved? Are home and nonfarm uses involved? Is the compound used on many million acres or only on a relatively few? The answers to these questions will help provide a basis to predict the future impact of the herbicide restriction on the adoption and use of possible substitutes.

In summary, restrictions on usage of a herbicide and the substitution of alternative herbicides or other weed controls create a complex problem that has many interacting economic facets. All aspects of overall problems must be considered if a realistic assessment of economic impact is to be made. For example, the use of national averages to evaluate the economic impact of restricting the use of a weed control practice can lead to misleading conclusions. Nationally, the reductions in yields for a particular crop might be only 1 percent as the result of a pesticide ban. However, the loss on one farm might be a 30-percent reduction--enough to force the farmer out of business. Thus, his part of the national loss could theoretically be his total farm output instead of 30 percent loss of one crop. If we project shifts in production from one geographic area to another to offset this theoretical 100 percent loss, the result would not be valid because of interactions of other economic components on both production areas.

Basic data on current losses and costs due to weeds are inadequate to make sound evaluations of the consequences of banning a particular herbicide or restricting certain uses. Even more inadequate is our ability to characterize not only the effects of second-round problems but also the resulting interactions from losing an important component of systems required for effective and efficient weed control.

Banning all uses of a pesticide is not generally wise. Pesticide usages need to be constantly reviewed from many standpoints. If circumstances and data show a need to restrict the usage of a given pesticide, then reviews should be made for each use and restrictions imposed as warranted by available data.

I hope we can continue to improve on our research evaluations and knowledge of herbicides. We should thus avoid the need to ban a compound after it has been adopted and integrated into production and management schemes on farms and in nonfarm weed control programs. Then economists can concentrate on providing the economic data needed on losses and costs due to weeds and the benefits of control by different methods. Such information will provide for sounder research and development decisions on how to improve the effectiveness and efficiency of weed control by chemical or nonchemical means. I predict this will be done.

RESTRICTING THE USE OF INSECTICIDES-- WHAT ARE THE ALTERNATIVES?

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The control of insects and other pests of crops and livestock is absolutely necessary if this country is to continue to have an abundance of high quality food, feed, and fiber. Insects must also be controlled if we are to enjoy freedom from the many diseases that they carry to plants, livestock, and man. Also, there will be need to meet the food requirements of an ever-expanding human population throughout the world. A variety of methods are used to control pests when they get out of balance with their natural enemies and cause important losses to agricultural crops and livestock.

EARLY METHODS OF INSECT CONTROL

There has been a long evolutionary period culminating in modern insect control measures coincident with growing single crops on large acreages with improved crop management practices. As farming methods and livestock management procedures have changed there has been need to alter the approaches to control different insects that attack plants from seed to maturity and animals at all stages. Beneficial insects, such as parasites and predators, have an important role in curtailing insect populations and efforts should be made to protect them.

Historically, cultural practices have aided in insect control and they are still used to great advantage against many insect pests. These practices include sanitation, early planting of crops, destruction of crop residues, tillage, crop and animal rotations, strip-cropping, destruction of volunteer plants, and improved harvesting procedures. With time and the desire to obtain improved and more dependable insect control, growers placed more reliance on the use of chemicals.

LATER METHODS OF INSECT CONTROL AND ASSOCIATED PROBLEMS

Since the early 1940's increasing dependence has been placed on new types of insecticides which are cheap and effective for controlling a vast array of insect pests. Although insecticides will maintain a prominent role in agriculture for many years to come as the primary way of controlling insect pests, we are now faced with many problems arising from the widespread use of persistent materials. Unfortunately such use has resulted in many insect species becoming resistant to insecticides (about 212 species on a global basis, one-half involving pests of agricultural importance), unwanted residues in plants and animals of economic importance, and residues that adversely affect beneficial insects--parasites, predators, and pollinators--as well as certain species of fish and wildlife. Such problems have been of national concern. A number of high-level studies have been undertaken to appraise the situation and to determine if more controls are needed on the use of these materials and if alternative methods of insect control would solve some of the major problems.

EFFECTS OF RESTRICTING THE USE OF CHLORINATED HYDROCARBON INSECTICIDES

Because of the hazard and resistance problems mentioned, there has been a gradual shift to the use of organophosphorus and carbamate insecticides. Previously there had been many shifts in use within the chlorinated hydrocarbon insecticides to meet urgent insect control problems. There is now considerable public concern over DDT restrictions already in effect. The public is particularly concerned about the impact of any move taken by the U.S. Department of Agriculture and some States in further restricting DDT and about similar restrictions on uses of several other longlasting chlorinated hydrocarbon insecticides where suitable alternative methods of insect control are available. Review studies by the USDA on possible restrictions began in March 1970.

Research is needed to determine the impacts of these changes in insecticide recommendations on the economic, health, conservation, and esthetic values in relation to the well-being of the Nation. Heretofore, changes in recommendations have been gradual but the pace has been hastened. The problem is complicated because of the large number of insecticides needed to control pests on a great variety of plants, animals, and man. I think the total impact will vary considerably depending upon whether a particular insecticide use is occasional and on small areas or if it involves extensive acreages which may require repeated treatments.

We are already aware of the action taken by USDA and some States to limit the use of persistent chlorinated hydrocarbon insecticides that have been extensively and effectively used for many years against soil insects--a group of insects of much importance to different control and regulatory agencies and to the public. Chlordane, the insecticide of choice, may well serve most of these needs until such time as the insect pests develop resistance to it, which I think is inevitable. DDT is no longer available for a number of large-scale agricultural, forest insect, shade tree, and pest mosquito control uses, nor for control of many minor insect pests that plague growers. This restriction is well justified on the basis of detrimental effects on certain species of fish and wildlife. However, there are other problems to be faced with alternative materials.

It is true that we have substitute materials for DDT and other chlorinated hydrocarbon insecticides but the main question is will they give the desired control. The great concern over the use of DDT for control of the European elm bark beetle, the most important vector of Dutch elm disease, has resulted in the recommendation of methoxychlor. This compound is inferior to DDT in controlling the beetle but less hazardous to birds. The disease is spreading almost unabated, and will probably result in the demise of elm trees throughout much of the country. Now, what kind of economic studies are needed to evaluate this situation--loss of shade trees of high esthetic value, loss of soil stabilization around streams and lakes, loss of animal habitats, and high cost of removing dead and dying elm trees in cities? Here we have a native tree species adversely affected by an introduced bark beetle carrying a devastating disease. The ecological upsets and economic values resulting from this introduction have not been well studied and documented.

There are similar problems associated with other introduced insect pests. For example, DDT has been the insecticide of choice for control of the gypsy moth. Alternative materials are available but they are not nearly as effective. There is every indication that the gypsy moth has increased its hold in infested States and that it has spread locally and also to Virginia and other previously uninfested areas, thus endangering valuable oaks and other tree stands to the south and the west.

Similar questions are being raised regarding the total impact of substitute insecticides for the control of insects that cause harm to man and that damage his crops. Another issue is the impact of substitutes on the control or eradication of introduced insect pests under cooperative Federal-State programs. Growers and others are much concerned because a number of serious pests cannot be controlled without greatly increased costs. And there is a lack of extensive information on possible side effects of alternative materials.

The general types of insecticides being substituted for the chlorinated hydrocarbon insecticides are organophosphorus and carbamate compounds. Though a variety of insecticides under each group is available, it is difficult to generalize because of differences in toxicity. However, we do know that certain organophosphorus materials, such as parathion, are highly toxic to mammals and that special precautions must be taken by applicators using these materials. Aerial application of parathion for insect control in California in 1968 is reported to have caused a dozen deaths to applicators. Such a situation serves as a warning on the hazard of using this insecticide or those of similar toxicity unless adequate precautions are taken.

In 1967, in an effort to prevent the spread of the pink bollworm from explosive buildups in Arizona into uninfested cotton areas of California, extensive aerial sprayings were undertaken with azodrin, methyl parathion, azinphosmethyl, and carbaryl in lieu of DDT since there was the hazard of the latter drifting to feed crops. This situation might eventually result in DDT occurring in milk. Elsewhere, because of the likelihood of DDT contamination in milk, malathion and carbaryl were used to control insect pests of corn and soybeans. The use of these organophosphorus and carbamate insecticides, which often means more frequent applications than with the chlorinated hydrocarbon insecticides, resulted in wildlife kills and heavy losses of insect parasites and predators. Whether the destruction of the latter natural enemies will result in insects heretofore of little consequence becoming pests remains to be seen. Yet this is likely on the basis of past experience.

Surveys made in 1967 by our honeybee specialists throughout the country indicated that the use of the above insecticides often in place of DDT resulted in a loss of 500,000 honeybee colonies, one-tenth of the U.S. total. Honeybees are required for the pollination of agricultural crops worth $1 billion. It is reported that many beekeepers are going out of business. This is of grave concern to growers of fruits, vegetables, and other crops requiring pollination.

A trend is underway in insecticide testing programs to find long-lasting organophosphorus and other materials that might be substituted for the chlorinated hydrocarbon insecticides. Some of these new materials show considerable promise; however, they may present hazards. The materials do not become fixed in the soil as do the chlorinated hydrocarbon insecticides. Consequently, there is the hazard that they will be readily moved about by water and may contaminate streams or deep wells. Also, as yet little information is available as to their effects on different soil organisms and food chain relationships.

Another consideration is the overall effect of demands for more research on the effectiveness and toxicology of pesticides. Such demands necessitate greater financial inputs by industry on long-term animal and other tests to meet product registration requirements of USDA and tolerance requirements of FDA. The development of a single pesticide is said to cost from $3 to $5 million. At a recent public meeting an industry man said that developmental work on aldicarb, a new insecticide, cost $11 million and that construction of a manufacturing plant would cost an additional $15 million. Such large expenditures in the development of insecticides have apparently discouraged investments in this field. Recently, six companies announced that they will no longer develop pesticides.

Research conducted by public agencies would also be affected by insecticide restrictions. Several high-level committees have recommended in their reports that greater consideration be given to controlling insect pests by means of parasites and predators, insect-resistant crops, attractants, cultural practices, bio-environmental procedures, or an integrated approach using a combination of methods. Such approaches are now employed for a limited number of insect pests, and research has been initiated on their development for controlling other pests. However, in many instances it will be necessary to conduct tests on an areawide basis to determine how useful such alternative methods will be.

Such research will be very expensive, involving several hundred thousand dollars over 2 or 3 years for each important insect. The primary object will be to develop alternative methods for insects of major economic importance. These ordinarily are those requiring the greatest amounts of insecticides today. Therefore, to the extent that biological or selective chemical methods can be developed we can avoid or reduce the amounts of insecticides required, mitigate the problems associated with residues, and reduce pollution in the environment.

CHANGES IN EMPHASIS IN ENTOMOLOGY RESEARCH DIVISION PROGRAM

The Entomology Research Division began to reorient its research program in 1955, long before the Rachel Carson era. It gradually shifted major emphasis from research on conventional insecticides to more selective chemical and nonchemical methods to control major insects, particularly those pests requiring heavy usage of insecticides year in and year out. At that time about two-thirds of our research program resources were assigned to conventional insecticides. Through reorientation of the research and additional research support it is estimated that 16 percent of our present research effort is devoted to conventional insecticides, 51 percent to biological and specific chemical control methods, and 33 percent to basic and fundamental research. The total budget for the Division amounts to about $18 million.

Thus, the bulk of our present program involves research on sterility, attractants, biological control agents (parasites, predators, and insect pathogens), insect-resistant crop varieties, and specific chemicals like hormones, and on combining certain of these methods with physical and cultural methods in an integrated insect management control system.

INTEGRATED INSECT CONTROL AND AREAWIDE POPULATION SUPPRESSION OR ERADICATION PROGRAMS

Integrated insect control often is limited to a combination of chemical and biological control methods. My concept of integrated control is much broader. It involves the use of all available practical and effective methods of insect control to bring full pressure on a destructive pest. Many of the integrated control techniques for the areawide population suppression or eradication of an insect pest depend upon striking at a time when the pest is vulnerable and at the lowest population ebb. At times, unusually low temperatures, typhoons, and other natural phenomena have practically wiped out insect infestations.

If advantage cannot be taken of adverse natural phenomena then it will be necessary to first drastically curtail the insect population by artificial means. For this purpose insecticides can play a major role. After the pest population is reduced to low numbers, then it is expedient to add other elements in the integrated control system such as sterile males, mass releases of biological control agents, or attractants.

Another principle that is becoming more and more evident is the need to test these integrated control or management procedures on the total insect pest population on an isolated island or on large nonisolated infested areas to avoid long-range immigration of insects. This requirement poses logistic and cost problems to researchers. These new techniques, to be effective, must involve large segments or the total population of a given pest. Accordingly, the approach is entirely different from the testing of an insecticide in a restricted field plot and its subsequent adoption by growers for use on their individual farms. In other words, the final utilization of some of these new approaches will depend on general acceptance and implementation that transcends individual farms.

Unlike a long-lasting insecticide, which often can be used to control several important insects on a crop, these specific methods will have to be developed for each insect. Thus, this increases the overall costs of controlling pests of a particular crop. Our primary interest in integrated control is to develop a compatible system of insect control that may suppress key insect populations (pests that usually require a large usage of insecticides annually) below economic damage levels throughout an area, or in some instances to eliminate the population if feasible and advantageous. The overall aim is to control these important insects economically, prevent insects formerly of minor importance from becoming serious pests, and also reduce the amount of chemical contamination in the environment.

STATUS OF SELECTED CURRENT PROGRAMS

Bearing in mind the above background information, let us now consider some current research and control programs. Some of these new approaches to insect control have been successful or have applicability and there are other studies underway for which we have great hopes.

Screw-worms

A Federal-State program in 1959 resulted in the eradication of the screw-worm from the Southeastern United States. This program was based on research work conducted many years before. A decision to undertake the eradication program followed the successful field evaluation study that resulted in elimination of the pest from the island of Curacao. Subsequently, much work was done to fully automate a rearing plant for the production of some 50 million sterile screw-worm flies per week for liberation on a sustained basis for the ultimate elimination of screw-worms from the Southeast. This program saved losses to cattle raisers as high as $20 million a year.

Presently, an extensive program is underway in the Southwestern United States and Mexico involving releases of 130 million or more sterilized flies per week in an area of about 300, 000 square miles. It is now supported largely by Federal funds, but the States and the livestock industry are contributing to the approximately $6 million per year spent on the program. It is under the overall leadership of the Federal Animal Health Division. Livestock growers are asked to inspect their livestock and report any screw-worm cases found so as to alert program officials where additional sterilized flies need to be released.

This sterile release program has on occasion eliminated the screw-worm from the Southwest. However, there is reinfestation each year because of long-range immigration of screw-worm flies from Mexico. Due to extremely wet favorable weather for screw-worm development, cases in livestock were more numerous in 1968 than in any year since the program was initiated. However, it is estimated that suppression was still around 99 percent. The 1969 infestations were quite low. Livestock growers estimated that their annual losses exceeded $100 million prior to the current sterile fly release program.

Subtropical Fruit Flies

Several fruit flies have been experimentally eradicated from islands by use of integrated control programs. In 1963 the melon fly was eradicated from the 33-square-mile island of Rota. Two or more biweekly applications of malathion-protein hydrolysate baits sprayed on heavily infested farms greatly reduced the number of wild flies. The entire island was then overflooded with flies sterilized by gamma radiation. In another operation, the oriental fruit fly was eradicated from Guam by releasing sterile flies after typhoons which greatly reduced natural populations.

Through radiation sterilization, research has provided tools that can be applied for the control or eradication of the Mediterranean, melon, Mexican, or oriental fruit flies in event they become established in the United States. The need is to establish fruit fly rearing plants in order to be prepared for emergency outbreaks that can be stemmed early at an economical cost by releasing sterilized flies and without adverse side effects.

Preliminary research also shows that the Caribbean fruit fly, which is increasing in numbers in backyard fruit trees and commercial orchards in Florida, can be reared in numbers and sterilized satisfactorily. It remains to be determined, however, if sterile flies integrated with prior suppression with insecticides will provide a practical solution to this new fruit fly problem. Thus, new techniques for controlling certain fruit flies are available to Federal and State agencies and others are under development in cooperative programs.

Boll Weevil

An insecticidal control program aimed at reducing the last reproducing generation and the diapausing boll weevil population is still underway in an eight-county area of the High Plains near Lubbock, Texas. This is a cooperative program between ARS, Plains Cotton Growers Incorporated, Texas A and M University, and Texas State Department of Agriculture. During 1965 and 1966 treatments consisted of four applications of malathion at 5-7 day intervals in late September to break the reproductive cycle. These were followed by three applications of malathion at 10-14 day intervals in October and November to kill diapausing adults that survived earlier treatments. The potential overwintering population in the treated area in 1966 was estimated by Adkisson and Sterling (Texas A and M University) to be approximately 99 percent less than in untreated acreages.

In 1967 and 1968 the number of insecticide treatments was reduced and a lesser but still high percentage of control was obtained. The demonstration that a high degree of boll weevil control is possible with insecticides alone was on target for predictions made by E. F. Knipling in a theoretical model study before the program was undertaken.

We think the stage is set for the other parts of an integrated program--the use of sex attractant traps and the addition of sterilized boll weevils--to determine if it is possible to wipe out the greatly reduced populations that remain following the use of insecticides. Unfortunately, it has been difficult to develop ways to sterilize weevils that will remain fully competitive with native weevils. Progress is being made, however, and future plans call for practical field trials to determine the competitiveness of the boll weevils by the best sterilization procedures available.

At its 1969 annual meeting, the National Cotton Council of America established a special study committee on boll weevil eradication. This committee is considering the initiation of a large-scale pilot test beginning in 1971 to determine the feasibility of eradicating the weevil with present research capabilities. The pilot test would involve the integration of insecticides (reproductive-diapause treatments), cultural measures, sex attractants (traps containing grandlure, the synthetic sex attractant produced by males to attract females)--and release of sterile insects in an all-out effort to show that the eradication of this major insect is practical and feasible.

No one can guarantee that such a program will work. However, since annual losses by the boll weevil range from $200 to $300 million, there is ample justification to try and eliminate this pest. It is estimated that about one-third of the insecticides used in the United States for agricultural purposes are required because of the boll weevil problem. Therefore, if the pest could be eliminated, it would be a major contribution to the current effort being made to reduce environmental pollution from broad spectrum insecticides.

Pink Bollworm

Hexalure, a potent synthetic sex attractant discovered by our scientists, is now available for use by the Plant Protection Division (PPD) and others for detection purposes in the pink bollworm control program. It is also used as a research tool to trap marked released adults so that scientists can determine the ratio of sterile to native male moths needed in a release program. Techniques for rearing the pink bollworm have been greatly improved and moths are reared in large numbers in the new rearing facilities of PPD at Phoenix, Ariz.

During 1968 several million pink bollworm moths irradiated with cobalt-60 were released in the San Joaquin Valley, Calif. This was an effort to prevent the establishment of the insects that may spread from the Imperial Valley to this major cotton-producing area. The adults were released from airplanes with drops beginning in May and ending in November. This program has been undertaken by regulatory agencies to help stem the immigration of this pest into the cotton areas even though the sterility technique for controlling the pink bollworm has not yet been proved on an experimental field basis.

Bollworm

This insect is a serious pest of cotton as well as other crops. Recent research is directed to the mass production and release of parasites or predators. By making them available in greatly increased numbers at the critical time needed in the field, more dependable control may be obtained. For example, recent tests have shown that the mass release of 200, 000 aphid lions (Chrysopidae) per acre for a sustained period was as effective against the bollworm on cotton as the best available insecticides.

Pea Aphid

In another study, the mass production of 100 million parasitic wasps was attained by using small portable heated greenhouses in alfalfa fields in Washington. Release of the parasites on 18, 000 acres of alfalfa early in the season controlled the pea aphids which are vectors of pea enation mosaic and pea streak virus which overwinter in alfalfa. By controlling the winged aphids and preventing their immigration some 130, 000 acres of freezing and canning peas were protected from the virus diseases.

Currently studies are underway in the Division to evaluate a special strain of Bacillus thuringiensis. Under laboratory conditions, this bacterium is about 100 times more virulent than strains commercially available against the bollworm on cotton and other insect pests. Promising results have been obtained in limited field tests, but more extensive field testing will be necessary before its practical value can be appraised.

Cabbage Looper

Some field studies have shown that a polyhedrosis virus spray used to control the cabbage looper, a serious pest of cole and other crops, is just as effective and economical as insecticides. However, until acceptable protocols are established for the registration and approval of exemption from a tolerance for this insect virus, its use and that of other insect viruses must be held in abeyance. Like chemical pesticides, necessary toxicological data are required to prove the safety of an insect virus before it has FDA and USDA approval.

Tobacco Insects

An experimental integrated control program involving light traps and tobacco stalk destruction to prevent late-season breeding of hornworms was conducted from 1962 to 1968 at Oxford, N.C. Light traps were installed over a large area to prevent strong flying moths from influencing the results in the center of the trapped area. Three light traps per square mile were used in an area of 113 miles square. In the center of the area about 50 percent control of the hornworm was obtained the first year and almost 80 percent the next 2 years. Subsequently, few insecticide treatments have been used by farmers within the experimental area as compared with usage outside of the area. In recent years the hornworm populations have been quite low and the experiment has been terminated.

At Quincy, Fla., outstanding results have been obtained with an integrated control program for tobacco insects grown under shade. A high degree of control has been obtained by using a combination of procedures, including systemic insecticides, light traps, and the insect pathogen Bacillus thuringiensis. Growers and the tobacco industry are gratified with the preliminary results which indicated an acceptable control of tobacco insects without any problem of insecticidal residue.

FUTURE NEEDS

The magnitude of the research and development job to find effective biological and specific methods of insect control is very great. Each of these methods, as well as integrated control methods, require much more information on the life history and population dynamics of insects than is generally required to employ insecticides successfully. Areawide programs, perhaps involving inputs of billions of sterilized insects or biological control agents, or large quantities of natural sex attractant, will require suitable rearing media and automated techniques for mass production of insects. After the basic data is fairly well worked out, it will be necessary to test the areawide control procedure for each insect in an isolated area, preferably an island. These tests are expensive.

Then, there remains the big gap between the favorable results obtained experimentally in small field tests and a large-scale pilot test to determine whether the method is practical. This is one of the greatest obstacles to the advancement of alternative means of insect control--lack of several million dollars in funds to conduct large-scale pilot tests on integrated control methods aimed at about two dozen major insect pests.

ECOLOGICAL CONSEQUENCES OF RESTRICTING THE USES OF CHEMICAL PESTICIDES

Roland C. Clement, Vice President
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It is unfortunate that so much of the damage done by long-lived, lipid-soluble insecticides was first identified as damage to bird life. To the ecologist, birds are highly sensitive indices to the health of ecosystems, but to the layman--including most nonecological scientists--birds are "hobby things" of special interest to a mere fraction of the human population. Concern for birds has thus been taken as frivolous, especially when compared to economic production or public health engineering.

Because, in effect, only the birdwatcher was an ecosystem watcher at first, and because his concerns were downgraded by those who should themselves have been better ecosystem watchers, we have poisoned the world with DDT (Sladen, Risebrough, Peterle, Woodwell, and others), and cannot yet begin to assess the damage done, nor where it will end.

When we first became aware of the acute toxicity of DDT to wildlife we thought that reduced exposure was all that was necessary to allow "safe use." In 1958, however, Roy Barker showed that there is no safe use because DDT's long life and fat-solubility make it act at a distance in both time and space. DDT applied in the spring to elm foliage kills robins the following year because it is meanwhile absorbed and concentrated by earthworms. This was the first ecological red flag but few heeded it.

Woodwell early showed that 50 percent of aerially applied DDT did not fall where intended, and although drift soon became a business risk, its ecological implications were disregarded. Risebrough's sampling of Atlantic trade winds for DDT showed that this pesticide is definitely part of the atmospheric circulation patterns. This helps explain the DDT in antarctic snow (Peterle), where it was never applied, and its presence in antarctic marine fauna. Incidentally, biological migration is one of the unmeasured causes of "disappearance" of DDT that agricultural scientists have pointed to so enthusiastically to assure us that things are not as bad as they seem.

We did not know, when we registered DDT for use, that as little as 10 ppb would inhibit photosynthesis in marine plankton; that only 3 ppm prevent lake trout fry (and probably other fish) from living beyond the yolk-absorption stage; nor that certain birds would lay thin eggshells, or eggs with no shells at all as a result of exposure to DDT at nonacute toxicity levels (for the adults). We know this now but have not yet withdrawn DDT from use.

One important, as yet neglected area of research is that involved in the total effects of DDT use on human nutrition. We know that crustacea are among the most sensitive of organisms to DDT and other chlorinated hydrocarbon insecticides. As crabs, prawn, and shrimp, crustaceans are also an important source of protein for man, especially in the tropics; and as copepods and other small marine forms, they are key links in oceanic food chains whose fish, again, are a principal source of protein for many nations. We may expect--until proven otherwise--that the use of these insecticides has been imposing a selective pressure against one of man's best sources of proteins, the crustacea and fish. This is ironic indeed, since the insecticides were brought into play to "save lives" and to produce "more food."

If we take entire ecosystems into account, agriculture may have been producing more carbohydrates at the expense of proteins. Public health malaria control programs may also have been pursued at the cost of protein starvation, with the special nervous system damage this involves. And all of this may have augmented total food demands in addition, thus inducing more agricultural production with its attendant imbalances.

The landscape is not a stage but a cybernetic system. A species not only takes up space, but it interacts with its prey, its predators, and its parasites. It may, sometimes, play a critical physical role in the ecosystem, not just an organismic role, as is true of the mussels that fix phosphates which enhance plant growth, etc. Our assessment of the structure and functions of ecosystems is still so rudimentary that we seldom know the role of a species until something goes wrong to call our attention to this role. Because of the interdependencies involved, however, we can expect the effects of exterminating a species to be complex and deleterious more often than not.1/

In order to ask "How important is the preservation of a single animal species?" we should specify which species we have in mind, where it fits in the food web, what fraction of the biomass it constitutes or affects, and many other specifications that cannot yet be made. Nor can we predict, without expensive testing, which organisms will be affected by new chemical parameters. We know only that the ecosystem will be impoverished thereby and that the new equilibrium will be different, but whether for better or worse we do not know.

1/ For documentation of this point of view, see L.E. Cronin's editorial on the estuarine ecosystem in BioScience for 1 April, 1970; and, particularly, G.M. Woodwell's article on "Effects of Pollution on the Structure and Physiology of Ecosystems," (Science, 24 April, 1970), suggesting that the function of species is to maintain a budget of mineral nutrients within ecosystems, thus holding them against the wastage involved in percolation, runoff and entropy; plus, of course, the maintenance of gene pools which are irreproducible records of evolutionary history.

Ecologically, then, restricting or eliminating the use of DDT and its relatives will help restore ecosystem balances we cannot afford to tinker with while we are so ignorant of their mechanisms. It will allow the trend toward diversification--which we believe makes for stability--to reassert itself, assuming that no serious extinctions have occurred during use. The effects on private entrepreneurs may involve higher labor-capital inputs, but only until a suitable alternative is found. Others can better specify these altered inputs. But it should be remembered that both the costs and the production affected are subject to substitution, whereas the loss of a species is not only nonquantifiable (except via surrogate valuation asserted against threats of extermination) but irreversible. Where widespread ecological effects occur, therefore, there can be no responsible unilateral decisionmaking. DDT, therefore, must be banned on principle even before we can quantify its full impacts.

More specifically, ecologists are asking for the withdrawal from use of those chemicals whose long life and lipid-solubility cause them to be cycled in food webs and magnified (concentrated) in the process. Although DDT's solubility in water is only about 1.2 ppb, it can be and often is magnified to levels involving 100 to 1,000 ppm in the tissues of predatory organisms at the ends of long food chains. Although many other currently "acceptable" insecticides may eventually prove ecologically disadvantageous, our acceptance of these seems to me to demonstrate the reasonableness of our objections to aldrin, dieldrin, DDT, endrin, and heptachlor.

Only two other points need be made here:

(1) There are no pests per se, only pest status which is a function of population level as a rule. The task is therefore not one of pest control, but of regulating damage in order to keep it below economic thresholds.

(2) This prevention of economic, public health, and other damage must become a fully internalized cost of production. The ecological crisis of our day calls for the same sort of broadening of awareness of responsibility that imposed labor costs on the employer in order to abolish slavery.

ECONOMIC CONSEQUENCES OF RESTRICTING OR BANNING THE USE OF PESTICIDES

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INTRODUCTION

Restricting or banning the use of pesticides, or for that matter any other input, deals with the basic problems of economic organization.

What will be produced? How and for whom will it be produced? Changes in these goals affect costs and benefits to farmers, to producers of inputs, and to consumers of food and fiber.

The initial reaction may be that restricting or banning the use of farm pesticides deals only with how crops and livestock will be produced. Or more specifically it deals with what alternative resources would be used to produce a particular kind of crop or livestock and how this would affect quantities produced and costs.

But alternative production practices for a given crop do affect what is produced. Then comes the question of whom it is being produced for, since farm products have different end uses. In addition, changes in production patterns may affect relative prices of food. For example, more meat might be consumed but less vegetables.

Banning the use of one or more pesticides will have an immediate impact on the farmer. His actions affect the producer of pesticides and the consumer of food and fiber. Their reactions will influence the farmer again at a later time.

This paper begins with a discussion of some basic economic relationships that must be considered in evaluating costs and benefits to farmers from restricting or banning the use of pesticides. Effects on individual farmers will be traced to show changes in aggregate farm production. Changes in farm production will then be followed to show the effects on pesticide manufacturers and on society, and how this once again affects the farmer. Some observations will be made about the effects of Government farm programs, and the primary and secondary effects from shifts in production within and among farm production regions.

We should not forget the basic assumptions on which our economic evaluations rest. Measuring the effects of banning pesticides in terms of benefits and costs to individual farmers, to all farmers, or to society as a whole, all assume some formulation of:

(1) Production functions,

(2) Cost functions associated with production, and

(3) Demand and supply functions.

Production Functions

First, we need to understand production functions as they relate to a single input such as pesticides, as they relate to other inputs, and as the various inputs interrelate with possible substitutes. Here the discussion is in terms of farm use of pesticides, but these same concepts also apply to nonfarm users and to pesticide manufacturers.

The production function in its simplest form (fig. 1) shows that as pesticides are added there will be--

First, increasing additional production for each additional unit of pesticide used (OX_1);

Second, decreasing additional production for each additional unit of pesticide used (X_1X_1''); and

Third, negative additional production for each additional unit of pesticide used ($>X_1''$).

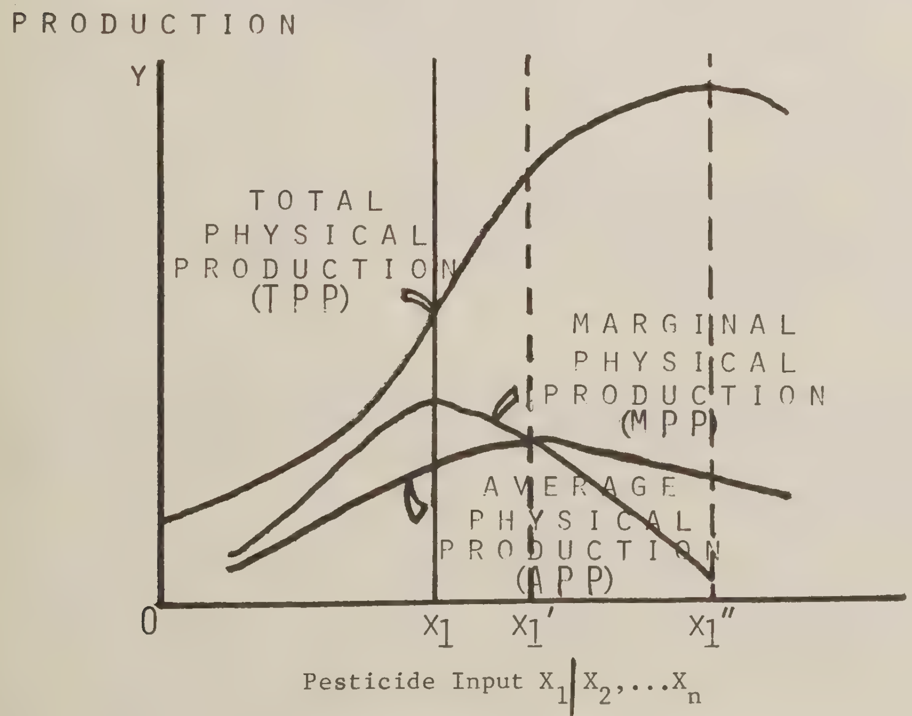
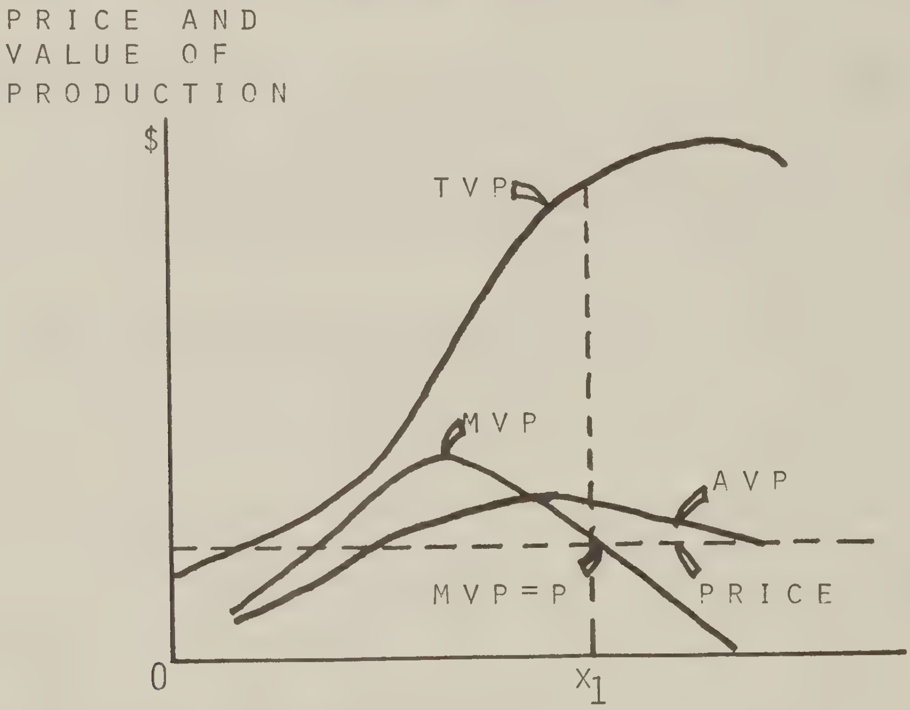


Figure 1

If it pays to use any pesticides, then regardless of pesticide costs or value of production, a farmer should always produce up to the point (OX_1') where additional production (MPP) from the use of another unit of pesticide is greater than the average production (APP) from the pesticide. Saying it another way, always produce at least to the point where average production (APP) reaches a peak (OX_1').

If capital for purchasing pesticides is unlimited and there is no opportunity cost (no other alternative for its use), then under the competitive structure of farming, production would be expected to be OX_1 (fig. 2).



Pesticide Input (X_1) / X_2,---X_n

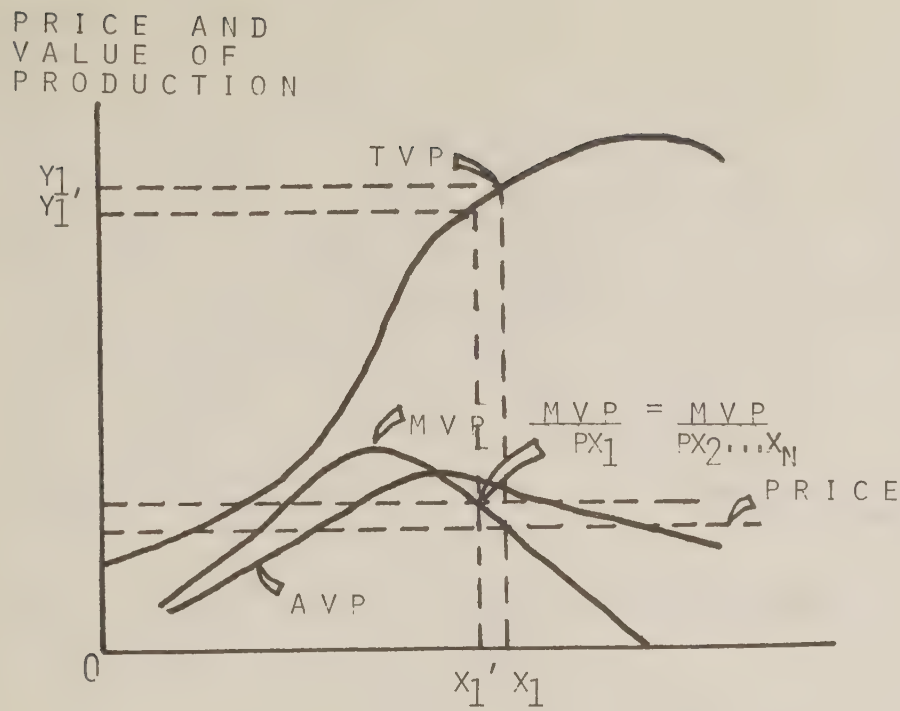
Figure 2

In this special case, additional units of pesticides would be added until the value of the last unit, marginal value of product (MVP), is equal to the cost or price (P) of the additional pesticide.

That is: MVP = P

If capital is limited, additional units of pesticides would not be added until the marginal value of product (MVP) of pesticides was equal to the price (P). The limited capital would be allocated among all inputs so that the returns per dollar of cost would be the same for each (fig. 3).

Instead of using X_1 quantities of pesticides to produce Y_1 product, the place where MVP=P, the individual farmer would use smaller quantities of pesticides (X_1') and produce less product (Y_1'). At this point, marginal returns to all resources would be equal.



Pesticide Input (X_1) / X_2---Xn

Figure 3

Whether or not capital available to farmers is limited, returns to farm resources compete with such nonfarm alternatives as interest on savings accounts or dividends on stocks. If we consider capital is not limited for purchasing only the alternative production inputs ($X_2, \ldots X_n$) used to produce farm products, then we add additional units of pesticides and all other inputs until the marginal value of product is equal to the price of the input.

$$MVP(X_1) = P(X_1),\ MVP(X_2) = P(X_2),\ \text{or } MVP(X_n) = P(X_n).$$

If capital available to purchase farm inputs is limited, the more usual case, we add additional units of pesticides or any input until the marginal value of production divided by the price is the same for all inputs.

$$\frac{MVP(X_1)}{P(X_1)} = \frac{MVP(X_2)}{P(X_2)} \text{ or } \frac{MVP(X_n)}{P(X_n)}$$

If we knew the production relationship for each pesticide or group of pesticides as well as for the substitutes, and if each of these were independent of the other, then given the kind of information suggested here, economic evaluations related to banning pesticides would be rather straightforward. However, this kind of information is seldom available and the substitute practices including crop rotation are generally not independent.

In the absence of productivity data related to separate inputs we need to think of a production function related to current pesticide use and a similar but lower function for combinations of alternative practices. These could be expressed as the functions YB and YA (fig. 4).

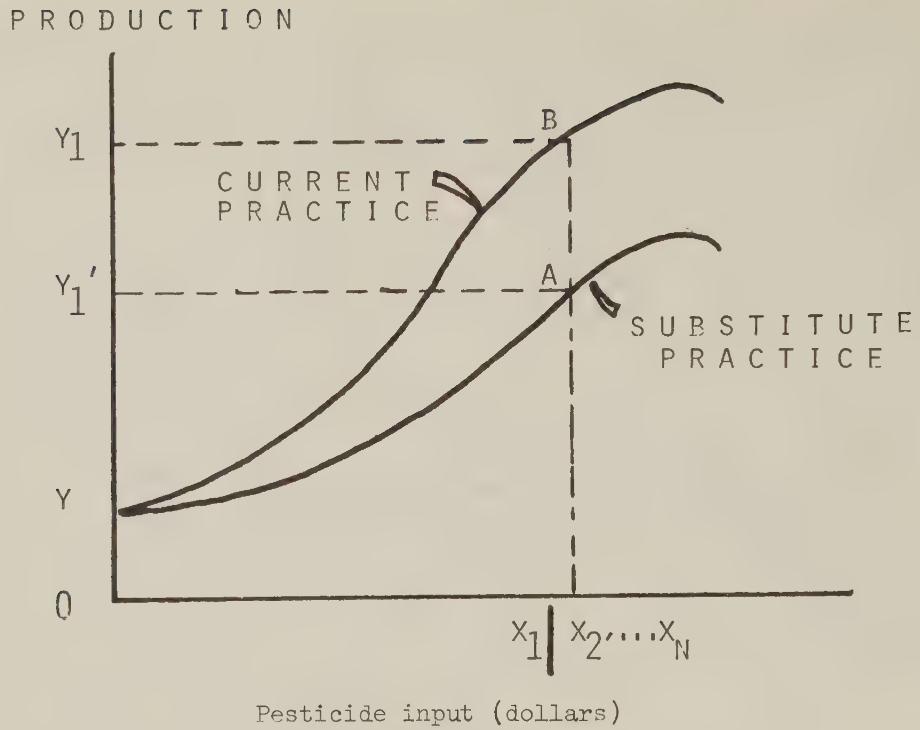


Figure 4

Then, the real benefits in terms of additional production of equal quality from any pesticide need to be thought of as the difference (AB) between the two functions for a given cost of inputs. The substitute pesticide practice could be another pesticide or a recombination of many other inputs, which might or might not include pesticides. Substitutes could also include integrated control and changes in rotations in combination with other inputs.

If we want to maintain production after banning or restricting the use of a pesticide or group of pesticides, we need to look at the substitute package of available resources (fig. 5).

In general it would be expected that the substitute practices would require more resources and be more costly. The increase in cost would be from OX_1 to OX_2.

In practice, adjustments in farming from banning pesticides would generally be some combination of lower production and higher costs rather than either separately.

Whatever the adjustments, with this kind of information for constructing production functions, an important part of an economic evaluation can be readily completed. But often the information is not available. Most of the data available is fragmentary and in the form of yields associated with current practices and estimated yields with zero applications.

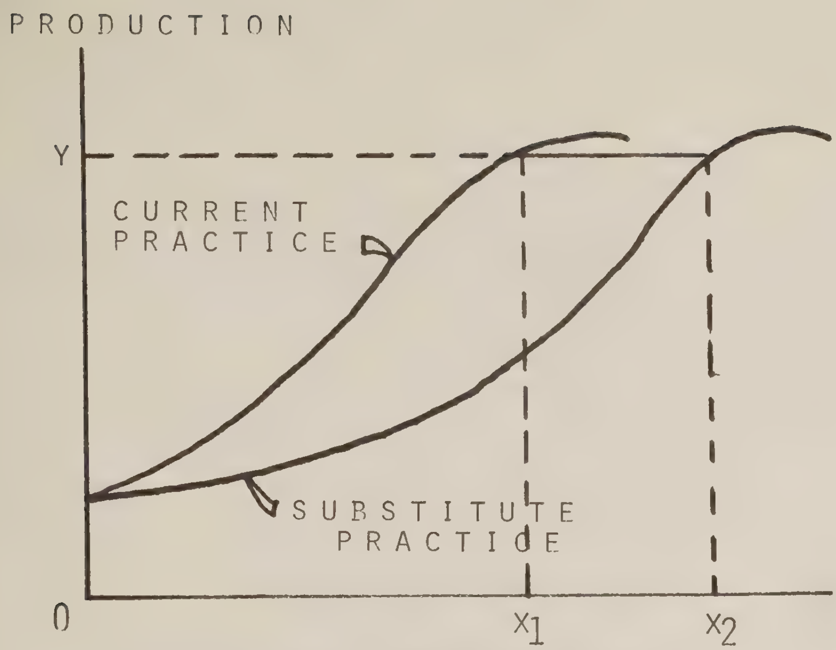


Figure 5

In the absence of production function relationships, economic evaluations may be made by using point estimates of production with and without the use of pesticides. Similar estimates may be made for single substitute pesticides and for substitute packages of practices (including pesticides or cultural practices). If substitute practices are not available, yield losses are evaluated.

Cost Functions

After determining production relations, we need to think in terms of the associated cost functions (fig. 6).

If costs of alternative pesticides or alternative packages of inputs are higher, the effect of banning pesticides is to raise all cost curves, assuming production remains the same. All cost curves, total cost (TC), average variable cost (AVC), average total cost (AC), and the marginal cost (MC), will rise. Most of the cost curves, the average variable cost (AVC), average total cost (ATC), and marginal cost (MC), will also rise if the cost of the alternative pesticide or alternative package of inputs remains the same and if production falls. However, in this case the total cost (TC) remains the same.

Price changes of pesticide inputs or changes in production associated with alternative pesticides and other inputs affect the cost curves differently. In most instances, shifts in the cost curves would not be expected to be the same among the different cost curves nor the same for all points on any single cost curve.

In budgeting the effects of a pesticide ban, changes in average variable costs and marginal variable costs are particularly important. Changes in

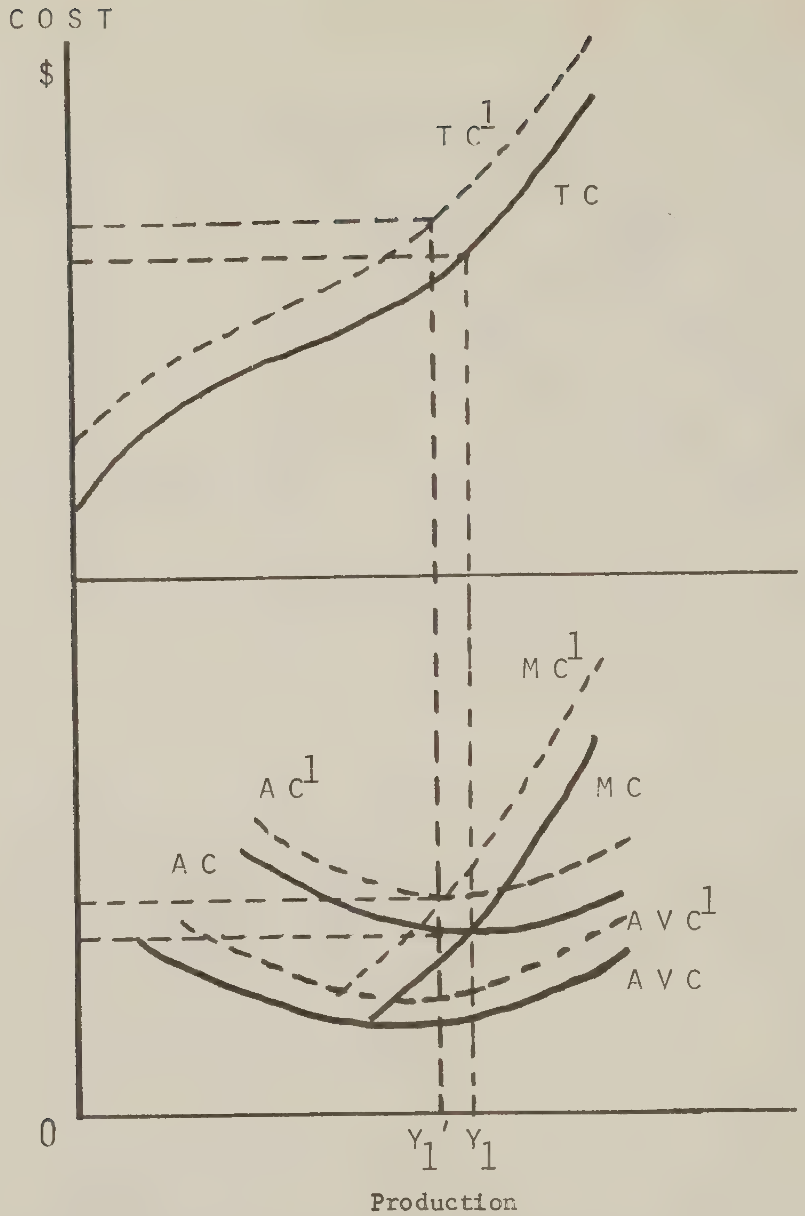


Figure 6

either the average variable cost or the marginal cost times any changes in production might be used to measure costs or benefits to farmers.

Supply and Demand Functions

The cost functions associated with the production function are related to supply and demand functions. Changes in the marginal cost curve are particularly important at the farm level and in the aggregate because this cost curve above the minimum average variable cost is, in effect, a supply curve.

Increases in the marginal cost curve for an individual farmer are in effect the same as a decrease or shift to the left in the supply curve for the given product (fig. 7). The demand curve to the individual farmer in pure competition is a horizontal line with infinite elasticity.

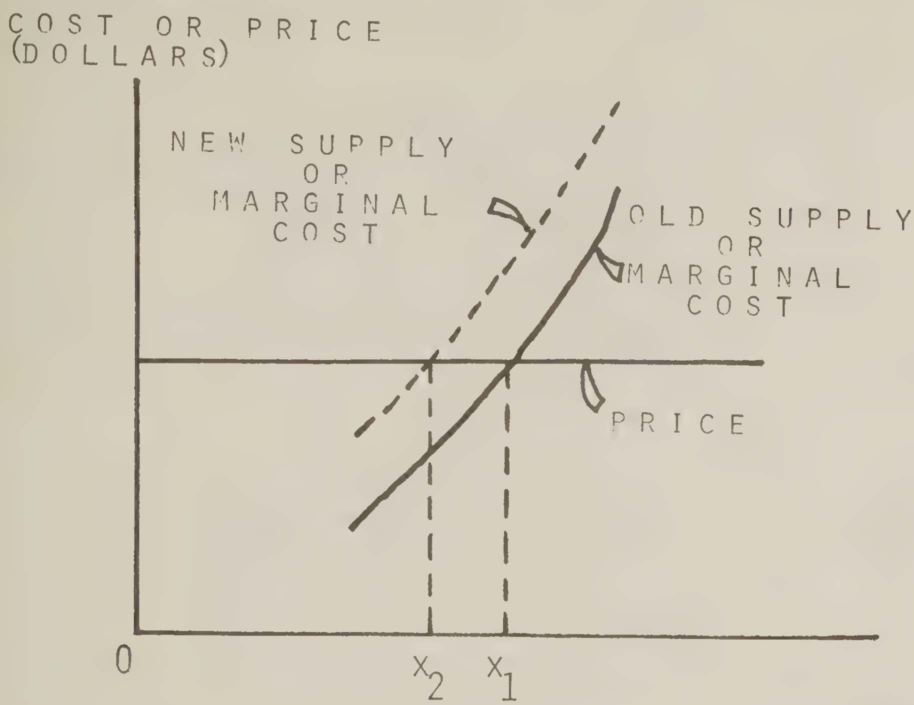


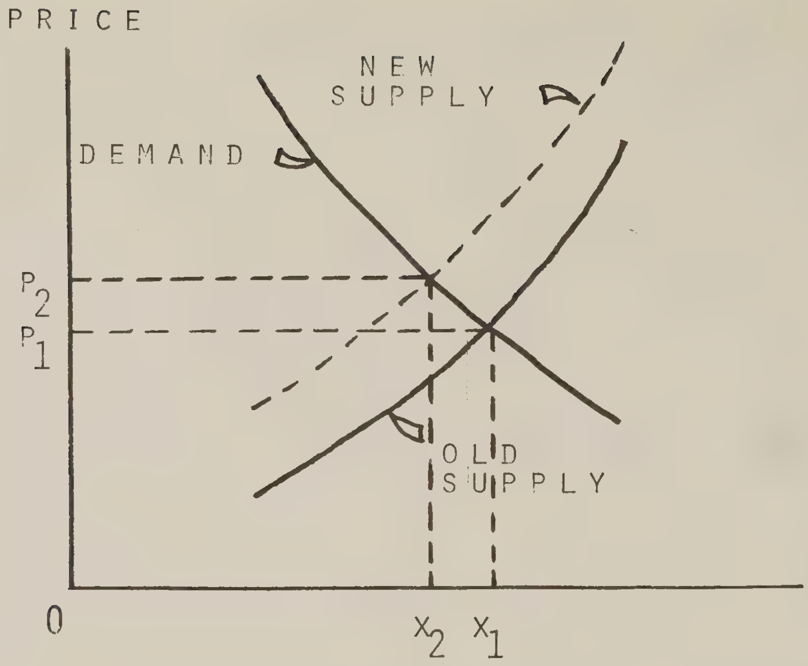
Figure 7

An anticipated price similar to the prevailing price (that is a horizontal demand curve) but with a reduced supply curve would result in lower production of the item by individual farmers (X_1 to X_2). Resources would be shifted to produce other products so that the net returns to factors or the marginal value of products would be the same for all commodities. Also, because of higher costs some farmers might go out of business.

The summation of the individual farm marginal cost curves becomes the industry supply curve (fig. 8). In the aggregate, reduced supplies would be further influenced by some farmers going out of business because of the higher costs. However, industry supply curves are generally similar to the individual farm supply curves.

In contrast to the supply curve, the market demand curve is altogether different from the demand curve for individual farmers. The market demand curve for all farmers' products is not a horizontal line but is negatively sloped and generally inelastic.

Because of the change in supply and the sloping demand curve for farm products, reductions in supply (X_1 to X_2) will result in higher prices paid for farm products (P_1 to P_2).



Quantity

Figure 8

ECONOMIC EFFECTS

The production and economic relationships associated with restricting or banning pesticides necessarily imply differing economic consequences to farmers, industry, and consumers.

In the absence of government price supports if production were maintained, farmers would have to absorb any additional costs. If production were lowered, generally higher prices to farmers would more than offset additional costs. The resulting higher income to farmers would be a cost to consumers in the form of higher food prices. If new alternative pesticides are developed, industry may presently benefit from selling more higher priced pesticides.

Farmers

The initial economic evaluation of costs of banning or restricting the use of pesticides for individual farmers suggested that they would produce less at higher costs. However, because there are no good substitutes for food, the demand is inelastic. Therefore, with lower food production and higher prices, farmers would receive more for their goods and services than they received before the ban.

The increase in prices would more than offset any lower production. Higher prices would encourage efficient farmers to produce more. Supplies might move toward earlier levels, and prices of products would move lower.

Again, there might be shifts to producing other crops, or some other farmers might go out of business. Over time as these forces brought about change, everything else remaining constant, the system would settle into a new equilibrium with smaller quantities being produced at higher prices.

Restricting the use of pesticides in producing commodities for which the demand is elastic would lower production and boost prices, leaving farmers with less farm income than before. The increase in price would not be enough to offset any loss in production.

Whether the demand is elastic or inelastic, the effect on the farmer would be the change in price he receives for his product times the change in quantity produced in addition to any changes in production or marketing costs.

<u>Industry</u>

Restricting the use of pesticides would generally raise production and distribution costs for those pesticides involved because of generally higher costs for lower volume of production. Conversely, when there is increased use of other pesticides, these would tend to be lower in cost. However, the present markup of some of the newer pesticides, particularly proprietary ones, is probably greater than for some of the older, established materials. Thus, on the average for all industry, it is unlikely that its losses would exceed gains.

In restricting or banning the use of any pesticide we need to consider the effect on producers individually and in total. Some companies would lose, others would gain. However, in general, pesticides are a small part of the business of most manufacturers, so that gains or losses would be small in relation to total sales.

Switching to alternative pesticides or other inputs may affect the costs of producing pesticides and in turn the prices farmers would have to pay. This again would be reflected in a different total cost curve for the farmer. Changes in the cost curves could be followed through the production and marketing processes to see the effects on consumer prices.

<u>Consumers</u>

The effect on the consumer of restricting or banning the use of pesticides is clearly in terms of higher costs for food and fiber. Costs will be considerably higher if the demand for a product is inelastic (as it is for most foods) and if the impact on production is great.

The decision to restrict or ban materials becomes a question of weighing added costs against any potential hazards from continuing their use. These added costs to consumers need to be considered for varying pesticide application rates and for limited use on selected crops. This might involve limiting the use to only selected crops or setting the maximum number of treatments for any one crop.

These additional out-of-pocket costs to consumers must be weighed against external costs associated with changes in the environment. Among others, things to be considered as external costs are illness, accidental deaths, longevity, and ecological changes. Social scientists, including economists, should attempt to assign values for these externalities.

The decision to restrict or ban would rest with the policymakers. They must weigh higher food prices or additional costs to farmers against the external costs generally associated with changes imposed on our environment.

GOVERNMENT PROGRAMS

The economic effects of restricting or banning the use of pesticides, described earlier, are for a competitive market. However, the support prices (OP_1) and acreage restrictions (OX_1) of current farm programs suggest that farmers would absorb most, if not all, additional costs (fig. 9). There would be no changes in food prices, unless the supply curve shifted to the left considerably--that is to the left of the new supply curve. Farmers were willing to supply a larger quantity (OX_2) at the support price (OP_1) before the restrictions on pesticide use. With the supply curve moving leftward because of higher costs and production still restricted to the current level (OX_1), consumers would not need to pay higher prices for food.

Since farm programs are often income supporting, they would probably be revised to maintain farm incomes. With increased payments to farmers equal to increased costs from restricting or banning pesticides, farmers would maintain their incomes. The additional payments to farmers would come from consumers in the form of higher taxes.

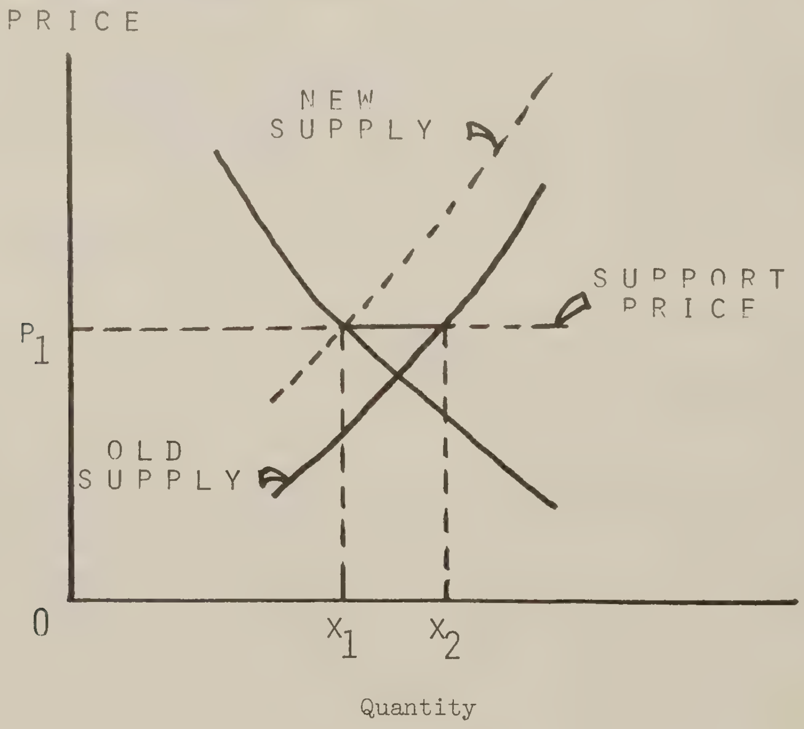


Figure 9

SHIFTS IN PRODUCTION

Who will produce and what will be produced? Total farm output is a package of different commodities produced by many farmers in all geographic regions with varying production practices. When looking at aggregate production, we should not ignore possible effects that might over time suggest changes in production patterns and even shifts in production.

Restricting or banning the use of pesticides for selected crops in specific areas might result in some regional shifts in production. For example, long-run adjustments from banning organochlorines could lead to higher production costs for cotton, particularly in the Southeast. This, plus the continued pressure from synthetics, might make the production of corn, soybeans, and cattle more attractive in this region. If the use of organochlorine were banned, incentives to grow corn in the South could be further increased because of possible insect problems in the Corn Belt.

Discontinued use of organochlorines for wireworm control might necessitate a return to producing corn in crop rotations if other effective pesticides are not available. This would be in contrast to the intensive production practices now being used in growing corn continuously. In addition, if the organophosphate and carbamate pesticides now being used to control corn rootworm were banned, this could further encourage shifts in corn production to other areas. More soybeans and small grains would be grown in place of corn.

Similarly, discontinuing the use of 2, 4, 5-T on pasture and rangeland, particularly in the Southern Plains, would eventually encourage some shifts in raising livestock to other areas. Livestock would still be produced in these areas. However, because of less pasture and rangeland available due to poor weed control, fewer livestock would be grazed. This, in turn, could be reflected in higher land and cattle prices which would make production in other areas, particularly in the Southeast, more competitive.

Banning the use of selected herbicides such as 2, 4-D probably would not encourage shifts in wheat production. Even though yields might be lower, there do not appear to be good substitutes. Thus, farmers would continue to grow wheat, especially with guaranteed prices for their production. However, with lower production and higher prices, more wheat would be grown in other areas.

Now how can we take these ideas and tie them together in a manageable framework?

ECONOMIC EVALUATIONS

The forces resulting from banning a pesticide or group of pesticides affect supply primarily. Studies related to the supply curve or changes in supply, either instantaneously or over time, have been much less frequent than those relating to demand. Much of the early work related to estimating supply curves or changes in supply was done by budgeting techniques. Most studies were for individual firms. Some were of a regional nature. A few focused on interregional competition.

More recent studies dealing with estimating supply curves and determining supply adjustments have relied more heavily on linear programming, mainly because of the ability to handle large and complex problems. Essentially the same kind of analysis might be done with budgeting but at much higher costs if many different alternatives were to be considered. Variations of the linear programming model include static linear programming, dynamic linear programming, and recursive programming.

Interdependence of decisionmaking within the farm, among farms, regions, and society as a whole may be considered. However, often the complexities of the problems are such that many restrictive assumptions are made that limit the usefulness of these analyses.

More recently formalized methodology has been developed that encompasses most tools of analysis commonly used by economists. It is generally more inclusive because it includes probabilities of occurrences as well as deterministic data. This overall tool of analysis, known as simulation, is really a means of describing systematically what is expected to happen in terms of statistical and mathematical concepts.

Comprehensive evaluations should consider possibilities for reducing pesticide use, for example, by lowering rates of application and spraying only when needed or by supplementing fewer sprays with some form of crop insurance. Several procedures for making economic evaluations are discussed in other papers of this symposium.

RESEARCH NEEDS

To evaluate the economic consequences of restricting or banning the use of pesticides, data needs include more information related to farm and industry--

(1) Production functions

(2) Cost functions

(3) Demand and supply functions

(4) Effects of alternative farm programs.

Production Functions

Generally, input-output data have not been available for economists to analyze changes in costs and returns associated with an innovation until after it was widely adopted. This is also true for the use of chemicals to control pests. This is especially true where chemicals are used for protecting and treating crops against insects and diseases.

Some input-output data on the chemical control of weeds in farm crops are available. Most of these data are from controlled experiments that compare crop yields of plots on which recommended levels of different chemicals are used, or from experiments that compare crop yields from plots using a specified chemical weed control with those not having any type of weed control.

There is a real need for more experiments designed to measure the yield variations among plots or fields with similar infestations under various degrees of chemical control, and among fields or plots under various degrees of mechanical or biological control. However, there is also a need for experiments to show how different applications of part chemical and part mechanical or biological controls affect crop yields.

To get the information needed to estimate production functions, economists must cooperate with biological scientists in designing experiments that yield data on different levels of pesticide use.

Until we get such information for production functions, it is also important to work closely with biologists for other reasons. Their aid in making estimates of yield losses and substitute practices is invaluable in any economic evaluation of the consequences of banning pesticides.

Cost Functions

Little detailed information is available on cost functions covering a wide range of production. Our analysis can be useful even with secondary data for point estimates of costs and changes in costs. However, we are still in need of accumulating cost data so that it is readily available when needed.

In evaluating costs, we need to consider such things as discounts received, special services accompanying purchases, and sources of supply. Our estimates of changes in costs could be more easily made if we had additional price data for most of the commonly used pesticides. I believe some of this information might be obtained by writing to State extension services and by getting suggested list prices from pesticide retailers.

Demand and Supply Functions

Because of changes in quantities of food and fiber produced when pesticides are restricted or banned, estimates of price elasticity of demand are particularly important in evaluating consequences. The varying price elasticities associated with different uses of the same product further complicate such an evaluation. For example, elasticities of demand related to food products are generally low. Those for feed products are higher, and those for exports are still higher. We may need to think in terms of applying the elasticities related to exports and imports for both larger and smaller supplies of individual farm products resulting from restricting or banning the use of pesticides. We also need to consider cross elasticities when they are important.

Movements along the supply function are easily understood, but there is only limited information on the initial specifications of these functions. Also, shifts in supply functions from restricting or banning pesticides or for that matter any other farm input are readily described but difficult to quantify.

Any additional information related to supply curves and changes in supply curves would be useful in providing better estimates of restricting or banning pesticides.

Effects of Alternative Farm Programs

In analyzing the effects of alternative farm programs, it is important to think in terms of current programs and feasible alternative programs. Farm programs are particularly important in evaluating changes in the supply curve and their effects on price.

EVALUATING THE ECONOMIC CONSEQUENCES OF BANNING OR RESTRICTING THE USE OF PESTICIDES IN CROP PRODUCTION

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INTRODUCTION

Pesticides have become an increasingly important tool to control pests in the United States. Pesticides are now an integral part of the production process that has evolved with increased specialization and more intensive farming. Their use in farm production and in nonfarm activities is now part of our way of life.

Because of possible hazards to man's health and the environment, the use of some pesticides is restricted and others are being considered for restriction. Any limitation on pesticide use requires an evaluation of the consequences to farmers and other members of society. The costs of restricting the use of pesticides must be estimated and the distribution of these costs to different segments of society determined.

The purpose of this paper is twofold. First, it summarizes recent research efforts by the U.S. Department of Agriculture that attempt to measure the economic consequences of restricting pesticides. Second, it points out the importance of underlying assumptions in assessing the costs of restriction.

In 1969-70 three reports prepared by the Department evaluated curbs on pesticide use. 1/ These reports focused on how restrictions on the use of organochlorine insecticides and phenoxy herbicides would affect the U.S. farm economy. They were prepared to provide policymakers with estimated aggregate costs of restricting the use of these important pesticides.

1/ Davis, Velmar W., Fox, Austin S., Jenkins, Robert P., and Andrilenas, Paul A.
1970. Economic Consequences of Restricting the Use of Organochlorine Insecticides on Cotton, Corn, Peanuts, and Tobacco. U.S. Dept. Agr., Agr. Econ. Rpt. No. 178. March.
Fox, Austin S., Jenkins, Robert P., Andrilenas, Paul A., Holstun, John T. Jr., and Klingman, Dayton L.
1970. Restricting the Use of Phenoxy Herbicides--Costs to Farmers. U.S. Dept. Agr., Agr. Econ. Rpt. No. 194. Nov.
Fox, Austin S., Jenkins, Robert P., Holstun, John T., and Klingman, Dayton L.
1971. Restricting the Use of 2,4,5-T: Costs to Domestic Users. U.S. Dept. Agr., Agr. Econ. Rpt. No. 199. March.

These studies first summarize trends in the production and utilization of the banned or restricted pesticides and examines their use in farming. Second, possible alternative weed or insect control practices are briefly discussed. Third, the economic effects of substituting these alternatives are estimated.

The reports do not evaluate losses that may occur from crops affected indirectly by pesticides. Nor do they assess social or environmental costs or benefits.

The report on banning 2, 4, 5-T differs from the other two studies by including changes in costs of banning 2, 4, 5-T for both farm and nonfarm uses. It also assumes that all users, farm and nonfarm, would bear the entire burden of restricting use of the phenoxy herbicides through higher costs.

In developing cost estimates, weed specialists, entomologists, and economists evaluated the necessary physical changes in production practices to adjust to a restriction or ban. Weed specialists and entomologists determined the substitute pesticides and substitute cultural practices that are available to replace the organochlorine insecticides or phenoxy herbicides. They also identified which uses of the organochlorines or phenoxys had no suitable substitutes. In these situations they estimated the yield loss caused by inadequate pest control.

Economists estimated the costs of using pesticides and cultural practices that were substituted for organochlorine insecticides or phenoxy herbicides. If suitable substitutes were not available, the value of production lost because of inadequate pest control was estimated. Changes in costs of using substitute pesticides and cultural practices, together with losses in income because of reduced yields, were aggregated into overall costs to farmers and nonfarm users of pesticides--whichever was appropriate.

RESTRICTING THE USE OF ORGANOCHLORINE INSECTICIDES ON COTTON, CORN, PEANUTS, AND TOBACCO

The analysis of organochlorine use identifies the possible alternatives to the organochlorine insecticides and discusses the extent that shifts to such alternatives have already occurred. It concludes with an estimate of the economic effect on U.S. farmers of restricting the use of organochlorine insecticides on cotton, corn, peanuts, and tobacco in 1966.

Basic Assumptions

In the analysis, restriction is viewed as a means of reducing, not banning, the use of organochlorines by farmers. Restriction was further interpreted to mean the substitution of other insecticides for the organochlorines to the maximum that would still provide effective control and maintain production at reasonable costs.

The major alternative for maintaining production was the substitution of the organophosphorus and carbamate insecticides for the organochlorines.

However, for a few insects we have no effective substitutes for the organochlorine insecticides. For corn, substitutes are not available for the control of wireworms and white grubs. For cotton, substitutes need to be supplemented with organochlorines for effective control.

Conclusions

More than three-fourths of the 72 million pounds of organochlorine insecticides used by farmers in 1966 on cotton, corn, peanuts, and tobacco could have been replaced by other chemicals without affecting production. However, costs for insect control on the four crops would have been increased $2.23 an acre treated, a total of $27 million. This was about 0.3 percent of their 1966 farm value.

To replace 55 million pounds of organochlorines, mainly toxaphene, DDT, and aldrin, used on the four crops in 1966, 42 million pounds of organophosphorus and carbamate insecticides would have been needed. The principal chemicals that would have been substituted in 1966 were methyl parathion, diazinon, and carbaryl. For effective insect control on cotton and corn, an additional 17 million pounds of organochlorines would have been needed. On cotton, some of the substitute chemicals would have needed supplementation, while on corn the organochlorines were the only effective insecticides for certain insects. For individual crops, estimates of additional costs, and quantities of insecticides which would have been replaced, still needed, or substituted in 1966 are shown in table 1.

Table 1.--Selective restriction of organochlorines, by crops, 1966

Crop	Farm value	Additional costs		Quantity of--		
				Organochlorines		Substitutes used 1/
		Total	Per acre treated	Replaced	Still needed	
	Million dollars	Million dollars	Dollars	Million pounds	Million pounds	Million pounds
Cotton	1,258	15.4	3.12	43.1	6.6	29.5
Corn	5,106	7.3	1.23	5.4	10.8	6.3
Peanuts	272	1.4	2.90	3.3	---	2.0
Tobacco	1,253	2.6	4.22	3.1	---	4.1
All crops	7,889	26.7	2.23	54.9	17.4	41.9

1/ Organophosphorus and carbamate insecticides.

Costs of replacing the organochlorines on cotton, corn, peanuts and tobacco for 1966 are considered by the authors to represent a maximum for the foreseeable future. Between 1966 and 1969, the trend in the substitution of organophosphorus and carbamate insecticides for the organochlorines on the four crops continued, but at different rates. The reduction in the use of organochlorines has been caused primarily by widespread insect resistance and the availability of new, more effective chemicals. In 1966, the Department discontinued recommendations for some organochlorines on these crops. The acreages of corn, peanuts, and tobacco also declined from 1966 to 1969, but acreage of cotton increased. After examining the trends in insecticides and changes in acreages for the four crops, USDA economists estimated that the cost of restricting the use of organochlorines in 1969 would have been about 18 percent less than in 1966--$22 million compared with $27 million. The reductions in additional costs from 1966 to 1969 were $2.5 million for corn, $0.9 million each for peanuts and tobacco, and $0.6 million for cotton.

ECONOMIC CONSEQUENCES OF BANNING THE FARM USE OF PHENOXY HERBICIDES

This analysis gives estimates of losses to farmers from banning all phenoxy herbicides used on crops and grazing lands. It does not consider such noncrop farm uses as treating fence rows, ditches, yards, gardens, and aquatic sites. The results probably represent current, 1969-70, economic consequences of banning these phenoxys.

Basic Assumptions

A basic assumption of the analysis was that the current level of production of all farm commodities would be maintained. To maintain production, we considered the most economical alternative herbicides and cultural practices to the phenoxy herbicides. For some crops, current yields could not be maintained on all the acreage without the phenoxys, so additional land was brought into production. This additional land was assumed to be available from the pool of about 55 million acres of cropland currently diverted from production under various Government programs. This analysis assumes that farmers would bear the entire burden of restricting phenoxy herbicides through higher production costs while maintaining constant production.

Alternatives for Maintaining Production

There are no perfect alternatives for the phenoxys. However, other herbicides and certain cultural techniques control some of the same weeds.

The role of the phenoxys in weed and brush control is complex. The land area protected greatly exceeds that treated in any year because the phenoxys are so frequently a part of integrated systems in which yearly applications are not necessary. If, however, the treatments or satisfactory alternatives were not applied when needed, the specific weeds controlled by the phenoxys would in crease rapidly, and yearly treatments would soon become necessary.

Dicamba probably is the best replacement for phenoxy herbicides in many situations. It is better than phenoxys for control of certain broadleaf weeds. It is effectively used and currently recommended over the phenoxys for control of these weeds in small grains. For many other broadleaf weeds and brush (such as wild mustard, curly dock, milkweeds, Russian knapweed, field bindweed, many species of oak, and mesquite), it is not a satisfactory alternative. Low crop tolerance, hazards from drift and persistence, and higher costs limit the usefulness of dicamba in certain other field crops and grazing land situations.

Postemergence treatments with such herbicides as atrazine, atrazine in oil-water emulsion, linuron, diuron, and chloroxuron, also control many species of weeds controlled by the phenoxy herbicides. Such postemergence treatments can be considered better alternatives than similar preemergence treatments. Postemergence treatments with one or more of these herbicides can be used on corn, sorghum, sugarcane, soybeans, and grass and legume crops grown for seed. Little or no use could be made of these treatments on grazing lands, rice, wheat, or other small grains. Almost without exception, none of these alternatives are effective if the weeds are much beyond the seedling stage when treated. Many of these alternative herbicides are also applied as preemergence treatments. In making preemergence and additional postemergence treatments, restrictions must be observed to avoid exceeding the total amount that can be used safely and legally within one crop season.

Postemergence treatments with some other herbicides such as propanil on rice, or bromoxynil on small grains, are useful for control of certain weeds in the named crops. These herbicides, however, fail to check many broadleaf weeds controlled by the phenoxy herbicides.

Many organic herbicides such as picloram, prometone, diuron, and others, and several inorganic herbicides such as sodium chlorate or borates can be used at high rates to destroy all plantlife in noncrop areas. In this sense, they check the weeds controlled by the phenoxy group, but are not considered as satisfactory alternates because of their possible adverse effects on the environment.

Some of the alternative herbicides, although they may be considered satisfactory, are less desirable because of their effect on crop production. For example barley has much less tolerance for dicamba than for 2, 4-D.

Cultivation and other types of mechanical control are possible alternatives to phenoxy herbicides in some situations. Additional cultivation of interrow spaces after emergence of crops, additional tillage before planting of crops; chain-dragging and bulldozing of brush, killing weeds with flame, and intensive fallowing over long periods of time (1 to 3 years) are examples.

Conclusions

Banning the use of 43 million pounds of phenoxy herbicides, primarily 2, 4-D and 2, 4, 5-T, on 62 million acres of crops would increase farmers' direct production costs about $290 million. This is about 1.5 percent of the farm value of all crops and 6.6 percent of farm value of crops treated. It is an increase in cost of $6.30 per acre treated with phenoxys. The impact would be much more severe for some crops and individual farmers than for others. Besides these losses, farmers would use about 20 million more hours of operator and family labor.

Dicamba could be used as an alternative herbicide on about half of the acres of corn, wheat, other small grain, and sorghum treated with phenoxy herbicides. On the remaining acreage of corn and sorghum, other herbicides could be used along with some additional cultivations and spot treatments or hoeing.

On all the remaining acres that would be treated with phenoxy herbicides, an alternative is additional cultural practices. Generally, where yields cannot be maintained by alternative herbicides and cultural practices at reasonable costs, more of the crop could be grown. For rice, the crop rotation is changed to control most weeds, and additional acreages are planted to offset losses.

Herbicides substituted for phenoxys increase farm costs $61 million. Added cultural practices on land now being treated with phenoxy herbicides increase costs $138 million. Additional variable costs for producing some of these crops on diverted acres increase costs $91 million. Over 5.7 million additional acres are needed to offset yield losses.

For individual crops, estimates of additional costs to farmers are shown in table 2.

Table 2.--Total restriction of phenoxy herbicides, by crops, 1966

Crop	Costs of restricting phenoxy herbicide use				
	Reduced materials and application	Substitute herbicides and application	Additional cultural practices	Production on additional acres	Net additional costs
	Million dollars				
Corn	-37.0	122.5	21.2	---	106.7
Wheat	-21.9	15.3	12.1	45.0	50.5
Other small grain	-14.6	10.9	9.1	23.1	28.5
Sorghum	-5.6	14.5	2.4	---	11.3
Rice	-0.4	---	1/6.4	1.6	7.6
Other crops	-5.4	---	---	21.3	15.9
Pasture and range	-17.6	---	86.4	---	68.8
All crops	-102.5	163.2	137.6	91.0	289.3

1/ Includes $2.2 million for lower income from loss in quality.

ECONOMIC IMPACT ON DOMESTIC USERS OF BANNING 2, 4, 5-T

The study on banning 2, 4, 5-T focuses only on changes in costs to the users. It evaluates the economic consequences to all U.S. users--farmers, utility companies, and others--of banning the use of 2, 4, 5-T.

Basic Assumptions

Costs for 1969 were estimated for two different sets of assumptions: (1) all other registered herbicides believed to be effective were considered available as substitutes for 2, 4, 5-T; and (2) no other phenoxy herbicides could be used as substitutes for 2, 4, 5-T.

Other important assumptions of the analysis were that the current level of farm production would be maintained and that weeds and brush on noncropland (both farm and nonfarm) would be controlled at present levels. Production would be maintained by substituting mechanical and cultural practices, as well as herbicides, for 2, 4, 5-T.

Alternatives for Maintaining Production

There are several chemical and other alternatives for 2, 4, 5-T, but all increase the cost of weed and brush control on grazing lands and on crop and noncrop areas. While it is the best general-purpose herbicide, there are others that will control some of the same woody plants and herbaceous weeds. Some of these are chemical relatives such as 2, 4-D, MCPA, dichlorprop, and silvex. Other partial alternatives for some uses include picloram and dicamba, and some inorganic compounds as well as other organic materials. However, some of these alternatives are not registered for use on feed or food crops, and do not control the same large number of woody plants and herbaceous weeds as 2, 4, 5-T. Because some reported uses were not registered in 1964 and have not been registered to date, they are not considered as usable alternatives in this report.

For many years, 2, 4, 5-T has been recognized as the most effective registered herbicide for brush on grazing lands. Even so, it does not completely control most brush. Because of this and because of the vast acreages infested with brush on rangelands, major herbicide companies have attempted to develop more effective chemicals. In the last 20 years, however, few herbicides have been registered for use on grazing lands, and none have been as effective as 2, 4, 5-T.

The major nonchemical alternative methods of maintaining farm production and controlling brush on nonfarmland involve other cultural practices and mechanical brush removal. On pasture and rangeland, periodic bulldozing, seeding, and reseeding coupled with annual mowing give reasonably effective control for brush and weeds. For rights-of-way, hand-cutting is the only effective nonchemical alternative, but is much more expensive than using 2, 4, 5-T. For weeds in aquatic areas, no mechanical controls are completely satisfactory.

Use of additional acres is particularly applicable for small grains, rice, and sugarcane. In this analysis, additional cropland from diverted acreage programs is assumed to be available where needed.

Conclusions

Table 3 shows estimated additional costs of restricting the use of phenoxy herbicides.

Table 3.--Costs of selected and total restriction of phenoxy herbicides, by farm and nonfarm use, 1964

Use	Costs of restricting phenoxy herbicide use	
	Only 2,4,5-T banned	All phenoxys banned
	1,000 dollars	
Farm	31,935	44,084
Nonfarm	19,737	127,858
Total, all uses	51,672	171,942

Under the first assumption, 2, 4, 5-T was the only phenoxy herbicide banned for domestic use. Some species of weeds and brush can be controlled by such closely related materials as 2, 4-D, silvex, dichlorprop, and MCPA. These registered herbicides could be used as substitutes on nearly 5.6 million acres of a total of 7.9 million acres treated with 2, 4, 5-T. On the average, costs of additional cultural practices for farmers and nonfarmers would have been about $16 an acre or over 39 percent of the acres treated with 2, 4, 5-T in 1969.

Without 2, 4, 5-T, a major problem exists on rangeland where some brush species could not be controlled with silvex, 2, 4-D, or other phenoxys. Most of this land must receive cultural treatment even if other phenoxys are available. For uses other than grazing land, several herbicides are registered and meet the required needs, but they usually cost somewhat more than 2, 4, 5-T.

Under the second assumption, when no other phenoxys could substitute for 2, 4, 5-T, alternative herbicides such as dicamba, atrazine, and picloram might be used on about 3.5 million acres of a total of 7.9 million acres. However, to maintain production on farms and to control weeds and brush on nonfarmland, mechanical and cultural practices and additional cropland would be substituted for 2, 4, 5-T. Costs would increase to $172 million, about four times the cost of using 2, 4, 5-T. The farmers' share of this cost increase would be $44 million and the nonfarm users', about $129 million. Costs of additional cultural practices would be about $22 an acre for about 73 percent of the acreage treated with phenoxys.

IMPORTANCE OF ASSUMPTIONS

In the three analyses just discussed, as in any analysis, the assumptions used are instrumental in dictating the final results. The assumptions establish the magnitude of the costs and designate who must bear the added costs of restricting the use of pesticides.

Maintaining production--an assumption applicable to the three analyses--limited the scope of the alternatives available. In the report "Economic Consequences of Restricting the Use of Organochlorine Insecticides on Corn, Cotton, Peanuts, and Tobacco," production was maintained by substituting organophosphorus and carbamate insecticides for about 75 percent of the organochlorines used on these four crops. In the analyses that estimated the cost of banning the phenoxy herbicides, farmers were to maintain production by using one or more of the following alternatives: (1) substitute other herbicides for the phenoxy herbicides, (2) switch to other cultural practices--additional cultivations, crop rotation, etc.--or (3) plant more acres.

The need to maintain production forced alternatives into the analyses that charged farmers with all of the costs of restricting or banning the use of pesticides. The maintenance of production prevented the evaluation of one of the farmers' most important adjustments--letting production decline and prices react to a change in supply.

In certain situations the maintenance of production may be the best alternative for the farmer. If so, the assumption is valid and should be used. However, other more profitable adjustments may be open if pesticide use is banned or restricted. If so, the assumption to maintain production should be modified.

Substitute Pesticides

If a pesticide is banned or restricted and a suitable substitute is available, farmers would probably use the substitute pesticide, maintain production, and absorb the additional cost of the pesticide.

Returns from using an effective pesticide are usually high in relation to the cost of the pesticide. For example, banning the use of phenoxy herbicides without substituting an effective weed control practice in their place would reduce estimated average yields of wheat and small grains by 30 percent on weed infested acres. For wheat farmers the average loss in income is estimated at $11.50 per acre, but the cost of applying the substitute herbicide--dicamba--is only $2.18 per acre. The cost of dicamba compared with the value of production lost would certainly encourage farmers to use dicamba and obtain production valued at $11.50 per acre.

Substitute Cultural Practices

Effective substitute pesticides are not always available. Pesticides, other than the one banned, may control the same pests as the banned pesticide, but the infested crop may be damaged by the alternative pesticide. Therefore, other cultural practices must be used to control pests and maintain production.

This is especially true of herbicides. A substitute herbicide may control a specific weed pest, but the crop that is infested may be damaged by this herbicide. Consequently, changes in crop rotations, more cultivations, and even hand weeding are used in lieu of an effective substitute herbicide.

If the costs of substitute cultural practices are relatively low, farmers would adopt the cultural practice, maintain production, and absorb the cost. However, inexpensive cultural practices that require more labor may not be acceptable to some farmers.

To reduce labor required in crop production, farmers have recombined their production inputs. Labor shortages have encouraged farmers to substitute mechanization, herbicides, and other inputs for labor. Additional cultivations and particularly hand weeding to control weeds would reverse this trend in labor use.

Unless the loss in yield because of inadequate pest control is substantial, farmers may accept a loss in yield--at least in those years immediately following a pesticide ban. It is doubtful whether some farmers would recruit the seasonal labor necessary to control certain pests.

Planting Additional Acres

The best interests of farmers may not be always served by planting more acres to maintain production. When a pesticide is banned or restricted and adequate substitutes are not available, the reduction in yield because of inadequate pest control may be advantageous to the farmer. Farmers may be better off to let production decline and let prices adjust to the reduced supply. Because demand for most farm products is inelastic, prices rise relatively more than output falls when there is a decline in production. Farmers, therefore, can increase their total returns by letting production decline and letting prices increase in response to the reduced supply.

But price reaction to a reduced supply may be slow in coming for crops plagued by surpluses. For these crops, ineffective pest control coupled with certain policy decisions may be an effective means to reduce surpluses. Government programs may be more important than a reduced supply in determining how a ban or restriction on pesticide use affects prices of farm products.

Wheat was chosen to illustrate changes in costs and returns to farmers that result from a change in assumptions. The assumptions of the report "Restricting the Use of Phenoxy Herbicides--Costs to Farmers" were modified to reflect situations where Government program payments are not maintained, where production is allowed to decline with no change in wheat prices, and where prices are allowed to react to a reduced supply. The impact of these modifications on costs and returns to farmers is given in table 4.

Assumption sets A, B, C, and D that are used as a basis for calculating the results presented in table 4, are defined as follows:

Table 4.--Net changes in costs and returns to farmers resulting from a ban on phenoxy herbicides used in wheat production, United States

Assumption set	Net changes								
	Costs							Returns	
	Reduced materials and application 1/	Substitute herbicides and application	Additional cultural practices	Production on additional acres	Lower diverted acre payments	Loss in income because of reduced yields	Net additional costs	Gains in income from price increase	Net additional income
	Million dollars								
A	-21.9	15.3	12.1	45.0	50.7	---	101.2	---	---
B	-21.9	15.3	12.1	45.0	2/	---	50.5	---	---
C	-21.9	15.3	12.1	3/	2/	4/86.8	92.3	---	---
D	-21.9	15.3	12.1	3/	2/	---	5.5	148.6	5/143.1

1/ Expenditures formerly made for phenoxy herbicides and their application.
2/ Farmers receive the same amount in diverted acre payments as they did before the phenoxy herbicides were banned.
3/ No additional acres were planted to maintain production.
4/ Yields decline 30 percent on 7.6 million acres because of ineffective weed control. Production declines 55.3 million bushels. An average price, $1.57 per bushel, is used to calculate loss in income.
5/ Net gain in income because of price increase less additional net costs. Assumes a price elasticity of -.33. Demand elasticities are based on estimates provided by USDA's commodity specialists.

A. Farmers maintain production by planting additional acres, but Government payments are reduced when additional acres are planted.

B. Assumptions are those used in the report "Restricting the Use of Phenoxy Herbicides--Costs to Farmers" (see footnote 1).

C. Farmers do not plant additional acres to maintain production. Government payments and prices do not change.

D. Farmers do not plant additional acres to maintain production. Government payments do not change. Prices are allowed to react to a reduced supply.

Assumption set A represents, possibly, the most costly set of circumstances faced by wheat producers that results from action taken to ban the use of phenoxy herbicides.

Farmers will maintain production by using substitute herbicides and additional cultural practices where these practices are applicable as an effective method of weed control. Where they are not, additional acres of wheat will be planted to offset yield losses. Farmers will also forego any diverted acre payments on any additional acres of wheat planted to maintain production. Given the above assumptions the banning of the phenoxy herbicides would cost farmers $101.2 million (table 4).

Assumption set B reflects the costs calculated under the author's assumptions. It illustrates the importance of Government payments in reducing the impact of a ban. If diverted acre payments are maintained on the additional acres planted, the cost of the ban to farmers is reduced by more than 50 percent. Their costs are reduced by $50.7 million--the amount received in diverted acre payments.

Although the intent of planting more acres is to maintain production, in the long run production may decline. The total returns from the acres on which yields decline, because of inadequate weed control, may be less than the total cost of producing a crop. If the returns to the farmer do not cover both the variable and fixed costs, farmers must make an adjustment. Inefficient producers will be forced out and production will either decline or shift to areas where effective weed control is possible.

This relationship of total cost to total returns illustrates the importance of another assumption--the amount that yields are reduced because of inadequate pest control. The higher the yield loss from inadequate pest control, the greater the economic pressure on the farmer to let production decline in the short and long run.

Assumption set C depicts the situation in which existing surpluses would offset any reduction in supply because of a decline in yields. Existing surpluses would prevent an increase in price. During the interim period when surpluses are being reduced, farmers would have their income decline because of smaller per acre yields.

Such a possibility would exist if Government programs are used to reduce excess supplies. Acreage restrictions could be used to prevent another build-up in surplus. Diverted acre payments would be maintained and the decline in production, caused by the banning of the phenoxy herbicides, would be used to help reduce surpluses.

Letting production decline without an upward adjustment in price would cost wheat farmers $8.9 million less than the $101.2 million cost of maintaining production. A 30-percent loss in yield on 7.6 million acres reduced their income by $86.8 million. Additional costs of using substitute herbicides and cultural practices add another $5.5 million to costs to increase total out-of-pocket costs to $92.3 million.

Assumption set D reflects the situation where prices can react to a reduced supply. The decline in wheat production because of a loss in yield was estimated at 55.3 million bushels or 4 percent of the total production. Assuming a price elasticity of -.33, prices increased 12 percent. Gross earnings of farmers increased by $149 million and net income increased by $143 million.

Allowing production to decline shifted most of the cost of banning the phenoxy herbicides from the farmer to the consumer. If production is to be maintained by planting additional acres, the ban on phenoxys would cost wheat farmers an additional $40.5 million to plant these acres. If these farmers allowed production to decline by not planting additional acres their costs would increase $5.5 million, but gross income would increase $149 million and net income $143 million. Consumers would absorb the price increase by paying farmers an additional $149 million for their production.

The situation depicted in D lacks stability. Unless production controls are used, an increase in price would encourage farmers to produce more wheat. Their increased production would cause wheat prices to decline, and the decline in price could again shift the cost of banning the phenoxy herbicides from the consumer to the farmer.

At the new equilibrium price, farmers may again absorb all or part of the cost of banning. The closer the new equilibrium price is to the price of wheat before the banning occurred, the greater the costs to the farmer compared with the costs to the consumer.

The increase in farmers' income, because of the price rise, provides an opportunity for additional flexibility in the administration of Government programs. Further adjustments are possible to transfer the cost of banning herbicides from one segment of our society to another. Part of the $149 million cost to consumers can be transferred back to farmers by reducing Government payments to farmers. Adjustments in Government payments to farmers could be used as a method to make farmers and consumers share equally the cost of banning phenoxy herbicides.

Selective Restriction

Selective restriction is another important aspect of estimating the costs of restricting the use of pesticides. When restriction is viewed as a means of reducing, not banning, the use of a pesticide the costs of a restriction in the use of a pesticide are materially reduced.

In certain uses the alternatives to using a restricted pesticide are very costly. If an effective substitute pesticide or cultural practice is very costly or is not available, the costs of selective restriction are less than the costs of a complete ban.

For example, a selective use restriction on organochlorine insecticides substantially reduced the cost of restricting the use of these insecticides on cotton, corn, peanuts, and tobacco. Organophosphorus and carbamate insecticides were substituted for only 75 percent of the organochlorine insecticides used on these crops. The partial restriction cost farmers $27 million--much less than the costs of a complete ban.

Given the assumption that production will be maintained, costs were reduced substantially by allowing cotton producers to continue to use 4 million pounds of toxaphene and 2 million pounds of DDT. Without them farmers would have suffered losses in income because of reduced yields.

A similar situation exists in corn production. Wireworm and white grub infestations in corn cannot be controlled as effectively by insecticides other than the organochlorines. Here again, as in cotton production, yields could not be maintained without using organochlorine insecticides.

ECONOMIC EXTERNALITIES IN THE FARM USE OF PESTICIDES AND AN EVALUATION OF ALTERNATIVE POLICIES

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In late 1966 we submitted a research proposal to Resources for the Future, Inc., Washington, D.C. for a study on the following problem: "What can be done with the present state of the arts to determine the optimum quantity of agricultural pesticides to use from a social welfare perspective for some geographic region."1/ My purpose here today is to outline briefly our research and resulting conclusions. But before doing so I would like to make a few comments to the noneconomists in the group, for in a few moments I will be using some economic terms and mathematical functions with which you may not be familiar. Therefore these preliminary comments are designed to give you some initial "feel" for the research method we used.

If we as a society decide to regulate the use of pesticides, then presumably we must feel that the value of doing so is greater than the value of not doing so; i.e., the overall benefits of regulating outweigh the costs to society. If I had to describe our research in one simple sentence, I would say that we tried to do a benefit-cost analysis of agricultural pesticide usage in Dade County, Florida.

Benefits and costs from pesticide usage could conceptually be broken into two categories--those internal to the farming industry and those external to that industry. A benefit or cost is internal if it is reflected in the demand or supply functions for the product, otherwise it is considered to be external. The following are examples:

(1) Internal benefit. If the introduction of pesticides lowers the cost of producing the crop or improves the yield or quality, then there is an internal benefit which is most likely reflected in producers' cost functions for the crops. (There may also be an external benefit, as in example 3.)

(2) Internal cost. The price of the pesticide which farmers must pay is an internal cost, again most likely reflected in the cost functions.

1/ For details of this research see Edwards, W.F., Economic Externalities in the Agricultural Use of Pesticides and an Evaluation of Alternative Policies, unpublished Ph.D thesis, University of Florida, 1969.

(3) External benefits. If the incidence of human disease is reduced through the use of pesticides for agricultural production, these effects are felt in part outside of the growing-consuming activities and constitute external benefits.

(4) External cost. If the environment is damaged through the use of agricultural pesticides, this is an external cost to the extent that it is borne by society.

Since internal benefits and costs are theoretically recognized in the estimation of demand and supply functions, traditional economic theory is adequate to analyze them. But economic theory does not provide an adequate means of empirically analyzing the external benefits and costs, and economists have devoted relatively little study to them through the years. The research on which I am reporting was an effort to measure the benefits and costs, both internal and external, of agricultural pesticide usage and to incorporate them into a measure of social welfare.

In selecting an area of study, we sought out one which was a heavy user of agricultural pesticides, one which offered significant urban-rural interaction, one which was relatively isolated physically, and one where there was some interest and perhaps research on pesticide usage. After considering three areas in Florida, we finally chose Dade County which seemed to have the best combination of characteristics. Dade County occupies the southern tip of Florida, including most of the city of Miami. It is bounded on the east by the Atlantic Ocean, on the west by the Everglades Swamp and the Gulf of Mexico, and on the south by the Florida and Biscayne Bays. The population of Dade County is more than a million and is growing rapidly. There is considerable opportunity for urban-rural interaction and conflict as the metropolitan area around Miami encroaches upon the agricultural interests in the southern part of Dade County. The climate in Dade County is subtropical and it seldom freezes. Farmers in the area grow many winter vegetables and fruits for northern markets. Farm operations tend to be very large and very high-risk ventures. The soils of Dade County are basically two types--Marl and Rockland. The Marl is a claylike composition on which the farmers grow mainly corn and potatoes. The Rockland, as the name implies, is almost solid rock. Farmers use large caterpillar tractors to plow or "chisel" this rock into fine gravel. They then plant their crop directly into this fine gravel. The main crops grown on Rockland are tomatoes, beans, and squash. It is necessary to fertilize and irrigate the Rockland soil extensively. Fruits--mainly avocados, limes, mangos, and papayas--are also grown on Rockland.

Our research study was limited to the eight major crops grown in Dade County. These are tomatoes, potatoes, beans, corn, squash, avocados, limes, and mangos. All together these eight crops account for approximately 85 percent of the agricultural output of the County. The remaining farm output is made up by approximately 14 crops and some livestock, dairy, and poultry operations.

It was necessary to limit our study another way. Rather than evaluating all possible pesticide usage policies, it was decided to concern ourselves with two alternative policies. The first, essentially a no-regulation policy, leaves current practices the way they are. The second policy is to reduce the usage of chlorinated hydrocarbons 50 percent per acre on all crops and to increase the usage of organic phosphates in order to maintain crop quality and yield.

Most of the controversy in the pesticide issue seems to center around these two categories. The chlorinated hydrocarbons are, by and large, those pesticides most persistent in the environment while the organic phosphates tend to be relatively nonpersistent, although they may be more toxic. Ecologists and conservationists favor a substitution of the less persistent pesticides for the more persistent ones. This is also the goal recommended by the President's Science Advisory Committee on pesticide usage.

The model which we used required a substitution rate between chlorinated hydrocarbons and organic phosphates. However, there was no way to empirically observe the region's substitution rate. Therefore a reasonable substitution rate was deduced through consultation with entomologists and growers in the area. To maintain crop quality and yield they believe that .3 to .4 pound of organic phosphates would be required to replace 1 pound of chlorinated hydrocarbons. We subsequently ran the model using rates of .3, .4, and .5. There was little difference in the results from using these three rates, so we concluded that this parameter was not crucial to the model and probably would not justify further research expenditure. The results reported here are those corresponding to the middle value, a substitution of .4 pound of organic phosphates per pound of chlorinated hydrocarbons.

Our analytical model employed a measure of welfare consisting of consumers' plus producers' surplus, modified for observable externalities neglected in the surplus calculation. For both pesticide usage policies, the model maximized this measure of welfare over production for eight major crops in Dade County. Finally, the policies were ranked by their maxima. The model can be stated in general terms as follows:2/

2/ In an earlier specification of the model, flexibility constraints were applied to the acreage of each crop in an effort to recognize the many factors--economic, technological, institutional, and sociological--that discourage large deviations from past cropping patterns. For the jth crop, the maximum and minimum flexibility constraints were specified as:

$$b_j(\max) = \frac{\sum_{t=2}^{m_1} \frac{y_j(t)}{y_j(t-1)}}{m_1} \qquad \text{for } y_j(t) > y_j(t-1)$$

$$b_j(\min) = \frac{\sum_{t=2}^{m_2} \frac{y_j(t)}{y_j(t-1)}}{m_2} \qquad \text{for } y_j(t) \leq y_j(t-1)$$

where m_1 and m_2 are the number of periods respectively. In the model runs these constraints were ineffective on the solution; therefore, we have omitted them from this specification of the model. For a discussion of the concept of a "flexibility constraint," see Henderson, James M., The Utilization of Agricultural Land, A Theoretical and Empirical Inquiry, Review of Economics and Statistics, Vol. XLI, No. 3, August, 1959.

For a set of subjectively chosen pesticide usage policies $(r, r = 1, \ldots, s)$ rank the associated estimates of welfare (W_r) where:

$$W_r = \underset{\substack{y_j \\ z_i}}{\text{maximum:}} \sum_{j=1}^{n} \left[\int_0^{y_j} \left[f_j(y_j) - g_j^r(y_j) \right] dy_j \right]$$

$$- \sum_{i=1}^{m} \left[h_i(z_i) \right] \qquad \begin{array}{l} j = 1, \ldots, n \\ i - 1, \ldots, m \\ r = 1, \ldots, s \end{array}$$

where the maximization for a given policy r is subject to:

[1] $\sum_{j=1}^{n} a_{ij}^{r} \; y_j - a_i = 0$

[2] $c_{ki}(z_i) \leq C_{ki}$ $\qquad k = 1, \ldots, p$

[3] $y_j, \; z_i \geq 0$

and where:

$f_j(y_j)$ = demand function for the jth crop.

y_j = acres of the jth crop.

$g_j^r(y_j)$ = supply function for the jth crop under the rth policy alternative.

$h_i(z_i)$ = an "externality function," a functional relationship between observed external effects expressed in dollars, and the quantity of the ith pesticide.

z_1 = quantity of the ith pesticide measured in pounds of 100 percent active material.

a_{ij}^r = the quantity of the ith pesticide used per acre of the jth crop under the rth policy.

$c_{ki}(z_i)$ = the quantity of the ith pesticide residue produced in the kth environmental element. The residue is assumed to be a function of the quantity of the ith pesticide used in the area, and c_{ki} represents this functional relationship.

C_{ki} = an arbitrary upper limit on the ith pesticide residue in the kth environmental element--a parameter to be determined "politically."

The demand and supply analysis illustrated in the objective function as:

$$\sum_{j=1}^{n} \left[\int_0^{y_j} \left[f_j(y_j) - g_j^r(y_j) \right] dy_j \right]$$

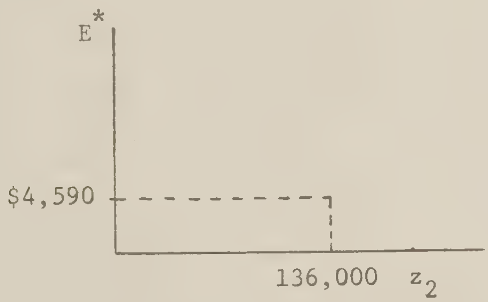
represents the analysis of internal effects. Since this is fairly traditional economic methodology, I propose to devote our limited time to a discussion of the other features of the model which are somewhat more unique and probably of greater interest to ecologists and conservationists.

The externality function was a source of considerable work and consternation on our part. The function we conceptualized was as follows:

$$E = h_1(z_1) + h_2(z_2)$$

where: E = a dollar measure of externalities, z_1 = pounds of chlorinated hydrocarbons, and z_2 = pounds of organic phosphates.

Data were not available on the z_1 (chlorinated hydrocarbon) portion of this function, and it was necessary for us to rely on sensitivity analysis to examine its effect on the objective function. We were able to gather data on the z_2 portion of this function. Our major sources for these data were veterinarians, insurance companies, growers, medical doctors, and biologists at the Everglades National Park, and the Audubon Society. The organic phosphate portion of the externality function can be illustrated by the following graph, where E^* is a part of E:



Our estimate of the externalities due to organic phosphates represented one point on this function. Since we did not have cross sectional or time series data on either externalities or the usage of organic phosphates we were unable to empirically estimate the shape of this function. Therefore, the following alternative shapes were assumed:

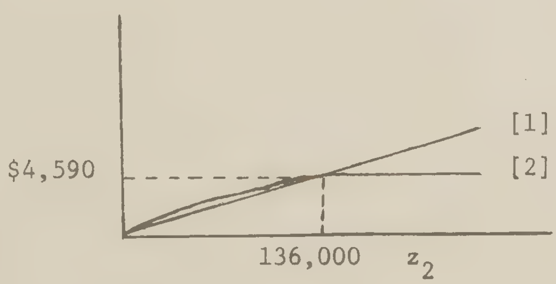
1 $\quad E = \phi z_1 + \theta z_2$

where: $\phi = 0, 1, \ldots, 5$

$\theta = 0, .0337, 1, 2, \ldots, 5$

2 $\quad E = \phi z_1 + z_2^{.708}$

where: $\phi = 0, 1, \ldots, 5$



Now consider the constraints on the objective function. The first constraint, $\sum_{j=1}^{n} a_i y_j - z_j = 0$, is simply a balance equation which insures that the quantity of the ith pesticide called for in the objective function will be exhausted over the crops in the model. The second constraint, $c_{ki}(z_i) \leq C_{ki}$, is one of the unique conceptual features of the model, but again we were frustrated in our attempts to identify it empirically. We called it an environmental constraint and it says, "the residue of pesticide i in the kth environmental element shall not be allowed to exceed C." C is a politically determined value representing a sort of group consensus. This constraint is important because it conceptually allows us to consider within the model those externalities which cannot be valued in monetary terms.

The third constraint, y_j, $z_i \leq 0$, simply prohibits the model from coming up with negative values for the solution variables.

Tables 1 and 2 contain the two solutions to the model corresponding to the first externality function. I would like to point out three conclusions that might be drawn from these tables:

(1) As we look at the changing coefficients in the externality function, it is clear that according to this model externalities would have to increase to many times their observed levels before the solution acreages would change.

(2) Nevertheless, Policy 2 could be implemented with less than a 1-percent decrease in the net social welfare (as defined) of the crops studied. This is seen by comparing Policy 1 with Policy 2 for observed externality levels, i.e., z_1 coefficient of 0 and z_2 coefficient of .0337.

(3) Sensitivity analysis on the coefficient of z_1 revealed that somewhere between a z_1 coefficient of 3.0 and 4.0 society's optimum strategy would shift to Policy 2. In other words, if the environmental damage from a pound of chlorinated hydrocarbons was between \$3 and \$4, society's optimum strategy would be to shift to Policy 2.

This concludes a summary of our research. We will publish several articles in the near future. A research monograph detailing our work will be prepared for Resources for the Future, Inc. Max Langham, your next speaker, will talk about the possibility of applying a similar model on a more aggregative basis such as at the U.S. level. Thank you.

Table 1.--Computer results for Solution Set 1, Policy 1

Solution vector coefficient of-- z_1	z_2	Objective function	y_1 Tomatoes 1/	y_2 Potatoes 1/	y_3 Beans 1/	y_4 Corn 2/	y_5 Squash 1/	y_6, y_7, y_8 Groves 1/3/	z_1 Chlorinated hydrocarbons 4/	z_2 Organic phosphates 4/
		Dollars	Acres						Pounds	
0	0	42,803	19,000	7,700	5,800	1,650	3,080	10,340	220,914	133,563
0	1	42,670	19,000	7,600	5,800	1,650	3,080	10,340	220,785	132,975
0	2	42,537	18,900	7,500	5,800	1,650	3,080	10,340	220,050	132,060
0	3	42,405	18,900	7,500	5,800	1,600	3,080	10,340	218,015	131,737
0	4	42,274	18,800	7,400	5,800	1,600	3,080	10,340	217,279	130,821
0	5	42,143	18,800	7,400	5,800	1,600	3,080	10,340	217,279	130,821
0	.0337	42,798	19,000	7,700	5,800	1,650	3,080	10,340	220,914	133,563
1.	.0337	42,579	18,900	7,600	5,800	1,600	3,080	10,340	218,143	132,325
2.	.0337	42,363	18,800	7,600	5,800	1,500	3,080	10,340	213,466	131,352
3.	.0337	42,151	18,800	7,600	5,800	1,450	3,080	10,340	211,431	131,029
4.	.0337	41,942	18,700	7,600	5,800	1,350	3,080	10,340	206,754	130,056
5.	.0337	41,736	18,700	7,600	5,800	1,300	3,080	10,340	204,719	129,733

1/ Solution differs from optimum by fewer than 100 acres.
2/ Solution differs from optimum by fewer than 50 acres.
3/ Grove acreage is constrained at the 1966-67 level.
4/ All quantities are in pounds of 100 percent concentrated material.

Source: Calculations made by the authors.

Table 2.--Computer results for Solution Set 1, Policy 2

Solution vector coefficient of-- z_1	z_2	Objective function	y_1 Tomatoes 1/	y_2 Potatoes 1/	y_3 Beans 1/	y_4 Corn 2/	y_5 Squash 1/	y_6, y_7, y_8 Groves 1/3/	z_1 Chlorinated hydrocarbons 4/	z_2 Organic phosphates 4/
		Dollars	Acres						Pounds	
0	0	42,418	18,800	7,600	5,800	1,650	3,080	10,340	109,764	176,298
0	1	42,242	18,800	7,500	5,800	1,650	3,080	10,340	109,610	175,683
0	2	42,067	18,700	7,500	5,800	1,600	3,080	10,340	108,379	174,505
0	3	41,893	18,700	7,400	5,800	1,600	3,080	10,340	108,314	173,891
0	4	41,719	18,700	7,400	5,800	1,550	3,080	10,340	107,297	173,161
0	5	41,547	18,600	7,300	5,800	1,550	3,080	10,340	106,929	172,098
0	.0337	42,412	18,800	7,600	5,800	1,650	3,080	10,340	109,764	176,298
1.	.0337	42,302	18,800	7,600	5,800	1,600	3,080	10,340	108,746	175,568
2.	.0337	42,193	18,800	7,600	5,800	1,600	3,080	10,340	108,746	175,568
3.	.0337	42,086	18,700	7,600	5,800	1,550	3,080	10,340	107,425	174,389
4.	.0337	41,979	18,700	7,600	5,800	1,500	3,080	10,340	106,408	173,659
5.	.0337	41,872	18,700	7,600	5,800	1,500	3,080	10,340	106,408	173,659

1/ Solution differs from optimum by fewer than 100 acres.
2/ Solution differs from optimum by fewer than 50 acres.
3/ Grove acreage is constrained at the 1966-67 level.
4/ All quantities are in pounds of 100 percent concentrated material.

Source: Calculations made by the authors.

POTENTIAL FOR APPLYING THE DADE COUNTY PESTICIDE MODEL TO A WIDER GEOGRAPHIC AREA

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INTRODUCTION

To appraise the potential for developing an aggregate welfare model to aid pesticide policy decisions we need to clarify what is expected of the model. If we require the model to provide accurate quantitative measures of welfare under alternative policy decisions, there seems to be very little potential for success, for we do not know how to define welfare, much less measure it. One would be quite pleased if he only knew that his criterion of welfare were a monotonic function of "true" welfare, for then he could use his criterion to rank policy alternatives. But, even this is beyond our present capabilities in theory and measurement.

These opening remarks are indeed discouraging. And it would be very comforting if as a society we could ignore the decision problem. But, of course, we cannot, and it behooves us to try to measure or order the social implications of policy alternatives so that we might obtain some better notions or hypotheses about their consequences. Because of difficulties in such measurement efforts we might ultimately have to appeal to revelations and emotions but I, for one, have faith that attempts at measurement will improve the revelations.

The major problems which must be confronted in developing an aggregate welfare model are, it seems to me, as follows:

(1) Concepts of social welfare are vague and controversial.

(2) The identification of externalities is nebulous.

(3) A sizable portion of the valuation problem is without benefit of market signals.

(4) We have very little definitive information about the environmental input-output relationships.

(5) We have very little definitive information about the substitution relationships between types of pesticides for control of the given pest and between pesticides and nonpesticide inputs.

(6) The time and space dimensions of the problem are complex.

My purpose this afternoon will be to consider the development of an aggregative model of the type used in Dade County, Fla., (1) 1/ and to discuss in a general way the resource requirements of such an effort. I will conclude with a few thoughts on what may be some advantages and disadvantages of such an effort. Perhaps what is said will provide a background for debate.

There is little question in my mind about whether it is possible to develop such a model for the United States. Ours was an aggregative areal model which could be adapted to a larger, more complicated area. It seems that the real questions concern the costs and benefits of such an effort.

THE CONCEPT OF SOCIAL WELFARE

The Dade County model--an areal nonlinear programming one--assumed, among other things, that social welfare was an increasing function of monetary value. The model valued a particular policy by measuring the producers' and consumers' surplus which was obtained from the production and consumption of agricultural products under the policy. This surplus measurement was in turn adjusted for those externalities which were created under the policy, were not included in the surplus calculation, and could be measured on a monetary scale.

We used the concept of producer and consumer surplus to represent welfare mainly because it provided a measure that was empirically operational. There has been considerable professional debate (2, 3, 4, 6, 7, 8) on the validity of consumers' and producers' surplus as a measure of welfare. We do not imply by its use that the measure is universally accepted as a means of evaluating the welfare implications of alternative policies.

The use of producers' and consumers' surplus as a measure of welfare requires some very strong assumptions--particularly about interpersonal comparisons of utility not only among those living today but also between the living and those yet unborn.

The long-run costs and benefits from the use of persistent pesticides accrue to a different set of persons (the source of utility) than those upon which the surplus calculations are based. People consuming and producing today (period t) get all of the benefits in the Dade County model and incur all of the costs--even those that may occur beyond their planning horizon, say in year t+s. If the decision was based on the utilities of people living in year t+s then it would always be best not to use any persistent pesticides in period t for which some negative net returns accrue in period t+s. The problem arises because society which eventually receives all the benefits and incurs all the costs is not a homogeneous entity over time as the model assumes.

1/ Underscored numbers in parentheses refer to References, page 79.

IDENTIFYING EXTERNALITIES

One's measure of welfare provides the basis for identifying externalities. For example, our concern was with those externalities that were not a part of the surplus calculation. One needs to be quite systematic in going about the process of identifying externalities, but it is not a well defined process. It turns out to be a cataloging of past events. Acute effects which create controversy are the easiest to catalog, but with these there may be some question regarding double counting.

> For example, since insurance premiums are a cost of production, one could reason that the costs of an accidental poisoning of an agricultural laborer would be included in computation of producers' surplus. However, insurance companies have no actuarial basis in their policies for accidental poisoning. As a result one could argue that the social cost of accidental poisoning is not reflected in the cost of production and to date has been so minor that it has not been of explicit concern to insurance companies in determining their rate structure. (5, pp. 1196-1197)

We had no success in attempting to determine the long-run chronic effects associated with the amounts of pesticides used. And this is where the ecologists believe the real issue lies. We assumed that since the organic phosphates were nonpersistent long-run effects could be ignored. We used sensitivity analysis to vary the costs of externalities associated with the chlorinated hydrocarbons and found that the solution was not very sensitive to these costs over the range of 0 to $5 per pound of 100 percent active ingredients. This result is somewhat comforting if the external costs are indeed in this range. But even then there remains the conceptual problem, mentioned above, concerning the intertemporal comparison of utility.

Obtaining information on externalities for the U.S. model would be a very difficult task. As a people, we have not made any systematic attempts to observe and record such externalities as animal deaths by probable causes. And the information available is in bits and pieces and not very accessible.

NONMARKET MEASUREMENT

Those externalities which we could measure on a monetary scale entered the objective function directly as a function of the amounts of pesticides (organic phosphates or chlorinated hydrocarbons) used. 2/ In general these externalities were acute external diseconomies which created some controversy. In many cases the dollar measure was subjective because it lacked a market determination.

2/ Externalities as used in this paper refer to benefits and costs accruing to persons other than producers or consumers of the agricultural commodities involved.

Our strategy was to value such externalities in terms of their replacement cost. For example, dogs killed by poison were arbitrarily valued at $50 each. This amount represents an approximate cost of obtaining a replacement dog, but it may be a very poor measure of the petowner's true loss.

ENVIRONMENTAL INPUT-OUTPUT RELATIONSHIPS

Very little is known about the environment as a system--not even about the inputs and outputs of the system. Knowledge of the dynamic microrelationships which make up the cause and effect structure of the system seems to be far away and very expensive to obtain. We abstracted from the physical cause and effect relationships by attempting to determine a mathematical relationship between pesticide inputs and external effects. Our effort was very crude. But it led us to believe that perhaps the best hope of gaining some general understanding of the environmental system will be through macro-simultaneous equation models which treat man's inputs as exogenous and certain variables which represent environmental quality as endogenous--a kind of Brookings' model of the environment. Unfortunately, we are just beginning to record data on inputs and outputs of the environmental system to support such an effort.

In fact, obtaining information on the amounts of pesticides used in Dade County proved to be a large empirical task for us. However, the national pesticide survey would provide these data by regions for a U.S. model. The cost of externalities believed to be associated with the use of pesticides has not been estimated and remains to be done.

I want to stress again the need for greater efforts to observe both the inputs and outputs of the environmental system. We need to begin recording time series data on the amounts of the different kinds of pollutants going into the environment by regions (say counties) and we need more accurate census and demographic information on representative life forms. Such information may not necessarily permit scientists to identify cause and effect relationships in the environment, but it may serve very well to emphasize areas of stress and help set priorities for phenomena needing detailed study.

SUBSTITUTION RELATIONSHIPS AMONG INPUTS

One needs definitive information regarding substitution relationships among types of pesticides and among pesticides and other inputs. This information is needed to synthesize shifts in the supply functions of agricultural commodities, which are likely to result from the adoption of a particular policy. For a given quantity of homogeneous product, a constant marginal rate of substitution was assumed between organic phosphates and chlorinated hydrocarbons over the range of pesticide inputs for the two policies. We did not consider the possibilities of substituting nonpesticide inputs for pesticide inputs and of making adjustments which lead to changes in product quality.

Admitting changes in product quality would be complicated by associated changes in the demand for the product. And it is doubtful if you can substitute nonpesticide inputs for pesticide inputs without some change in product quality--particularly for the types of products we were dealing with in Dade County.

The entomologists were quite cooperative in our work but I would like to see them take more interest in the substitution relationships between different kinds of pesticide controls for a particular pest. Likewise, the agronomists and entomologists should study the possibility of substituting other inputs for pesticides. We found that the entomologists were willing to state that organic phosphates could be substituted for the hydrocarbons up to a 50-percent reduction in the chlorinated hydrocarbons. However, they were not willing to consider further reductions or the possibility of a ban on the chlorinated hydrocarbons. Hopefully, a national effort would permit resources for more definitive information in this area.

TIME DIMENSION

Problems created by the time dimension are paramount and do more to negate the value of a national effort than perhaps any other difficulty. There is no theoretical basis for making interpersonal comparisons of utility in situations involving income redistribution. If the persons living today are able to react to policy decisons which concern them, a government has feedback to help guide policy. If, on the other hand, a government makes decisions today, as it must, which affect the utility of future citizens then it is on more dangerous grounds. The tendency will be to exploit resources today to raise the utility of persons living today. There is a particular danger of this exploitation when many of the people living today are seriously deprived, or worse, on the verge of starvation.

As long as technology continues to "bail man out" and let him enjoy an increasing standard of living, the next generation will never begrudge previous generations for some exploitation of resources for a better life. However, if man so crowds himself that he begins diminishing the stock of flow resources in the environment at an increasing rate, then the requirements of technology may become so great that he will be faced with a declining level of living (and possibly chaos). At this point, in my opinion, further exploitation becomes untenable.

Our social and environmental problems today begin to make one realize that perhaps man cannot rely on exploitative technology for an increasing level of living ad infinitum. If so, then perhaps from a long-run social welfare point of view we can argue for admitting only those technologies which are in general environmentally neutral--a criterion which implies that we can with suitable tests determine what is environmentally neutral.

Those agricultural inputs which are not environmentally neutral can be restricted by the environmental constraints in our model. We attempted to activate at least one of these constraints but found little basis in fact for doing so. Perhaps the ecologists and political scientists can help provide a basis.

Once we considered developing the model in a multiperiod nonlinear programming framework but abandoned the notion because of the data requirements. Likewise we tentatively considered a dynamic programming approach to the problem. The dynamic models were appealing because of the nature of the problem but datawise it will probably be some time before we can accomplish such an approach.

Resource Requirements for a National Model

The detail of the model and one's time schedule are probably the major determinants of the resource requirements. Our project required a great deal of time in deciding on an area to study, in specifying a model to use, and in estimating the quantity of pesticides used. These items would require less time for a national model.

Demand and Supply Functions

We spent considerable time estimating long-run price elasticities of demand and supply for commodities produced in Dade County. The amount of time spent doing such estimations to support a national model would depend in part on the transferability of the demand and supply work that has already been done. If one started from scratch to obtain these requirements, the results would provide byproduct information which may be of interest and use to other agricultural policy decisions.

The model as we specified it had a separable objective function. Such a function assumes that products are independent in demand and in supply. If a similar specification were used at the national level, close substitutes (complements) in demand would need to be aggregated for the analysis. Likewise products which were close competitors (or complements) in production would need to be aggregated.

There is danger of double counting in the surplus calculations. To help guard against such double counting I would suggest that demand and supply functions be estimated at a common point in the production-consumption process--for example at the farm level. Intermediate agricultural products which required pesticides could be included in the model to contribute to final products but need not contribute to consumer and producer surplus in the functional. The pesticides required to produce them would of course enter the externality functions in the functional.

The Externality Function

Externality functions also entered the functional separably. This procedure assumed that there were no synergistic effects between organic phosphates and chlorinated hydrocarbons. To my knowledge, there is no empirical basis for changing this assumption.

The externality functions require two kinds of information--quantities of pesticides used by groups of pesticides and a value measure of the net external effects caused by each group. National surveys provide a measure of the quantity of pesticides used by commodity. The task of estimating the cost of externalities would require considerable input and probably should involve ecologists. Assumptions about the externality function can of course be varied with sensitivity analysis. This possibility suggests that researchers should attempt in their empirical work to obtain hypotheses about bounds on the externality functions.

Shifting the Supply Functions

It is doubtful whether available experimental data will provide a basis for synthesizing shifts in supply functions under specified policy alternatives. Here the economists will probably have to rely on opinions of knowledgeable entomologists and agronomists. We found it most helpful to approach the entomologists with a set of questions which when answered would permit us to make the required assumptions.

As indicated earlier, we did not admit the possibility of substituting other productive inputs for pesticides. Perhaps the agronomists could aid in this task in much the same way as the entomologists aided us in synthesizing supply shifts due to changes in pesticide inputs.

DISADVANTAGES AND ADVANTAGES IN SUCH AN EFFORT

Disadvantages

The major disadvantage is the resource requirement. I would suggest that at least three economists be involved--one estimating demand and supply parameters, another estimating externality functions, and the third coordinating the effort and working on supply shifts under alternative policies. Agronomists, ecologists and entomologists should also be involved. There is not much definitive information or data available to support such an effort. However, there is probably more usable data available at the U.S. level than at a small area level. In this sense, there is an advantage to a more aggregative model.

Scanty data and information plus the conceptual difficulties of attempting to measure welfare make the actual numerical results generated by the model of questionable value.

Advantages

The real advantage which I see to such an effort come from the byproducts which it generates. The expertise and knowledge gained by those involved in the project would be a valuable resource for policymakers. In addition, the effort would emphasize those areas where information to support policy decisions is sorely lacking. This might be a very significant advantage by helping to establish future research priorities--particularly if the research effort were able to effectively involve other disciplines. The demand, supply, and externality estimates would also provide additional information for policy purposes.

This may sound somewhat heretical coming from an economist but I do not see such an effort as one which would justify large amounts of net new resources. I would favor spending net new resources to obtain time series data on all forms of pollutants going into our environment and on census and other demographic data on certain representative forms of life in the environment. I think net new money should also be involved in getting teams of entomologists, agronomists, economists, and ecologists to study some of the substitution relationships and ecological consequences of alternative pesticide programs at farm levels.

CONCLUSION

The main thrust of my remarks has been toward empirical measurement. Perhaps more important in the pesticide issues--as well as many others concerning the environment--are problems of social choice from among the set of admissible courses of action available to society. There is little question that the problems of measurement are primarily the concern of scientists. And although the social choice problems create the need for measurement, the problems as such remain those of the citizenry. There is some danger of falling into the trap of believing that more accurate measurement, which may reveal portions of the unknown state of nature or lead to more well-defined hypotheses about the state of nature, will resolve the problem of social choice. The scientist who does not escape this pitfall is likely to confound his role as a citizen with his position as a scientist. Further, it is difficult not to confuse these roles when one's own environment is at stake.

To elaborate this point at the risk of being somewhat redundant, consider the two hypothetical descriptions of the states of nature shown in figure 1. Path A depicts the view held by some that continued use of chlorinated hydrocarbons will have serious consequences. Path B represents a more optimistic view. Both curves represent alternative hypotheses about the true state of nature and both exist because of our inability to measure and to know.

Now suppose for a moment that we could know the true state of nature under whatever policy or course we choose to follow. Let C and D in figure 1 trace out the time paths of the social consequences of two such alternatives. For example, curve C represents the true measure of net social payoff if we continue our present policies regarding the use of chlorinated hydrocarbons and path D represents a policy of banning these persistent substances. Solution of the problem of measuring the consequences of the two alternatives does not resolve society's problem of choosing a path--unless the measurement results in an obvious choice such as when one policy turns out to be uniformly better over time.

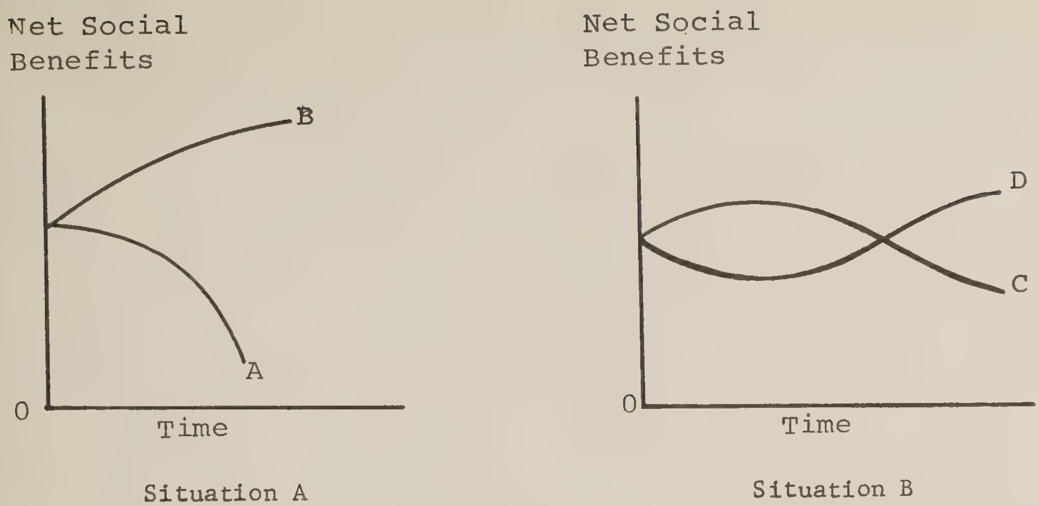

Figure 1

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PRODUCTIVITY OF AGRICULTURAL PESTICIDES1/

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INTRODUCTION

Studies in the productivity of agricultural pesticides across firms and regions are not extremely prevalent. In contrast, estimates of the production gains from individual experiments with chemical pest controls in agriculture are numerous and many were reported at the Ribicoff Hearings (5) in 1963.2/ Most of the prevailing "opinion" concerning pesticide productivity in agriculture represents an intuitive aggregation of the results of similar experiments, reinforced by a market for agricultural pesticides that has grown in both dollar volume and physical magnitude since the close of World War II.

It is, however, one thing to know that an input is useful in the production process and quite another to know how useful. One of the tenets of production theory that is most widely known and accepted is that maximum returns above costs occur when the value produced by the marginal unit of an input is just equal to the cost of that marginal unit. So, knowledge of the behavior of agricultural output with respect to pesticide inputs is an important part, yes an essential part, of the proper allocation of agricultural resources.

Now that chemical pest control has come to be recognized as a potential source of a number of undesirable effects outside the agricultural producing firm, knowledge of the productivity of pesticides is essential to an informed change in the amounts of pesticides used, the kinds of materials used, and the ways these materials are dispersed. As uncertainty and lack of knowledge characterized the expansion of pesticide technology, so the abatement of it proceeds with almost equal uncertainty and lack of knowledge.

EMPIRICAL STUDIES

Based on data obtained from the Farmer Cooperative Service which estimated farmer expenditures for pesticides by State in 1963, the marginal contribution of pesticide expenditures was estimated by combining these data with data from published farm income and expenses for 1963 (3). While there are statistical and economic limitations to these estimates, the results showed that $1 of

1/ Research on which this paper is based was supported by a grant from Resources for the Future, Inc. and data were supplied through a cooperative agreement with the Economic Research Service, USDA.

2/ Underscored numbers in parentheses refer to References, p. 88.

expenditure at the margin was associated with a $4-increase in the value of farm sales based on variations between State totals in 1963. This result did much to reinforce those who had argued that pesticides were a profitable part of farm technology. This estimate suggests that while there may be pest, chemical and crop situations where marginal expenditures were not this productive, the average effect of an increase or decrease in the mix of pesticides used by farmers would result in a four-unit change in output for a one-unit change in input in value terms. Farm income, however, might not respond in similar fashion due to the effects of the quantity supplied on average revenue. 3/ It did not provide any insights into differences between types of farming or geographical areas nor did it provide any insights into differences between chemicals in various uses.

Another study was undertaken to provide estimates of the marginal contributions of pesticides in different uses in agriculture and in various regions of the country where the pesticide inputs were measured in ounces of technical material applied rather than expenditure values. These data were made available from the 1964 Pesticide Use Survey conducted by the USDA. Data measuring reported pesticide use by farm from this survey were aggregated into county estimates and combined with measures of other farm inputs and crop sales in the 1964 Agricultural Census. Marginal contributions for herbicides, insecticides and fertilizer for 10 production regions and the nation are given in table 1 as computed from statistically estimated input-output functions.

Several interesting aspects of these results bear discussion. First, the marginal contribution of insecticide materials was positive in all regions with the exception of the Northern Plains and the variable was dropped from the equation in that region. Second, the estimated contributions in all regions were in excess of what would constitute a weighted average cost per ounce of technical insecticide material with the exceptions of the Southeast and the Southern Plains. Third, the production regions that are primarily cotton areas such as the Appalachian, Southeast, Delta and Southern Plains showed the lowest estimates for insecticides. Fourth, the estimated marginal contribution of herbicides was largest in the Corn Belt--where they are widely used--and the average estimated contribution in the national function showed herbicides with a negative contribution. Fifth, the estimated marginal contribution of fertilizer was uniformly large relative to the cost of a ton of normal analysis fertilizer and all estimates were positive.

It is reasonable to ask what these estimates might mean to those concerned with agriculture and policies directed at pest control in agriculture. If the estimates are valid, i.e., measure what they purport to measure, one interpretation is that additional insecticides in the Southeast and the Southern Plains and to some extent the Delta and Appalachian regions cannot be expected to generate much additional output, if any. Similarly, using less of a given amount of technical material in these regions would result in a relatively small reduction in output compared with other regions. Why might this be so?

3/ This refers to the inelasticity of demand for farm products in the aggregate resulting in lower total revenue as quantity sold increases.

If the regions where productivity is estimated as low are essentially using all of the insecticides that they can and still get an effect then this could be the cause of the low estimate. Alternatively, if there is very little variance remaining to be explained by variation in insecticide treatment or if there was very little variation in insecticide applications between counties then a low estimate would result. Inspection of the standard deviations for the insecticide variable does not show the latter to be true. The reason why the partial correlation of insecticides and crop sales is low in the regions is not known, but it could be due to input complementarity. The results do indicate that insecticide applications cannot be used to explain differences in output within the Southeast, Southern Plains, and perhaps the Appalachian regions.

For the remaining production regions, the results suggest considerable ability to explain differences in crop sales between counties based on insecticide applications. The pattern seems to be that the more heterogeneous the agriculture, that is crop production versus livestock or dairy, the more pronounced the partial correlation between insecticide use and crop sales. Therefore, these results are perhaps as much indicators of variation in output due to type of farming as they are indicators of variation due to insecticide use per se. This doubt is weakened somewhat, however, by the large statistically significant coefficients for commercial fertilizer, which should also reflect variation due to type of farming.

If one does not look too far for limitations of the measurement device, the results for insecticides support the hypothesis that the marginal productivity of insecticides is least where the use is the most intensive. This conclusion certainly is consistent with expectations based on economic theory.

The measurement of the marginal contribution of herbicides on a regional basis was not as consistent or as impressive as the results for insecticides. Table 1 indicates that only in the Corn Belt and the Southern Plains were the contributions based on statistically significant regression coefficients.

As a region, the Corn Belt uses more herbicide materials than any other region and the Southern Plains, while not the smallest regional user, did not rank second. 4/ It seems that these results run contrary to the economic theory hypothesis that was supported for insecticides. One explanation for the Corn Belt result could be that there were differences in herbicides used in the counties surveyed. Since the preponderance of herbicide material used in the Corn Belt is applied to corn and soybeans, the two principal cash crops, the differences in output not explained by other inputs were attributed to herbicides. While the Corn Belt was the largest user of herbicides there was not, in 1964, the uniformity in use of herbicides on corn and soybeans from farm to farm that there was in the use of insecticides on cotton, for instance. Farmers who grow corn and soybeans in rotation with grain or pasture do not have the weed problems found under more intensive cultivation such as continuous corn programs.

4/ See Eichers, Theodore, et al (2) for the regional use statistics tabulated for 1964.

Table 1.--Estimated marginal contributions of selected farm chemicals, by region, United States, 1964 1/

Region	Chemical category			R^2 of estimating equation
	Herbicides	Insecticides	Fertilizer	
	Dollars per ounce	Dollars per ounce	Dollars per ton	
Northeast	---	2/1.31	2/157.39	0.84
Appalachian	0.60	.31	2/310.22	.76
Southeast	---	.005	2/157.24	.94
Delta States	.22	2/.30	217.17	.95
Corn Belt	2/2.38	.76	2/198.87	.75
Lake States	-1.02	2/11.09	2/388.35	.66
Northern Plains	.13	---	2/302.71	.70
Southern Plains	2/1.05	2/.06	2/158.66	.96
Mountain	---	2/13.85	2/633.55	.88
Pacific	---	2/1.74	2/669.71	.97
United States	-.21	2/1.52	2/270.31	.76

1/ All contributions computed at the geometric means for 1964.
2/ Estimates derived from partial regression coefficients that were significantly different from zero at the 95 percent level ($\alpha = 0.05$).

The explanation then resolves to saying that herbicide applications differentiate cash grain counties from more diversified ones in the Corn Belt. Further, if that measure is valid, the difference exists because of herbicides.

Herbicide use in the Southern Plains is largely confined to grains, hay, and pasture including rangeland (2). What the result for this region measures is not clear. The dependent variable in the regression equation was crop sales so it is not measuring animal output from improved ranges and must, therefore, be an indication of variations in output due to higher production of grains such as barley, rice, and mixed grains. There is also the possibility that herbicide applications, to some extent, measured differences in intensity of farming between counties in the region.

For the Nation as a whole, the herbicide variable did not perform as expected and its regression coefficient was negative and nonsignificant. This indicates that herbicides are not associated with the residual variance in crop output after other factors have been taken into account, either because its effect is measured by some other complementary input such as fertilizer or because the national level of herbicide use is sufficient to deal with most of the important weed and brush problems. Given the rapid expansion of the herbicide market in the last 5 or 6 years, this may be worth considering.

As the Congress, State legislatures, and the USDA are faced with considerable pressure to act on the pesticide question as a part of the concern for the environment, it becomes necessary to consider various alternative actions. Some steps have been taken, including registration cancellation of certain compounds and more research on biological control, integrated control, and "clean" chemicals.

Production theory suggests still another possibility, that is, policies that favor input substitution. In other words, can policy be used to take the pressure off development and use of technology such as chemical pesticides and increase net social benefits?

It has been argued by the author and others that, among other things, agricultural policy that restricts land use encourages the adoption of chemical pest controls and other techniques to enhance the productivity of limited land combined with machinery, fertilizer, and new varieties. The policy has been one of substitution--substitution of technology for the natural resource land. While this policy has affected the pattern of land use, it has shifted the use of the natural ability of the biological system to control pests toward the present and has put pressure on the disposal capacity of the system.

The question being asked is that we reconsider our agricultural price and income policy and its methods to see if this is what the Nation wants as a policy result or if what has happened is merely an unexpected outcome of a policy action.

After estimating the productivity of agricultural pesticides, we can consider the possibility of estimating the rates of input substitution. It is apparent that pesticides have been substituted for land and labor, to mention only two inputs. Agricultural chemicals, new varieties, and machinery have made possible increased output from a land base that has been held relatively constant through various land retirement schemes. Can this process be reversed?

Production theory states that the marginal rate of substitution of one input for another is given by a ratio of their marginal products. In addition, an elasticity of substitution can be computed which measures the percentage change in one input given a 1-percent change in another input while maintaining the same level of output.5/

Before beginning an agricultural policy of replacing pesticides with other inputs, one needs some idea of the relative changes in the levels of the inputs to determine the impact on input use and to assess the effects on agricultural resource use and output. The input-output functions estimated for the regions can provide a starting point for this idea.

5/ This is not the same definition of the elasticity of substitution found in Allen (1, pp. 340-343), where the elasticity of substitution is defined as the percentage change in the input ratio for a 1-percent change in the marginal rate of substitution.

Table 2 presents the marginal rates of substitution of cropland for insecticides and the elasticities of substitution of cropland for insecticides based on the statistical input-output functions. Each measure is explained in the table. There are estimates for eight production regions and the national estimate. Two regions were excluded--the Northeast because of the absence of a coefficient for cropland and the Northern Plains because of the absence of a coefficient for insecticides.

Large elasticities of substitution of cropland for insecticides were found in the Southeast and Southern Plains regions. You will recall that these were the regions where the marginal contributions of insecticides were the lowest. For the other regions the elasticities ranged from -2.70 in the Appalachian region to -14.9 in the Delta. These are the percentage decreases in ounces of technical insecticide material applied because of a 1-percent increase in cropland, all other inputs held constant. The elasticity computed from the national function was -6.49.

Applying these estimates to the regions, or to the Nation as a whole, provides an estimate of the possible reduction of insecticides as land is returned to production. We thereby have some basis for evaluating the effect of more land on insecticide use.

In 1967, 40.8 million acres of cropland were diverted from production under various government land retirement programs (4, p. 544). These programs included the Conservation Reserve, the Feed Grain programs for corn and grain sorghum, the cotton program, the cropland conversion program and

Table 2.--Marginal rates of substitution and elasticity of substitution of cropland for insecticides, by region, United States, 1964

Region	Marginal rate of substitution of cropland for insecticides 1/	Elasticity of substitution of cropland for insecticides 2/
Appalachian	-33.19	-2.70
Corn Belt	-10.03	-4.35
Delta States	-256.47	-14.89
Lake States	-.80	-8.16
Pacific	-24.06	-6.49
Mountain	-.97	-7.77
Southeast	-3,257.00	-326.67
Southern Plains	-547.17	-170.04
United States 3/	-13.24	-6.49

1/ Ounces of insecticide reduced per 1-acre increase in cropland.
2/ Percentage decrease in insecticides per 1-percent increase in cropland.
3/ Does not include Alaska and Hawaii.

the cropland adjustment program. Most of this land is suitable for regular cultivation with no additional investment. Returning all of this land to production would constitute about a 12-percent increase in the cropland base currently in use.

Using -6.0 to -7.0, as an estimate of the elasticity of substitution of cropland for insecticides leads to the conclusion that a 12-percent increase in cropland harvested would reduce insecticide use by 70 to 80 percent and maintain output.

Before considering the quality of this result let us look at some effects of such an action. First, compared with present situations, return of this diverted cropland would mean that farmers would be deprived of the government payments received currently under the program. Second, farm costs would be reduced by the amount of the value of the reduction in the use of insecticides plus application costs. Many costs on farms would remain unchanged, based on the assumption of the existence of a certain amount of underemployment of labor and excess machinery capacity.

Now let us look at the reasonableness of the result. The mathematics of the process proceeds in a very mindless manner. The result requires the assumption that the land returned is equal in quality to that in use. This we are sure is not the general rule. So the decrease in insecticide use would need to be made smaller to account for this factor.

The result also requires that other inputs are sufficient to operate the added land at a level such that output lost by reducing insecticides could be made up from the added land. It is reasonably certain that the functions used for estimation are subject to some specification bias and that increasing cropland implies adding other correlated inputs, particularly seed, petroleum and fertilizer. Therefore, farm costs would be increased to the extent that these additional inputs were required. Of course, the level of fertilizer use per acre would perhaps decline, since without insecticides the same level of fertility would no longer be profitable unless the prices for farm products were to increase. How much additional labor and machinery would be required is anybody's guess.

Finally, the effects of changes in the product mix of agriculture under such a policy are ignored by the mathematical result, and there would certainly be some changes. If farmers were to revert to use of rotations in cash crop areas to control insects, weeds and fungi, relatively more forage and small grains might be produced. Finally, there could be a change in soil erosion due to bringing land back into cultivation. What the change would be would depend on the resulting changes in cropping patterns.

A similar exercise could be performed with herbicides although it was not done here because of the instability of the coefficients estimated for the herbicide variable. It is certain that a substitution of land for insecticides would have some interacting effects on herbicide use depending principally on how the product mix of crop production changed with the substitution. Fungicides might also be affected.

CONCLUSIONS AND IMPLICATIONS

Decisionmaking in the area of chemical pest control is fraught with an enormous amount of uncertainty. Congressional and USDA policymakers are in an unenviable position where there is considerable pressure from a largely urban populous to take positive steps to prevent irreversible damage to the environment. At the same time the pressure of hunger around the world and the welfare of the farmers and consumers at home makes it extremely important that the effects of a policy action on the output of food and fiber be understood.

The results of pesticide productivity studies indicate that chemical pesticides are definitely making a positive contribution to agricultural output across the country. At prices currently prevailing for pesticides relative to product prices, the level of adoption of the technology is high and expanding. However, as pointed out, this expansion has been encouraged by an agricultural price and income policy that has restricted land inputs and increased the relative price of cropland. If the price of pesticides does not reflect the full costs of their use due to spillover effects on the environment, now as well as over time, then the combination of pesticides, land, and other inputs used may not be the least-cost combination.

Given such a disequilibrium situation, the direction of adjustment is easily discerned--reduce the level of chemical pest control relative to land used in the agricultural production system. What is not so easy to discern is where and how much.

It seems that agricultural science is in a better position to assess the impact of a change in our system of pest control on agricultural output than it is to determine the full costs of pesticides. However, even here the orientation of the research program has provided precious few answers to questions relating to the time patterns of pest populations under various kinds of cultural practices, the impact of these populations on agricultural output, and the adjustments in resource use that result. Of course, these effects are eventually transformed into the supply function for agriculture and ultimately into agricultural income.

We may be at a turning point in agricultural policy. For years the conventional wisdom in policy circles has urged the control of output with land and the movement of surplus labor out of agriculture. This is a very partialized argument based on elementary demand theory and the rather tenuous argument, without benefit of rigorous demonstration, that the interest of society was being served. We may now be seeing, if not too clearly, the social costs of this policy solution.

In my opinion the U.S. Department of Agriculture and the agricultural experiment stations have operated with this policy condition as a given or a constraint, if you will, and have attempted to maximize farm income subject to that constraint. Little has been done to estimate the implied price of the policy constraint. The pesticide problem and other agricultural residue problems are certainly a part of that implied price.

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THE MICROECONOMICS OF CROP LOSSES

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Crop yield reductions due to insects, diseases and weeds represent a major production economics problem to which economists have devoted little attention. The allocation of resources to reduce crop losses, investment activities to discover new pest controls, and depreciation of chemical and information stocks when pesticide resistance develops appear to be important questions. Nonmarket costs of agricultural chemicals and heavy population demands on food supplies bring these economic questions into sharper focus.

In spite of their adverse publicity, pesticides remain the farmer's most powerful tool in reducing crop losses. At present levels of use, rates of returns to farmers for additional pesticide expenditures appear to be high. 1/

This paper is directed at understanding what it pays the individual farmer to do; what the private incentives are for pesticide use under conditions of uncertainty and through time. Are there ways of maintaining low levels of crop losses with less pesticides? A clear appreciation of the benefits of pesticides to individual farmers is necessary in both policy formulation and implementing regulatory programs. 2/

Agro-ecosystems are quite complex with thousands of organisms that threaten the various crops. Each pest species is influenced by crop conditions, weather variables, and its group of enemies. Watt (33) has argued that pest-control systems are often "counterintuitive," that is, linkages between controls taken and final production may be the opposite from that which observation and reason suggest. How can we hope to reduce pest control systems to manageable terms?

1/ Headley (12) estimates marginal products for the United States to be about 4, Strickland (26) estimates 500 percent rates of return for pesticides in England, and Carlson (unpublished data) estimates that marginal products on U.S. cotton farms are 1.2-2. Underscored numbers in parentheses refer to Literature Cited, p. 99.

Note: The assistance of Jim Seagraves and Richard Perrin in preparing this paper is gratefully acknowledged. The responsibility for the final statement should be placed on me.

2/ The importance of social benefits and costs of pesticides in formulating public policy is recognized, but left to others to discuss at this conference.

In what follows, I plan to discuss various concepts that might be useful in detection and control of pests. Decisions involving timing and nonuse of chemical controls will be illustrated with a brief review of some work on fruit rot in California. I'll discuss collection and analysis of data on chemical effectiveness, potential crop loss, and disease loss forecasts. I'll then develop what I believe to be implications for future data collection and research relating to public policies on pesticide use.

THE NATURE OF CROP LOSSES

First, the bulk of crop losses are due to a limited number of disorders on a few crops. Recent FAO estimates indicate that 72 percent of the value of crop losses in all developing countries is centered on five crops: rice, cotton, corn, millet, and fruit (6). A single insect species, the European corn borer, is credited with annual damages valued at over $350 million in the United States alone (28). One of the most detailed studies of yield reductions due to plant diseases is that conducted for California (27). Table 1 shows that about 56 percent of all disease-induced crop losses can be assigned to the two major diseases of only six crops. There is this concentration of disorder even in the diverse agriculture of California. Morris and others have forcefully argued that, even though pest population density is affected by many variables, it may be determined by only a few key factors (17, 30). This key-factor principle permits simplification of predictions of pest populations and crop damage.

The second general feature of crop losses that will influence the model chosen for economic analysis is the high variances of crop losses. Weather-induced classes of disease such as mildews, molds, blights, rust, and brown rots develop to damaging levels at irregular intervals, especially in more arid climates (27). What causes drastic population fluctuations of some insect species is the major concern of many entomologists (5, 15). The negative bionomial distribution has been used to summarize data on insect spatial aggregation (1, 31). Skewed distributions such as the log normal, Weibull, or Beta can be fitted to crop loss data over time. Figure 1 shows frequency polygons of crop damage to cotton and tobacco prior to the introduction of organic pesticides. The important feature of these distributions is the dispersed nature of damage magnitudes. Wide fluctuations in damages have direct implications for using models which include risk features as well as mean income.

The dosage-response relationship of pesticides on crops is generally thought to be sigmoid in form. 3/ The efficacy of pesticides varies with pest dispersion, mobility, temperature, crop biomass, and other factors. Most modern insecticides are highly toxic with sharp increases in yield from slight increases in dosage. There is a narrow range of dosages which might be optimal for a single application. 4/

3/ Finney and others have compiled evidence on the normal distributions of mortality of pests when treated with chemicals (10, 13).

4/ There are several questions about pesticide response function which production economists have not resolved. What are the joint responses of pesticides and fertilizer? What shape does the negative (due to phytoxicity) segment of the function assume?

Table 1.--Estimated disease losses in California crop production

Crop	Disease	Percentage of crop loss	Value of crop losses	Percentage of crop total
		Percent	Million dollars	Percent
Grapes..........	Powdery mildew	7.5	12.3	48
	Postharvest rot	5.0	8.2	
	Total, all diseases	26.0	42.4	
Cotton..........	Verticillium wilt	5.0	16.7	90
	Seedling diseases	3.0	10.0	
	Total, all diseases	9.0	30.2	
Lettuce.........	Mosaic	8.0	6.8	60
	Tip burn	7.0	5.9	
	Total, all diseases	25.4	21.4	
Alfalfa.........	Root rot	6.0	10.7	76
	Leaf spots	2.0	3.6	
	Total, all diseases	10.5	18.8	
Tomatoes........	Fruit rots	6.0	6.6	83
	Verticillium wilt	3.0	3.3	
	Total, all diseases	10.8	11.8	
Oranges.........	Psorosis	3.0	3.5	65
	Quick decline	3.0	3.5	
	Total, all diseases	9.3	10.9	
All crops......	All crop diseases	---	241.0	56

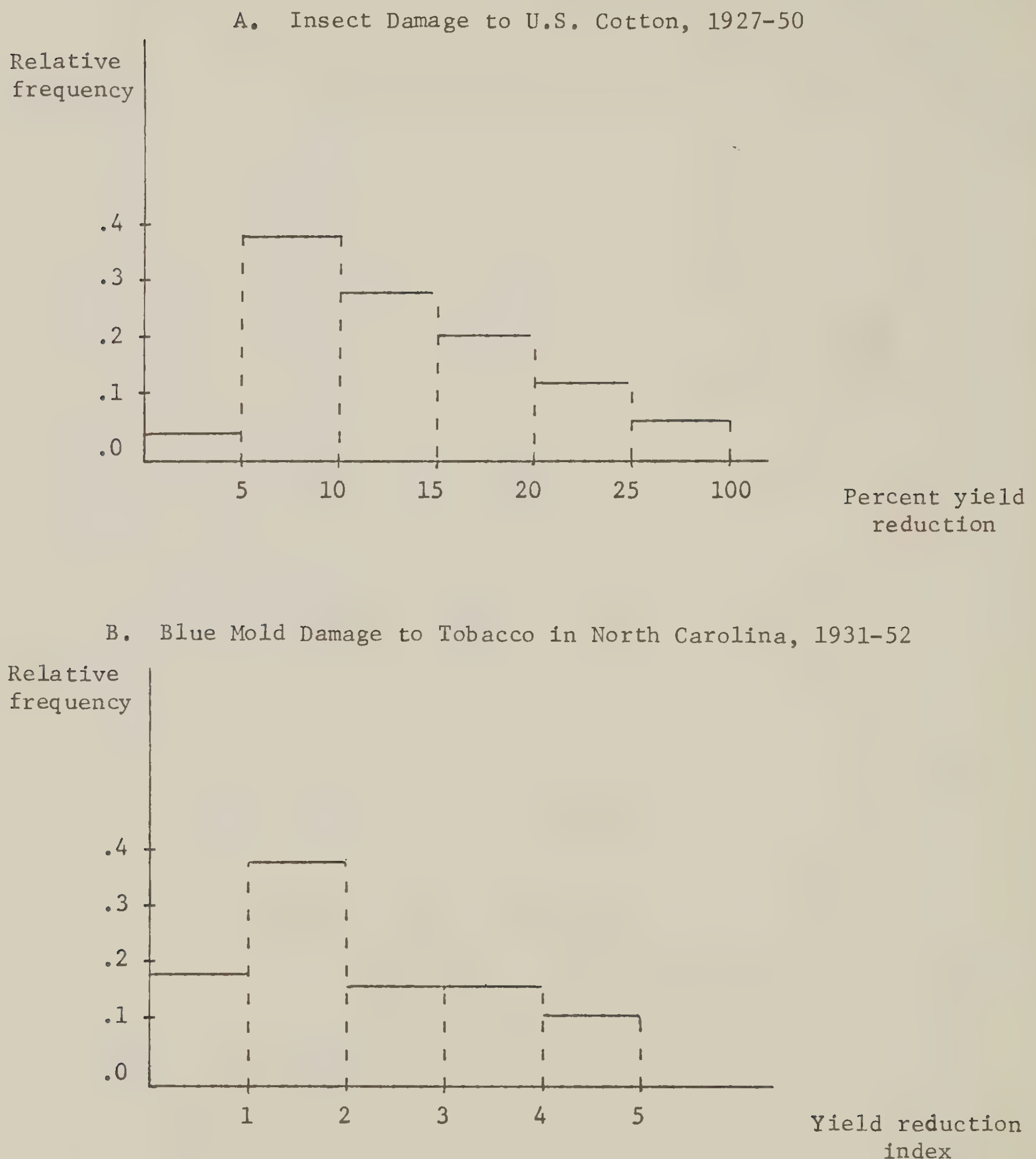
Sources: References (27,28).

There are other features of the dosage-response function which are important in determining private gains from alternative dosages. At what population infestation level will yield reductions equal control costs? What effects will dosage have on application intervals? How does application rate influence yields in future crop years?

The questions on dosage and application rate relate to two limitations of pesticide use. Rapid pest resurgence after chemical treatments may be due to elimination of natural enemies and relief from density dependent factors. The productivity of agricultural inputs in future periods may be influenced by how pesticides affect the development rate of resistant strains of pests. Comments about research on these two topics will be made later.

The other question pertains to what entomologists have called the economic threshold (22, 25). Although entomologists have not carefully considered economic variables relating to control thresholds, they have emphasized the

FREQUENCY POLYGONS OF CROP LOSSES THROUGH TIME



Sources: References (16,18).

Figure 1

importance of infestation level on optimal treatment decisions. The relationship between pest numbers and plant damage is complex and rarely linear in form (24, 32). The important point is that most crops can tolerate significant levels of pest species. Economists interested in optimum use of pesticides should recognize and build on the economic threshold work that has been completed. The following analysis attempts to include biological components in refining application thresholds.

BAYESIAN ANALYSIS OF PESTICIDE USE

The pesticide use decision can be analyzed in the conventional decision theory framework (21, 3). The major source of uncertainty which will influence level of pesticide dosage is the magnitude of pest infestation. Let discrete intervals of crop damage (assumed proportional to infestation level) from 0 to 100 percent be the states of nature ($\theta_1 \ldots \theta_n$). The alternative actions ($a_1 \ldots a_m$) available to the farmer are the quantity of pesticide or other control measures to apply. The monetary payoffs for each crop loss level and pesticide use pair $U(a, \theta)$ can be computed for the representative firm by considering the additional harvest and pesticide costs and the additional returns from crop saved.

The Bayesian guide for pesticide use, based on subjective expected utility maximization, can be written as:

$$E(U) = \underset{h}{\text{Max}} \left[\sum_{\theta}^{n} U(h(z),\theta) \quad P(\theta | z) \right]$$

where: $E(U)$ = subjective expected utility,

$U(h(z),\theta)$ = payoff (utility) derived from each decision function,

$[h(z)]$ = state of nature pair ($a = h(z)$),

and $P(\theta | z)$ = posterior probability of crop loss level given crop loss forecast z. 5/

The basic components of the model are the subjective prior distributions of crop loss held by farmers, crop loss forecasts, and associated actual crop losses.

For California peaches and other stone fruit, brown rot occurs infrequently but causes large losses when it does develop because many farmers do not apply "insurance" fungicides. Chemical control is not effective once the fungus-inducing summer rains begin.

5/ The posterior distribution is the standardized product of the subjective prior distribution and the conditional distribution from crop forecasts, $P(z|\theta)$. Crop loss components of the decision model are further explained in (2,4).

Subjective probabilities of brown-rot loss to peaches were assessed by interviewing a random sample of peach farmers. The mean subjective distribution of crop loss was very similar to relative frequency of rainfall. Table 2 shows subjective probabilities of crop loss by peach varietal group.

Two forecasts were devised to predict brown-rot damage in particular orchards for a given year. The intensity of brown rot (and many other crop diseases) is influenced by rainfall, host susceptibility, and quantity of spores present (7, 19). The first model merely used 24-48 hour rainfall forecasts by the weather bureau as a treatment indicator. Conditional probabilities of daily precipitation forecasts and corresponding actual rainfalls were compiled from newspaper files and weather bureau records for the 3 weeks prior to harvest in the 1952-1966 period.

Table 3 indicates Bayesian pesticide use strategies and corresponding expected returns for each rainfall forecast(z). The optimal pesticide dosages were sensitive to the predicted crop damage. They did not vary greatly with changes in product price, production costs, or pesticide costs. It is important to note that no pesticide is recommended whenever fair weather is forecast for the next day. This is a frequent $[P(z_1)=.86]$ rainfall forecast in the peach growing region. If optimal practices based on this simple model were followed, they would result in sharply reduced pesticide applications.

The second forecast model was based on a linear regression of spore count, fruit maturity, and predicted rainfall on disease loss. A cross-section survey of 64 orchards and observations from greenhouse trails of simulated rainfall of various durations, provided data for the analysis. Table 4 shows the expected net income (M) and standard deviation of net income (S) for the various disease-loss forecasts($\hat{z}$). The inclusion of standard deviations of income permits a grower to select the action which reflects his risk aversion. It is apparent from table 4 why farmers might apply pesticides as insurance; by applying 1 captan rather than no spray, mean net income is only reduced $2 per acre, but the standard deviation of net income is reduced by $11.

Table 2.--Subjective probabilities: Means of grower responses

Peach varietal group	Percent loss intervals				
	0-4.9	5-9.9	10-19.9	20-29.9	30-100
Extra Earlies	.760	.128	.034	.032	.046
Earlies	.698	.132	.048	.062	.060
Lates	.632	.104	.060	.038	.166
Extra Lates	.540	.061	.069	.072	.158

Source: Table 4.1 in Carlson (4).

Table 3.--Bayesian strategies and associated expected returns for alternative rainfall forecasts and varietal groups 1/

Peach varietal groups	Rainfall forecasts				
	Fair z_1	Cloudy z_2	Sprinkles z_3	Showers z_4	Rain z_5
	Dollars per acre				
Extra Earlies	73 NS	62 1S	54 1C	26 1C	-36 2C
Earlies	13 NS	1 1C	-8 1C	-34 1C	-88 2C
Lates	116 NS	91 1C	81 1C	42 2C	-22 2C
Extra Lates	126 NS	98 1C	87 1C	51 2C	-9 2C

1/ Pesticide-use actions: NS = no spray, 1S = 1 sulfur, 2S = 2 sulfur, 1C = 1 captan, and 2C = 2 captan.

Table 4.--Mean and standard deviations of returns from various disease loss forecasts and various actions 1/

Action	Brown-rot loss forecasts (percent) 2/													
	$\hat{z}_1$		$\hat{z}_2$		$\hat{z}_3$		$\hat{z}_4$		$\hat{z}_5$		$\hat{z}_6$		$\hat{z}_7$	
	M	S	M	S	M	S	M	S	M	S	M	S	M	S
	Dollars per acre													
NS	75	20	--	--	--	--	--	--	--	--	--	--	--	--
1S	74	14	72	20	--	--	--	--	--	--	--	--	--	--
1C	73	9	72	14	71	18	67	26	53	48	--	--	--	--
2C	62	8	61	11	60	15	57	21	46	39	-16	62	-99	35

1/ Based on subjective priors from the extra early varietal group.
2/ $\hat{z}_1$ = 0-4.9, $\hat{z}_2$ = 5-9.9, $\hat{z}_3$ = 10-19.9, $\hat{z}_4$ = 20-29.9, $\hat{z}_5$ = 30-49.9, $\hat{z}_6$ = 50-69.9, $\hat{z}_7$ = 70-100.

The complete crop-loss detection and control procedure is described in the following steps:

(1) Peach growers have expressed their long-run view of how risky peach growing is by giving their subjective probabilities of disease potential.

(2) Farm advisers, supervised pest-control specialists, or growers record such disease indicators as fruit maturity, rainfall forecasts, and spore levels.

(3) Potential crop loss $P(z \mid \theta)$ is predicted from past parameter values relating indicators (x) to crop losses (θ).

(4) Upon observation of various indicators, $P(\theta \mid z)$, farmers' subjective views and the forecast, $P(z \mid \theta)$, are combined to form the loss probability.

(5) Posterior probabilities $P(\theta \mid z)$ are used to weight returns from each possible pesticide action.

(6) The action which maximizes expected net returns for a given variance of returns is presented to the farmer for execution.

VALUE AND COSTS OF BAYESIAN TREATMENT PROGRAMS

Though this economic analysis is limited to a single crop disease, the procedures appear applicable to many insects and diseases. These procedures apply when disease control costs are high relative to the income from the crop, when potential damages are highly variable from year to year, and when outbreaks can be predicted with some reliability. Basic crop loss-control systems can be modified to apply to other regions by revising weather or soil parameters.

Several countries have had insect and disease warning systems, both public and private, for a number of years. Waggoner (30) has surveyed the literature on crop-loss forecasting up to 1960 and concludes that much more effort is needed. The Bayesian model adds to these efforts by providing a framework for combining forecast information with farmer subjective probabilities of loss. One benefit of this approach is that it points to the following sources of data:

1) Pest population surveys, host susceptibility indexes and weather variables can be used to forecast crop damage.

2) Plant pathologists have systematically recorded experimental data on the efficacy of fungicides and nematocides.

3) Farmers can give probability estimates of losses on untreated crops.

4) Objective probabilities of crop losses related to weather variables allow us to draw on a large stock of information collected at many stations for the past 50 years.

Pesticide-use recommendations have value if they change present application practices. Survey results showed that 44 to 66 percent of the California peach farmers did not apply fungicides regardless of weather forecast received. Expected losses from following the "no spray" strategy rather than the Bayesian strategy were estimated to be $5 to $25 per acre for individual farmers (2). The estimated increase in aggregate benefits (producers' plus consumers' surplus) from following the recommended spray program would be about $3.6 million. Additional costs for fungicides, harvesting and processing these peaches would be about $2.5 million (4).

The costs of monitoring and predicting insect and disease outbreaks are related to acreage, spatial variability of infestations, ease of detection, and other typical sampling variables. Among the most promising recent developments are the contributions of aerial surveys, insect life tables, microclimate studies of pest development, and improved weather forecasting with the aid of satellites (15).

The evaluation of the costs and benefits of public and private information services to assist farmers in reducing crop losses and pesticide use is just beginning. Measurement and prediction of crop losses are complex. The economic question is one of substituting management services for chemicals.

RELATIONSHIP TO FUTURE RESEARCH AND POLICY

The foregoing discussion emphasizes the possibilities for economic analysis in setting treatment thresholds on individual farms. Predictions of low crop loss conditions may enable farmers to increase net private returns and at the same time lower external costs by using less pesticide material. The President's Science Advisory Committee recently reported that substantial (up to 50 percent) reductions in dangerous insecticide use can be made by replacing routine treatment schedules with treat-when-necessary schedules (20). A leading entomologist estimates that 70 to 80 percent of all pesticides used on cotton in California is a needless waste of money. 6/

We found that use of pesticides as insurance for reducing income variance is consistent with risk aversion. The peach brown-rot case suggests that such behavior may be common when potential crop losses are high relative to a farmer's net worth. What contribution to reduced pesticide use can crop insurance have? During 1961-67 use of all-risk crop insurance rose by 190 percent while pesticide use increased only 50 percent (9). Investigations of the rates of substitution between insurance and pesticides are needed to evaluate policies for making less expensive crop insurance available.

Since a pesticide-free environment is a public good, there is an economic argument for public policies aimed at reducing pesticide use. Perhaps, some level of subsidized crop insurance or subsidized information services will have lower social costs than high pesticide use.

6/ Private communication from V.M. Stern, University of California, Riverside.

The effects of pesticide treatments on future productivity may be important. There seem to be two aspects of this problem: (1) ecological factors which lead to rapid resurgence and secondary outbreaks of pests, and (2) development of strains of pests resistant to pesticides.

Over 200 species of insects are known to have developed resistance to one or more pesticides (8). Initially, dosages may be increased as resistance develops. However, resistance to insecticides such as DDT and other hydrocarbons will eventually reduce their use more readily than laws restricting or banning them. An eminent entomologist, R.F. Smith, has suggested that as a planning measure we must assume that any arthropod exposed to intensive pesticide pressure will develop resistance (23). He suggests that we minimize the selective pressure on the pest populations by avoiding all but absolutely necessary treatments. In addition to the methodology explained above, Smith emphasizes monitoring major pest populations for level of resistance and using supervised control specialists to recommend selective treatment of local areas. Forecasts of potential resistance development would assist in evaluating new chemical investments.

We need data on pesticide use and pest populations on individual farms to measure the economic impact of resurgence and outbreaks of secondary pests. These phenomena have been widely recorded in recent years and usually are attributed to destruction of natural enemies by broad-spectrum chemicals. Biological scientists are requesting public research to discover and produce selective chemicals (14). What is the long-run rate of return for chemicals selective to a group of pests? There appear to be sizable returns, but scale economies in research, testing, and production will be sacrificed if many specialized chemicals replace the relatively small number of chemicals produced today. In my opinion some basic economic research is needed to evaluate costs and benefits of public investments in selective insecticides.

The substitution of highly toxic organophosphorus compounds for the persistent hydrocarbons is closely connected with resurgence and insecticide resistance. The less persistent, more toxic materials which can speed the development of resistance because they must be applied more frequently. Highly toxic materials may eliminate natural enemies of major pests and retard vegetative growth, thereby reducing crop yields (23). Such costs should be included in economic studies of pesticide substitution and policy formulation.

Pesticide use policies should be designed with full consideration to several other government policies and programs. Land diversion programs, minimum wage laws, and immigration policies have affected agricultural resource supplies. Limitations on allotment transfers restrict crop location. Each of these resources may be substituted for pesticides. Income policies for farm operators and laborers are intertwined with pesticide use regulations.

Today economists, government administrators, and biologists appear to be at odds in their approaches to pesticide use decisions. I have tried to outline what I believe to be some common areas where important questions can be raised and where research has potential for success. The focus is on efficient crop production with minimal pesticide treatments. The hope is that fundamental biological data can be utilized to devise economic alternatives and public policies of pest management.

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A SYSTEMS APPROACH TO PEST CONTROL

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WHY SYSTEMS ANALYSIS

Systems analysis would be a useful tool for certain kinds of pesticide research, particularly that involving decisions affecting the environment or the ecosystem. I believe that a well-designed systems analysis would permit researchers and policymakers to learn more about the complete effects of their decisions relating to pesticides. I doubt whether any person or group of persons can fully understand all the complex effects of a pesticide on the environment, on optimum farm organization and practices, on human welfare, and on the myriad of other interrelated factors.

Some USDA policymakers recognize that we must start thinking in terms of systems when evaluating the effects of pesticides. Let me quote some particularly interesting statements made by T.C. Byerly. 1/ Referring to pesticides and animal wastes, Byerly said, "a joint USDA-State Task Force reviewed current research programs, needs and opportunities in 1968 . . . . The task force clearly saw the need for systems analysis in solving pollution problems . . . important and urgent is the development and application of systems which will (1) protect our crops, livestock, ourselves and our environment from pests without hazardous pollution of the environment . . . . Pollution of environment with agricultural chemicals . . . can be reduced or avoided. Our systems for doing so are imperfect; they will require more sophistication in their application.

"Agricultural pollution can be solved by development and application of systems which are technologically effective and socially and economically acceptable.

"Agro-ecosystems in the U.S. are highly varied -- don't let the word throw you. You've thought in terms of types of farming all your lives; dairy -- fruit -- cash grain -- corn -- hog -- cotton. Our thinking has focused on commodities, not systems. But the systems were there. We've been busy building large-scale, highly mechanized commodity production systems without sufficient regard for the agro-ecosystems in which the commodities are produced."

1/ T.C. Byerly, The Environment and Agriculture. Paper delivered at the 1970 National Agricultural Outlook Conference.

SYSTEMS ANALYSIS CONCEPTS

This paper first discusses the concept of a system and next the use of systems analysis in research. It then identifies some promising levels of systems analysis and lastly begins developing one of them.

Since the word "system" is at the heart of this paper, let's define it. Webster 2/ defines a system as a regularly interacting, or interdependent, group of items forming a unified whole. The word "system" has a slightly more technical meaning when used in the framework of the research methodology commonly referred to as systems analysis. For such work, it is defined as a set of objects together with relationships between the objects and between their attributes. 3/ Attributes are properties of objects and we can describe any object by listing its attributes. The nature of the relationships between objects and attributes needs to be understood if an analysis is to be meaningful.

We generally speak about the environment of a system. This is "the set of all objects, a change in whose attributes affects the system, and also of those objects whose attributes are changed by the behavior of the system." 3/

Within any system, many subsystems exist. All systems are subsystems of the next higher one. This is particularly obvious for pesticide research. The major hierarchies of subsystems for studying pesticide effects are discussed in the next section of this paper.

A major feature of any system which makes its study useful is the existence of an information feedback system. This means that whenever a change in the environment leads to a decision that results in an action within the system, this action affects the environment and thereby influences future decisons. We say a system is in equilibrium if in the absence of external shock (environmental change) the system remains unchanged, or after external shocks are received it returns to the position occupied before the shock.

USING SYSTEMS ANALYSIS IN RESEARCH

How do we scientifically use systems analysis as a pesticide research methodology? The first step is to observe and delineate events in the system. The second is to build a model (hypothesis) describing the relationships believed to exist in the system. (Because systems analysis depends so heavily on computer technology and is so integrally related to it, the model usually is called an algorithm or an arithmetic-logic sequence of events.) The model should (1) account for all known facts and (2) help make predictions which can be tested by any unbiased independent observer. The final step in using systems analysis is to evaluate the model (test the algorithm) by using real world data.

2/ Webster's Seventh New Collegiate Dictionary, G. & C. Merriam Co., 1965.

3/ McMillan, C. and Gonzalez, R. Systems Analysis, A Computer Approach to Decision Models. Richard D. Irwin, Inc. 1968.

Simulation is one application of systems analysis. This process seems particularly appropriate for research involving pesticides because it is adapted to situations in which relationships are very complex and hard data are often lacking. Simulation is defined as a dynamic representation achieved by building a model and proving it through time. According to Halter and Miller, "Simulation is a means of modeling reality. To simulate means to duplicate the behavior of the system or activity under study without actually attaining reality itself."4/ A model is developed which "can be manipulated to describe a dynamic process in a specified environment for which formal mathematical analysis is an impractical and inefficient way of getting answers."4/ The model is varied for testing and experimentation. This is in contrast to ordinary scientific experiments in which real world circumstances (test plots) are varied.

Simulation is appropriate for problems having three basic characteristics, all of which exist when choosing an appropriate pesticide policy. First of all it works most efficiently with complex systems. Second, it is particularly useful when existing random variables are difficult to measure with any certainty. Third, it is useful when the relationships are not mathematically tractable. Simulation models are usually written in mathematical terms which are designed to represent the internal relationships and external linkages of real economical, biological, sociological and technological systems.

Simulation can help with the pesticide problem in two ways. First, we find simulation useful in designing a system for subsequent analysis. This is usually accomplished by developing several alternative systems and choosing the one that most nearly behaves like the real world. Second, we can vary the parameters until we find the necessary values to duplicate any existing real world system. This helps us understand the functional relationship between the various objects and their attributes in the real world system.

A great advantage of simulation models is their flexibility. They are not subject to rigid mathematical constraints such as those required in linear programming. Although simulation models are not usually optimizing, they can show the path toward the optimum by appropriate variation and testing of the model's parameters.

PESTICIDE RESEARCH SYSTEMS

I would like to outline my views concerning systems involved in a study of pesticides. An analytical model of a pesticide research system can be developed at no less than five different levels. Beginning at the highest and going toward the lowest these are: The ecological system, the production system, the enterprise system, the pest control system, and the chemical control system.

4/ Halter, A. N. and Miller, S. F. Simulation Techniques and Their Application to Economic Research. (Mimeographed.)

The Ecological System

The highest order of these systems is an ecological system. A study of this system would involve such matters as the relationship between plants using carbon dioxide and giving off oxygen with animals using oxygen and giving off CO_2. It would also be concerned with both farm and nonfarm variables affecting the balance of nature, the food chain, oxygen levels in water, the relationship of green space to the total land area, the health of the peregrine falcon, and other environmental variables. Obviously, this system, while by far the most complex, represents the ultimate way to analyze the pesticide problem.

The simulation model finds its greatest usefulness in the ecological system model. To develop this model, we must start with such questions as how much grass do we need? How much water can be used? What effects of pesticides can we endure? What values do we place on our health and comfort relative to our economic gain from pesticide use? How shall all aspects of the environment be treated? How can we develop our pesticide policy in harmony with our national values?

At this level the only disadvantage of a simulation model would be the extremely large input of time and effort required to make it operational. The ecosystem is so complex that millions of interrelated decisions would have to be considered.

The Production System

A second-level system can be labeled a production system. Here we are concerned in the aggregate about how our food is produced, what crops and animals shall we produce, how shall we use our agricultural water and our soil to maximize their conservation and our benefits from them. Obviously this system is oriented more closely to the traditional USDA spectrum of concern than the ecological model described above.

To use the production system in simulation we consider the problem of how agriculture should be organized to maximize consumer satisfaction and producer profits. One pest-related question is what level of control is most economical in the aggregate production scheme.

It may be profitable and desirable not to control some very destructive, localized economic pests when decisions are made on an aggregate basis. It may not be feasible for individual farmers to make this decision if they must bear the consequences. Systems analysis might be most useful if the findings were implemented by an area-wide pest control organization, a quasi-public body like irrigation or mosquito control districts. This organization might employ various scientists to make overall decisions concerning minimum effective pest controls for the area. When isolated pest outbreaks occur, it might be cheaper to sacrifice part of a crop than to upset the ecological balance of the area. Funds collected from those benefiting from pest control efforts could be used to reimburse those for whom control was not provided.

A simulation model would be most useful for planning the pesticide programs of this organization. It would be considerably simpler than the ecological model. However, it might not fully consider the question of overall environmental pollution.

The Enterprise System

Coming down the systems ladder we find that a third type might be an enterprise system in which the amounts of available machinery, labor, pesticides, and other inputs on an individual farm would be studied to insure their most effective use in producing any given crop, livestock, or other enterprise on that farm. In other words, which enterprises should an individual farmer operate and how should he operate them?

In the enterprise system all of the components that go to make up the individual farmer's decision to produce must be considered. Such matters as how much machinery, capital and labor to use, how best to use it in view of pest infestation and available controls, how should the production be marketed, and other similar problems must be answered. For some problems at this level, linear programming or simpler models may be more appropriate than simulation models.

A related idea which can probably be treated most appropriately at this level was presented at the 1970 annual meeting of the Weed Science Society of America. It concerns pesticides and production technology. The point made was that herbicides have largely been injected into the existing production scheme rather than adapted to their most advantageous use. For instance, we typically follow a plow-till-plant-cultivate scheme with the herbicide being used in place of cultivation. It was suggested at the meeting that perhaps with effective herbicides, some of the other practices should not be used or used at a different phase in the production cycle.

If we look closely at conventional production technologies we find that they were partly designed to facilitate pest control. But with effective pest control measures, some of the old technology may be unnecessary. Based on our ability to control pests chemically, can we change basic production patterns? For instance, could we go to autumn or winter seeding of summer crops? Could we plant two succeeding crops like corn and hay together, one being suppressed until the other is growing? Is it feasible to develop perennial varieties of major crops such as wheat? Should we emphasize greenhouse production of winter vegetables rather than warm climate production with all the vagaries of uncertain supply? Do herbicides by eliminating the major problem of weed control permit this shift? Could we apply fertilizer to last several seasons if we could prevent weeds from depleting it? Do we need to plant crops in rows? Can we use herbicides applied in the winter? Is stripcropping more feasible?

These and many other involved questions could be studied with an appropriate systems analysis model.

The Pest Control System

An even lower level systems analysis might analyze pest control systems. Here we would choose between alternative control measures available to the individual producer such as manual control, chemical control, rotation of crops, biological control, spacing of plants, date of planting, varieties produced, and others. This seems to conform closest to a system of "integrated weed control" now espoused by biological scientists. I believe these decisions could be made more efficiently by simpler models than simulation although many complex, interrelated variables must be considered even at this relatively low level.

The Chemical Control System

The lowest level of systems analysis which I envision as useful could be called chemical pest control. The major components of this system are simply a set of chemicals and devices to apply them. The only basic questions here are what chemical we should use, how it should be applied, and under what circumstances. I'm afraid that some of our extension service recommendations have been made at this level.

Important variables in this model are how much and which chemical should be used. Is the chemical registered for its intended use? When, where, and how shall it be used? Obviously simulation is not the most effective technique here since a well-trained scientist often can mentally solve this system more accurately and quickly than a computer.

Many people would object to this system as unrealistic. But is it? Given the current minimum restraints placed by society on pesticide use, and the current levels of pesticide prices, chemical alternatives are nearly always the most profitable. Then why should farmers and extension specialists use or recommend nonchemical alternatives if their only constraint is production of food and fiber at the lowest possible cost? We must not expect individual farmers to exercise the conscience of total society. They are not equipped for it, either by training or incentive. Society must define its goals more clearly and use pesticides to help advance those goals.

Developing the Ecological Model

In the preceding section we have outlined the several levels of systems we might use for evaluating pesticide policy. Obviously there are economic, social, legal, and technological decisions which must be made at each system level just described. The answers become more complex as we move toward the higher systems. But they also become more relevant to the total society.

We now proceed to develop a model for this ecological system. We judge that the basic purpose and goal of a national pesticide policy is to maximize net social welfare or equivalently to find a basic pesticide policy that will be the best for all of our people. Obviously developing a system to implement this policy will require the best efforts of entomologists, weed scientists, horticulturalists, agronomists, economists, ecologists, medical personnel, and others.

Ideally, we would like to develop a system so that anyone concerned with pesticides can test any policy or pesticide recommendation to see what its effects would be on the environment, on human health, on farm income, and on net social welfare as the policy or recommendation is carried out through time. No individual, however well-trained, can keep all of the needed information in his head, nor can he develop a manual system which will permit timely consideration of all the detail. This is why simulation is so attractive. We use the vastly superior powers of the computer for handling large volumes of data and making the innumerable calculations involved in extending conditional probability estimates through many steps. The simulation model is a powerful device, particularly if used with probability theory. Work such as that reported by speakers at the pesticide policy symposium will be most useful as part of the larger simulation model.

The first major step in simulating an ecological system, assuming a problem has been identified (e.g. possible adverse pesticide effects on the environment), is to develop a flow chart showing the nature and direction of activity and relationships. As a beginning I have attempted to outline some of the interconnected subsystems composing the ecological system. Note in figure 1 that I identify six basic subsystems: Agriculture, government, environment, human, commercial, and the world. The relationship of these subsystems to each other depends on one's point of view. From the standpoint of agriculture (fig. 2), the major component is the agricultural sector with the other subsystems of less significance. Note that the other subsystems are dependent on agriculture. Therefore the needs of agriculture must receive top priority from this viewpoint.

From the ecologist's vantage point figure 3 shows a logical perspective. From this position, the environment is the major component with the other subsystems largely dependent on the correct functioning of the environment. This implies that it must receive first consideration, often at the expense of the other subsystems. Which of these two viewpoints we hold largely determines our position on the current controversy about pesticides. It may even carry over into differences between government agencies as a reflection of their differing missions.

Tables 1-6 at the end of this paper detail some of the areas of each subsector affecting or affected by pesticide policy in the ecological model. These areas seem to cover almost every aspect of our national life. In fact they do. Yet it does not require much imagination to see their relevance. They should be considered when developing a pesticide simulation model. Each of these subsystems could usefully be the subject of a simulation model. Eventually, however, they must be combined to provide an adequate basis for decisionmaking.

I have developed a preliminary flow chart showing directional relationships within the agricultural subsystem (fig. 4). Note that this model would be much simpler if we could treat the amount and location of production as parameters that are exogenous to the model.

For each pesticide use decison I have branched to the pesticide subroutine shown in figure 5. This figure shows in detail, but with considerable condensing, the subroutine required simply to make the economic decison as to whether a pesticide should be used (disregarding other considerations).

I have shown an optional test for registration. For pesticide development work this test could be suppressed. But for many policy decisions it is one of the most important considerations.

In this preliminary work I have made no attempt to specify either type or magnitude of the functional relationships and frequency distributions involved. Note that many interconnecting links to other subsystems are needed to use this one small pesticide subroutine (fig. 5). This indicates the vastly complicated problem that any simulator would have in developing a model of the ecological system.

Since a simulation model of the ecological system would be so large and complex, I believe that ERS should develop it in cooperation with the Agricultural Research Service, State universities, and possibly industry personnel. This is particularly true because ERS personnel may not have the necessary technical background to specify the magnitude and direction of the functional relationships. It would be most desirable if environmental and ecological specialists from the Departments of HEW and Interior and other agencies could also be involved.

I know this model would be costly and time consuming to develop. But I believe the results would more than make up for this by their contribution to a cleaner environment, more efficient production, and faster, more complete responses to national policy questions.

SUBSYSTEMS INVOLVED IN A SIMULATION APPROACH TO PESTICIDE POLICY

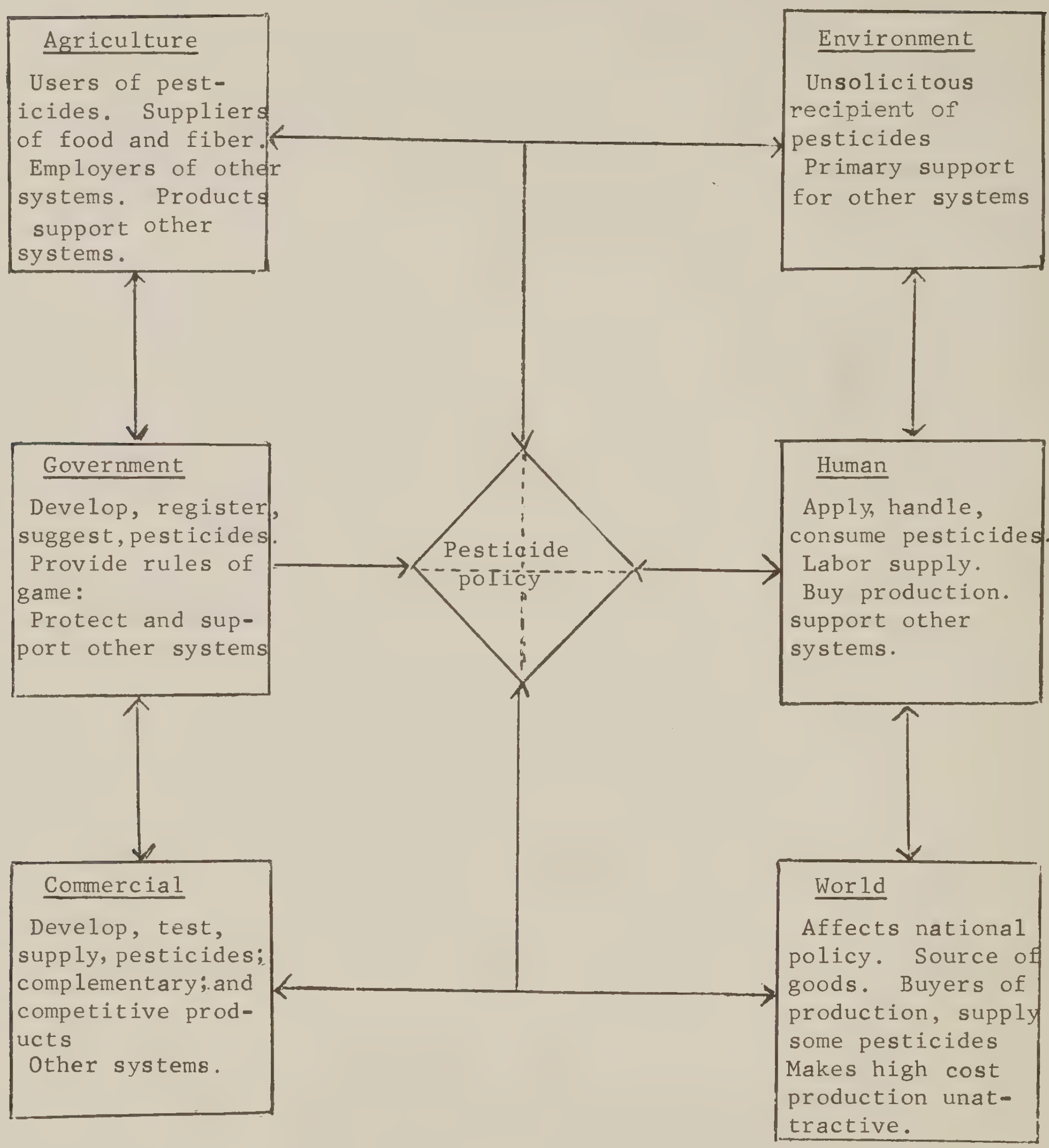


Figure 1

SCHEMATIC DIAGRAM OF THE ECOLOGICAL MODEL VIEWED FROM AN AGRICULTURAL VANTAGE POINT

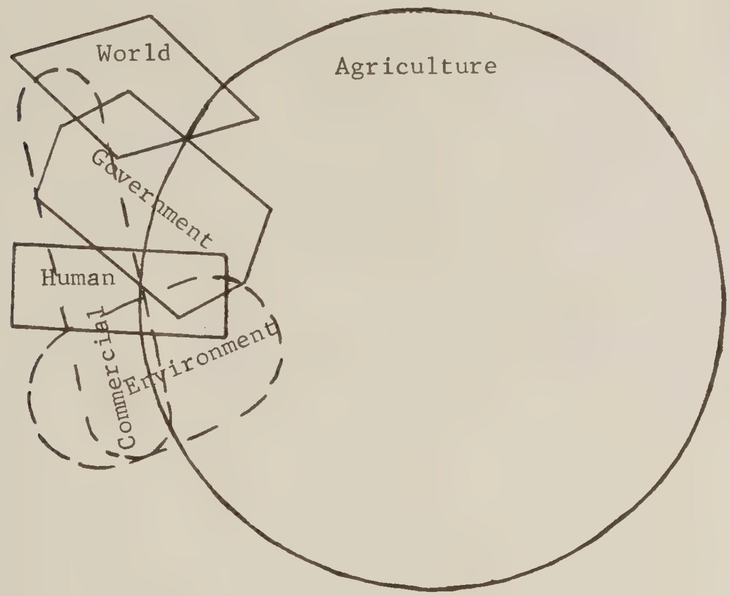


Figure 2

SCHEMATIC DIAGRAM OF THE ECOLOGICAL MODEL VIEWED FROM AN ENVIRONMENTAL VANTAGE POINT

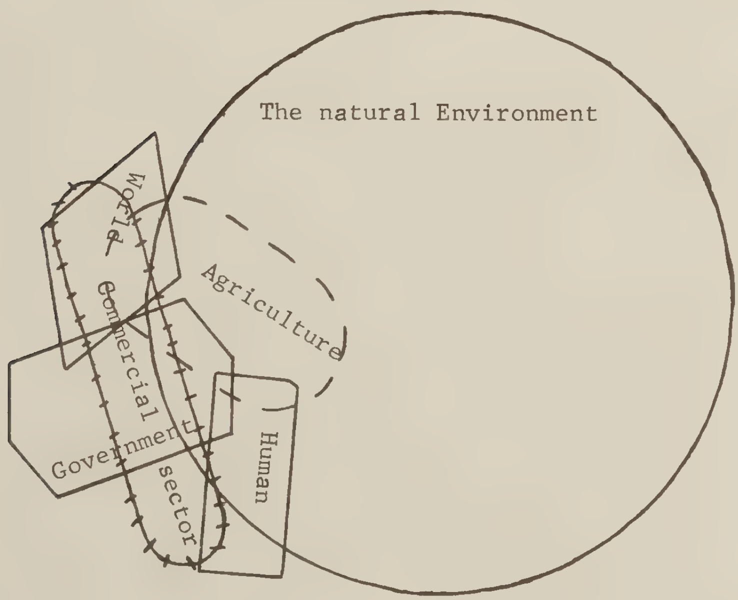


Figure 3

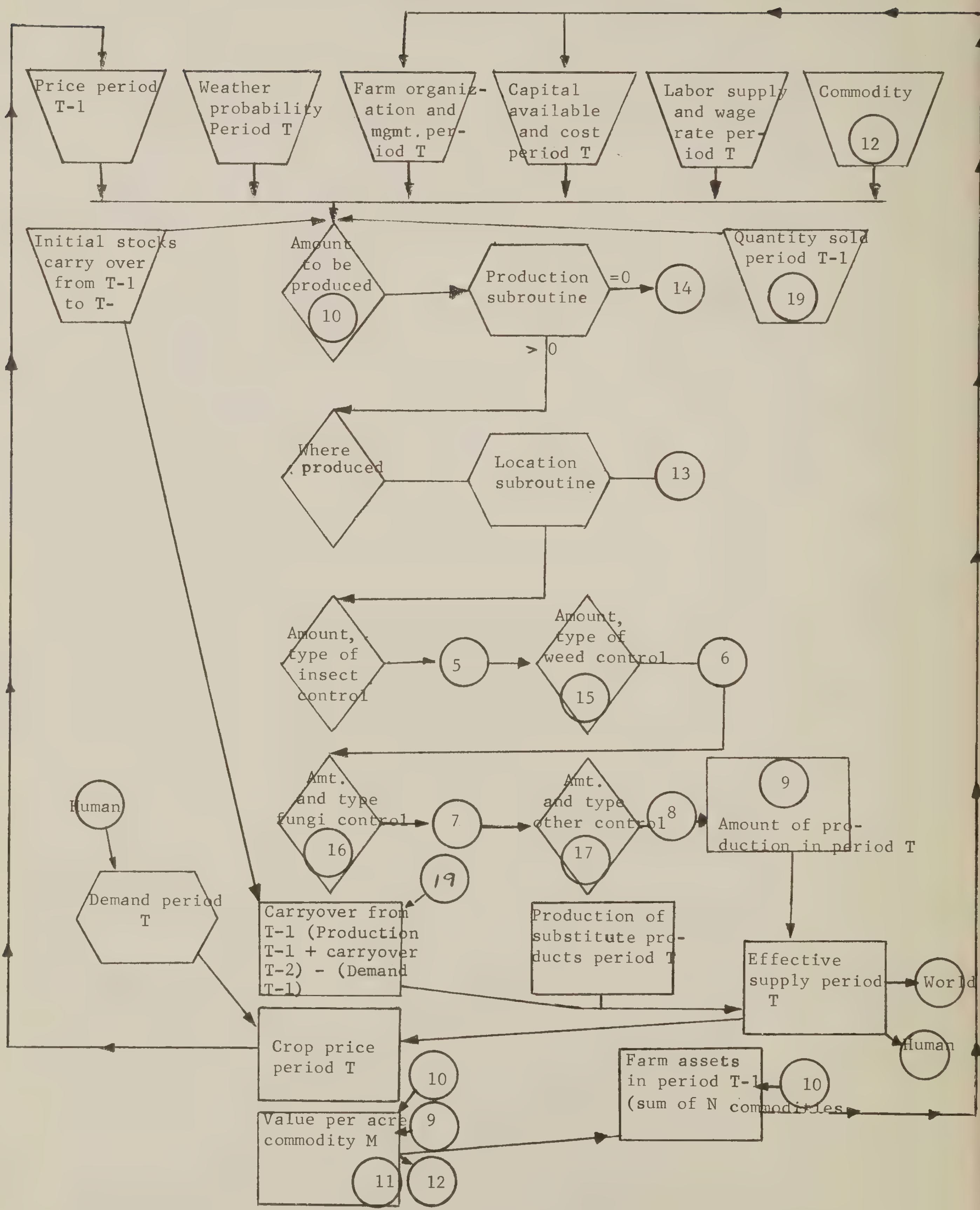
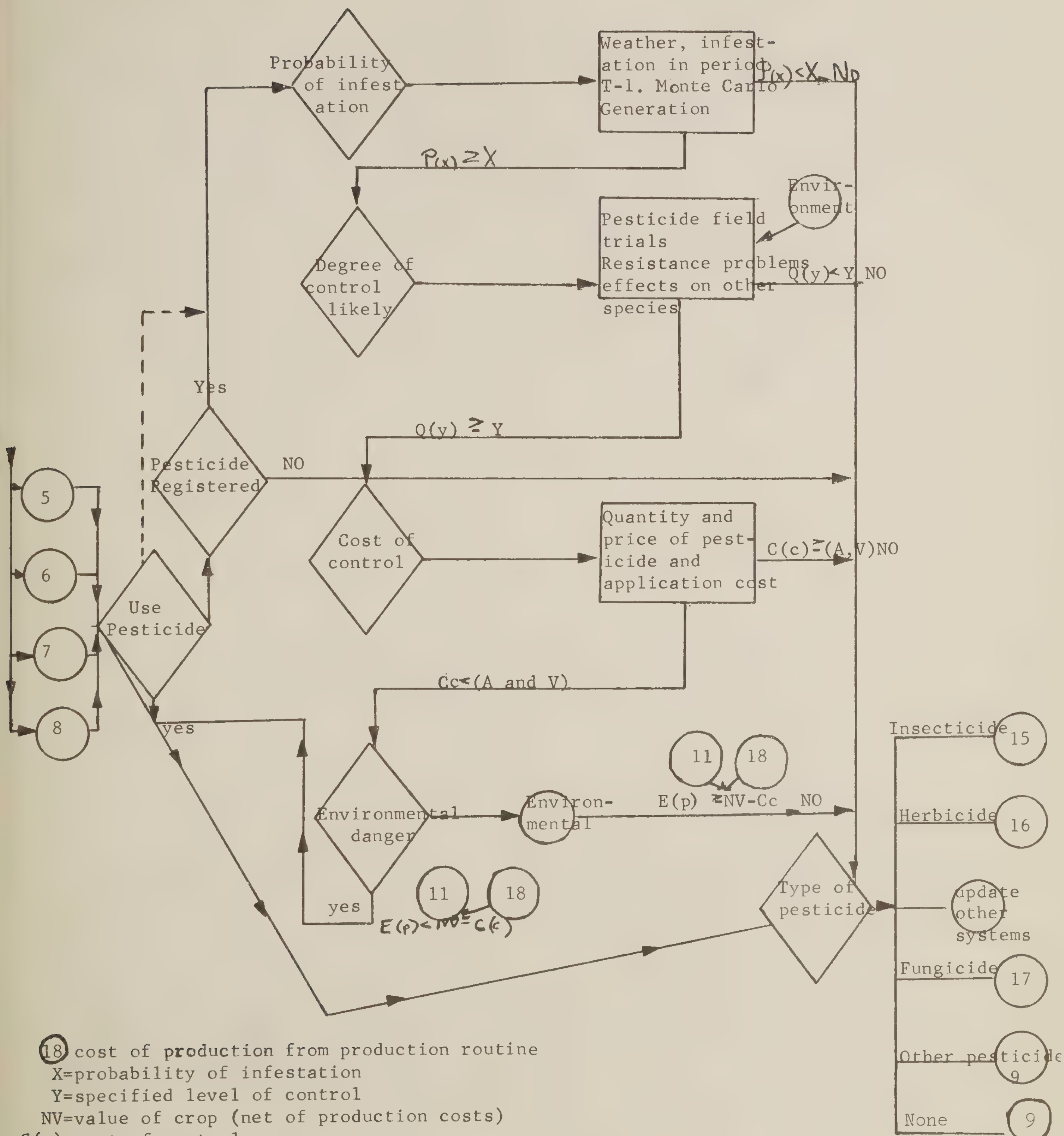

Price period T-1
Weather probability Period T
Farm organization and mgmt. period T
Capital available and cost period T
Labor supply and wage rate period T
Commodity
12
Initial stocks carry over from T-1 to T-
Amount to be produced
10
Production subroutine
=0
14
> 0
Quantity sold period T-1
19
Where produced
Location subroutine
13
Amount, type of insect control
5
Amount, type of weed control
15
6
Amt. and type fungi control
16
7
Amt. and type other control
17
8
9
Amount of production in period T
Human
Demand period T
19
Carryover from T-1 (Production T-1 + carryover T-2) - (Demand T-1)
Production of substitute products period T
Effective supply period T
World
Human
Crop price period T
10
Value per acre commodity M
9
11
12
Farm assets in period T-1 (sum of N commodities
10

Figure 4

PESTICIDE SUBROUTINE



(18) cost of production from production routine
X=probability of infestation
Y=specified level of control
NV=value of crop (net of production costs)
C(c)=cost of control
E(p)=Environmental damage
A=cost of alternative control methods
V=value of crop

Figure 5

Table 1.--Agricultural subsystem components involved in a simulation approach to pesticide policy

Pesticide Policy: Affects or is affected by--

(1) Food supply--
  (a) Acreage manageable
  (b) Losses sustained

(2) Food quality

(3) Cost and value of production

(4) Organization for production

(5) Technological advancement

(6) Location of production

(7) Labor usage

(8) Cropping system (past, present, and future)

(9) Enterprise produced

(10) Capital available

(11) Pest infestation (level and type)

(12) Government programs and policies

(13) Weather and moisture levels

(14) Land tenure arrangements

Table 2.--Government subsystem components involved in a simulation approach to pesticide policy

Pesticide Policy: Affects or is affected by--

(1) Government pesticide use

(2) Social welfare programs

(3) Public opinion

(4) Research programs

(5) Regulatory programs

(6) Educational programs (safety, efficiency)

(7) Farm use of pesticides, complementary, competitive products

(8) Pesticide manufactures

((9) Imports and exports

(10) Labor and employment

(11) Standard of living

(12) Supply of food, fiber

(13) Demand for food and fiber

(14) Liability for pesticide misuse

(15) Quality of environment

(16) Quality of human health

(17) Kinds of pesticides developed

Table 3.--Environment subsystem components involved in a simulation approach to pesticide policy

Pesticide Policy: Affects or is affected by--

(1) Effect on target species (e.g. resistance)

(2) Effect on predatory species (food chain)

(3) Effect on target species prey (does it become pest)

(4) Effect on competitive species (particularly weeds)

(5) Effect on exposed species (persistency, toxicity)

(6) Effect on nonrelated species (solubility, persistency)

(7) Effect on general environment:
- (a) $O_2 \rightleftarrows CO_2$ balance
- (b) Hydrological cycle
- (c) Soil pollution
- (d) Water pollution
- (e) Aesthetics
- (f) Human health
- (g) Support of other systems
- (h) Public opinion

(8) Effect of level of infestation

Table 4.--Commercial subsystem components involved in a simulation approach to pesticide policy

Pesticide Policy: Affects or is affected by--

(1) Kind and number of pesticides developed

(2) Initiation of registration

(3) Safety checks

(4) Marketing channels

(5) Instructions for use

(6) Financing

(7) Corporate structure and profits

(8) Demand for and supply of fertilizer, machinery, other technology

(9) Wages paid and people employed

(10) Funding of public and private research, educational and welfare programs

(11) Corporate liability for adverse pesticide effects

Table 5.--Human subsystem components involved in a simulation approach to pesticide policy

Pesticide Policy: Affects or is affected by--

(1) Concentration of population

(2) Attitudes of people

(3) Economic level of people

(4) Size and composition of labor force

(5) Consumption of pesticides in food

(6) Exposure to pesticides in handling and applying

(7) Type and quality of food and fiber purchased

(8) Expenditure for food and fiber

(9) Comfort of surroundings

(10) Health and well-being

(11) Amount of leisure time

(12) Amount of strenuous labor or exertion required

(13) Income available for luxury items

Table 6.--World subsystem components involved in a simulation approach to pesticide policy

Pesticide Policy: Affects or is affected by--

(1) Competitive food and fiber situation

(2) Government-sponsored food and fiber distribution abroad

(3) Labor supply and wage rate abroad

(4) Health and safety requirements for exported food

(5) Quality of food and fiber required for export

(6) Need to be nationally self-sufficient (security)

(7) World public opinion

(8) World pesticide policies

(9) Agricultural production costs

(10) Balance of payments (low cost production spurs exports)

(11) Abundance of production

(12) World environment

(13) World health

DATA SOURCES FOR ECONOMIC EVALUATION OF PESTICIDES

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Economic research to evaluate the total impact of pesticide use requires much information that is difficult to obtain. Researchers need data on costs and benefits, direct as well as indirect, if any. The data needs discussed here refer to comprehensive statistical information. I will review present and potential sources of statistical data, but make no attempt to give complete coverage.

At present, there are limited numerical data of the type economists would like for overall evaluations. In fact, of three general areas in which data are needed--use and direct costs, benefits, and detrimental effects--detailed information is available only for use and direct costs.

More and more information is becoming available on farm use of pesticides. We may soon have a fairly good impression of how much of which pesticide products farmers use on what crops in different sections of the country. In addition, for most pesticides we know the formulation type, whether it is custom applied, banded or broadcast, and whether it is applied say one or 10 times. Information of this nature is available from USDA surveys, from census data, from various State studies, and from other sources.

However, the existence of any systematic tabulation of pesticide use and effects ends here. While we have several recent enumerations attempting to identify farm use of pesticides, there is almost no statistical information on nonfarm use (by public agencies, industry, and homeowners). And to my knowledge, there are no current proposals for obtaining information on these areas of use. Yet farmers account for only slightly more than half of all pesticides used in the United States.

Probably Federal and State government use could be determined with little difficulty by obtaining reports from those agencies that use pesticides. However, information on local government, industrial, and home use might be more difficult to obtain.

Regarding the beneficial aspects of pesticides, many studies are probing the effects of a certain product on a particular crop or kind of livestock in a certain area of the Nation. However, statistical summations or evaluations of these studies on a broad scale are lacking.

If statistical data for evaluating the benefical aspects of pesticides are limited, data on the detrimental effects are even more scarce. Again many individual studies cover the effects of some pesticide on a species of wildlife in some section of the country. Although many of these are brought together in a report by the Department of Interior, there are apparently no summary statistics that show how these chemicals affect the Nation's animal species as a whole, or how they affect all life.

A major weakness in most information on farm pesticide use is the lack of yield data associated with the use of pesticides on certain classes of crops and livestock. In our own surveys we have not obtained such information. In addition there is a complete lack of pest infestation data associated with the pesticide use. And there is a general lack of information on related inputs by kind of crop or livestock.

ERS NATIONWIDE SURVEYS

The Economic Research Service conducted nationwide surveys of farm pesticide use in 1964 and in 1966. Detailed information was obtained on individual commercial pesticide preparations used by farmers on individual crops and kinds of livestock. These data were expanded to U.S. total and regional estimates of pesticide use for leading chemicals and leading kinds of crops and livestock.

We have published a series of reports based on these surveys. The reports include information on amounts spent by farmers for pesticides used on different classes of crops and livestock; quantitites of specific pesticides used on different crop and livestock categories; and acres of different crops treated with individual pesticide products. They also show formulation types, equipment used for application, and extent of custom application.

In general, we feel that our estimates for the major pesticides on the major crop and livestock categories in the major production regions, are reasonably good. For minor products, crops, or regions, our estimates may be rather weak. These impressions were reinforced in discussions with chemists, biologists, and industry market researchers.

ERS COTTON SURVEYS

The cotton surveys conducted by ERS probably obtained the best available aggregate data for cost-benefit pesticide analysis of a specific crop. These studies, undertaken at congressional request, provide guidance in developing cotton production programs. Information was obtained for 1964, 1965, and 1966 and is currently being gathered for 1969.

These surveys obtain approximately the same information as the ERS surveys covering the use of pesticides on cotton. In addition they provide information on many other inputs and practices directly related to the production of cotton--information which is not available elsewhere. They provide cross-sectional and some time-series data.

They include information on fertilizer, labor, machinery, and other direct inputs; and on such practices as solid or skip-row planting, and irrigation. Thus they identify the contribution of pesticides more accurately than do the more general surveys, such as our own and those of the Census.

SOIL MONITORING PROGRAM

The soil monitoring program started on a limited basis in 1965 at six locations scattered around the country. The program appeared to have great possibilities for obtaining information on pesticide use, identifying pesticide residues in soils and water, and studying how pesticides affect crops, domestic animals, aquatic organisms, wildlife, and soil organisms.

The monitoring program was scheduled to be expanded eventually to about 15,000 ten-acre sites across the United States. Of these about 10,000 were to be on farmland and the rest on other land. Cropping and pesticide use information was to be obtained annually, together with soil residue samples at 4-year intervals.

The expanded program got underway in 1968 with a total of about 2,000 sites, of which 1,800 were on cropland. However, the program was for all practical purposes discontinued in 1969. Approximately 400 sites in the Corn Belt and 200 in the Cotton Belt were represented in 1969. The future of the program at present looks doubtful. If the program is revived, it could provide economists with much information on what specific pesticide products are used on various crops around the country, as well as information on how pesticide use affects the environment.

Soil monitoring data obtained under the program for Illinois were compared with data obtained by ERS and by the Illinois State Department of Agriculture. All three studies showed consistency in the relative distribution of acreages treated with different pesticide products. Whether the soil monitoring data could actually be expanded to total use--either national, State, or regional--is questionable. However, these data might guide us in distributing the use of different pesticides on different crops.

WEED CONTROL SURVEYS

Periodic weed control surveys are conducted by USDA's Agricultural Research Service, Economic Research Service, and Extension Service. Findings of these surveys have been published for 1959, 1962, and 1965 and are being compiled for 1967. The surveys contain estimated data on specific types of weed infestation and on the extent and cost of herbicide use on agricultural, forest, and other land areas. Information is provided on all major farm crops. The estimates are based on reports from extension crop and weed scientists in each State.

These reports could provide some basis for comparing weed infestation, method and cost of control, and the effectiveness of control. They also could provide valuable information on trends.

CENSUS OF AGRICULTURE

The Census of Agriculture obtains information on pesticide use. But apparently the Census staff has not decided on a reporting procedure to use on a continuing basis. Before 1964 the census had obtained little information on pesticides, except for a special farm-cost survey in 1955.

In 1964 the census collected more pesticide data, including information on costs of custom application. For several crops, it obtained information on farms reporting and on acres treated with insect and disease control chemicals and weed control materials. Also, it reported farms using livestock pesticides and listed separately the number of cattle and calves, hogs, sheep, and goats treated.

Information requested in the general census survey form for 1969 was reduced considerably. The 1969 approach was to limit general questions for all farmers and ask appropriate questions for different types of farm operations. Pesticide information was limited to acres treated and expenditures for various types of pesticides with little breakdown by type of crop or class of livestock use.

Some of the individual census type-of-farm surveys obtain considerable information on pesticides. For example, the survey of grain, bean, and pea crop farms obtains data on acres treated, times treated, ownership of application equipment, and custom application separately for insect, disease, and weed control for 18 different crops.

The problem with the special type-of-farm surveys is that there is no way to bring all the information together and obtain U.S. total usage for many items, since appropriate questions are asked only for certain types of farms.

An advantage of the type-of-farm survey is that some comparability can be obtained between farms. Because the different farms surveyed are classified according to similar land, labor, and capital inputs, the impact of pesticide use is easier to identify than in a generalized survey.

REGIONAL STUDIES

Another possible source of information on pesticide use and effects is regional studies. An excellent example is the Pesticide Committee report of the "Four-State Enforcement Conference on Pollution of Lake Michigan." The States involved--Wisconsin, Illinois, Michigan, and Indiana--are concerned about the general deterioration of Lake Michigan, and are studying pesticides as well as other types of pollutants in the lake.

As part of this pesticide pollution study, a variety of research activities were undertaken. These include: (1) surveys of use by farmers, (2) a survey of the manufacture and formulation of pesticides in the area, (3) monitoring programs to measure residues in the soil and water, and (4) tissue tests to determine pesticide accumulation in aquatic animals.

Soil and water monitoring activities are being conducted by USDA's Agricultural Research Service, by the Interior Department's Fish and Wildlife Service, and by the Wisconsin Alumni Research Foundation.

Farm use of pesticides in the Lake Michigan area is being studied by five State departments of agriculture (Minnesota is included as well as the four Lake Michigan study States). These five have prepared farm surveys on insecticide and herbicide use, obtaining data comparable to those obtained for several years by the Illinois Department of Agriculture on the use of herbicides.

A report on insecticide-herbicide use was published by the Wisconsin Department of Agriculture for the 1969 crop year. It was based on over 7,000 questionnaires returned by Wisconsin farmers. The replies represent about 6 percent of the farmland in the State. Information for some of the other States has also been tabulated.

Other regional pesticide evaluation studies, possibly even interregional ones, may be undertaken in the future as the effects of pesticide use can seldom be contained locally.

STATE GOVERNMENT STUDIES

In the past, State departments of agriculture have not generally obtained much statistical information on pesticide use. Most States report pesticides registered locally but little else is reported. A new situation is developing, however, because of the concern over pesticide pollution, and some States now require pesticide reporting as part of control and restriction programs.

The program undertaken in Maryland may illustrate what is likely to come in this area. Under legislation passed in the last session of its legislature, Maryland will obtain considerable data on local pesticide sales. All dealers selling pesticides in Maryland must now not only have permits to sell but also record and report to the State office all sales of aldrin, BHC, chlordane, DDT, lindane, and heptachlor. In addition, custom applicators must be licensed and must report application amounts and sites of certain pesticide chemicals.

CURRENT PROJECT REVIEW SYSTEMS

The Current Research Information System (CRIS) and the Smithsonian Institution Science Information Exchange are data banks. They provide brief resumes of objectives and study procedures, of current projects in the USDA, State agricultural experiment stations, and other research organizations. A researcher can review the summary statements and write to the researchers for additional information if he desires.

A review of the information obtained through the Smithsonian retrieval system shows some projects that appear promising. For example, some of the studies look into such matters as: (1) comparisons of cost of pest control practices currently used in marketing farm products with costs of available alternatives, (2) economic evaluations of general pasture weed control, (3) comparative costs of chemical and mechanical weed controls, (4) evaluation of weed control, yields, costs, and other pertinent data about herbicide use on corn, (5) use of biological weed controls to reduce cotton production costs and pesticides used, and (6) development of integrated programs to reduce the costs of cotton insect control.

CRIS has about 20,000 active projects, and 5,000 or 6,000 expired projects on file at any one time. Expired projects are kept on file for about a year until published reports can be catalogued. The system has been developing over about 3 years, but has been operational only since July 1969.

DATA FROM MANUFACTURERS

The U.S. Tariff Commission and the Bureau of the Census publish data on production, sales, imports, exports, and inventories of pesticide materials. This information is based on reports from pesticide manufacturers. Until recently these were about the only sources of aggregate statistical data on pesticides.

Tariff Commission and Census Bureau data should provide fairly good estimates of total U.S. pesticide use by subtracting exports from production. It is also possible to determine nonfarm use of pesticides indirectly by subtracting farm use from domestic use.

Pesticide data from these sources as well as from other government sources are summarized and consolidated in the "Pesticide Review," a report published annually by the Agricultural Stabilization and Conservation Service.

SUMMARY AND EVALUATION

Certain information is available on farm use and costs of pesticides. But there is little or none on nonfarm pesticide use, which is nearly 50 percent of the total. Also there is little general information on yield effects or infestation levels associated with pesticide use, and very little general data on the detrimental effects of pesticide use.

Worthwhile data improvement projects might be: (1) to obtain yield, quality, and infestation data along with farm use, (2) to determine the extent and nature of nonfarm use of pesticides, and (3) to coordinate, consolidate, and evaluate existing studies of the beneficial and detrimental aspects of pesticides.

THE EFFECT OF RESTRICTING DDT OR CHLORINATED HYDROCARBONS ON COMMERCIAL COTTON FARMS IN THE MISSISSIPPI DELTA

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The Mississippi River Delta region of Arkansas, Louisiana, and Mississippi is an area of intensive insecticide and herbicide use. As a native of the Delta and a landowner, as well as a researcher working in this region, I know you can understand that I have many misgivings about this paper. To live in the Mississippi Delta is to know firsthand the dangers of agricultural pesticides. As a boy, the river that I grew up alongside yielded many a catfish and bream to my cane pole and worms. To fish that river today would be as futile as fishing in my kitchen sink. Yet some of the things that killed this river, and all that killed it were not pesticides, have more than doubled agricultural production in this region. That is the issue. How do we preserve our environment and at the same time maintain farm production and income?

I could discuss with you the impact of restricting selected pesticides on cotton farms in California, Texas, or South Carolina. But the technical problems in these regions vary greatly, and I do not have access to the entomologists and weed control agronomists in these areas who have sufficient knowledge and experience to speculate on the impact of restricting certain pesticides. For this reason I am going to discuss the possible impact of this in the Mississippi Delta.

At the outset we could conclude that any region which relies heavily on insecticides and herbicides to produce cotton would be greatly affected by the restriction of certain of these materials. Because of the time I am going to limit my discussion to insecticides. It would be well to point out that 15 years ago Mississippi Delta farmers used one chemical application along with 6 to 10 mechanical cultivations and 25 hours of hand weeding to control grass and weeds in cotton. Today they use three to six chemicals in six or more applications along with 4 to 8 hours of hand weed control and four to six mechanical cultivations. Without herbicides these farmers cannot produce cotton because the labor to chop and hoe is gone and would cost too much if it were available.

Let us look at insect control on a representative large commercial cotton farm in the Mississippi Delta with two different management situations. This farm situation is an attempt to describe an average cotton farm in the Mississippi

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1/ Stationed at the Delta Branch Experiment Station, Stoneville, Miss.

Delta with 500 or more acres of cropland. Farms in this group make up only 16.5 percent of the farms in the 10 Delta counties but account for 77.8 percent of the cropland.2/ The cropland organization of this farm is presented in table 1. Research work at the Delta Branch Experiment Station at Stoneville, Miss., indicates that few farms could be accurately described as average.

Among farmers who consistently produce high yields of cotton (800 or more pounds of lint per acre), two management approaches are generally taken regarding insect control. One group tends to rely on many applications of insecticides on a more or less automatic schedule. This group will be referred to as high-use insecticide farmers. The other group tends to make fewer applications of insecticide based on an "as needed" basis rather than a schedule. This group will be referred to as low-use insecticide farmers. The kinds, rates, and number of applications of insecticides are based on surveys taken from 214 farmers on the 1967 and 1968 crops. The kinds, rates, and numbers of applications of insecticides without DDT or chlorinated hydrocarbons are based on the best estimates of Federal and State research entomologists located at the Delta Branch Experiment Station.3/ Without the help of these research workers this paper would have been impossible to prepare.

We will look at the farm first under the high-use insecticide situation. Table 2 presents insect control practices and costs associated with the high-use farmer in a typical year with DDT being available. In this situation the farm is using a systemic insecticide at planting plus one postemergence application of insecticide for thrips control. This is followed by one application of insecticide for plant bugs in mid- or late June. In mid-July the farmer begins to control bollworms and boll weevils with a mixture of toxaphene-DDT-methyl parathion on a fairly rigid schedule. In late August he switches to two applications of straight methyl parathion to suppress the late hatch of bollworms. After this he switches back to the DDT mixture and continues treatments until late September. This program results in 17 applications of insecticides which costs $31.99 per acre. Twelve of these 17 applications were with DDT mixtures.

Table 3 presents the best estimate of what this farmer would do if he were not allowed to use DDT. He would probably switch to a toxaphene-methyl parathion mixture which would cause him to increase his applications to 20. He must treat more frequently with this mixture to get the same control he would get from the mixture with DDT in it. His costs under this insecticide program would be $48.94 per acre.

Table 4 presents the best estimate of what this farmer would do at the present time if he could use no chlorinated hydrocarbons. Methyl parathion is used exclusively for bollworm and boll weevil control. Twenty-one applications of insecticides are made for a total insect control cost of $38.18.

2/ From the 1964 Census of Agriculture.
3/ Dial F. Martin, Laboratory Director, Bioenvironmental Insects Control Research Laboratory, ENT, ARS, USDA; Theodore R. Pfrimmer, Investigations Leader, Cotton Insects Research Branch, ENT, ARS, USDA; and Marion L. Laster, Entomologist, Delta Branch Experiment Station, Stoneville, Miss.

Table 1.--Organization for a representative large commercial cotton farm, Mississippi Delta, 1969

Crop	Acres
Cotton	304
Soybeans 1/	506
Wheat	74
Idle	100
Total	984
Less double crop	84
Cropland in farm	900

1/ 84 acres of soybeans double-cropped after wheat.

It would be proper to ask why this farmer would not shift to methyl parathion instead of a toxaphene-methyl parathion mixture as it would be $9.76 per acre cheaper. Table 5 presents the expected insect control program for this farmer after several years of exclusive use of methyl parathion. The number of applications has not increased but the rate applied per acre is up. Based on experiences in South Texas and Mexico 4/ it has been found that the bollworm and the tobacco budworm become resistant to methyl parathion very rapidly. This necessitates increasing rates and increasing costs. The program would cost $47.18 per acre. Based on experience in South Texas and Mexico, entomologists at the Delta Branch Experiment Station feel that after a few years it could require as much as 3 or 4 pounds of methyl parathion per acre per application, resulting in poorer control and lower yields.

Table 6 presents the control program for a low insecticide use farmer at the present time. If needed he will treat one time for thrips after the cotton comes up. He delays his initial application for bollworms and boll weevils until late July. This protects the predators which eat bollworm larvae and suppress the population of bollworms in the field. In mid-August he will make three applications of methyl parathion very close together to suppress the late bollworm hatch and will then switch back to the DDT mixture. This farmer generally quits treating by mid-September. He has made 10 applications of insecticides at a cost of $18.46 per acre and will make as much cotton as the farmer who poisoned a great deal more.

Table 7 presents the insect control program for the low-use farmer who did not use DDT. It is a parallel of the high-use farmer and requires 12 applications of insecticides at a cost of $27.26 per acre to get the same control as with DDT.

4/ Lukefahr, M.J. The Tobacco Budworm Situation in the Lower Rio Grande Valley and Northern Mexico. Second Annual Texas Conference on Insect, Plant Disease, Weed, and Brush Control, Proc., pp. 140-145, Feb. 24-26, 1970.

Table 2.--Insecticide use on an acre of cotton in the Mississippi Delta for a high-use producer with DDT, Situation I

Operation	Total ground machine costs	Aerial application costs	Labor costs	Materials			
				Kind	Rate per acre	Costs	Date applied
	Dollars	Dollars	Dollars			Dollars	
Apply systemic insecticide	0.15	---	0.02	Di-Syston	4 lbs.	1.00	5-1
Poison for thrips	.49	---	.15	Bidrin	0.1 lb.	.34	5-21
Poison for plant bugs	.49	---	.15	Bidrin	.1 lb.	.34	6-15
Poison for bollworm and boll weevil:							
1st application	.49	---	.15	1/4-2-0.5	.5 gal.	1.30	7-15
2nd application	.49	---	.15	1/4-2-0.5	.5 gal.	1.30	7-22
3rd application	---	0.85	.02	1/4-2-0.5	.5 gal.	1.30	7-29
4th application	.49	---	.15	1/4-2-0.5	.5 gal.	1.30	8-5
5th application	.49	---	.15	1/4-2-0.5	.5 gal.	1.30	8-15
6th application	---	.85	.02	1/4-2-0.5	.5 gal.	1.30	8-20
7th application	---	.85	.02	1/4-2-0.5	.5 gal.	1.30	8-25
8th application	---	.85	.02	Methyl Para.	1 lb.	1.00	8-28
9th application	---	.85	.02	Methyl Para.	1 lb.	1.00	9-1
10th application	---	.85	.02	1/4-2-0.5	.5 gal.	1.30	9-5
11th application	---	.85	.02	1/4-2-0.5	.5 gal.	1.30	9-10
12th application	---	.85	.02	1/4-2-0.5	.5 gal.	1.30	9-15
13th application	---	.85	.02	1/4-2-0.5	.5 gal.	1.30	9-20
14th application	---	.85	.02	1/4-2-0.5	.5 gal.	1.30	9-25
Totals	3.09	8.50	1.12			19.28	
Total insect control costs						31.99	

1/ 4 pounds Toxaphene, 2 pounds DDT, 0.5 pound Methyl Parathion.

Table 3.--Insecticide use on an acre of cotton in the Mississippi Delta for a high-use producer without DDT, Situation II

Operation	Total ground machine costs	Aerial application costs	Labor costs	Materials			
				Kind	Rate per acre	Costs	Date applied
	Dollars	Dollars	Dollars			Dollars	
Apply systemic insecticide	0.15	---	0.02	Di-Syston	4 lbs.	1.00	5-1
Poison for thrips	.49	---	.15	Bidrin	0.1 lb.	.34	5-21
Poison for plant bugs	.49	---	.15	Bidrin	.1 lb.	.34	6-15
Poison for bollworm and boll weevil:							
1st application	.49	---	.15	1/6-3	1 qt.	1.35	7-15
2nd application	.49	---	.15	1/6-3	1 qt.	1.35	7-20
3rd application	.49	---	.15	1/6-3	1 qt.	1.35	7-25
4th application	---	0.85	.02	1/6-3	1 qt.	1.35	7-30
5th application	.49	---	.15	1/6-3	1 qt.	1.35	8-5
6th application	.49	---	.15	1/6-3	1.5 qts.	2.03	8-10
7th application	.49	---	.15	1/6-3	1.5 qts.	2.03	8-15
8th application	---	.85	.02	1/6-3	1.5 qts.	2.03	8-20
9th application	---	.85	.02	Methyl Para.	1 lb.	1.00	8-25
10th application	---	.85	.02	Methyl Para.	1 lb.	1.00	8-28
11th application	---	.85	.02	1/6-3	1.5 qts.	2.03	9-1
12th application	---	.85	.02	1/6-3	1.5 qts.	2.03	9-5
13th application	---	.85	.02	1/6-3	2 qts.	2.70	9-10
14th application	---	.85	.02	1/6-3	2 qts.	2.70	9-15
15th application	---	.85	.02	1/6-3	2 qts.	2.70	9-20
16th application	---	.85	.02	1/6-3	2 qts.	2.70	9-25
17th application	---	.85	.02	1/6-3	2 qts.	2.70	9-30
Totals	4.07	9.35	1.44			34.08	
Total insect control costs						48.94	

1/ 6 pounds Toxaphene, 3 pounds Methyl Parathion.

Table 4.--Insecticide use on an acre of cotton in the Mississippi Delta for a high-use producer without chlorinated hydrocarbons (present), Situation III

Operation	Total ground machine costs	Aerial application costs	Labor costs	Materials			
				Kind	Rate per acre	Costs	Date applied
	Dollars	Dollars	Dollars		Pounds	Dollars	
Apply systemic insecticide	0.15	---	0.02	Di-Syston	4	1.00	5-1
Poison for thrips	.49	---	.15	Bidrin	0.1	.34	5-21
Poison for plant bugs	.49	---	.15	Bidrin	.1	.34	6-15
Poison for bollworm and boll weevil:							
1st application	.49	---	.15	Methyl Para.	1	1.00	7-15
2nd application	.49	---	.15	Methyl Para.	1	1.00	7-20
3rd application	.49	---	.15	Methyl Para.	1	1.00	7-25
4th application	---	0.85	.02	Methyl Para.	1	1.00	8-1
5th application	.49	---	.15	Methyl Para.	1	1.00	8-4
6th application	.49	---	.15	Methyl Para.	1	1.00	8-7
7th application	.49	---	.15	Methyl Para.	1	1.00	8-15
8th application	.49	---	.15	Methyl Para.	1	1.00	8-18
9th application	---	.85	.02	Methyl Para.	1	1.00	8-21
10th application	---	.85	.02	Methyl Para.	1	1.00	8-24
11th application	---	.85	.02	Methyl Para.	1	1.00	8-27
12th application	---	.85	.02	Methyl Para.	1	1.00	8-30
13th application	---	.85	.02	Methyl Para.	1.5	1.50	9-2
14th application	---	.85	.02	Methyl Para.	1.5	1.50	9-7
15th application	---	.85	.02	Methyl Para.	1.5	1.50	9-12
16th application	---	.85	.02	Methyl Para.	1.5	1.50	9-17
17th application	---	.85	.02	Methyl Para.	1.5	1.50	9-22
18th application	---	.85	.02	Methyl Para.	1.5	1.50	9-27
Totals	4.56	9.35	1.59			22.68	
Total insect control costs						38.18	

Table 5.--Insecticide use on an acre of cotton in the Mississippi Delta for a high-use producer without chlorinated hydrocarbons (future), Situation IV

Operation	Total ground machine costs	Aerial application costs	Labor costs	Materials			
				Kind	Rate per acre	Costs	Date applied
	Dollars	Dollars	Dollars		Pounds	Dollars	
Apply systemic insecticide	0.15	---	0.02	Di-Syston	4	1.00	5-1
Poison for thrips	.49	---	.15	Bidrin	0.1	.34	5-21
Poison for plant bugs	.49	---	.15	Bidrin	.1	.34	6-15
Poison for bollworm and boll weevil:							
1st application	.49	---	.15	Methyl Para.	1.5	1.50	7-15
2nd application	.49	---	.15	Methyl Para.	1.5	1.50	7-20
3rd application	.49	---	.15	Methyl Para.	1.5	1.50	7-25
4th application	---	0.85	.02	Methyl Para.	1.5	1.50	8-1
5th application	.49	---	.15	Methyl Para.	1.5	1.50	8-4
6th application	.49	---	.15	Methyl Para.	1.5	1.50	8-7
7th application	.49	---	.15	Methyl Para.	1.5	1.50	8-15
8th application	.49	---	.15	Methyl Para.	1.5	1.50	8-18
9th application	---	.85	.02	Methyl Para.	1.5	1.50	8-21
10th application	---	.85	.02	Methyl Para.	1.5	1.50	8-24
11th application	---	.85	.02	Methyl Para.	1.5	1.50	8-27
12th application	---	.85	.02	Methyl Para.	1.5	1.50	8-30
13th application	---	.85	.02	Methyl Para.	2.0	2.00	9-2
14th application	---	.85	.02	Methyl Para.	2.0	2.00	9-7
15th application	---	.85	.02	Methyl Para.	2.0	2.00	9-12
16th application	---	.85	.02	Methyl Para.	2.0	2.00	9-17
17th application	---	.85	.02	Methyl Para.	2.0	2.00	9-22
18th application	---	.85	.02	Methyl Para.	2.0	2.00	9-27
Totals	4.56	9.35	1.59			31.68	
Total insect control costs						47.18	

Table 6.--Insecticide use on an acre of cotton in the Mississippi Delta for a low-use producer with DDT, Situation V

Operation	Total ground machine costs	Aerial application costs	Labor costs	Materials			
				Kind	Rate per acre	Costs	Date applied
	Dollars	Dollars	Dollars			Dollars	
Poison for thrips	0.49	---	0.15	Bidrin	0.1 lb.	0.34	5-10
Poison for bollworm and boll weevil:							
1st application	.49	---	.15	1/4-2-0.5	.5 gal.	1.30	7-25
2nd application	.49	---	.15	1/4-2-0.5	.5 gal.	1.30	8-1
3rd application	.49	---	.15	1/4-2-0.5	.5 gal.	1.30	8-8
4th application	.49	---	.15	Methyl Para.	1 lb.	1.00	8-15
5th application	---	0.85	.02	Methyl Para.	1 lb.	1.00	8-18
6th application	.49	---	.15	Methyl Para.	1 lb.	1.00	8-21
7th application	---	.85	.02	1/4-2-0.5	.5 gal.	1.30	8-28
8th application	---	.85	.02	1/4-2-0.5	.5 gal.	1.30	9-5
9th application	---	.85	.02	1/4-2-0.5	.5 gal.	1.30	9-15
Totals	2.94	3.40	.98			11.14	
Total insect control costs						18.46	

1/ 4 pounds Toxaphene, 2 pounds DDT, 0.5 pound Methyl Parathion.

Table 7.--Insecticide use on an acre of cotton in the Mississippi Delta for a low-use producer without DDT, Situation VI

Operation	Total ground machine costs	Aerial application costs	Labor costs	Materials			
				Kind	Rate per acre	Costs	Date applied
	Dollars	Dollars	Dollars			Dollars	
Poison for thrips	0.49	---	0.15	Bidrin	0.1 lb.	0.34	5-10
Poison for bollworm and boll weevil:							
1st application	.49	---	.15	1/6-3	1 qt.	1.35	7-25
2nd application	.49	---	.15	1/6-3	1 qt.	1.35	8-1
3rd application	.49	---	.15	1/6-3	1 qt.	1.35	8-5
4th application	.49	---	.15	1/6-3	1 qt.	1.35	8-10
5th application	---	0.85	.02	Methyl Para.	1 lb.	1.00	8-15
6th application	.49	---	.15	Methyl Para.	1 lb.	1.00	8-18
7th application	---	.85	.02	Methyl Para.	1 lb.	1.00	8-21
8th application	---	.85	.02	1/6-3	1.5 qts.	2.03	8-28
9th application	---	.85	.02	1/6-3	1.5 qts.	2.03	9-2
10th application	---	.85	.02	1/6-3	2 qts.	2.70	9-7
11th application	---	.85	.02	1/6-3	2 qts.	2.70	9-15
Totals	2.94	5.10	1.02			18.20	
Total insect control costs						27.26	

1/ 6 pounds Toxaphene, 3 pounds Methyl Parathion.

Table 8 presents this farmer's insect control program without chlorinated hydrocarbons at the present time. He uses methyl parathion for bollworm and boll weevil control and makes 13 applications at a cost of $25.27 per acre.

Table 9 presents the insect control program that the low-use producer would have to use after several years of depending on methyl parathion alone. This program requires 14 insecticide applications at a cost of $34.14 per acre.

What does all this mean? If we look at table 10 we see that the high-use farmer's cost would increase from $31.99 per acre of cotton to $47.18. This is an increase of $15.19 per acre or a 47-percent increase in insect control costs. For the low-use producer who is trying to restrict insecticide use, costs would go from $18.46 per acre presently to $34.14. This is an increase of $15.68, or 85 percent in insect control costs per acre. It is doubtful if adequate insect control could be maintained without even more additional expenditures to maintain yields. Several years of high rates of methyl parathion usage have resulted in a buildup of resistance in some areas. In an unpublished report Lukefahr reports a 500-percent increase in tobacco budworm resistance to methyl parathion at Tampico, Mexico (see footnote 4).

What does all this mean on a large commercial cotton farm in the Mississippi Delta? Table 11 presents the insect control costs per pound of lint and for the farm giving the various situations that I have discussed. If we look at situations I and IV we see that insect control costs for the high-use farmer increase 2.08 cents per pound of lint produced on this farm. For the low-cost producer insect control costs increase 2.15 cents per pound of lint produced. The impact of this can best be understood if we recall that production costs in the Mississippi Delta averaged 24.4 cents per pound of lint in 1966 5/ and the present loan value for this cotton is 21.76 cents per pound.

Most of my research at the Delta Branch Experiment Station is aimed at reducing production costs for cotton. It is doubtful that cotton production could continue to be profitable in the Mississippi Delta if insect control costs become much greater than those for situations IV and VIII in table 11. These cost increases would tend to nullify at least half of the effect of cost reduction practices in other areas which seem to have some promise.

In summary we can say that the loss of chlorinated hydrocarbons would increase cotton production costs for almost every producer in the Mississippi Delta. We can also say that these increases in cost will be proportionately greater for the low-use producer than for the high-use one. Based on current research in South Texas and Mexico, it is doubtful that cotton yields can be maintained after several years of dependence on methyl parathion for bollworm and budworm control. Considering the present situation in the cotton industry, any increase in production costs is most serious.

5/ Starbird, I.R. and French, B.L. Cost of Producing Upland Cotton in the United States, 1964, 1966 Supplement. U.S. Dept. Agr., AER 99, Sept. 1969.

Table 8.--Insecticide use on an acre of cotton in the Mississippi Delta for a low-use producer without chlorinated hydrocarbons (present), Situation VII

Operation	Total ground machine costs	Aerial application costs	Labor costs	Materials: Kind	Materials: Rate per acre	Materials: Costs	Materials: Date applied
	Dollars	Dollars	Dollars		Pounds	Dollars	
Poison for thrips	0.49	---	0.15	Bidrin	0.1	0.34	5-10
Poison for bollworm and boll weevil:							
1st application	.49	---	.15	Methyl Para.	1	1.00	7-25
2nd application	.49	---	.15	Methyl Para.	1	1.00	7-28
3rd application	.49	---	.15	Methyl Para.	1	1.00	8-1
4th application	.49	---	.15	Methyl Para.	1	1.00	8-10
5th application	---	0.85	.02	Methyl Para.	1	1.00	8-13
6th application	.49	---	.15	Methyl Para.	1	1.00	8-16
7th application	---	.85	.02	Methyl Para.	1.5	1.50	8-20
8th application	---	.85	.02	Methyl Para.	1.5	1.50	8-23
9th application	---	.85	.02	Methyl Para.	1.5	1.50	8-26
10th application	---	.85	.02	Methyl Para.	1.5	1.50	9-5
11th application	---	.85	.02	Methyl Para.	1.5	1.50	9-10
12th application	---	.85	.02	Methyl Para.	1.5	1.50	9-15
Totals	2.94	5.95	1.04			15.34	
Total insect control costs						25.27	

Table 9.--Insecticide use on an acre of cotton in the Mississippi Delta for a low-use producer without chlorinated hydrocarbons (future), Situation VIII

Operation	Total ground machine costs	Aerial application costs	Labor costs	Materials			
				Kind	Rate per acre	Costs	Date applied
	Dollars	Dollars	Dollars		Pounds	Dollars	
Poison for thrips	0.49	---	0.15	Bidrin	0.1	0.34	5-10
Poison for bollworm and boll weevil:							
1st application	.49	---	.15	Methyl Para.	1.5	1.50	8-1
2nd application	.49	---	.15	Methyl Para.	1.5	1.50	8-4
3rd application	.49	---	.15	Methyl Para.	1.5	1.50	8-7
4th application	---	0.85	.02	Methyl Para.	1.5	1.50	8-10
5th application	.49	---	.15	Methyl Para.	1.5	1.50	8-15
6th application	.49	---	.15	Methyl Para.	1.5	1.50	8-18
7th application	---	.85	.02	Methyl Para.	2.0	2.00	8-21
8th application	---	.85	.02	Methyl Para.	2.0	2.00	8-24
9th application	---	.85	.02	Methyl Para.	2.0	2.00	9-1
10th application	---	.85	.02	Methyl Para.	2.0	2.00	9-4
11th application	---	.85	.02	Methyl Para.	2.0	2.00	9-7
12th application	---	.85	.02	Methyl Para.	2.0	2.00	9-10
13th application	---	.85	.02	Methyl Para.	2.0	2.00	9-15
Totals	2.94	6.80	1.06			23.34	
Total insect control costs						34.14	

Table 10.--Summary of insecticide costs for an acre of cotton in the Mississippi Delta for high- and low-use producers

Item	Situation 1/							
	I	II	III	IV	V	VI	VII	VIII
	Dollars							
Total ground machine costs	3.09	4.07	4.56	4.56	2.94	2.94	2.94	2.94
Aerial application costs	8.50	9.35	9.35	9.35	3.40	5.10	5.95	6.80
Labor costs	1.12	1.44	1.59	1.59	.98	1.02	1.04	1.06
Materials costs	19.28	34.08	22.68	31.68	11.14	18.20	15.34	23.34
Total	31.99	48.94	38.18	47.18	18.46	27.26	25.27	34.14
	Number							
Ground applications	7	9	10	10	6	6	6	6
Aerial applications	10	11	11	11	4	6	7	8
Total applications	17	20	21	21	10	12	13	14

1/ Situation I, high-use producer with DDT; Situation II, high-use producer without DDT; Situation III, high-use producer without chlorinated hydrocarbons (present); Situation IV, high-use producer without chlorinated hydrocarbons (future); Situation V, low-use producer with DDT; Situation VI, low-use producer without DDT; Situation VII, low-use producer without chlorinated hydrocarbons (present); Situation VIII, low-use producer without chlorinated hydrocarbons (future).

Here are some questions we need to consider. Why can the low insecticide user obtain sufficient insect control to produce cotton yields equal to those of the high insecticide user? Can we measure economic thresholds as well as agronomic thresholds of insect damage? What impacts would effective bioenvironmental insect controls for cotton have on production costs and insecticide usage?

Table 11.--Insect control costs, for a representative large commercial cotton farm, Mississippi Delta 1/

Situation 2/	Insect control costs per acre	Cost per pound of lint	Farm total
	Dollars	Cents	Dollars
I	31.99	4.38	9,725
II	48.94	6.70	14,878
III	38.18	5.09	11,607
IV	47.18	6.46	14,343
V	18.46	2.52	5,612
VI	27.26	3.73	8,287
VII	25.27	3.46	7,682
VIII	34.14	4.67	10,379

1/ 304-acre unit with average yield of 730 pounds of lint per acre.

2/ Situation I, high-use producer with DDT; Situation II, high-use producer without DDT; Situation III, high-use producer without chlorinated hydrocarbons (present); Situation IV, high-use producer without chlorinated hydrocarbons (future); Situation V, low-use producer with DDT; Situation VI, low-use producer without DDT; Situation VII, low-use producer without chlorinated hydrocarbons (present); Situation VIII, low-use producer without chlorinated hydrocarbons (future).

EFFECT OF RESTRICTING THE USE OF PESTICIDES ON CORN-SOYBEAN FARMS

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That some technologies used by man cause undesired external effects on the environment is well recognized. The discussion of pesticide residues, and their effect on the environment, makes that point clear. Thus, agriculture has implicitly been charged with evaluating alternative means of crop and livestock pest controls. This important sector of the economy must be in position to show the effects of restricting or banning the use of chemical pesticides, especially organochlorine insecticides and phenoxy herbicides since the continued use of these two chemical groups has been questioned.

Since a restriction on the use of specific chemical pesticides will not affect all farm firms equally, policy decisionmakers need more information on the distribution of effects. Much of agriculture's contribution to the gross national product is derived from a few commodities; and although the average effect on all farm firms of restricting the use of pesticides may appear small, the effect on some specialized producers may be large. The group of producers discussed here consists of those specializing in corn and soybean production.

THE ECONOMIC IMPORTANCE OF CORN AND SOYBEANS

Curbs on pesticide technologies used by corn and soybean firms could have a sizable effect on the agricultural sector and the socioeconomic system. These firms supply two of the most economically important crops, and they use significant quantities of pesticides in crop production. In 1968, the estimated farm value of the Nation's corn and soybean production was $7.2 billion, or 32.2 percent of the total value of the 78 most important crops (11).1/ Corn was the most valuable crop, followed by all hay and soybeans.

Although corn and soybeans are important sources of crop income to some farmers in a large number of States, the benefits provided by pesticides are especially important to farmers in a much smaller geographic area. In 1968, these two crops in a six-State region (Illinois, Indiana, Iowa, Minnesota, Missouri, and Ohio) accounted for more than 75 percent of the value of all crops

1/ Underscored numbers in parentheses refer to Literature Cited, p. 149.

produced in the region. Nationally, these same States provided approximately 70 percent of all corn and soybeans produced. Thus, the production region we are primarily concerned with is relatively small. It only accounts for about 15 percent of total farmland and less than 27 percent of the total cropland used for crops (11).

Favorable climatic conditions and level productive soils have been partially responsible for the production concentration. However, the availability of low-cost fertilizers and pesticides have been dominant factors in shaping the individual firm organization which has evolved. In 1964, more than half of all commercial farms in Illinois were cash grain operations (12). More than 70 percent of the State's total cropland was planted to corn and soybeans in 1968. Without pesticides, production organization on these farms would probably change. Such adjustments would have some spillover effects on consumers and the region's supporting industries and communities.

THE ROLE OF PESTICIDES IN CORN AND SOYBEAN PRODUCTION

While the basic reason for using pesticides in agriculture is generally understood, just how important is this group of chemicals in corn and soybean production? In use terms, more than 31 million pounds or approximately 25 percent of all organochlorine insecticides and phenoxy herbicides used in 1966 crop production were applied to land planted to corn and soybeans (1). These two groups of pesticides accounted for less than half of all pesticides applied to the two crops in that year, and they have become relatively less important over time as substitutes have become available. Yet, the demand for these controversial chemicals continues to be strong throughout much of the corn-soybean region.

The economic value that pesticides can have in protecting crops from pests in the natural environment is shown by the results of two studies. In Nebraska in 1961, an estimated $30 million, or an amount equal to 10 percent of the value of the State's harvested corn crop, was lost because of failure to control the western corn rootworm (10). With effective insecticides now being used, estimated losses due to rootworm damage have been reduced to only $6 million to $8 million, or about 2 percent of the value of corn production. On a per harvested acre basis, this loss averages slightly more than $2 per acre (about equivalent to a single treatment cost of an insecticide).

In the other study, University of Illinois scientists spent 3 years comparing corn and soybean yields in weed-free plots with yields in plots infested with smooth pigweed. The results showed that a 4- to 6-inch band of pigweed over the row reduced the corn yield by 39 percent (8). 2/ In the same experiment, a band of pigweed reduced the 3-year average soybean yield 55 percent. By thinning the pigweed infestation to one plant every 1, 5, 10, 20 and 40 inches, both corn and soybean yields increased although at a decreasing rate. With only one pigweed every 40 inches, there were yield reductions of only 5 percent for corn and 17 percent for soybeans, compared with weed-free plot yields.

2/ Similar results were obtained in a study to evaluate the economic loss due to giant foxtail in corn and soybean production (7).

Although chemical pesticides are one alternative means of controlling crop pests, they have provided secondary benefits to corn and soybean farmers. Corn rootworms, a major corn insect pest, can be controlled acceptably well by rotating corn with other crops. However, in the major corn-producing States, no other crop generally provides net returns as high as corn. Thus, the use of chemical insecticides has allowed the adoption of continuous corn on several farms, and has been responsible for more efficient utilization of land resources.

Weeds can generally be controlled mechanically, but this method requires timely and frequent cultivations. The use of herbicides have allowed farmers to increase their acreages of row crops without the risk of heavy weed infestations (and sizable yield losses) due to untimely cultivation.

Reasons why pesticides have become important to corn and soybean farmers are evident, but the impact of restricting selected pesticides is not as clear. We will next look at some of the changes that have occurred in the use of pesticides on corn and soybean farms. Also an alternative which reduces the quantity of pesticides used will be evaluated. It is hoped that some of the problems in such an evaluation can be pointed out.

PESTICIDE USE DATA

The current controversy over chemical pesticides has caused several agencies to begin collecting detailed information on their use. However, the data are still scarce and are not available by type of farm. Therefore, only changes in pesticide use in Illinois will be reviewed. It is felt, however, that Illinois statistics are the most representative data available for the group of agricultural firms we are concerned with for three reasons: (1) they are current, (2) Illinois has a very large percentage of its cropland in corn and soybeans, (3) the State is near the center of the major corn and soybean production region.

USE OF PESTICIDES ON CORN-SOYBEAN FARMS IN ILLINOIS

Since we are interested in the effect of restricting the use of two groups of pesticides, herbicides and insecticides, each will be discussed separately. In either group, some of the chemicals and alternative pest control methods are nearly direct substitutes, but most of them are only partial substitutes. These conditions make it very difficult to analyze the economic effect of restricting the use of specific pesticides. Yet, the extent of use of each pesticide, and changes in its relative importance, are initial indicators of the effect of a pollution control measure such as the one discussed here.

Use of Herbicides

Since 1964, the percentage of Illinois corn and soybean growers applying herbicides has steadily increased (table 1). In 1969, 86 percent of the growers treated 8.4 million acres, or 86 percent of their corn acreage (table 2). This usage rate represents an increase of 47 percent over the corn acreage treated in 1964. The use of herbicides on soybean acres has also increased rapidly during the 6-year period. In 1964 only 24 percent of the soybean acreage was treated with herbicides. But by 1969, this had increased to 69 percent. Currently, the combined acreage of these two crops treated with herbicides is equivalent to about 65 percent of the total cropland harvested in Illinois.

Although the data do not prove an unquestioned economic need for using herbicide chemicals at the current level, they do suggest that farmers rely heavily on pesticides to control weed pests. Alternatively, perhaps the data may indicate the ability of pesticide distributors to persuade farmers to use these chemicals. In an attempt to get closer to the reason why herbicide use has been increasing rapidly, the data were stratified by size of farm. The hypothesis is that herbicides are substituted for labor and timeliness of operations--two factors which become increasingly critical as farm size increases. The strong correlation between size of farm and the percentage of acres receiving a herbicide treatment (tables 2 and 5) tends to support this hypothesis. It also suggests that farmers recognize the potential consequences of poor weed control. At current prices, the yield loss due to weed competition does not have to be very great--possibly 10 to 15 percent--to make the difference between a profit and a loss.

While the Illinois data suggest reasons for the large and increasing use of this group of pesticides, no data are available to evaluate the economics of observed use. Is weed infestation severe enough to economically justify the quantity of herbicides being used? Are alternative control methods more costly in terms of relative net returns? Can per acre rates of herbicide application be reduced economically? Answers to many of these, and other, questions require more information than is currently available.

Even though the effect of restricting specific herbicides cannot be analyzed completely now, one alternative weed control method demonstrates the importance of questions raised. The alternative is restricting the use of herbicides to only band application, supplemented with cultivation between rows. The effect of this alternative on the quantity of 2, 4-D and atrazine used in Illinois in 1968 was measured. These were the two chemicals that were applied in significant quantities (table 3). It is assumed that yield loss would not increase.

In 1968, approximately 5.7 million pounds of atrazine material were applied to Illinois cornland. Of the total quantity, about 4.5 million pounds were broadcast and the remaining 1.2 million pounds were applied as band treatment. If the use of atrazine had been restricted to band applications, the total quantity used would have been reduced about 40 percent, or 2.2 million pounds (table 4). The potential quantity reduction would have been equivalent to approximately $3.26 per acre treated with a broadcast application of atrazine. However, it is assumed that one additional cultivation would be required which would reduce the cost savings to $2.51 per acre. Although the estimated cost savings from applying less atrazine is not very great, the quantity of herbicides used could be reduced considerably. Also the nonselective characteristics of mechanical cultivation reduce the probability of increasing problems from resistant weeds.

The quantity of 2, 4-D would have been reduced about 20 percent, or 145, 000 gallons of material, by switching from a broadcast to a band application (table 4). Most of the 2, 4-D used in 1968 was applied as a postemergence, broadcast treatment, but the application rates were almost identical for both broadcast and band applications. The similarity of application rates raises some question about the economics of 2,4-D used in band treatment or about the reliability of the data. However, a broadcast rate of about 0.5 quart per acre suggests that a much lesser rate would have surely been optimal for band treatment.

Switching from a broadcast to a band treatment with 2,4-D in 1968 would have reduced chemical expenditures by approximately $670,000. The additional cultivation would increase costs $3.18 million. As a result, net costs would increase about $2.5 million. This added cost is equivalent to about 60 cents per acre treated with a broadcast application of 2,4-D in 1968.

The alternative weed control practice considered--and it is only one of several possibilities--raises as many questions as it answers. We have assumed that every acre treated in 1968 had a weed problem severe enough to justify some use of herbicides, that the yield loss due to changing treatment methods would not increase, and that the band application rates observed were most economical. Each assumption was important in the analysis. While the substitute practice suggests a smaller quantity of herbicides and slightly lower cost, farmers have apparently felt that the added costs of broadcast applications have been an economical form of insurance against the ravages of weeds.

Use of Insecticides

The use of insecticides increased steadily during 1964-69 (table 7).3/ Corn acreage treated in 1969 was equivalent to approximately 70 percent of the planted acreage. Although annual data for the use of specific insecticides were not available until 1969 (table 8), we do know that the number of acres treated with organochlorine insecticides is no longer increasing. In fact, the corn acreage treated with this group of insecticides has declined since 1967. The increased number of acres treated with organophosphate and carbamate insecticides, however, has more than made up the loss.

While aldrin and haptachlor were still two of the important insecticides used in 1969 corn production (table 8), resistant corn rootworms are now found throughout most of Illinois (and the western portion of the major corn-soybean region). Therefore, none of the organochlorines are recommended, although they do control wireworms better than any substitute. Aldrin and heptachlor are not currently recommended in Illinois because the wireworm population is so low that a special treatment is not considered to be economical. The next 2 to 4 years will probably indicate whether a new infestation of this insect is likely. Thus, aldrin and heptachlor (and other organochlorine insecticide) use could be reduced to zero for a few years. However, unless new control agents for wireworms are found, spot treatment might be needed in later years.

Current available data lead us to this conclusion: A ban on the use of all organochlorine insecticides would not be any more costly than the pesticide changes that corn and soybean farms will have to make anyway. One exception

3/ The discussion of the use of insecticides will be confined to the applications on corn only. Insecticides were applied to only about 0.5 percent of the Illinois soybean acres in 1969.

is the control of wireworms. If a severe wireworm infestation is noted, a logical alternative would be to allow spot treatment with the organochlorine insecticides on an as-needed basis. Another exception applies to the eastern portion of the major corn producing region, where organochlorine insecticides are still used extensively to control all corn insect pests. An immediate ban on the use of organochlorine insecticides would increase control costs about $1.23 per acre (1). However, the spread of resistant corn rootworm may soon make it necessary for Illinois corn farmers to use substitute materials as has occurred elsewhere.

If substitute chemicals are not used to replace organochlorine insecticides, the next best insect control method available to corn-soybean farmers is to decrease the proportion of corn in the crop rotation. Since soybeans are the second most profitable crop and receive only small quantities of insecticides, this appears to be an ideal alternative. However, the price of soybeans is currently under pressure, and an expansion in soybean output is likely to depress prices even further--or at least cause a sizable crop surplus.

ECONOMIC IMPLICATIONS AND SUGGESTIONS

Time and the general scarcity of needed data have not allowed us to be very explicit about the economic implications of restricting the use of selected pesticides on corn-soybean farms. However, the data do provide information to draw some qualified conclusions.

(1) Because large farms tend to be heavier users of pesticides than small farms, they would be affected more from a restriction placed on the use of selected pesticides. The magnitude of the differential effects would most likely be a function of the timeliness of pest control practices.

(2) Applications of two important herbicides (2, 4-D and atrazine) by band treatment instead of broadcast would reduce the combined cost of these chemicals approximately 35 percent. But per acre costs would be lowered only about 30 cents due to the additional cultivation required. Yield losses in some years may exceed that value. Accurate estimates of this alternative weed control method, therefore, require information on (a) the probability of timely cultivation, (b) the severity of the weed problem, and (c) the effectiveness of substitute weed-control practices.

(3) If 2, 4-D (the most important phenoxy herbicide used in the corn-soybean area) were banned from farm use, the economic consequences would be even greater production costs. Atrazine or propachlor would probably be used as a substitute on some acres, and the added cost of chemicals would average about $5.25 per acre at current usage rates. Also, additional cultivations would probably be required--an operation which would cut into corn production returns even further.

(4) The economic impact of restricting the use of organochlorine insecticides would probably be negligible for corn and soybean farms--at least in the short run. Because the corn rootworm, the major corn insect pest, has developed a resistance to aldrin and heptachlor in much of the area, substitute chemicals

are being used more extensively. Populations of wireworms, which are still most effectively controlled with organochlorines, were so low in Illinois in 1969 that a specific treatment was not recommended in 1970. If infestations of this insect were to increase after a few years of non-organochlorine use, spot treatment with aldrin might be needed to prevent wireworms from becoming the major corn insect pest.

The data discussed above suggest only a few areas which need further study if we are to provide policy decisionmakers with responsible information. Restricting any pesticide calls for an evaluation of several alternatives, and the evaluation of each alternative requires a better understanding of the economic threshold of pesticide use. This is no easy task. Optimum pesticide rates depend on the pest being controlled, the level of infestation, weather conditions, and other factors. The number of acres which can be treated economically depends on the pest population--many times an unknown factor at the time pesticides are generally applied. Also we need to know the loss function of delaying weed control during the growing season in the major corn-soybean region. Few data are now available to answer these questions; but they are obtainable, and they can be useful in analyzing the effect of restricting the use of pesticides. Also, this information could help the farm entrepreneur understand what pesticide usage is most economical.

Table 1.--Percentage of operators growing corn and soybeans who applied herbicides, by size of farm, Illinois, 1964-69

Size of farm	Percentage of operators applying herbicides					
	1964	1965	1966	1967	1968	1969 1/
	Percent					
Acres						
0-99	34.0	34.5	53.0	49.0	61.5	63.5
100-259	57.5	64.0	71.0	79.5	85.5	83.0
260-499	74.5	82.5	88.0	92.5	94.5	93.5
500 or more	86.0	88.0	96.0	95.0	94.0	97.0
All farms	63.5	69.5	78.5	83.0	87.0	86.0

1/ Preliminary.

Sources: (2),(3),(4), and (5).

Table 2.--Corn: Percentage of planted acreage treated with herbicides, by size of farm, Illinois, 1964-69

Size of farm	Percentage of corn acreage treated					
	1964	1965	1966	1967	1968	1969 1/
	Percent					
Acres						
0-99	44.0	44.0	52.5	59.5	71.0	69.5
100-259	51.5	59.0	68.0	72.0	81.0	79.5
260-499	61.5	68.5	76.5	79.5	87.0	86.0
500 or more	70.0	74.0	84.5	86.0	88.0	91.0
All farms	60.0	66.5	77.0	79.5	86.0	86.0

1/ Preliminary.

Sources: (2),(3),(4), and (5).

Table 3.--Corn: Percentage of planted acreage treated with specific herbicides, by time of application, Illinois, 1964-69

Chemical	Percentage of planted acreage treated 1/					
	1964	1965	1966	1967	1968	1969 2/
	Percent					
Preemergence						
Atrazine	9.5	9.5	14.5	19.0	17.5	19.0
Atrazine and propachlor	---	---	---	1.0	2.5	5.0
Randox (CDAA)	9.0	11.0	12.5	7.0	5.5	2.5
Knoxweed	3/	1.5	5.0	4.0	5.0	5.0
Propachlor	---	.5	3.0	12.0	19.0	23.5
2,4-D	4.0	7.0	7.0	4.5	3.5	2.5
Other	4.0	5.5	6.5	5.0	2.0	6.0
All chemicals	26.5	35.0	48.5	52.5	55.0	63.5
Postemergence						
Atrazine	---	---	---	2.0	2.5	2.0
Atrazine with oil	---	---	---	---	5.5	3.5
Dicamba	---	---	---	3/	.5	1.0
2,4-D	39.0	39.0	39.0	39.0	44.5	29.0
Other	1.0	1.0	2.0	1.0	1.5	1.0
All chemicals	40.0	40.0	41.0	42.5	54.5	36.5

1/ Acres treated more than once are counted for each treatment.
2/ Preliminary.
3/ Less than 0.5 percent, but included in "other."

Sources: (2),(3),(4), and (6).

Table 4.--Corn: Costs of substituting band herbicide treatment for 1968 practices, Illinois

Herbicide	Total area treated	Application rate/acre 1/	Quantity of material 1/	Value of material 2/
	Mil. acres	Pounds/quarts	Million lbs/qts	Million dollars
Present Practice				
Band treatment:				
Atrazine (preemergence).....	0.81	1.2	0.97	2.43
Atrazine (postemergence)....	.17	1.6	.27	.68
2,4-D (preemergence)........	.07	.6	.04	.05
2,4-D (postemergence).......	.69	.4	.28	.32
Broadcast treatment:				
Atrazine (preemergence).....	1.01	2.7	2.73	6.83
Atrazine (postemergence)....	.67	2.6	1.74	4.35
2,4-D (preemergence)........	.30	1.2	.36	.41
2,4-D (postemergence).......	3.94	.5	1.97	2.27
Total atrazine............	---	---	5.71	14.28
Total 2,4-D..............	---	---	2.65	3.05
Total cost.............	---	---	---	17.33
Substitute Practice				
Band treatment:				
Atrazine (preemergence).....	1.82	1.2	2.18	5.45
Atrazine (postemergence)....	.84	1.6	1.34	3.35
2,4-D (preemergence)........	.37	.6	.22	.25
2,4-D (postemergence).......	4.63	.4	1.85	2.13
Total atrazine............	---	---	3.52	8.80
Total 2,4-D..............	---	---	2.07	2.38
Additional cultivation....	5.92	---	---	4.44
Total cost.............	---	---	---	15.62
Cost savings of substitute practice....................	---	---	---	1.71

1/ All quantities of atrazine are pounds of material, and all quantities of 2,4-D are quarts of material.

2/ Atrazine was valued at $2.50 per pound, and 2,4-D was valued at $1.15 per quart.

Table 5.--Soybeans: Percentage of planted acreage treated with herbicides, by size of farm, Illinois, 1964-69

Size of farm	Percentage of soybean acreage treated					
	1964	1965	1966	1967	1968	1969 1/
	Percent					
Acres						
0-99	22.5	19.0	26.5	26.0	36.0	50.0
100-259	17.0	21.0	31.0	38.0	51.5	63.0
260-499	23.0	29.5	40.0	50.0	59.0	69.0
500 or more	31.0	37.5	52.5	55.0	69.0	78.0
All farms	24.0	30.5	42.5	48.0	61.0	69.0

1/ Preliminary.

Sources: (2),(3),(4), and (5).

Table 6.--Soybeans: Percentage of planted acreage treated with specific herbicides, Illinois, 1964-69

Chemical	Percentage of planted acreage treated 1/					
	1964	1965	1966	1967	1968	1969 2/
	Percent					
Amiben	12.0	15.5	24.5	29.5	36.5	38.5
Trifluralin	3/	2.0	4.0	8.0	12.0	14.0
Randox (CDAA)	6.0	8.0	7.5	6.0	5.5	4/
Vernolate	3/	3/	3/	.5	3.0	4.5
Alanap plus	4.0	3.0	3.5	2.0	1.5	4/
Linuron	.5	.5	1.0	1.0	1.0	3.0
4-(2,4-DB) 5/	---	---	.5	.5	.5	4/
Other	---	1.5	2.0	1.0	1.5	9.0
All chemicals	24.0	30.5	43.0	48.5	61.5	69.0

1/ Acres treated more than once are counted for each treatment.
2/ Estimates for 1969 were made from a different sample than was drawn in previous years.
3/ Less than 0.5 percent, but included in "other."
4/ Not reported in 1969 estimates, but included in "all chemicals."
5/ 4(2,4-DB) is used as a postemergence herbicide, but all others are generally used as preemergence herbicides.

Sources: (2),(3),(4), and (6).

Table 7.--Estimated corn acreage treated with different types of insecticides, Illinois, 1964-69

Year	Insecticide	
	Organochlorine	Organophosphate and carbamate
	1,000 acres	
1964	4,009	82
1965	4,544	189
1966	5,117	327
1967	5,602	603
1968	5,171	1,091
1969	4,518	1,990

Source: (9).

Table 8.--Estimated corn acreage treated with insecticides, Illinois, 1969 1/

Insecticides	Preemergence	Postemergence
	1,000 acres	
Aldrin	3,500	12
Buxten	1,237	---
Heptachlor	1,131	---
Phorate	424	---
Diazinon	389	130
Dasanit	212	---
Dyfonate	106	---
Dieldrin	11	---
Toxaphene	---	17
Carbaryl	---	15
DDT	---	9
All insecticides	7,071	208

1/ Acres treated more than once are counted for each treatment.

Source: (6).

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EFFECT OF RESTRICTING PESTICIDES ON COMMERCIAL WHEAT FARMS IN THE NORTHERN PLAINS

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The economic impact of restricting pesticide use on commercial wheat farms varies considerably within the Northern Plains. This variation is due to differences in weed, insect, and disease problems throughout the region.

Weed control is a major problem in North Dakota and South Dakota where 70 to 90 percent of the Hard Red Spring (HRS) wheat acreage is treated with herbicides annually. In contrast, only 2 to 5 percent of the Hard Red Winter (HRW) wheat acreage is treated in Nebraska and Kansas. Insecticide use varies from year to year. In recent years there has been a serious infestation of pale western cutworm in the HRW wheat area of Nebraska and Kansas. About 250,000 acres of HRW wheat were treated with insecticides in western Nebraska in 1969. Fungicide use in the Northern Plains is limited. About 300,000 acres of wheat were treated there in 1966, primarily for leaf and stem rust.

PROCEDURE

In analyzing the effect of pesticide restriction, two case farms were considered--both commercial wheat farms with no livestock. They are larger than the average farm in the area. One farm is in southwestern Nebraska and the other in north-central South Dakota.

Partial budget analysis was used to estimate the change in farm income if pesticide use was restricted. Gross income and variable costs for the case farms were computed with and without herbicide treatment. The herbicides considered were 2,4-D and MCPA. Barban for wild oat control was not used on these farms. The insect problem on the Nebraska farm was analyzed independently of the weed control problem. There was no insect problem on the South Dakota farm. Disease control was not practiced on either case farm.

Only those variable preharvest and harvest costs affected by the pesticide restriction are included in the analysis. Data sources used in budgeting were operator's records and published material. No charge was made in the budgets for increased labor requirements because it was assumed the additional labor would be supplied by the operator or unpaid family labor. However, an estimate was made of the number of hours of additional labor required in the farming operation if pesticides were restricted.

The following general assumptions were made:

(1) Outputs and inputs would be available at current prices.

(2) The farm program for 1970 would continue in effect.

(3) No additional labor would be hired.

SOUTHWESTERN NEBRASKA

This case farm contains 1,480 acres, of which 1,400 are cropland. Historically farms in this area operated on a 50-50 wheat-fallow rotation. Because of the reduced wheat allotment in recent years the operator summer-fallows some of his land for 2 years. He also substitutes wheat for feed grains up to the maximum allowable. The insect and weed problems on his farm are analyzed separately.

Insect Problem

This farm is located in Perkins County. Heavy infestations of pale western cutworm occurred in 1968 and 1969 with a severe outbreak predicted for 1970. Pale western cutworms generally take 100 percent of the crop in heavily infested areas. The operator indicated that there was a heavy infestation in all of his land which is spread out over 10 miles.

Most of the insect damage generally occurs in May, when it is impracticable to replant to a substitute crop. Endrin is the only registered insecticide effective for controlling pale western cutworm. This farmer paid $2.15 per acre for material and application, or a total cost of $1,451 for insect control. The gross return for the farm is $21,620 (with insect and weed control). When heavy infestations of pale western cutworm occur, the farmer's crop is generally a complete loss unless insecticides are used. Thus, from the above cost and return data, the economics of pale western cutworm control are quite evident.

A situation not covered in this analysis is when the cutworm damage is less severe or when only scattered damage occurs. If the wheat stand is reduced because of cutworm damage it increases the probability of having a weed problem which will affect returns and costs.

Weed Problem

HRW wheat is an excellent weed competitor except when there is winter damage or winter kill. This farmer indicated that he had a weed problem about 1 year in 5 and then on only 50 percent of the acreage. Thus, over time, 10 percent of the acreage would be infested annually (table 1). The farmer indicated that if weeds were allowed to grow all season, yields would be reduced 25 percent. Also, at harvest it would be necessary to windrow the wheat before combining. He concluded that the best farming practice would be to plow under the weed-infested fields.

Income on this farm would be reduced by an estimated $1,800 annually over time if herbicides were not available (table 2). There is a reduction in variable costs. The increase in summer fallow costs is more than offset by eliminating herbicide and harvesting costs on the acreage abandoned. In addition, 124 hours of labor would be required for an extra operation on the summer fallow and for tillage on the abandoned acreage.

NORTH-CENTRAL SOUTH DAKOTA

This case farm contains 1,110 acres of which 1, 050 are cropland. This farmer is using a 3-year rotation with HRS wheat being planted on summer fallow and oats, flax, and barley being planted on stubble ground.

Insects are not a problem on this farm, so only the weed problem is analyzed. The farmer estimated that if herbicides were not available, yields for crops planted on summer fallow would be reduced 10 percent. For crops planted on stubble ground a 15-percent reduction in yield was estimated except flax which was 25 percent (table 3). It was assumed that 5 percent of the crops on summer fallow and 10 percent on stubble ground would have to be replanted each year. In addition, about 10 percent of the crop planted on stubble ground would be abandoned each year because of heavy weed infestation when it was too late to replant.

Income on this farm would be reduced by about $4, 000 annually over time (table 4). There would be a slight increase in costs because of additional tillage operations. However, the biggest effect is from reduced yields. An additional 114 hours of labor would be needed for replanting and additional tillage operations.

SUMMARY

The reduction in farm income from restricted herbicide use was twice as large on the South Dakota farm ($4, 094) as on the Nebraska farm ($1, 835). This is due to a more severe weed problem in South Dakota. When herbicides were not used, gross returns were reduced because of lower crops yields. The change in variable costs was small, with the increase in tillage costs being offset by the reduction in herbicide costs. The additional operator or unpaid family labor required for extra tillage operations was about 120 hours on both case farms.

Table 1.--Changes in yields and selected variable costs per acre for crops in southwestern Nebraska 1/

Item	With herbicides		Without herbicides	
	Yield/acre	Dol./acre 2/	Yield/acre	Dol./acre 3/
HRW wheat on summer fallow	29	8.29	21.8	8.11
Rye on summer fallow	35	7.16	26.2	7.16
Summer fallow	---	1.03	---	1.20
Abandoned acres	---	---	---	.85

1/ Does not include a charge for fertilizer because none of the farmers contacted used fertilizer.

2/ Cost per acre with herbicides assumes that a tenth of the HRW wheat acreage and none of the rye acreage is treated annually.

3/ Includes the cost of an additional tillage operation.

Table 2.--Herbicide effects on gross returns and selected variable costs for a 1,400-acre wheat farm in southwestern Nebraska 1/

Item	With herbicides		Without herbicides	
	Acres	Dollars	Acres	Dollars
GROSS RETURNS				
HRW wheat on summer fallow	610	19,459	549	17,513
Rye on summer fallow	65	2,161	59	1,962
Summer fallow	725	---	725	---
Abandoned acreage	---	---	67	---
	1,400	21,620	1,400	19,475
Decrease in gross returns	---	---	---	2,145
COSTS				
HRW wheat on summer fallow	610	5,057	2/610/549	4,601
Rye on summer fallow	65	465	65/59	431
Summer fallow	725	747	725	870
Abandoned acreage	---	---	67	57
	1,400	6,269	1,400	5,960
Decrease in variable costs	---	---	---	309
Decrease in farm income if herbicides were not used	---	---	---	1,836

1/ These returns and costs reflect annual change in farm income over time.

2/ The first number is acres planted and the second the acres harvested. The variable costs from table 1 were prorated on this basis.

Table 3.--Herbicide effects on yields and selected variable costs per acre for crops in north-central South Dakota 1/

Item	With herbicides		Without herbicides	
	Yield/acre	Dol./acre 2/	Yield/acre	Dol./acre 3/
HRS wheat on summer fallow	28.0	5.55	25.2	5.40
Oats on summer fallow	70.0	3.40	63.0	3.65
Barley on stubble	27.0	4.07	23.0	4.00
Oats on stubble	50.0	3.70	42.5	3.83
Flax on stubble	9.0	5.00	6.75	5.07
Oats on replanted acres	---	---	35.0	3.91
Summer fallow	---	1.25	---	1.50
Abandoned acres	---	---	---	1.30

1/ Does not include a charge for fertilizer because none of the farmers contacted used fertilizer.

2/ The cost per acre with herbicides assumes that 1/2 of the oat acreage and 1/3 of the flax acreage is treated annually. All of the wheat and barley acreage is treated annually. None of the oats on summer fallow is treated with herbicides.

3/ Includes the cost of an additional tillage operation.

Table 4.--Herbicide effects on gross returns and selected variable costs for a 1,050-acre wheat farm in north-central South Dakota 1/

Item	With herbicides		Without herbicides	
	Acres	Dollars	Acres	Dollars
GROSS RETURNS				
HRS wheat on summer fallow	325	12,285	309	10,512
Oats on summer fallow	25	875	24	756
Oats on stubble	175	4,375	139	2,954
Flax on stubble	100	2,475	80	1,485
Barley on stubble	75	1,620	59	1,086
Summer fallow	350	---	350	---
Acreage replanted to oats	---	---	53	928
Abandoned acreage	---	---	36	---
	1,050	21,630	1,050	17,720
Decrease in gross returns	---	---	---	3,910
COSTS				
HRS wheat on summer fallow	325	1,804	2/325/309	1,727
Oats on summer fallow	25	85	25/24	89
Oats on stubble	175	648	175/139	614
Flax on stubble	100	500	100/80	480
Barley on stubble	75	305	75/59	276
Summer fallow	350	438	350	525
Acreage replanted to oats	---	---	53	207
Abandoned acreage	---	---	36	46
	1,050	3,779	1,050	3,965
Increase in variable costs	---	---	---	186
Decrease in farm income if herbicides were not used	---	---	---	4,095

1/ These returns and costs reflect the annual change in farm income over time.

2/ The first number is the acres planted and the second the acres harvested. The variable costs from table 3 were prorated on this basis.

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APPLIED USE OF ECONOMICS IN CHOOSING ALTERNATIVE HERBICIDE PRACTICES IN A TECHNICAL ASSISTANCE RESEARCH PROGRAM

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This paper outlines the approaches and results of research conducted in an International Technical Assistance Program to determine economic use rates of herbicides as well as the most economical alternative methods of weed control. It summarizes our efforts to integrate economic studies of pesticide use into technical research programs.

Substantial research on crops led to recommended use rates for farmers. But recent economic studies and analysis have departed from this to examine the economics of recommended rates. At the same time, the reliability and accuracy of these analyses are being checked.

In the limited work thus far conducted, experimental design and models for production functions that best describe the data are still being determined. A particular interest has been expressed in the use of herbicide mixtures to achieve effective control at lower cost and with reduction in total herbicide product used. Approximations of most economical use rates in combination are determined as well as maximum rates for either product if used singly.

Comparisons of costs and yields are also made between the best chemical practices and the results of the mechanical or hand-weeded plots. These reflect only direct cost-benefit relationships. Specific examples of experimentation are utilized and interpretations of results are discussed. These include potential changes in cost and productivity for areas corresponding to experimentation.

Interest in the area of economic analysis of the use of pesticide use began with an expression of need to compare alternative chemical practices in winter wheat in Oregon. Oregon wheat farmers had asked for better information on a specific weed control problem where more than one alternative was available to them. What methods were available to help them select for good weed control practices? Several chemicals were available at different prices, and at different levels of activity and selectivity.

This was a beginning point that aroused my interest in approaching solutions to these questions. Appropriate analyses were conducted and models tested to determine their validity and application. It was at this point that I realized that there was a large breakdown in communication between the economists and the production research people. The local system did not seem very responsive to an expression of need for this type of information. Little pressure was brought to bear to proceed with integrated studies of this type in the area of economic evaluation of the use of pesticides. Herbicide use by farmers was by and large not considered to be an economic question. This time just preceded the rapid development of public and political concern for studies of pesticides in the environment. This concern has grown to such a degree that it has come down to specific cases of pesticide control in various facets of agriculture as well as other environmental uses.

Personal interests meanwhile directed my activities into an AID-University technical assistance program, in which U.S. foreign policy was directed to increasing food and fiber production in the so-called LDC's. This was the commitment, a massive effort to promote agricultural development, the economic base of many of these countries. Weed control, one of the limiting factors in increasing production, was grossly neglected because of weed competition as indicated in crop loss studies. Here is a tabular example of typical long-term losses and indicated increases in crop yield with weed control from the Republic of Colombia.

Effect of weed competition among selected Colombian crops 1/

Crops	Average loss	Yield increase over hand weeding
	Percent	
Rice	54	24
Cotton	31	13
Maize	46	21
Beans	51	24
Wheat	29	17
Barley	19	16
Potatoes	17	20

1/ Based on recent 12-year average.

The Oregon State University program found itself in Colombia, working into a weed control program with little definition or direction. Research had been conducted for a period of 12 years with no results passed onto the farmer level. A new program was planned with a very basic yet comprehensive approach. From previous experience it appeared desirable to design and organize research so that the production and economics people could work together toward a better planned agricultural development. There were many justifications for this approach:

(1) Experience in the United States indicated that such planning was desirable for a new program.

(2) Increasing the low food and fiber production would lead to a general increase in economic activity.

(3) Both groups needed to study the common question of the economics of the introduction of agriculture technology and effects on a traditional agricultural economy.

(4) Information was needed on economics of labor use and displacement, and their effects.

(5) Comparisons were lacking on all alternative practices; hand, mechanical, chemical practices and biological control.

Basic yield research with direct costs and benefits appeared to give substantial evidence that weed control research could increase agricultural production in many crops.

The need for involvement of the two disciplines was evident. Economic studies were initiated in corn, a crop on which extensive production research had been conducted. The primary objective here was not to determine definite research results but more one of how to organize the agronomists and economists in gathering meaningful research information. An experiment was designed to demonstrate the type and magnitude of information that could be developed from a well-designed trial.

The study I will show you was taken on the use of a herbicide mixture of atrazine and linuron on corn. This mixture was of practical interest in that the two used in combination held distinct advantages over either alone, controlling a broader weed spectrum at lower rates and lower cost, as well as reducing soil residue.

Nineteen rates of products alone and in combination were used and yield data were subjected to a multiple regression analysis to arrive at an approximation of a production function.

Differences were shown between rates of maximum and a determined economic optimal level of production, given the condition of availability of capital. Even with these conditions, results indicated that lower than recommended use rates could economically be used. This indicated that less than 100 percent weed control could economically be tolerated.

Maximum production as determined on the function where

$$Y = B_0 + B_1A + B_2L + B_3AL + B_4L^2 + B_5L^3$$ was as follows:

Atrazine = 1.349 kg./ha.

Linuron = 0.9412 kg./ha.

The economical optimum rates determined from this function using current (1969) prices of corn and herbicide were:

Atrazine = 0.823 kg./ha.

Linuron = 0.9405 kg./ha.

Comparisons were made as well with handweeding to compare direct cost and return. Mechanical cultivation is not available in many cases and information of this type is essential in these studies. Results of this analysis are summarized in the following tabulation.

Method	Rate	Yield	Total cost
	------Kg./ha.-------		Pesos
Maximum production atrazine and linuron.....	1.3 + 0.9	5,254	275
Economic optimum atrazine and linuron.......	0.8 + 0.9	5,243	221
Handweeding................................	10 + 30 days	5,100	250
Recommended practice atrazine and linuron...	1.0 + 1.0	5,250	248
Atrazine alone.............................	2.4	5,674	250

The information from the regression analysis indicated a much flatter production function than indicated by the original data which showed a 20-percent yield increase over hand labor at comparable costs. It points out, however, quite definitely that there can be substantial cost difference in maximum and optimum levels of herbicide use.

The results from this particular example raise questions resulting from a difference in activity between the two herbicides used. Atrazine on corn represents a linear-type relationship, while linuron with toxicity to corn at high rates represents a curvilinear function. Therefore there are faults in this particular model and the function used to express the results.

This was, however, the first trial analyzed and served as an indication for future research and methods of analysis. We are currently conducting similar research and attempting to refine the evaluation procedure through more reliable analyses.

This whole program brings up a lot of questions.

(1) What parameters should we research in the use of pesticides in agriculture and in our environment?

(2) How should our concern be reflected in our foreign policy as it involves these types of technical assistance programs?

(3) How should research programs be organized so that production agronomists and economists might identify, gather, and interpret the information needed to answer the questions addressed to them--questions involving both micro and macro economic effects?

(4) How can we restrict or limit the use of pesticides in the environment?

(5) What specific programs can be initiated by economists and production people mutually supported to answer these questions?

COSTS AND BENEFITS OF PESTICIDES TO SOCIETY (WELFARE MODEL)

Work Group 1

Max R. Langham, Chairman
Austin S. Fox, Secretary
W. Frank Edwards
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D. Lee Fowler
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Douglas L. Worf

Objectives of this session were to consider those research approaches aimed at evaluating external costs and benefits of pesticides--that is, the effects of pesticides on the environment as well as their direct effects on farmers. This type of economic intelligence weighing both direct and indirect costs and benefits of pesticides is essential for policy decisionmaking.

RESEARCH APPROACHES

Economic models should assist policymakers to sponsor programs and propose legislation that are consistent with overall goals. The models should be useful in analyzing alternative regulatory policies on pesticide usage. They could be focused on specific classes of pesticides.

Certain models were considered as a first step in evaluating the total pesticide problem. Approaches less formalized or restrictive than a comprehensive economic model may also prove rewarding. For example, summarizing available quantitative data on the direct and indirect costs and benefits of pesticide use should prove worthwhile even though the information does not approach the data needs of a comprehensive economic model.

Mathematical programming models of the general nature of the "Consumers' plus Producers' Surplus" model proposed by Edwards and Langham, could be useful in considering external costs and benefits. Other models encompassing complete systems and using different approaches might also be useful. However, it was felt that the real need was to begin with some kind of a model without being overly concerned about the initial specification. Model specification would force researchers to identify the problem more clearly. Necessary changes could be made later.

Economic models must be sufficiently flexible to consider interregional shifts in production and long-range as well as short-range effects.

In defining or structuring models, overall goals must be kept clearly in mind. For example, if the objective is lower levels of pesticide use rather than a complete ban, it becomes important to identify the relationship between pesticide use and accumulation in the environment. When data are not available, imputed costs will need to be used for externalities.

Such models would provide a tremendous amount of "spin off" in terms of useful information and a better understanding of the total problem. They could also pinpoint areas where additional research is needed. Furthermore, they might show more specifically how cooperative studies with other disciplines might be organized to be most useful.

DATA AVAILABILITY

The lack of data on external costs and benefits from pesticide use is a serious handicap to research in this area. It was suggested that we could make greater use of available data. There may be considerable unpublished research data in the files of government, college, and industry specialists on both beneficial and detrimental aspects of pesticides. If so, examination of such information might prove rewarding by providing quantitative data on cost and benefits of pesticide use. It is also possible that environmental and health specialists could provide broad guidelines on the "external" costs of pesticide usage.

INTERDISCIPLINARY INTERESTS

If quantitative estimates are to be made on external costs and benefits of pesticides, the basis for these estimates must come from a number of disciplines. Interior Department representatives considered that dollar estimates of environment damage due to pesticides would be difficult to arrive at and that few would agree on the figures selected. However some type of quantitative loss estimates might be possible.

As an initial proposal for interdepartmental or interdisciplinary efforts, the Research Subcommittee of the Environmental Quality Council would serve as a vehicle for initiating, handling, and processing interdisciplinary economic research on pesticides. How the programs could be implemented would also be the responsibility of this group.

It would be of interest to all government agencies to develop an economic mission for pesticides. It was suggested that this might be accomplished by amending the Federal Insecticide, Fungicide, and Rodenticide Act to include a statement on the economic justification for the use of pesticides.

RESEARCH PRIORITIES

An important part of additional research should be oriented toward assisting policymakers in evaluating external benefits and costs of pesticides.

Some additional resources, probably 2 or 3 man-years, are needed to construct a formalized model to evaluate externalities. An initial feasibility study of a national consumers'-producers' surplus model is one approach.

Other resources should be used for conducting joint research with agronomists, biologists, and entomologists to determine the benefits of pesticides in farm production. This would include determining the relations between production and alternative methods of pest control as well as the effects of varying levels of control with specific methods.

Some resources, possibly 1 man-year, should be used to examine the secondary sources of information related to benefits of pesticides and evaluation of externalities. Initially, this effort would be in terms of seeing what is available from the Pesticide Regulation Division in the USDA and from HEW.

COSTS AND BENEFITS OF PESTICIDES TO FARMERS AND CONSUMERS

Work Group 2

Joseph C. Headley, Chairman
Robert P. Jenkins, Secretary
James M. Anderson
Paul A. Andrilenas
Gerald A. Carlson
John T. Holstun, Jr.
Ronald D. Krenz

This group was concerned with needed research on costs and benefits of pesticides to farmers and consumers. Its approach is based on the neoclassical theory of the producing firm, industry, and consumer. Research needs related to this approach were discussed first, followed by a discussion of data availability and possible contributions by other disciplines. Finally an attempt was made to specify the relative priority of each research approach recommended.

RESEARCH NEEDS

Chairman Headley outlined three areas of need for research on the economics of the use of pesticides. These are the farm firm, the agricultural industry, and consumers. Variables include profits and costs for the firm, output and prices for the industry, and cost and quality of food and fiber for the consumer. The discussion subsequently was confined to the farm firm and the agricultural industry.

A general need was expressed for better data on infestation. First, pest intensity, location, duration, and relation to production damage must be documented. Second, long-run means of predicting infestation are needed to guide research efforts. Also the phenomenon of pests that are resistant to pesticides requires further study, including better documentation of their existence and better predictive capability. Spore counts of wheat stem rust by aerial survey were cited as an example of such work.

The study group felt a need for a longer run examination of alternative technological systems used in production. Several alternative methods of reducing environmental pollution were cited. These include substitution of other input factors for pesticides, diversification of production, alternative crops and regional shifts in production. Before using substitute products or shifting production to other areas we must first identify subsitute products, or production areas where pest infestations are low. An evaluation of the relative pollution effects of heavy pesticide use per acre in a concentrated monoculture area as compared with less intensive use over many acres would be useful for policy planning. The interactions between pesticides with other inputs should be determined.

The group suggested distributional studies of alternative pest-control systems to determine cost-benefit relationships for various sectors of the economy. Costs may be easier to assess with organophosphates than with some other pesticides because their effects are easier to document and legally redress. This enables them to be evaluated internally by the using firm.

Potential and actual changes in pesticide use need to be studied. Major expected changes in prices because of new competitors, expiration of patents, and the like should be identified. Data on major aspects of pesticide use, as well as infestation levels, should be collected and reported.

DATA AVAILABILITY

Infestation

Infestation data are not generally available. This was regarded as the most critical need. Several data sources were suggested. The Statistical Reporting Service (SRS) could collect pesticide and infestation data in the annual objective yield survey. This would require a contract with SRS and a source of funding.

A section concerning yield effects of reported infestation levels could be added to subsequent issues of such USDA reports as "Extent and Cost of Weed Control," ARS 34-102. Such a section, however, would require several changes in survey techniques. Quantitative information would need to be obtained about levels of infestation by specific pests during at least the major periods of production (i.e., stand establishment, growth, and maturation and harvest periods). Additional research would also be needed to associate infestations described by surveys with effects on yield and quality.

It was proposed that infestation effects be documented for several stages of plant growth by use of factorial-type test plots. Nationwide surveys of infestation would be used to determine the actual infestation level for calculating losses and costs. The research plots and the surveys should involve three periods--stand establishment, growth, and maturation.

Some data on population dynamics of insects are available from USDA's Boll Weevil Laboratory and probably other sources.

Alternative Production Systems Analysis

Cooperative research efforts between economists and those in other disciplines would be helpful. Data from prior experiments by entomologists, weed scientists, and others would form the basis for this work.

Documentation of Pesticide Effects on Yield and Quality

The ERS pesticide group is the major source of information about pesticide use. This work should be expanded to include data on all uses of pesticides.

Contributions from plant and animal biologists of the Crops Research Division, and the Entomology Research Division (ARS), and the State agricultural experiment stations are essential in formulating survey questions and in interpreting the results.

Documentation of Pest Effects on Yield and Quality

Plant and animal biologists of the Crops Research Division, Entomology Research Division, and possibly other ARS divisions, and the State agricultural experiment stations will be major sources of information about the effects of pests on yield and quality of crop commodities, livestock, poultry, and others. Their work needs to be expanded to include measurement of the effects of interactions among various treatments, different pests, and different crops. It should also include effects on life factors other than yield and quality factors. Contributions from ERS personnel would be essential in conducting the research, and in extending of experimental results to national application.

CONTRIBUTION OF DISCIPLINES OTHER THAN ECONOMICS

Those in other disciplines could make substantial contributions to the pesticide evaluation work by economists. Biologists in active cooperation with economists could obtain test plot data on yields, as they relate to levels of infestation and resistance of insects and weeds to pesticides. Biological scientists could also assist economists in screening data from previous experiments. The legal profession could help evaluate externalities. These remain an obvious need for expanded interdisciplinary research in pesticide use and effects.

PRIORITY OF RESEARCH

Highest priority should be assigned to infestation studies. The second priority should include evaluation of alternative production and pest control systems. Relatively low priority should be given to productivity analysis and consumer utility analysis.

Highest priority should be given to studies that attempt to include infestation levels, resistance levels, and other uncertainties. Studies that try to evaluate alternative methods of production are also ranked high. Little can be gained from productivity or consumer surplus studies that do not include the above items.

ECONOMIC EFFECTS OF RESTRICTING FARM USE OF PESTICIDES

Work Group 3

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John H. Berry, Secretary
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Herman W. Delvo
William B. Ennis, Jr.
Ronald L. Mighell

The total economic effect of restricting the farm use of pesticides may not be distributed evenly among production regions nor among individual farm firms. Since the topics assigned to the other two work groups suggest an aggregate or total society analysis, this work group directed much of its attention to micro-level analyses that can provide useful information to policy decisionmakers.

As a starting point, the group assumed that a need exists to minimize the quantity of pesticides used. Also, two levels of pesticide use restriction were considered: (1) a complete banning of the use of a specific pesticide and (2) a restriction on the use of all pesticides to their optimum economic levels. Although the second level of restriction is difficult to impose on individual farm firms, it was felt that farmers would voluntarily reduce pesticide use to the most economic rates if information were available. On the basis of these considerations, the following research needs were suggested.

SUGGESTED RESEARCH AREAS

Much of the current economic research which evaluates the effect of restricting pesticide use has been commodity oriented, pesticide group oriented, or both (e.g., effect of restricting the use of organochlorine insecticides in cotton production). The work group felt that the information provided was useful to policy decisionmakers, but should be supplemented with more basic research incorporating the following points:

(1) Emphasis should be placed on determining the economic thresholds of pesticide use. A first step is to determine the input-output relationship between individual commodities and specific pesticides.

(2) Cooperative research involving economists, pest-control scientists, and agricultural engineers is needed to evaluate the full spectrum of insect and weed control alternatives. This research area is related to the one above, but it includes combinations of pest control methods (e.g., band herbicide treatment and cultivation, broadcast herbicide treatment, spot treatment of pests, changing maturities of crops, and pesticide application on an as-needed basis vs. preventive treatments).

(3) On a national or regional basis, probable regional shifts in commodity production must be determined if specific pesticides were banned from farm use. The possible distribution of effects on entrepreneurs, landowners, and regions is important information for policy decisionmakers.

(4) Current attempts to control or eradicate major crop pests must be researched further. What new pest problems can be expected, and what control methods are desirable from a society standpoint? This problem adds a time dimension to the pesticide use problem.

SUGGESTED PROCEDURES

All of the procedures discussed in the symposium are useful in analyzing the various problems at different levels of aggregation, but the following were thought to be most useful in analyzing the above research areas:

(1) Regression analysis. Observed commodity yields and various use rates of pesticides under controlled experiments applied to a statistical model can provide benchmark information on the economic threshold of pesticide use.

(2) Budgeting or programming analysis. Partial budgeting has been used to assess the costs associated with restricting or banning the use of pesticides on specific crops. This continues to be a useful tool in comparing alternative control methods. The same concept can be extended to evaluating probable changes in production organization by including the budgets in a programming model.

(3) Bayesian decision theory. Since the crop losses due to pest infestations in a given year are very uncertain, the Bayesian decision theory approach discussed earlier in the symposium offers a possible means of arriving at an optimum disease control practice for farm entrepreneurs.

DATA AVAILABILITY

The data necessary to analyze the proposed research areas are sparse at best. The observations needed to estimate crop yield-pesticide use relationships could be provided with the cooperation and leadership of pest-control scientists. Much useful data could be obtained by increasing the number of replications and applications rates in each pesticide experiment. By allowing crop pest populations to increase in selected areas we could obtain most useful information from these experiments.

Much of the previous budgeting work on costs of alternative pest control methods has been constrained to assuming all acres treated with pesticides have a pest problem that would produce an economic loss. Information on pest infestations and forecasted infestations by small geographic areas would be useful in evaluating that assumption. A pest-infestation monitoring system could provide the needed information for both budgeting analyses and Bayesian decision theory applications.

Budget data to evaluate possible regional shifts in commodity production are available, to a limited extent, from the "FPED National Model" work. These budgets may have to be modified to reflect changes in pest control practices, but they are a starting point.

The list of data needs could be extended manyfold. However, the largest voids appear to be in the information about prospective insect, disease, and weed populations and their characteristics, and in the economic rates of application of pest control practices for various pest infestations.

DIRECTIONS FOR FUTURE RESEARCH ON PESTICIDES

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I think the papers and discussions of the last 2 days have been very good. I don't intend to summarize since you all have copies of the papers and I couldn't do justice to them in a brief summary. However, I would like to take just a few minutes to categorize the several types of research on pesticides which seem to me to have particular promise on the basis of our experience and the topics developed in this workshop. I have roughly and rather arbitrarily categorized these into four groups.

First is the rather straightforward assessment of the direct (and typically short-run) costs of restricting or banning certain pesticides. We have already been doing some of this analysis in conjunction with our colleagues in ARS and we likely will have need to do more such analysis in the future. In fact, I strongly suspect that there will be a need to make such appraisals for a number of individual pesticides. Here, I think both the recent experiences in this area and our discussions at this workshop give us more common ground from which to mount such appraisals. I hope discussions at this workshop can provide the basis for more imaginative approaches to these kinds of cost questions. By this, I do not mean to discount the work that has been done to date. On the contrary, I think some of it has been necessary spadework and some has provided very useful results. I believe we need to bear in mind that some intelligence of this type, even if it is subject to a sizable error of estimate, is better than no quantitative intelligence at all.

A second area of research investigation might be generally categorized as one of minimizing pollution hazards as well as pest control costs by using more sophisticated approaches--with respect to both managerial strategies and technology--in the use of pesticides. The paper presented by Dr. Carlson provides some real insight into the type of considerations I have in mind here. Also, several people have mentioned that equally effective pest control could be achieved through better placement methods, by improved cognizance of the pollution hazards from excessive pesticide applications, and through more extensive use of the "economic threshold of loss" concept. This general research could be summarized as that aimed at improved technology and managerial strategies to effectively control pests with the application of reduced amounts of pesticides.

As a third area of inquiry, it appears that we could go much further in exploiting the possibilities of substituting other inputs, particularly land, for pesticides. Dr. Headley provided some very useful discussion of this topic in his paper. Having spent a great deal of time in the last 2 or 3 years in activities to estimate the amount of land which would need to be diverted or set aside in order to maintain a supply-demand balance for farm commodities at reasonable commodity prices, I am aware that we have several million acres of land that could be substituted for pesticides or other inputs. For example, current estimates are that about 40 million acres of cropland will be diverted in the feed grain program alone in 1970. And, there is a significant amount of land being held out of production in other programs. Moreover, this experience has suggested that such a substitution does not have to mean a reduction in Government payments to farmers. In fact, the most common assumption getting consideration in appraising alternative farm programs has been the one of maintaining Government payments to farmers at or near recent levels.

I do think, though, that it is unrealistic to assume that additional farmers or additional labor can be brought back into our farm production sector. A more reasonable possibility, I believe, is that we can make adaptations in technology and labor use which would permit the farming of a larger land base than is currently operated with at least some restrictions on pesticide use and with the same or with even smaller quantities of labor. The set of production technologies currently being evolved seems to require an ever-decreasing quantity of labor.

A fourth area is that of systems approaches of the type outlined by Edwards and Langham on the one hand and those outlined by Jenkins on the other. These seem to me to have substantial potential. Here, I am really talking about any analyses which systematically takes into consideration the costs and benefits accruing to several groups of people--one of which may be society as a whole. The discussions here have pointed out that even though we have big data gaps on the "economics of production" side (both those related to infestation and those related to control measures), the most difficult items to handle empirically are those externalities dealing with environmental damage and particularly those of a long-term nature. I believe though, as Langham suggested, a systematic procedure (or procedures) for reasoning even with some very gross empirical estimates is better than no quantitative system at all. The latter often results in the cost-benefit appraisals being entirely those of emotions and personal values.

As we proceed to plan future research and data collection, I think we will be addressing all of these topics in some degree. Crude as our knowledge is now, it is much better than it was when we had a brief workshop 2 or 3 years ago and I hope it will be better a year from now and 2 years from now than it is today. One thing appears certain, this will be a research area of high priority for a number of years to come.

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