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Crop Insurance and Information Services to Control Use of Pesticides

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CROP INSURANCE AND INFORMATION SERVICES TO CONTROL USE OF PESTICIDES

by

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ABSTRACT

This study analyzes the relative effectiveness and efficiency of pest information and crop insurance programs in encouraging farmers to use potentially harmful pesticides more sparingly by eliminating wasteful applications. Possibly excessive applications of pesticides can be attributed to poor timing of applications and to the risk-averse behavior of farmers. Focusing on insecticide use in cotton production as a major policy problem, the study employs a decision-theoretic framework to simulate the farmer's pesticide use decisions under alternative program options and subsidy levels. To the extent possible, empirical data are analyzed to complement the findings of the simulation analysis.

The study framework allows for an internally consistent evaluation of a set of program alternatives from which the policy maker can select the most promising option that is feasible within the existing political and economic context. Since neither the methods nor the data exist to assess the social costs and benefits of alternative policy options in a reliable manner, an optimal solution cannot be determined.

The theoretical and empirical analysis in this study indicate that pest information programs are potentially more effective than crop insurance programs in reducing insecticide usage. These reductions resulting from compliance with pest control recommendations provided by information programs are associated with economic gains by the farmer. Both the simulation experiments and available evaluations of the USDA Pest Management Program indicate that a maximum insecticide use reduction of 30 percent can be achieved through information programs. Subsidies to such programs appear an effective means to encourage adoption by farmers, at least in the initial phases.

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ACKNOWLEDGEMENTS

This study has depended on access to unpublished research and unpublished data. A number of individuals have been critical in providing assistance in this endeavor. We would like to thank Professors Gerald A. Carlson and J.R. Bradley, Jr., who served as consultants to the study. They contributed to the development of the methodology and made available data needed in the investigation. In addition, members of the USDA's Pest Management Program and cooperating state personnel were very helpful in providing data and background information on the current pest information program. Richard Dyrness of the Federal Crop Insurance Corporation's Actuarial Division played a crucial role in obtaining the crop insurance data used in this investigation. Naturally, none of these individuals should be blamed for any shortcomings of the study.

What follows constitutes a cooperative effort on the parts of Francis Cummings, Ulrich Ernst and John Miranowski. Sally Wand showed remarkable patience in typing and retyping various drafts for this report.

SECTION I

CONCLUSIONS

Three major policy conclusions emerge from the microeconomic simulation analysis of farmers' responses to the pest information and crop insurance policy options examined:

- Pest information programs are potentially effective in reducing insecticide use in cotton production without adverse economic effects on the farmer. The analysis indicates that compliance with pest control practices recommended by pest information programs would actually increase expected net incomes for the farmer. Both the simulation experiments and the available evidence on the USDA Pest Management Program suggest a potential reduction of insecticide use by up to 30%.
- Without information programs, crop insurance programs appear questionable as instruments to reduce the social costs of insecticide use. Farmers would substitute insurance for pesticides, but at a high cost to society.
- With information programs, crop insurance programs could reduce insecticide use within reasonable limits. However, the required subsidies for the relevant insurance options would be relatively high.

On the basis of these conclusions, pest information programs appear to be a more viable policy option. Attracting more (cotton) farmers into information programs therefore is a reasonable policy objective.

One effective instrument for this purpose is the subsidization of the cost of pest information services to the farmer. A statistical analysis of the responsiveness of the demand for pest information services to variations in the cost of these services to the farmer indicates a fairly high price elasticity, estimated at slightly less than -2.0. For that elasticity, a subsidy of the cost of information services of 10 per cent would imply an increase in participation rates by 20 per cent. Subsidies could therefore be used, at least in the initial phases, to establish widespread acceptance of pest information programs.

SECTION II

RECOMMENDATIONS

The results of this study encourage the deliberate expansion of pest information programs and dissemination of information about potential program benefits to non-participating farmers and to regions not covered by existing programs. In addition, the results indicate a need for subsidies to pest information programs, at least in the short term, to shorten the adoption lag that normally accompanies any innovation or new production technology. The potential effectiveness and efficiency of pest information services in reducing excessive pesticide use should result in a net benefit to society, without creating shortages or higher prices for farm commodities.

Crop insurance programs appear to be less promising as instruments to reduce pesticide use in agricultural production. However, further research is required before this policy option can be disregarded.

Additional research is required in a number of other policy relevant areas. First, the present investigation focused on one type of pesticide for one crop, using data from one region. The generalization of the findings to other crops and regions is therefore somewhat unreliable. Greater reliability could be achieved by applying the methodological framework to other cases. Secondly, various delivery systems exist for pest information services. An economic evaluation of these alternative systems would be necessary to determine the more effective and efficient methods under given production conditions. Thirdly, the present investigation had to use data for the average farm. Variations in the scale of farm operations may affect the results of the analysis significantly. Such variations should be introduced into the analysis, if the necessary data can be gathered. Finally, more knowledge is needed on effective means for disseminating new technologies for agricultural production. Although information program subsidies appear to be effective, other methods may be more efficient.

SECTION III

INTRODUCTION

THE POLICY PROBLEM

Chemical pesticides have played an important part in raising productivity in agriculture by lowering the incidence and severity of crop losses caused by disease, insects or weeds. However, pesticides currently used may produce substantial negative side effects in the form of health and reproductive damage to fish and wildlife, domestic animals and even humans. These damages constitute real costs to society. Since negative externalities or social costs of pesticide use fail to influence the farmer's production decisions, actual pesticide use is likely to exceed the level that would be chosen if all (private <u>and</u> social) costs were considered.

The present state of the art prohibits a reliable comparison of the social costs and benefits of alternative pesticide use patterns in agriculture. The socially most desirable level of pesticide use therefore cannot be determined. Public health considerations suggest a reduction in the use of chemical pesticides. It is unclear, though, at what point reductions would lower agricultural productivity sufficiently to create a net loss to society.

Under these conditions, the public policy option most consistent with market mechanisms -- manipulation of resource prices through taxes and subsidies to internalize external costs -- may result in serious inefficiencies and distortions. It is therefore necessary to examine alternative policy approaches to reduce the harmful side effects of chemical pesticide use in agriculture. The present study focuses on policy options other than the introduction of less harmful pesticides, such as natural predators or biologically derived means of pest control. The identification of such alternatives requires a clear understanding of the role of pesticides as inputs into agricultural production.

More than in any other industry, production conditions in agriculture are subject to elements of chance. Weather conditions, plant diseases and insect infestations -- all crucial in determining actual yield -- cannot be predicted with certainty. Pesticides offer the farmer a way of reducing at least part of the resulting risk. Their use raises expected yield and lowers the uncertainty associated with actual output.

The effectiveness of pesticides depends on the timing of the application in response to observed indicators of pest infestation, as well as the selection of the proper type and dosage of pesticide chemicals. Poor timing results in wasteful pesticide use. If the farmer lacks the information or experience to interpret indicators of potential pest damage, he typically attempts to reduce his risk by periodic or programmed applications of pesticides. In other words, he is likely to apply pesticides "mechanically" regardless of the need for these chemicals. This procedure may actually increase the need for pesticides by destroying the natural predators of crop pests and increasing pest resistence to the chemicals used.

One option for the policy makerto curtail such wasteful pesticide use lies in improving the farmer's understanding of the importance of pest infestation indicators and of the appropriate pest control response through pest information programs. Programs currently operating involve two components: (1) scouting of fields to determine the level of pest infestation, and (2) disseminating of recommendations concerning the appropriate response to the observed pest problem.

A second policy option derives from the view that programmed application of pesticides constitutes a form of "insurance" against the occurrence of crop pests. Since the (private) cost of pesticides is relatively low, this approach can be a rational strategy. Thus a potential reduction of pesticide use could be achieved by providing the farmer with low-cost crop insurance programs. Subsidized crop insurance is a means of sharing the risk of crop losses between the farmer and society; it is a viable policy option, particularly if farmers exhibit risk-averse behavior -- which implies "overreaction" to perceived pest threats.

Both information and crop insurance programs are currently in effect. Their operating experience is fairly limited, though. Their potential in changing the farmer's choice of pesticide application levels has therefore been assessed only in a very rudimentary way. The design of policies geared toward greater overall efficiency of pesticide use necessitates a better understanding of the ways in which they can influence the pesticide use decision process. Such an understanding is the basis for an assessment of their relative strengths. This study presents a framework for this type of assessment, combining theoretical and empirical analysis. The nature of the actual analysis is predominantly exploratory; the resulting policy recommendations are therefore limited to suggestions for potential policy emphasis and for areas needing additional study.

STUDY DESIGN

The assessment of the relative effectiveness of crop insurance and pest information programs as policy instruments involves two major issues:

1. How effective are these programs in changing the farmer's decision parameters and, in turn, pesticide use levels?
2. Under what circumstances would these programs be adopted by the farmer?

Since participation in either program is voluntary, an important element in the evaluation of these policy instruments is the conditions under which they would be adopted. This aspect is addressed by the second issue The first issue concerns the degree to which insurance or information, once adopted by the farmer, alters his pesticide use patterns.

The design of the present study is based on the assumption that the understanding of the "mechanics" of the pesticide decision process is critical to resolving both issues. Unless it is clear what the decision parameters are, it is futile to speculate about the ability of the policy instruments considered to change these parameters. The first step in the analysis therefore consists in a conceptual clarification of the decision process determining the level of pesticide use.

The conceptual framework employed in this study derives from the interpretation of the role of pesticides as an input into agricultural production as discussed above. If their function is to reduce the likelihood of pest damage and to lower the associated risk, the farmer's problem corresponds to the general problem of decision-theoretic research: the choice of an optimal (pesticide application) strategy under conditions of uncertainty. The central components of the decision-theoretic framework applied to the pesticide use problem can be summarized as follows:

- For each level of application, the farmer formulates his expectations concerning the likelihood of different levels of crop loss and the variance of this crop loss.
- Given the price of the crop, the cost of production, and the cost of pesticides, loss expectations can be translated into expectations of net income associated with alternative application levels.
- Net income expectations and the variance of these expectations form the basis for the determination of expected utilities associated with each application level. Expected utilities reflect both the expected net income and the magnitude of risk.
- The farmer chooses the application level that maximizes his expected utility.

The analysis in this study uses this structure to develop a formal model of the farmer's decision process concerning the level of pesticide use.

The formal model is subsequently used in a series of microeconomic simulation experiments of the decision process under alternative assumptions. The purpose of these experiments is to generate the information required to resolve the first issue stated above, concerning the impact of changes in decision parameters on the choice of pesticide application levels.

The experiments are conducted by means of a digital-computer program that uses numerical estimates of the parameters of loss expectations and variance of these losses for different application levels and application strategies, and of other factors involved in the pesticide use decision. The validity of such a "quasi-empirical" analysis depends on the validity of empirically relevant parameters and the theoretical specifications of the model. Parameter estimates have therefore been statistically derived from available data. This approach necessitates a specific empirical focus. While the model itself is sufficiently general to handle a wide variety of cases, the implementation concentrates on one crop, one region and one type of pesticide. This restriction is necessary to control for the influence of different pest problems, pest control alternatives and crop production environments.

Insecticides were selected as the type of pesticide to be investigated, since these chemicals have been found to be both the most toxic and the most persistent. The dangers associated with their use are reflected in the recent ban on DDT, except for isolated uses, as well as restrictions on other organochlorine insecticides. Neither herbicides nor fungicides, the other types of pesticides, raise the same public policy concerns. Fungicides account for less than 10 per cent of the active pesticide ingredients applied; in addition, they have been considered in a previous decision-theoretic analysis by Carlson [3].* While herbicides are the fastest growing pesticide, their usage does not appear amenable to any significant reduction through subsidized crop insurance or information services. Weed detection and multiplication problems call for other solutions, such as mechanical cultivation and crop rotation.

The choice of insecticides as the relevant pesticide category suggests cotton as the most suitable crop, since insecticide usage is most important in cotton production. Cotton accounted for 47 per cent (65 million pounds) of total crop insecticide usage in 1966, the most recent year for which reliable published data are available [8]. Unpublished estimates from the 1971 Farm Expenditure Survey indicate an increase of over ten per cent in insecticide use on cotton between 1966 and 1971. In addition to the relatively intensive use of insecticides in cotton production, there are also significant qualitative reasons for choosing cotton. This crop uses the largest quantities of organochlorine insecticides, accounting for approximately 70 per cent of total organochlorines used in agricultural production. With the current ban on DDT, though, cotton farmers are substituting methyl parathion (organophosphorus compound) for the organochlorine compound DDT.

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* Figures in brackets refer to the references listed in Section VIII.

Concentration on a single region is justified by the greater sensitivity of the results to actual production conditions. Parameters estimated on a national basis could introduce considerable "noise" into the analysis by concealing significant differences among regions. For the present study, the South has been chosen, including the Mississippi Delta, the Southeast, and parts of Appalachia. This area accounts for slightly less than half of the total 1972 cotton output, according to data released by the Department of Agriculture [22]. In addition, insecticide usage in cotton production is higher in this region than in others.

The choice of cotton as the focal crop provides a comparatively favorable data base for the analysis of the first issue, the potential of pest management information and crop insurance programs to "reach" the farmer. Cotton has already been subjected to extensive analysis with respect to the insecticide problem. Although research efforts have focused on the impact of bans on specific insecticides on production costs and yields,* the information gathered in previous studies establishes an empirical background for the present investigation. In addition, cotton producers have participated in scouting and pest management information programs for a number of years. While these programs have been isolated and limited in scope, some data have been collected, program structures have been established, and rudimentary evaluation studies have been conducted. These data are essential for going beyond the assessment of the potential impact of the policy options studied here under idealized conditions. For example, data from the Federal Crop Insurance Corporation can be used to assess subscription patterns on an empirical basis.

The results of the simulation experiments and the findings of the empirical analysis concerning the ability of information and insurance programs to secure participation by farmers are subsequently combined to formulate policy recommendations of a more general nature. The design structure of this study is presented in graphical form in Figure 1.

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* Examples for these studies are Cooke [4], Cooke, Berry, and Fox [5], Texas A&M University [19], and Pimentel and Shoemaker [16]; for an evaluation of alternative approaches to change insecticide use, not specific to cotton, see Dixon, Dixon, and Miranowski [7].

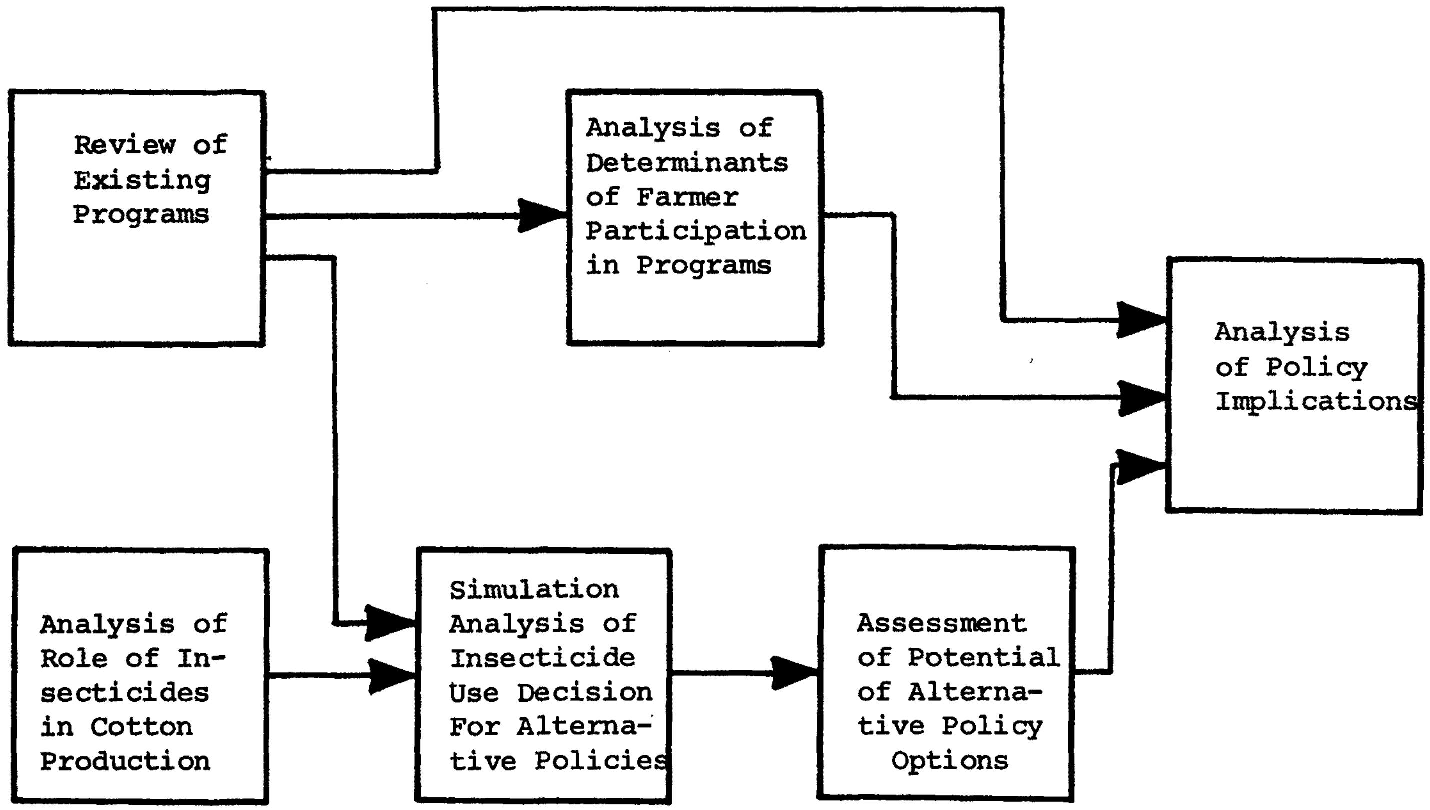

Figure 1. Schematic Structure of Study Design

STRUCTURE OF THE REPORT

The structure of the presentation in this report reflects the overall design of the study. The first step is the establishment of the context within which pest information and crop insurance programs in cotton production. Section IV presents an overview over the role of insecticides in cotton production and reviews the experience of public programs currently in operation. This review establishes the basis for the development of the decision-theoretic analysis, presented in Section V.

The discussion of the results of the simulation analysis, indicating the potential impact of pest information and crop insurance programs, is followed by an assessment of the factor influencing the participation of farmers in these programs. Section VI presents empirical evidence on the sensitivity of participation patterns to variations in the cost of participation to the farmer. The policy implications of the findings of this study are examined in Section VII.

SECTION IV

THE POLICY CONTEXT

INTRODUCTION

This section presents an overview of pest management problems in cotton production and describes current policy programs in pest information and crop insurance. This review establishes the macro-analytical framework for the microeconomic investigations described in subsequent sections.

The first section focuses on the extent of insecticide use in cotton production and examines the role of these chemicals as productive inputs. This analysis includes the specification of empirical production functions for insecticides. The next section reviews the characteristics of pest management information programs currently operating and presents the available evidence as to the effect of these programs on insecticide use patterns. This discussion is followed by an overview of the major public crop insurance program offered through the Federal Crop Insurance Corporation.

INSECTICIDES IN COTTON PRODUCTION

It is difficult to estimate current insecticide use in agricultural production. Reliable data are available only for 1966, before the ban on DDT. These data were compiled by Eichers for the Economic Research Service of the Department of Agriculture [8]. Table 1 shows the amounts of different types of insecticides used in cotton production for 1966. The second column shows estimated usage pattern under the assumption of a ban on DDT. These estimates can be used as approximations of current insecticide use. Although acreage changes have occurred, quantities of insecticides used on cotton have not changed significantly.* However, unpublished estimates from the 1971 Farm Expenditure Survey indicate some

* Source: Conversation with Dr. Austin Fox, Head, Pesticide Research Group, ERS, USDA.

Table 1. TOTAL U.S. COTTON INSECTICIDE USAGE IN 1966

(In 1,000 Pounds of Active Ingredients)

Type of Insecticide	Actual Usage	Estimated,[a] Assumed Ban on DDT
Organochlorines		
Lindane	163	163
Strobane	2,016	2,016
DDT	19,213	0
Endrin	510	510
Aldrin	123	123
TDE	167	0
Toxaphene	27,345	49,228
Others	166	166
Organophosphorus		
Disulfoton	300	300
Bidrin	2,857	2,883
Methyl Parathion	2,181	2,181
Malathion	559	559
Trichlorfon	963	1,447
Azinphosmethyl	200	442
Others	285	285

[a] Insecticide usage under a DDT ban was estimated on the basis of the following assumptions: 1.2 treatments of toxaphene-methyl parathion would be needed to replace the former toxaphene-DDT-methyl parathion combination; new application rates would be 50% higher for toxaphene and six times greater for methyl parathion. Other minor changes were needed in bidrin, trichlorfon and azinphosmethyl to adjust for situations in which DDT was used alone.

Sources: Eichers <u>et al.</u> [8], Davis <u>et al.</u> [6], and Cooke [4].

increase in the total quantities applied.

The intensity of insecticide use in cotton production is relatively high compared to other crops; it is surpassed only by apple growing. Usage in 1966 amounted to approximately 6.3 pounds per acre of cotton cultivated; the amount per acre appears to have slightly decreased by 1971. There are significant interregional variations in the intensity of insecticide use: for 1966, the quantity of active insecticide ingredients applied per acre per year averaged approximately 9 pounds in the Mississippi Delta, over 15 pounds in the Southeast, and more than 5 pounds in the Appalachian states. All other cotton-producing regions averaged less than 5 pounds. These averages abstract of course from substantial variations among subregions and among individual cotton producers.

These data provide an impression of the magnitude of the insecticide use problem in cotton production. A more differentiated assessment of the importance of insecticides requires an understanding of their function in reducing the likelihood and severity of insect damage to the cotton crop. It is difficult to develop such an understanding on the basis of "real-world" data, since insecticides constitute only one input among many. Their effectiveness depends on the application "technology," cultivation methods, infestation levels, and weather conditions. This interaction with other factors partially under the control of the agricultural producer necessitates a large data base for determining the impact of insecticides empirically. Such a data base does not exist in the form required.

Fortunately, the analysis of the relationships between agricultural inputs and outputs can draw on data obtained under experimental conditions in agricultural research stations. For the present purpose, a review of available data relating crop yields to different levels of insecticide application indicated that the most appropriate data described the results of experiments conducted during 1962-1964 at the Wiregrass Substation in Alabama, as provided by Watson and Sonyers [24]. These experiments were designed to test various insecticide treatment schedules. They included variations of application patterns. Two experimental alternatives have been selected for the analysis here, since they describe two extremes in application procedures. The "complete season control" alternative consisted of automatic sprayings at prespecified intervals, yielding between 24 and 26 applications per season. This application pattern can be viewed as typical for the farmer who lacks the information or experience to interpret indicators of impending pest damage, and who attempts to minimize risk by using pesticides "blindly," regardless of need. The second experimental alternative selected for the analysis presents a more differentiated approach: insecticides were sprayed only when scouting information showed current infestation levels exceeding a 25 per cent threshold. This alternative can be interpreted as representative of a farmer who makes maximum use of available information. These two data sets have been used in this study to derive statistical estimates of the relationship between amounts of insecticides used and the associated crop yield. This relationship is akin to a (one-factor) production function.

The statistical analysis requires the prior specification of a functional form of the relationship. This specification should reflect assumptions about the marginal productivity of insecticides; if other inputs are held constant, it is reasonable to expect declining marginal productivities. This assumption precludes the use of a linear functional form, since such a production function would imply constant marginal productivities. This elimination leaves the quadratic and multiplicative (Cobb-Douglas) forms as alternatives. The multiplicative form, which allows for declining marginal productivities, creates a serious estimation problem, once zero input levels are allowed.* Because of these shortcomings of the two major alternatives, the quadratic form of the production function has been used in the empirical analysis. It allows for declining marginal productivities of insecticide use without raising estimation problems. This form has been applied to the analysis of the results of experiments conducted by agricultural research stations with some success, e.g. by Heady and Tweeten [12] and Heady and Dillon [11]. Other investigators, such as

* Zero input levels prohibit the logarithmic transformation required for linear-regression analysis; the addition of a constant to all observations may introduce biases into the resulting estimates.

Sutherland, Carlson and Hoover [18] and Huffman [14], have used the quadratic production function successfully in the analysis of actual farm survey data.

These considerations delineate the insecticide production function tested as follows:

$$Y = b_o + b_1 X + b_2 X^2 + u \qquad (1)$$

where Y = cotton yield, pounds of cotton lint per acre;
X = insecticides, pounds applied per acre;
b_i = regression coefficients (i = 0, 1, 2);
u = disturbance term.

The assumption of declining marginal productivities implies that b_2, the coefficient of the squared term, is negative.

The regression parameters for the two data sets were estimated by ordinary least squares. The results are shown in Table 2 for the two alternative application patterns, "complete season control" and for 25% infestation levels only. In both cases, the regression coefficients b_1 and b_2 are significantly different from zero; in addition, they exhibit the expected signs. The regression equations also provide satisfactory explanations of the behavior of the dependent variable, as indicated by the multiple correlation coefficients which are significantly different from zero (at the 95% confidence level).

If the marginal physical product of insecticides implied in the regression equations displayed is used as a measure of overall efficiency of the two application methods, switching from "mechanical" application to spraying in response to need would imply a 10% increase in production efficiency at the average application level of 6.3 pounds per acre. This figure is of course illustrative only; the decision-theoretic analysis in Section V uses the evidence presented here and subjects it to a more formal assessment of the implications of alternative insecticide use patterns.

Table 2. INSECTICIDE PRODUCTION FUNCTION ESTIMATES

Regression Coefficients	Programmed (Periodic) Application	Application As Needed (25% Infestation)
b_0	516.75	574.61
b_1	21.80	24.13
	(5.53)	(5.43)
b_2	-.23	-.32
	(-4.61)	(-4.58)
R^2	.804	.653
Sample Size	12	21

t-Statistics in parentheses.

This brief analysis of the role of insecticides in cotton production establishes the background for a review of the experience of existing pest information and crop insurance programs. Such a review is necessary to direct the analysis of the pesticide decision. In addition, it provides the background for the analysis of the feasibility of desired changes in institutional and financial arrangements.

PEST INFORMATION SERVICES

Pest management information services can assist the cotton farmer in three ways: first, by providing him with accurate and up-to-date data on the level of pest infestation in his fields; secondly, by making recommendations for insecticide applications on the basis of field data; and thirdly, by providing suggestions improved techniques of pest management. Infestation data are gathered through scouting efforts, in which workers trained in the recognition of harmful and beneficial insects, as well as diseases and other important crop conditions, are paid to check fields once or twice a week.

Insecticide application recommendations are based on the rationale that insect control measures are necessary only when infestation in a particular field reaches an economic threshold level. This concept is defined as the infestation level at which the economic cost of reduced crop sales is predicted to exceed the cost of applying corrective pesticides or taking some other pest control measure.* The application of this concept to pest management requires data on actual infestation levels, as well as the expected yield reduction caused by different levels of infestation under given cultivation methods and weather conditions. In addition, the prediction of monetary losses requires assumptions about the future market price of the crop. The estimation of the total cost of corrective action must account for direct costs of application, as well as the indirect effects through disturbances of the ecological balance between harmful insects and their natural predators.

* Another, less rigorous definition is also widely used; it sets the threshold at that level of infestation that is expected to cause any reduction in crop yields.

Scouting programs are a crucial input into <u>integrated pest management systems</u>. Such systems employ a combination of pest control techniques, ranging from utilization of natural controls to a variety of countermeasure by the farmer. Because of the extreme complexity of such a comprehensive approach to effective pest control, it demands reliable data. In addition, integrated pest management by the farmer necessitates assistance in interpreting scouted field data and in the selection of the most appropriate control techniques. By establishing an on-going relationship with farmers, scouting programs are able to fulfill this assistance role.

The rapid development of private and public sector pest information services is the result of a combination of increasing environmental concerns, the growing difficulties of pest control through chemical insecticides, and a growing body of research indicating that insecticide applications can be reduced substantially with little or no adverse effects on yields.

By 1972, about one-fourth of the U.S. acreage planted to cotton was scouted, or about 3.4 million acres [20]. The largest share of this acreaged, 1.3 million acres, is scouted by private-sector entomological or general agricultural consultants. Extension trained scouts cover approximately 866,000 acres of cotton through the USDA-sponsored Pest Management Program and various state scouting programs. Growers themselves, or their employees, scout an additional 791,000 acres. The remainder of the acreage covered is scouted by the local sales representatives of the chemical industry (332,000 acres) and cotton gins and cooperatives (105,000 acres).

<u>The USDA Pest Management Program</u>

During its first year of full-scale operation in 1972, the USDA Pest Management Program provided Federal funds to 22 programs in selected counties in several states to establish new or subsidize existing field scouting operations, to develop computer data management systems for information on pest populations and other aspects of farm conditions and operations, and to make recommendations to growers about pest management practices. This program can be regarded as a model for a Federally-sponsored information service.

Over the period 1972 through 1974, the Cotton Pest Management Program received a total of $650,000; these funds financed operations in fourteen states. In 1972, the Cotton Pest Management Program covered almost 5,000 producers with 574,000 cotton acres in 111 counties. Participating producers averaged 125 acres of cotton, which is high compared with the U.S. average of 70 acres per cotton farmer. The Program employed 484 scouts with an average workload of roughly 1,200 acres each. On the average, one scout supervisor was responsible for every twelve scouts. These figures are of course only average; Program characteristics varied substantially among cotton producing regions and states.

Available data indicate a total cost per acre scouted of $2.99 for 1972 and $3.18 for 1973. The following breakdown describes the sources of funds:

	1972	1973
PMP Grant Funds	.82	1.13
Producer Payments	1.40	1.36
Extension Contributions	.70	.63
Other	.07	.06
Total Cost per Acre	$2.99	$3.18

The 1973 Pest Management Program contribution of $1.13 per acre in grant funds to the scouting programs constitutes a 36% subsidy of the total cost of $3.18; if other direct and indirect subsidies are included, this percentage increases to 57%.

Our survey of persons responsible for Cotton Pest Management Programs in most cotton-producing states indicates that the total per acre varies from $2.00 to $5.00, depending on the services provided, and -- to some extent -- on regional characteristics such as the length of the growing season. Costs can run higher for private-sector programs which essentially assume decision-making responsibility for a grower's pest control program.

Private Scouting Services

Private entomological consulting firms have been active in scouting and formulating recommendations for pest management for a number of years. The first private sector scouting services available were operated by chemical companies and distributors. More recently, entomological consultants and consulting firms have begun to offer producers a wide range of pest management services, including scouting and recommendations based on infestation data.

In some states, the USDA Pest Management Program has relied heavily on these private firms. For example, the California program contracts out its scouting with Federal funds. In many other states, the USDA Pest Management Programs see their role as initiating scouting programs only in areas where private scouting services have not covered most of the acreage. This need varies among regions. In Mississippi, for example a single company (Agriculture Consultants) scouts more than half of the state cotton acreage.

This important role of private scouting services suggests that the need for Federally-sponsored programs may be limited. It is conceivable to view such programs as "seed efforts," operating only for a limited time in areas not participating in scouting programs as yet -- until producers have realized the potential of these services and are willing to purchase pest management information services on their own and to comply with recommendations based on the economic threshold concept.

Evaluations of Existing Pest Information Programs

Most of the state-level Cotton Pest Management Programs have undertaken or sponsored evaluations of the effectiveness of the services provided to farmers in reducing pesticide use and in improving farm incomes [23]. A survey in Alabama showed that participants in the scouting program made two less applications of pesticides in 1972 than in 1971, for a saving of $4.00 per acre, corresponding to an average of nearly $500 per farmer. Two applications less represent a reduction in pesticide use of about 13 per cent, given an average of 14 to 16 applications per year for the state. Data for other states are comparable; Arkansas reported an average reduction of insecticide use by four applications per year, Mississippi almost three, and Louisiana two to three. Generally, these reports did not contain data on the associated impact on cotton yields realized by participants. It is therefore impossible to assess the net benefit (cost) to the cotton farmer.

A more detailed evaluation of their program has been prepared by Arizona program personnel, entitled "An Evaluation of Pesticide Use Practices by Pinal County Cotton Pest Management Program Participants in 1972." The data summary presents no data on cotton yield, but it does contain detailed data on the effectiveness of pest information services. Three principal findings are of interest here:

1. About 50% of the cotton acreage covered by the scouting program was sprayed according to need, that is, in compliance with recommendations based on scouted field infestation information. The other 50% was sprayed ac- to automatic schedules or other previously established patterns.
2. The acreage sprayed according to need was treated with insecticides about 30% fewer times per acre per year than the rest of the acreage in the program. This is the amount of pesticide reduction that could have been achieved by all participating farmers if all of them had followed the program recommendations based on scouted field information.*
3. The total acreage covered by the scouting program was treated 16% fewer times than the portion of the acreage sprayed according to previously established patterns. It falls short of the maximum of 30%, since only half of the participating acreage was sprayed according to recommendations.

Although the variation between large and small farms in Pinal County, Arizona was significant, the reduction in pesticide usage was substantial for all farm sizes. The data reported show a clear trend for larger farms to devote a smaller share of their acreage to treatment based on need than smaller farms. In addition, larger farmers who follow program

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* It is interesting to note that this percentage reduction corresponds almost exactly to the percentage reduction resulting from the introduction of information program recommendations in the simulation analysis discussed in Section V.

recommendations tend to achieve less reduction in the number of applications than smaller farmers.

It is difficult to interpret or generalize these findings adequately, partially because of the small sample size (54 growers with about 18,000 acres), and its limitation to one state. The analysis also assumes that the number of applications can be viewed as a satisfactory approximation of the amount of insecticides applied, and that growers participating in the information program who failed to follow program recommendations are typical for farmers who lack scouting information. These assumptions may be somewhat simplistic. Furthermore, it is possible that reductions in pesticide use should be attributed to factors other than participation in scouting programs. Even so, the evaluation of the Arizona experience suggests the dimensions of the potential of pest information services.

Ganyard and Worley [9] have examined the impact of pest information programs on farm profits. They analyzed the yields and the costs of insect control among farmers participating in the Cotton Pest Management pilot projects in North Carolina. Their results indicate that participants in the projects, which coordinate scouting programs, the purchase of chemicals, and the arrangements for aerial applications, obtained substantially higher yields with only slightly higher insect control costs than producers who did not participate. The specific contribution of the scouting and information component to the greater profitability among participants could not be quantitatively isolated, but the authors believed that this component had a highly positive effect.

Summary

The available evidence on the impact of pest information services on insecticide usage patterns is sketchy. It does not allow for a clear determination of the implications of participation in such a program on farm income. However, it appears that compliance with pest information program recommendations may reduce insecticide usage by as much as 30 per cent. This reduction does not appear to entail reductions in farm income.

CURRENT CROP INSURANCE PROGRAMS

One of the premises of this study states that pesticide use in agricultural production is a means by which the farmer reduces his risk. An alternative method consists in purchasing risk coverage in the form of an insurance policy. It is possible that a sharing of the risk associated with agricultural production between the farmer and the public sector through some form of crop insurance would result in a reduction of pesticide application levels. The following discussion provides a brief overview of crop insurance programs currently available to the farmer.

Federal Crop Insurance

Federally sponsored crop insurance is made available to farmers by the Federal Crop Insurance Corporation (FCIC). This insurance program covers all risks of crop loss encountered by the farmer, but the FCIC program is not intended to compensate farmers for the full crop value lost. Federal crop insurance coverage is limited to production expenses, which cannot exceed 75 percent of county average yield. Although production expenses as a share of average yield vary from county to county, they typically constitute roughly 60 percent of county average yield. Thus, FCIC coverage is limited to losses exceeding 40 percent of average yield in the county; essentially a 40 percent deductible provision for the average cotton farmer.

The FCIC program is also restrictive in the determination of indemnity payments. If the actual yield for a particular crop on the entire farm* falls below the county average yield at harvest time, the farmer receives an indemnity payment based on the difference between actual and (county) average yield. The dollar value of coverage is determined by the price option the producer selects when he purchases the insurance coverage. The actual indemnity payment is the product of the price option, the difference between actual and county average yield (expressed on a per acre basis), and the number of cotton acres on the farm.

*All fields of the particular crop on a farm must be insured if the farmer wants to participate in the FCIC program. The average yield used to determine losses is computed across all fields used in growing the particular crop on the participating farm.

Premium levels are determined by actuarial statistics for the given crop in the particular county. These levels vary with the price option selected by the producer, who can choose one of three price options -- rather abritrarily established by the FCIC -- to determine the dollar value of his insurance coverage.

The FCIC program is less flexible than specific-risk insurance programs offered by the private insurers, although it provides coverage for a wider variety of risks. The structural provisions of the FCIC insurance program reduce its potential as an effective means of reducing cotton production losses due specifically to insect damage. As noted above, FCIC cotton coverage is limited to losses exceeding approximately 40 percent of county average cotton yields. At the same time, the maximum loss from insect damage in cotton production seldom exceeds 40 percent of cotton yields. With the equivalent of a 40 percent deductible, FCIC coverage for losses due to insect damage alone would seldom become effective, if at all. Although some variation in yield guarantee within a county is possible and other risks are covered, there is little incentive to purchase current all-risk crop insurance to cover the losses from insect damage.

Another provision makes the FCIC insurance program a doubtful policy instrument for reducing insecticide use. Program participants are required to employ "good production practices," including accepted insect control measures. Under the present legislative structure of the FCIC program, participating producers do <u>not</u> have the option of using insurance as a substitute for "necessary insecticide treatment"; such a substitution could only be made for "excessive treatments" resulting from a programmed insecticide application procedure.

Private Crop Insurance

Private insurance companies offer specific-risk crop insurance to farmers, primarily against hail damage. This type of insurance can be purchased with yield and price coverage up to the full value of the expected crop. Indemnities are generally based on the portion of the growing crop lost to hail; the percentage of the crop lost is determined immediately after occurrence of the damage by an adjustor. Under specific-risk insurance, indemnities are calculated on the basis of the loss percentage times the coverage for individual acres damaged by a specific threat. Private insurance options differ from the FCIC provisions in two other respects: coverage can be purchased for part of the crop, and it can be purchased at any time as opposed to planting time for FCIC coverage.

Specific-risk insurance could be extended to cover insect damage to the crop. The provisions of such an insurance scheme could be analogous to the hail insurance framework currently offered by private insurance companies. The program could be operated either by the public sector or by private companies, possibly with appropriate subsidies to reduce the premium cost to the farmer. Variations in the pest control requirements for subscribers (such as participation in an integrated pest management program) could be integrated into the insurance provisions. Although these variations are of interest to the policy maker, the theoretical analysis in Section V focuses on simpler insurance schemes.

SUMMARY

The discussion in this section provides an overview over the current context of the insecticide problem in cotton production. The available evidence indicates that insecticides are an important input into the production process for the cotton crop. Pest information exhibit some potential to improve the efficiency of insecticide usage, leading to a reduction in application levels without lowering farm incomes. Public crop insurance programs currently are limited to the all-risk FCIC scheme which shows some deficiencies as an instrument for reducing insecticide usage. Specific-risk insurance, similar to insurance against hail damage currently offered by private insurance companies, appears to offer greater flexibility.

SECTION V

ANALYSIS OF THE INSECTICIDE USE DECISION

THE CONCEPTUAL FRAMEWORK

The analysis of the role of insecticides as inputs into cotton production in Section IV establishes the basis for the conceptual framework for the decision-theoretic analysis here. The production functions describe the expected yield for any given amount of insecticides; viewed from a different angle, they specify the expected loss relative to some maximum yield. The actual loss for a given amount of insecticide varies in response to other factors, but is likely to fall within a definable range. Given the shape of the production functions estimated in Section IV, the expected loss decreases with increasing amounts of insecticides at least up to a point. It is reasonable to assume that the range (variance) of percentage losses also decreases with increasing application levels. This relationship is illustrated in Figure 2. In this schematic presentation, the average loss for each level of insecticide use is indicated by the solid lines, while the likely range of percentage losses is sketched by the shaded bands.

For the farmer's decision concerning insecticide use, this relationship is not immediately relevant. The farmer is concerned about (net) income levels, rather than the physical crop yield. If the relationship between monetary income and physical yield were linear, the solution to the decision problem would be obvious: since lower losses are always preferable to higher ones, and smaller preferable to greater risks, the farmer would apply that amount of insecticides for which the production function attains a maximum. However, the relationship between net incomes and percentage crop losses is non-linear. This feature may raise the need for evaluating tradeoffs between expected loss and risk.

In simplified terms, the necessity of a tradeoff between expected monetary income and risk may occur as a result of increases in the cost of production caused by higher expenditures on insecticides. The farmer's net income is

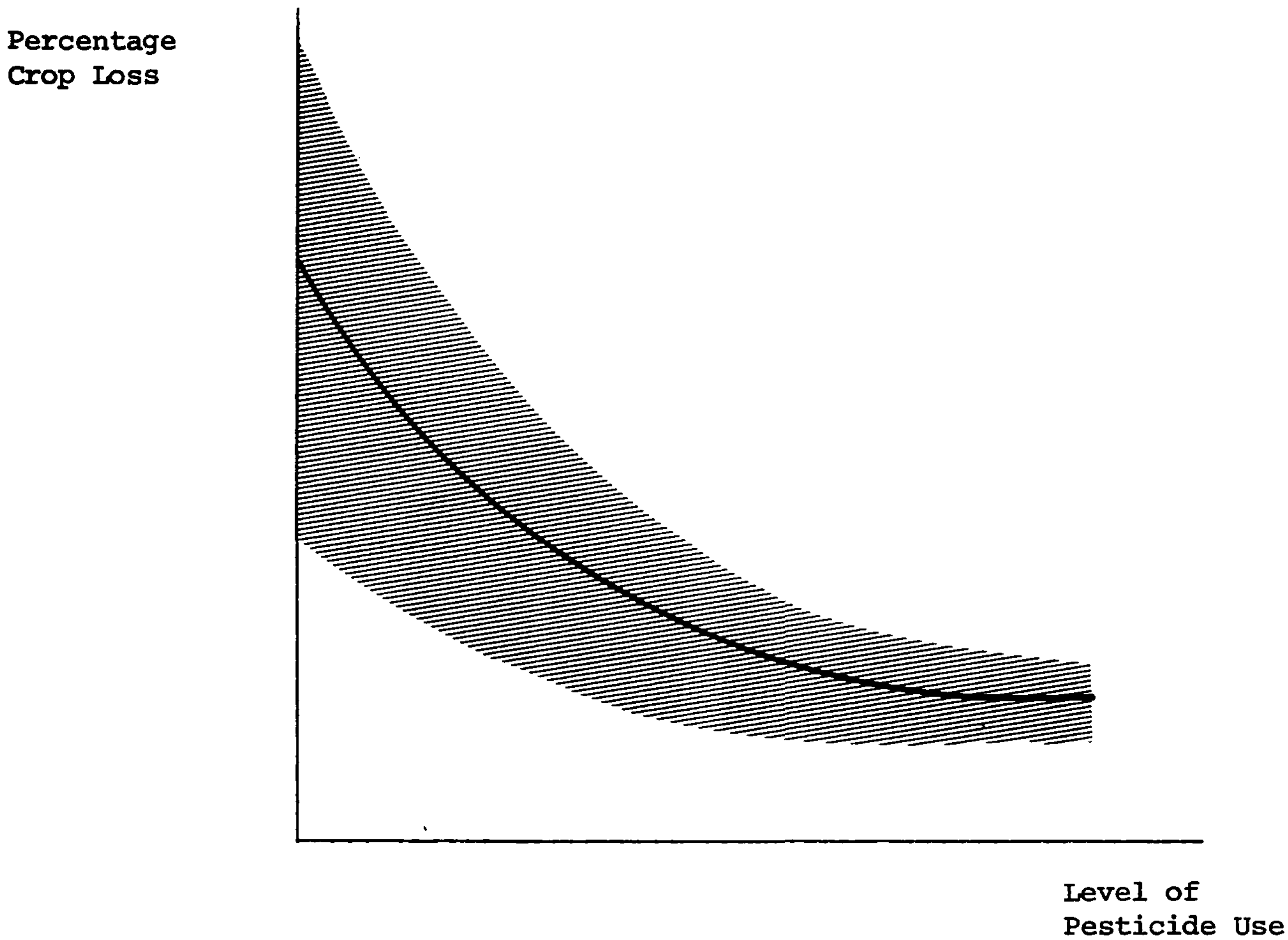

Figure 2. Relationship Between Pesticide Use and Crop Loss, with Risk Band

defined as total revenue less cost of production. The cost of production can be broken down into "fixed costs" and the costs of insecticides. Under conditions of price maintenance programs, as in the case of cotton, total revenue is directly proportional to actual physical crop yield. Since actual crop yield can be expressed as maximum yield less pest losses, total revenue becomes a direct function of the percentage crop loss. The percentage crop loss is assumed to be a function of the amount of insecticides applied. If the cost of production (other than insecticide costs) remain constant for different loss levels, the <u>expected</u> net income becomes a function of two factors that depend on the amount of insecticides used: expected crop loss and insecticide costs.

The level of insecticide use also affects the variance of net income expectations, or the monetary risk. This risk factor declines consistently with increasing amounts of insecticides. The expected net income, however, is likely to increase initially in response to lower crop losses; there is a point, though, at which the increasing costs of greater amounts of insecticides will outweigh the gains from reduced losses. These relationships are illustrated schematically in Figure 3. In this illustration, the expected net income reaches a maximum for the insecticide application level OA. To the right of A, the achievement of lower risk must be "paid for" by a reduction of expected net income. From that point on, the selection of a particular level of insecticide use depends on the relative weights that the farmer attaches to his two decision criteria, expected net income and risk.

This simple framework facilitates the understanding of the basic nature of the problem. However, it is inadequate for studying more complex situations. A decision-theoretic approach allows for a more rigorous analysis.* Two elements are important in such an approach. First, the rather loose concepts of expected loss and risk are replaced by subjective expectations of the likelihood of different loss levels for a given level of insecticide application. For each level of insecticide use, these subjective expectations can be described in terms of a probability density function

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* Perhaps the most useful reference work on decision-theoretic research -- with a number of examples from agriculture -- is Halter and Dean [10].

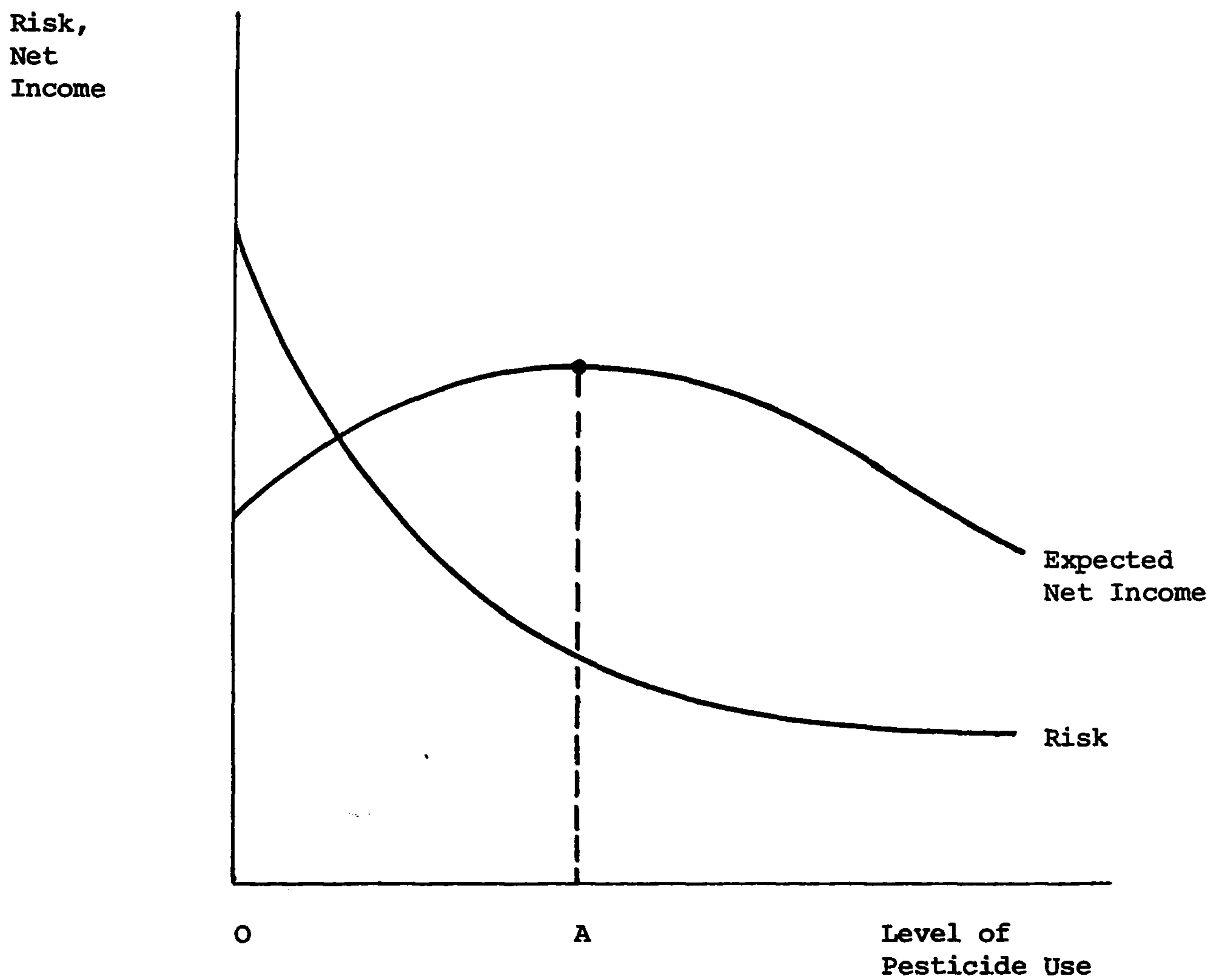

Figure 3. Relationship Between Pesticide Use, Expected Net Income and Risk

that specifies the conditional probabilities the farmer assigns to different loss levels, given a particular level of insecticide use. For example, if all losses within the "risk band" are equally likely, the farmer's loss expectations could be described by a uniform distribution. It is reasonable to assume, though, that the likelihood of losses is clustered around the expected values, and that higher loss levels have lower probabilities. These assumptions can be sketched in graphical form in a three-dimensional version of Figure 2, as shown in Figure 4.

The second important element in the decision-theoretic approach is a utility function that assigns a single value to any given combination of expected net incomes and risk. Generally, the utility measure is directly related to expected net income; if the decision maker (farmer) is risk-averse, utility is inversely related to risk. Thus, the utility function describes in quantitative form the tradeoffs the farmer is willing to make between expected net income and risk.

ANALYSIS APPROACH

The decision-theoretic framework for the analysis of the insecticide use problem forms the basis for a microeconomic model used in this study to simulate the farmer's decision process. This model incorporates the following elements:

- the possible actions of the farmer are described in terms of different amounts of insecticides applied on a per-acre basis in 5-pound increments;
- for each insecticide amount, the farmer's loss expectations are described in functional form on the basis of empirically derived parameters for the relationships sketched in Figures 2 and 4;
- for each insecticide amount, there exists a unique functional relationship between crop losses (percentage of maximum possible yield lost to pests) and net income; this relationship expresses net income as total possible income minus the value of the crop lost and the cost of pesticides;
- associated with each income/risk combination is a utility measure that reflects the farmer's preferences between expected income gains and increases in risk.

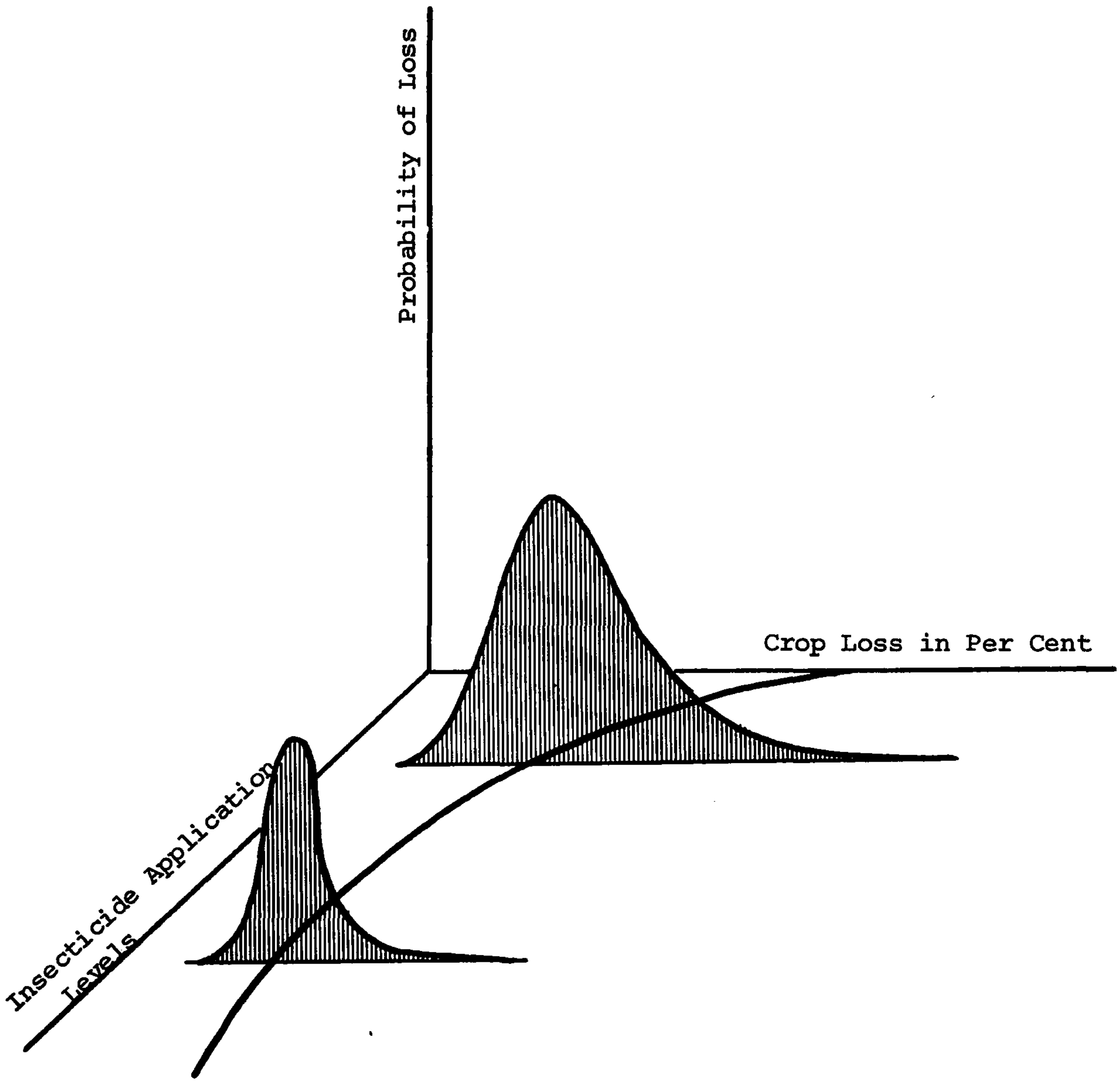

Figure 4. Probability Distributions of Loss Levels

These components outline the structure of the simulation model.* The decision rule used in the actual simulation states simply that the farmer selects the action (applies the amount of pesticides per acre) that maximizes his expected utility.

The model was subsequently translated into a computer program to perform the required computations.+ This procedure requires quantitative estimates of the parameters of loss expectation functions for different levels of insecticide use, and the specification of the net income and utility functions. In addition, the simulation experiments necessitated the specification of "prototypical" policy options for Federally subsidized crop insurance. In the case of information programs, data limitations constrain the analysis to two extreme cases, as discussed in greater detail below.

PARAMETER SPECIFICATIONS

The most important input into the simulation of the farmer's decision process are the parameters of the (conditional) loss expectation functions for alternative levels of insecticide use. Carlson [3] has developed a survey approach to obtain estimates of loss expectations for crop diseases in peach production. This approach could not be used in the present study, primarily because of resource constraints. A suitable alternative is the use of the production functions presented in Section IV.

The use of these functions in deriving expected losses is relatively straightforward. The first step consists in determining the maximum possible crop yield for each of the two application patterns. The second step uses five-pound increments of insecticides (from 0 to 40 pounds) to compute expected yield for any of the nine actions considered in the model. The comparison of expected yield for each level of insecticide use with the maximum possible output yields the percentage of crop lost to pests. These estimates are reported in Table 3.

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* The mathematical structure of the model is discussed in greater detail in Appendix A.

\+ Appendix B presents the flowchart of the FORTRAN IV program used as well as a printout of a sample run.

Table 3. EXPECTED PERCENTAGE LOSS ASSOCIATED "RISK" (STANDARD DEVIATION), AND RELATED PROBABILITIES AREAS WITHIN RISK BAND FOR GAMMA-FUNCTION

Pounds of Insecticides Per Acre	Uninformed Application Patterns			Informed Application Patterns		
	Expected Loss (μ)[a]	"Risk" (σ)[b]	Risk Band Probability[c]	Expected Loss (μ)[a]	"Risk" (σ)[b]	Risk Band Probability[c]
0	50	50	.865	38	48	.875
5	40	49	.872	27	44	.888
10	32	46	.881	18	38	.904
15	24	43	.893	11	31	.923
20	17	38	.906	6	24	.944
25	12	32	.920	2	14	.972
30	7	25	.939	.4	6	.991
35	4	19	.956	.4	6	.991
40	2	14	.972	2	14	.972

[a] The expected percentage of crop loss to insects at alternative insecticide application levels.

[b] "Risk" is represented by the standard deviation (percentage units) of the expected crop loss at alternative insecticide application levels and is based upon the variance formula for a Bernoulli trial.

[c] Probability that the actual loss falls in the interval ($\mu-\sigma,\mu+\sigma$), given a gamma-type probability density function (with unadjusted probabilities).

The determination of the loss variance (risk) for each level of insecticide application raises a number of problems. One possibility is the use of the confidence bands around the regression line as measures of risk. However, this possibility has the disadvantage that the estimate of risk would become sensitive to the sample size used in the specification of the regression equation. For example, the procedure would yield higher risk factors for the "as-needed_ application pattern than for the programmed application, which does not appear intuitively acceptable.

Because of these problems, an alternative procedure has been used in specifying the risk factors for each level of insecticide use. For each quantity of insecticides applied, the expected percentage loss can be interpreted as the probability of losing one unit of the crop because of the occurance of pests. In other words, the expected percentage loss for each unit of the crop represents the "success probability" p on a Bernoulli trial which has two possible outcomes -- pest damage (loss) or no damage. The variance of the expected percentage loss for a particular action is given by $p(1-p)$, and this parameter represents the risk factor for each action. The results of these calculations for the two application patterns,plus the probability that the actual loss falls in a given confidence interval, are shown in Table 3.

The basic structure of the relationship between percentage crop loss and net income has already been discussed above. For the actual simulation, these assumptions were summarized in the net income function:

$$y = p_Y \ (1-s) \ Y^* - TC - p_X X, \qquad (2)$$

where y = net income per acre,

p_y = fraction of crop lost due to insect damage, a function of the amount of insecticides applied;

Y^* = maximum possible crop yield per acre;

TC = cost of production per acre, assumed to be constant;

p_X = price per pound of insecticides used;

X = amount of insecticides used, in pounds per acre.

This specification of the net income level as a function of loss identifies the remaining parameters to be estimated for the simulation model.

The price per pound of cotton lint has been set at $0.40, which corresponds to recent price levels in the cotton market. For determining the maximum possible yield of cotton lint per acre, the data from the agricultural research used in estimating the insecticide production functions were compared to actual production data published by the Department of Agriculture [22]. The maximum derived from the regression equations appeared too high for a realistic simulation. Based on USDA data, the maximum yield per acre was therefore estimated at 700 pounds of cotton lint. The "fixed cost" of production also has been estimated on the basis of USDA data; the figure used is $170.00 per acre.

One of the most difficult parameters is the price per pound of insecticide. Given the wide variety of possible insecticide combinations, corresponding to different treatment mechanisms, prices per pound of "average" insecticide are only crude approximations. For the simulation, this parameter has been established at $1.70 per pound of active ingredients. This estimate is based on the assumption that the average price per pound of insecticides used in the study region amounts to $1.50, and that the cost of application per pound per acre is $0.20. These estimates were derived from a number of sources, primarily USDA data.

The utility function, finally, has been specified consistent with the assumption of risk aversion as a behavioral characteristic of farmers. As long as this assumption is satisfied, the specific functional form does not alter the results significantly. The form finally used is the logarithmic one.*

SPECIFICATION OF POLICY OPTIONS

The simulation experiments focused on the effects of pest management information and crop insurance programs on the decision parameters of the farmer and the resulting variations in insecticide use. For greater reliability of the results of the simulation analysis, it is desirable to examine a number of policy options.

* For a more detailed discussion of the characteristics of the utility function, see Appendix A.

In terms of pest information services, data constraints allow only for a binary comparison. The agricultural research station data used in estimating the insecticide production functions, and the parameters of the loss expectation function can be interpreted as describing two extreme cases: the "programmed" application pattern is typical for the farmer who lacks pest infestation information, or is unable to interpret it. These data can therefore be treated as describing the behavior of farmers not utilizing a pest information program. The second data set, which describes the relatinship between insecticide use and yield for the policy to spray whenever the infestation level reaches 25 percent, can be used to represent the application pattern recommended by the typical pest information program. These data can therefore be used to represent the farmer enrolled in such a program and following its recommendations.

The comparison of insecticide use levels for these two types of farmers -- "uninformed" and "informed" -- can be used to assess the potential of pest information programs under the best of all possible circumstances. In the real world, it would be unlikely that the farmer not enrolled in the program would be completely oblivious to signs of insect infestation, just as the participating farmer cannot be expected to follow recommendations to the letter.

The analysis of the potential impact of crop insurance programs allows for greater variation of policy options. Insurance programs affect the relationship between the percentage of crop lost and monetary net income. Three parameters are important in changing this relationship; these parameters describe the obligations of the insurer against the insured in case of loss (assumed here to be attributable to insect damage). The first parameter is the deductible, defined in terms of some percentage of crop lost. As long as the loss falls below the deductible percentage, the farmer bears the full loss. If the loss exceeds the deductible, the insurer may pay all or part of the loss beyond the (monetary) value of the deductible. The second parameter is the coinsurance percentage which specifies the portion of the loss born by the farmer himself. Finally, a third parameter can be distinguished for the specification of insurance options which describes the maximum loss (or minimum income) that the insured is guaranteed. Strictly speaking, this parameter results from a combination of the other two. For example, if the insurer agrees to pay the full value of the loss incurred minus the deductible, the maximum possible loss is given by the value of the deductible. If a coinsurance scheme without deductible is used, the maximum loss of the farmer is the value of his maximum possible net income times the coinsurance fraction (i.e., share of loss covered by the insurance program). In the specification of insurance options for the analysis here, the maximum loss parameter has therefore not been used explicitly.*

The effect of the coinsurance factor (c) and the loss deductible (D) on the relationship between percentage loss and net income described in Equation (2) can be shown as follows:

$$y = \begin{cases} p_Y\ (1 - c \cdot s)Y^* - TC - p_X X - p_I, & \text{for } s \leq D; \\ p_Y\ (1 - c' \cdot s)\ Y^* - TC - p_X X - p_I, & \text{for } s > D. \end{cases} \qquad (3)$$

where c = coinsurance fraction up to deductible;

c' = coinsurance fraction beyond the deductible;

p_I = insurance premium.

These specifications have been used in the simulation model to describe alternative insurance options.

The simulation analysis focuses on a total of seven insurance options, including the no-insurance alternative. The options considered are "pure" cases, that is, either coinsurance or deductible. However, the decision model (and the simulation routine) can be used to examine more complex options and combinations. The six effective insurance alternatives have been specified as follows:

- 50% coinsurance, with the insurer and the insured each bearing one-half of any loss incurred because of insect damage; the annual premium cost required for full cost recovery has been estimated at $34.00 per acre covered;

*The maximum loss parameter could be useful separately in the specification of more complex insurance schemes, such as a deductible, plus some coinsurance arrangement beyond the deductible up to a maximum amount to be born by the insured, and full coverage beyond that point. In the present analysis, the insurance options considered are simpler than that.

- full coverage of the loss incurred beyond a deductible of:

  0%; premium estimated at $69.00 per acre;

  10%; premium estimated at $67.00 per acre;

  20%; premium estimated at $54.00 per acre;

  25%; premium estimated at $43.00 per acre;

- the insurance option currently offered by the Federal Crop Insurance Corporation; this option has been interpreted as full loss coverage beyond a deductible of 40%. This interpretation is the most appropriate approach to translate the provisions of the insurance services offered into the specification used here. The annual premium per acre amounts to $32.00.

The annual premium payments required for full cost recovery under the hypothetical insurance options have been estimated on the basis of the total cost of indemnities to be paid, given historical loss distributions for cotton producers due to insect damage.

The analysis of the impact of insurance programs on insecticide usage in cotton production includes an assessment of the effects of price (premium) variations through subsidies paid by the Federal government. Five subsidy options have been used in the analysis; in addition to full-cost pricing (zero subsidy), the simulation analysis considers reductions in premium costs to the farmer by 10, 25, 50 or 100 per cent.

These specifications establish the background for the discussion of the results of the simulation experiments. This discussion focuses first on the comparison of insecticide use patterns for "uninformed" and "informed" farmers. This comparison also provides some insight into the procedures involved in obtaining the expected net utilities for each alternative considered. The discussion then proceeds to an examination of the impact of insurance alternatives, based on the maximum expected utility for each insurance/subsidy combination. In interpreting the figures displayed, it is important to realize that the expected utilities are expressions of relative preferences only. The numerical values as such are unimportant; they certainly do not figure in this form in the farmer's decision making process. Relevant to the analysis are the values of the expected utilities relative to each other.

Table 4 displays the expected net incomes and associated expected utilities for each of the nine insecticide application levels considered, both for the "uninformed" and the "informed" farmer. The comparison of these data shows clearly that expected net incomes are generally higher for the "informed" farmer; the differences are substantial, reaching a maximum at the 15-pound application level ($43.30).

Correspondingly, expected utilities are generally higher for "informed" farmers. At all application levels, knowledge of the most appropriate application pattern would make the farmer better off. The only exception to this pattern is the maximum application level (40 pounds); this result is partially explained by the curvature of the quadratic production function for the "informed" farmer. In general, though, the subscription charge of $3.00 per acre for participation in the pest management information program is more than offset by increases in application efficiency.

The comparison of expected utilities for different levels of insecticide application indicates that the optimal action (application level) for the "uninformed" farmer is 35 pounds. It is interesting to note that expected utilities reach a maximum at a different application level than expected net incomes. In other words, the risk factor at 30 pounds (for which expected net income reaches a maximum) is sufficiently high to induce the "uninformed" farmer to prefer the next higher application level, even though it yields a lower expected net income.

In the case of the "informed" farmer, both expected net income and expected utility reach a maximum at 25 pounds. In this instance, a decision rule based on the maximization of expected net income would yield the same decision (application level) as the optimization of income/risk combinations. This result suggests that participation in a pest management information program lowers the associated risk sufficiently to encourage the farmer to forego additional applications whose only function is the reduction of risk. In other words, pest management information not only increases the efficiency of insecticides, but it also reduces the need to use them as an "insurance" against risk.

Table 4. EXPECTED NET INCOMES AND UTILITIES WITH AND WITHOUT INFORMATION PROGRAMS

	Programmed Application (Without Information Program)		Following Recommendations of Information Program	
Pounds of Insecticide per Acre	Expected[a] Net Income Per Acre	Expected Utility	Expected[b] Net Income Per Acre	Expected Utility
0	- $30.00	84.4	$ 0.60	88.6
5	- $10.60	87.2	22.90	91.5
10	3.30	89.2	39.50	93.5
15	17.30	91.1	50.60	94.9
20	28.40	92.6	56.20	95.7
25	34.00	93.5	59.00	96.2
30	39.50	94.3	54.90	96.1
35	39.20	94.5	46.40	95.4
40	36.50	94.4	33.50	94.2

[a] The maximum expected net income per acre is achieved by using 33 pounds of insecticides per acre without information programs

[b] Using 23 pounds per acre with information programs yields the maximum expected income.

The comparison of the optimal insecticide application level for the two types of farmers indicates that complete compliance with information program recommendations could reduce insecticide use by as much as 10 pounds per acre, a reduction of almost 30 per cent.* This reduction would be accompanied by an increase in the efficiency of cotton production. There are no direct costs to the public, since the simulation assumes full-cost pricing ($3.00/acre) for information services. Universal acceptance of information program recommendations therefore would result in an overall increase of resource efficiency.

A caveat is in order concerning this interpretation. The amounts of insecticides selected under the specifications of the simulation model are high (roughly 10 pounds) compared to average usage patterns. It is likely that these differences between actual and hypothetical usage patterns can be attributed to the data used in deriving the parameters of the loss expectation functions. Since these data were obtained under experimental conditions, they may represent a somewhat atypical situation. However, even if the absolute amounts may be overstated, the relative impact of pest management information programs indicated by the results of the simulation experiments are representative of the gains reported by existing pest information programs.

The potential benefits of participation in a pest management information program are sufficiently high to raise the question why adoption is not universal as yet. The probable explanation of the lack of universal participation is that the farmer is uncertain of the gains from adoption. This contention is supported by the experience of existing programs, which have witnessed widespread acceptance after initial success. The farmer finds himself in a situation analogous to that of the potential adopter in the literature on the diffusion of innovation. This aspect is explored further in Section VI.

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*This potential insecticide use reduction compares favorably with the results reported in our discussion of existing pest information programs and is identical to the maximum reduction attained.

IMPACT OF CROP INSURANCE PROGRAMS

Tables 5 and 6 present composite pictures of the outcomes of the simulation experiments for alternative crop insurance options for both "uninformed" and "informed" farmers. The individual entries in the tables specify the maximum expected utility the farmer can achieve under each insurance/subsidy combination; the figures in parentheses give the amount of insecticides (in pounds per acre) that would maximize expected utility. For the "uninformed" farmer, the potential of crop insurance as a viable policy option to reduce insecticide usage appears extremely limited. At subsidy levels of less than 50 per cent, only one insurance option would be preferred over no insurance, namely the full loss coverage with a zero deductible. This option is of course somewhat hypothetical; in essence, it is an income maintenance program for cotton farmers. Regardless of the level of loss incurred, the farmer is assured of the maximum income possible. Since the value of the expected loss exceeds the premium (at any level of subsidy), the farmer would of course substitute this insurance program for the use of insecticides. For practical purposes, though, this insurance alternative does not appear feasible; it would be extremely inefficient from a social point of view.

The same holds essentially for the other options involving full loss coverage beyond a given deductible. Since they tend to induce the farmer to stop using insecticides altogether, they are likely to create serious inefficiencies in social resource allocation. The two remaining options, 50% coinsurance and FCIC, become attractive to the farmer only if they are provided free of charge, i.e. at a 100% premium subsidy. These options would lead to a reduction of insecticide use of five pounds per acre. The cost of this reduction to the public would be $32 to $34 per acre; dividing the required subsidy by the five pound insecticide reduction achieved would yield a public cost figure of roughly $6.60 per pound of insecticide use eliminated. Although the social costs of insecticide use are unknown, detrimental side effects would have to be extremely high to warrant this level of expenditure.

Table 5. MAXIMUM EXPECTED UTILITIES FOR UNINFORMED APPLICATION PATTERNS

Insurance Option[a]:	None	50% Coinsurance	Full Loss Coverage With Deductible				
			0%	10%	20%	25%	FCIC
Premium Subsidy in Per Cent	($0)	($34)	($69)	($67)	($54)	($43)	($32)
0	94.5 (35)	92.3 (30)	95.1 (0)	93.0 (0)	92.1 (0)	92.2 (0)	92.3 (30)
10	94.5 (35)	92.5 (30)	95.7 (0)	93.6 (0)	92.6 (0)	92.6 (0)	92.6 (30)
25	94.5 (35)	93.0 (30)	96.5 (0)	94.4 (0)	93.3 (0)	93.1 (0)	93.0 (30)
50	94.5 (35)	93.7 (30)	97.7 (0)	95.8 (0)	94.4 (0)	94.0 (0)	93.7 (30)
100	94.5 (35)	95.0 (30)	100.0 (0)	98.2 (0)	96.5 (0)	95.7 (0)	95.0 (30)

[a]Annual premium in parentheses.

Table 6. MAXIMUM EXPECTED UTILITIES FOR INFORMED APPLICATION PATTERNS[a]

Premium Subsidy in Per Cent / Insurance Option[b]	None ($0)	50% Coinsurance ($34)	Full Loss Coverage With Deductible: 0% ($69)	10% ($67)	20% ($54)	25% ($43)	FCIC ($32)
0	96.3 (25)	93.9 (25)	94.9 (0)	93.0 (0)	92.5 (10)	93.2 (15)	93.8 (25)
10	96.3 (25)	94.1 (25)	95.4 (0)	93.5 (0)	93.0 (10)	93.5 (15)	94.0 (25)
25	96.3 (25)	94.6 (25)	96.2 (0)	94.4 (0)	93.6 (10)	94.1 (15)	94.4 (25)
50	96.3 (25)	95.2 (25)	97.5 (0)	95.7 (0)	94.7 (10)	94.9 (15)	95.0 (25)
100	96.3 (25)	96.5 (25)	99.8 (0)	98.1 (0)	96.8 (10)	96.6 (15)	96.3 (25)

[a] No subsidy for information services; full-cost price of $3.00 per acre.

[b] Annual premium in parentheses.

For the "informed" farmer, the results of the simulation experiments suggest that the no-insurance option is preferable to any other one, as long as the premium subsidy offered is less than 50 per cent. At that subsidy level, the "informed" farmer would prefer the full loss coverage with a zero deductible. However, this option again would induce him to abandon insecticides completely; as in the case of the "uninformed" farmer, this insurance alternative would fail to pass the feasibility test.

For a complete subsidization of insurance premium costs, the farmer would prefer any insurance over the no-insurance option. However, neither the 50% coinsurance scheme nor the FCIC alternative would alter insecticide use. These options would therefore serve only to raise the net income of the farmer without lowering the social costs of insecticide use. The full loss coverage with a deductible of 10 per cent would lead to a complete elimination of insecticides, while the 20 and 25 per cent deductible alternatives would induce reductions by 15 and 10 pounds, respectively. These results indicate that the "informed" farmer reacts much more flexibly to variations in insurance provisions. Full loss coverage with deductibles of 20 and 25 per cent would create substantial reductions of insecticide use without eliminating it completely. However, the subsidy cost of these reductions is substantial; per pound of reduction, the 20 per cent deductible option would require a subsidy of $3.60, while the 25 per cent deductible would require $4.30 per pound.

CONCLUSION

The simulation experiments lead to three major conclusions concerning the relative effectiveness of pest management information and crop insurance programs:

1. Pest information programs can lead to a reduction of insecticide use in cotton production of up to 30%; this reduction is accompanied by substantial improvements in production efficiency, leading to higher expected net incomes and higher expected utilities.

2. In the absence of information programs, crop insurance programs could reduce insecticide use only at a high cost to the public; in most cases, the farmer would substitute insurance for insecticides, which would entail a number of indirect costs to society, such as higher commodity prices or shortages.

3. For the "informed" farmer, full loss coverage beyond deductibles of 20 or 25 per cent would reduce insecticide usage at a relatively high price to the public. However, a full substitution would not occur.

These findings of the simulation analysis form the background for the discussion of the potential of information and insurance programs to "reach" the farmer, i.e., to alter the inputs into his decision process.

SECTION VI

DETERMINANTS OF PROGRAM PARTICIPATION

INTRODUCTION

The results of the decision-theoretic analysis indicate that farmer behavior is sensitive to variations in insurance premium levels. In the case of information programs, variations in price did not show any effects on relative preferences;* application according to need would be preferred at any price up to the price level required for full cost recovery. However, the theoretical analysis fails to clarify the response of farmers under conditions of uncertainty.

In order to arrive at an assessment of the relative potential of the two types of programs, it is necessary to review their experience under actual operating conditions. To what extent have they been able to gain the cooperation of farmers? The data available for examining this question are rather limited, which constrains the scope of the empirical analysis to some extent. For example, the results of the simulation model indicate that "informed" farmers differ from their "uninformed" counterparts with respect to their willingness to purchase insurance services. This aspect cannot be explored here, since data are lacking that would describe both subscription to information services and purchase of insurance coverage. Even so, the empirical analysis of farmer response to variations in program characteristics provides some guidance to the development of broad policy recommendations.

PURCHASE OF CROP INSURANCE COVERAGE

Microeconomic theory implies that the quantity of a good or service purchased increases with decreasing price, provided all other factors influencing demand are held constant. Since qualitative variations of crop insurance programs are currently limited, the analysis of the determinants of participation here focused on the relationship between the insurance coverage purchased and the price of that coverage.

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*Because the relative preferences were not altered, these results are not reported.

The sample for the analysis was drawn from cross-section data for 1972 on counties participating in both the Federal Crop Insurance Corporation program and USDA Pest Management Programs. The data are limited to 1972, since it was the first year that an effective public pest management program existed for cotton. Although some public and private programs were in existence prior to 1972, they operated at a small scale; comparable data for different programs are lacking.

The FCIC provided previously unpublished cotton insurance data on a per county basis. These data include:

- acres insured,
- acres eligible for insurance,
- liability,
- premium rates,
- indemnity payments,
- loss ratios.

This information allows for a calculation of the share of eligible acres insured, the average liability per acre, and the premium rate per dollar of coverage. These variables were used in the statistical analysis.

To estimate the cotton farmer's responsiveness to price variations in terms of different premium levels, ordinary least squares estimation techniques were applied to a single-equation demand model. The demand equation for crop insurance coverage expresses the amount of insurance coverage purchased per acre as a function of the cost to the farmer per dollar of that coverage. The functional form chosen for the analysis is the multiplicative one:

$$C = a_0 \, p_I^{\,a_1}, \qquad (4)$$

where C = dollars of coverage purchased per eligible cotton acre in the county;

p_I = price of insurance per dollar of coverage in the county;

a_i = coefficients ($i = 0, 1$).

The linear regression analysis used the logarithmic transformation of Equation (4). The estimation based on data for 72 counties yielded the following parameters:

$$\ln C = 4.16 - \underset{(-4.12)}{1.71} \ln p_I, \tag{5}$$

where the figure in parentheses denotes the t-statistic of a_1. The explanatory power of this regression equation is somewhat disappointing; the R^2 is rather small (.19). However, the t-statistic indicates that the estimated value of a_1 is significantly different from zero at the 99% confidence level. Also, cross-section investigations of this nature, where a number of environmental variables are excluded, cannot be expected to have strong explanatory power.

This equation implies that a Federal subsidy of, say, 10 percent on the cost of the premium would induce a 17 percent increase in the amount of insurance coverage purchased per acre of cotton eligible for all-risk FCIC insurance. Thus, U. S. cotton farmers are far less responsive to a premium subsidy than their Canadian counterparts. In a study of the experience with crop insurance in the Canadian Province of Manitoba it was found that a 25 percent premium subsidy raised participation from 10 to 60 percent of eligible acreage. (The initial 10 percent rate is similar to the current U. S. participation rate.) Three possible explanations of the discrepancy are: (1) Canadian farmers are producing different crops (principally wheat); (2) other price support and income maintenance programs do not exist; and (3) coverage is extended to a greater portion of the potential loss.

It is difficult to relate these results to the findings of the simulation analysis which indicates that farmers would adopt insurance (or at least feasible insurance options) only at a 100% subsidy. One factor should be kept in mind, though. A more important difference between the analysis here and the simulation analysis concerns the character of the insurance coverage. The FCIC coverage includes all risks, while the simulation analysis was based on the assumption that insurance coverage would be specific to insect damage. It is possible that these differences account for differences in behavior patterns with respect to the purchase of insurance coverage. These differences could conceivably be reconciled by regarding the coverage of risks other than insect damage by the FCIC insurance as an indirect "premium subsidy," which would induce farmers to purchase this coverage. However, without evaluating the expected values of other risks, this interpretation cannot be tested.

The statistical analysis included a number of other factors that failed to show significant relationships to the dependent variable. The theoretically most interesting aspect, demand effects in the insurance market variable in explaining subscription to FCIC crop insurance.

SUBSCRIPTION TO PEST INFORMATION SERVICES

The simulation analysis and the review of currently operating pest information programs suggest that the farmer is likely to benefit substantially from participation in information programs. However, participation is by no means universal as yet. The likely reason for this phenomenon is that farmers cannot know the likely benefits of participation with certainty. Variations in the subscription price may therefore influence the decision of the farmer. In addition, it is reasonable to expect that the perceived quality of pest management information programs affects the farmer's assessment of likely benefits. Finally, it is conceivable that the price of substitutes to information services, such as insurance, influences the demand for pest management information.

These factors have been tested in a demand equation for information services. The pest management data were obtained from the Department of Agriculture and cooperating state pest management programs for cotton. As observed above, 1972 was the first year the program had reached a sufficient magnitude to permit any statistical analysis of cross-section data. This concentration on the first year of full operation may affect the results of the regression analysis. This possible bias should be taken into account in interpreting the estimates obtained.

Perhaps the most interesting outcome of the statistical analysis of the demand for pest information services is the failure of proxy variables for service quality to perform satisfactorily in explaining subscription patterns. The proxies used included the ratio of supervisors to scouts, since closer supervision should be an important component of higher-quality services; the acreage covered per scout, since smaller acreage should permit more thorough scouting and greater client contact; and the number of fields per scout as a measure of the average workload and travel required. The poor performance of these quality proxies can be attributed to two reasons: (1) they tend to correlate highly with the price of information services, and (2) they frequently reflect regional differences in production conditions, e.g., scale of cotton production, rather than actual quality differences.

The demand equation that performed best in the statistical analysis is a multiplicative model incorporating prices for both information services and insurance coverage as independent variables:

$$W = a_0 \, p_W^{a_1} \, p_I^{a_2} \tag{6}$$

where W = the ratio of cotton acres participating in a pest management information program to total cotton acres in the county;

p_W = the per acre cost to the farmer of subscribing to information services in a particular county;

p_I = the price of insurance per dollar of coverage in the county;

a_i = parameters (i = 0, 1, 2).

The parameter estimates based on the logarithmic form of this demand equation are significantly different from zero; however, the explanatory power of the model is somewhat limited, as indicated by an R^2 of .29 for a sample of 43 observations:

$$\ln W = .26 - \underset{(-3.41)}{1.92} \ln p_W - \underset{(-2.24)}{.96} \ln p_I \tag{7}$$

Figures in parentheses denote the t-statistics for the parameter estimates.

The results of the analysis would imply that a subsidy for insurance premiums would lead to an increase in the share of total cotton acreage participating in the pest information program, the response elasticity being close to -1.0. However, this result should be treated with some caution. First, the approach used here to incorporate the complementary relationship between insurance and information into a single-equation framework may not be appropriate, possibly introducing a bias into the estimation procedure. Secondly, the price of insurance may be a proxy for other variables not included in the analysis. For example, Carlson has found that larger farmers used both more insurance and more pesticides than smaller-scale operators.* It is possible that the operators of larger farms, who are frequently better trained, are more likely to realize the value of both information and insurance services offered. In this interpretation, the insurance price effect in the demand equation for information services would be attributable to the effects of farm size variations and the associated variations in educational background and training of farm operators.+ It is reasonable to conclude, therefore, that the direction of the impact of a subsidy on insurance premiums on the demand for information services is correct, but that its magnitude is uncertain.

The estimates reported in Equation (7) also imply that the direct price elasticity of the demand for information services is approximately -1.9; this figure does not change significantly, if the price of insurance coverage is dropped from the equation. A 10 per cent decrease in the cost per acre scouted would lead to a 19 per cent increase in the share of total cotton acreage participating in the pest management program. Because the elasticity analysis was based only on regions conducive to scouting, this elasticity is of course only relevant in such regions. Some regions are not amenable to scouting,≠ and of course the analysis does not apply in these cases.

* Unpublished research by Professor Gerald Carlson; in reviewing the analysis reported here, he indicated the need for caution in interpreting the cross-price elasticity estimate.

\+ Another possibility is of course that the provisions of the FCIC insurance program ("good pest management") constitute an incentive to subscribe to information services.

≠ Source: private conversation with Professor John Thomas.

The problems associated with the interpretation of the cross-price elasticity of the demand for information services suggests that a different approach may be fruitful, based on the interpretation of the participation in pest management programs as an innovation in cotton production. Research on the diffusion of innovation, summarized by Brown [2], has focused on the interaction between "adopter" characteristics (e.g., education, farm size, operating efficiency) and policy characteristics of the "diffusion agency". However, an application of this approach to the analysis of the adoption patterns for pest management programs goes beyond the scope of this study.

CONCLUSIONS

The results of the analysis of the responsiveness of farmers to variations in the prices of insurance and information services complement the simulation analysis of the potential impact of such programs. Although FCIC insurance utilization is responsive to price variations per unity of coverage, the simulation experiments suggest that little change in insecticide use can be expected. Subsidizing the current FCIC program therefore would be unlikely to bring about significant reductions in insecticide use; in addition, the stipulations of the program in its current form do not directly encourage such reductions.

Pest information utilization appears to be sensitive to variations in the cost of subscription to the farmer. This result is important, since it provides an impression of the assessment of relative benefits of participation by the farmer. The findings of the demand analysis for pest information, coupled with the results of the simulation experiments and available data on the program experience, demonstrate the potential of providing information subsidies to encourage the adoption of pest information programs. Such an approach is likely to yield a net social benefit in the form of reduced damages to the environment.

SECTION VII

POLICY IMPLICATIONS

INTRODUCTION

The nature of this study is largely exploratory. Its principal value lies in demonstrating the potential of a comprehensive framework for evaluating policy alternatives to regulation and tax/subsidy schemes in protecting the environment from harmful effects of pesticide use. The methodological structure developed here reflects the functions of the policy options studied, pest information and crop insurance programs. It organizes theoretical and empirical analysis around a conceptual model of the farmer's pesticide use decision process. This approach is shown to be an effective tool for the assessment of new policy initiatives.

The application of the methodological framework to the insecticide problem in cotton production, however, goes beyond the mere demonstration of this approach. The theoretical and empirical evidence organized under this structure allows for an assessment of "real" policy alternatives. This section summarizes the findings of the analysis focusing on the implications for new policy initiatives geared toward the reduction of environmental damages associated with insecticide use in cotton production. The discussion here proceeds from a summary of the major findings of the decision analysis to an assessment of the expansion potential of currently existing pest information and crop insurance programs.

MAJOR FINDINGS

The simulation results of the potential insecticide use of cotton pest information and crop insurance programs indicate that improved information can cause significant reductions in application levels without adverse economic effects to the farmer. The 30 percent insecticide use reduction resulting from the introduction of pest information in the simulation model is corroborated by available evidence regarding the experience of the USDA Pest Management Program.

In contrast, the potential of crop insurance programs to reduce insecticide use among farmers who do not participate in pest information programs appears to be fairly limited. As soon as the risk reduction associated with the purchase of insurance coverage reaches a certain level, the simulation model yields a "radical" solution: the farmer would simply substitute (heavily subsidized) insurance for insecticide use. Such a result is feasible on economic grounds. For insurance options where the farmer assumed a greater share of the risk without the benefit of pest information, he would reduce his insecticide use somewhat, provided the subsidy reaches a sufficiently high level.

The potential impact of insurance programs appears somewhat better for farmers who do participate in pest information programs. In these cases, appropriate subsidies on insurance premiums can induce substantial reductions in insecticide use without causing a complete abandoning of insecticides. However, the cost of these reductions is substantial.

While the available evidence for pest information programs allows for a crude verification of the simulation results, available data on insurance programs fail to provide a basis for such a check. The most widespread crop insurance program in existence, provided by the Federal Crop Insurance Corporation, is an all-risk insurance. Therefore, even if data had been gathered on insecticide use by participating farmers and others, the comparison with the results of the simulation experiments (which assumed insurance specific to the insect damage) would be misleading. In any case, the required data are simply not available. The assessment of crop insurance program potential thus rests on the simulation analysis alone.

The examination of farmer responsiveness to price variations in the insurance and information programs shows that the price elasticity of demand is comparable for pest information and crop insurance programs: slightly less than -2.0. These results indicate that a 10 percent subsidy of the farmer's participation cost would lead to a 20 percent increase in the overall participation rate. Given the relatively low cost of pest information services per acre, combined with their effectiveness in reducing insecticide use for participating farmers, a policy focusing on subsidized pest information services appears to be most promising. Since the simulation experiments indicate that farmers accrue a net benefit, even if they pay the full cost of pest information services, it is possible that these subsidies can be phased out, once widespread adoption has been achieved.

This summary of the major findings of the study provides the background for an exploration of the potential for expanding currently operating programs.

POTENTIAL FOR EXPANSION OF FEDERAL CROP INSURANCE

If, contrary to the simulation results of this study, it is decided to expand insurance, the following issues are relevant. Bailey and Jones [1] observe that participation by cotton producers in the FCIC program varies widely by region. Sixteen percent of the total eligible cotton acreage was insured by the FCIC in 1968. Among regions, the percentage ranged from half the cotton acreage in Alabama to cover a fourth in Arizona and New Mexico to a tenth in Mississippi and Arkansas. The reasons for these variations are not immediately obvious, three factors appear most important:

local FCIC sales efforts;

historical relationship of premiums paid and indemnities recovered;

farmer's assessment of his risk and FCIC's ability to cover his potential loss.

These factors suggest areas of greatest potential for increasing participation in crop insurance, should this strategy be adopted as a (temporary) complement to expanding pest information services.

One potential modification of the current crop insurance structure deserves special attention. FCIC insurance should cover cotton yield losses incurred as a result of the producer's decision to spray only as recommended by pest management personnel. Such a provision could be a powerful incentive to comply with pest management recommendations. The incentive could even be increased by stipulating the adoption of integrated pest management practices, including spraying according to scouting information, as a condition for eligibility. The provisions of the Crop Insurance Act can be interpreted to establish such a criterion. The Act rules out losses due to "failure of the insured to follow established good farming practices." The decision on the operational definition of "established good farming practices" is left to local committees. These committees are likely to accept local production practices that are used by the majority, or the leaders, of local cotton growers. It is therefore possible that compliance with pest management recommendations is regarded as "established good farming practice." Under this interpretation, no legislative changes would be required to use the FCIC program to encourage participation in pest information programs.

POTENTIAL FOR THE EXPANSION OF PEST INFORMATION PROGRAMS

The apparent effectiveness of cotton pest information programs in reducing insecticide use without adverse economic effects on producers suggests the need to substantially increase the total acreage scouted. A Federally sponsored pest information service would supplement existing scouting programs. Farmers may shift from other scouting programs or from scouting their own fields to such a program if the cost of subscription is sufficiently low.* However, the acreage covered by non-Federal programs would not likely decrease because of the rapid expansion of the overall "market" for pest information services

An assessment of the expansion potential of Federal pest information services requires answers to a number of questions: How many additional cotton acres are amenable to scouting? What would be the annual cost of an expanded program. How many years would it take to realize such an expansion? An exploration of these issues in discussions with pest management personnel suggests the following conclusions:

- The total remaining cotton acreage that could be covered by an expanded program would range from a minimum of approximately 5 million acres to a maximum of about 9 million acres, out of the total of 13.5 million acres of cotton.

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*A potential problem is the possibility of unfair competition with private pest management services. One alternative would consist in subsidizing farmers without regard to the source of their pest information and recommendations.

Although our simulation results indicate that utilization of information services is potentially profitable even in the absence of subsidies, the expansion of existing information programs would imply continued subsidization, thus the Federal subsidy required per acre would range from a minimum of $1.50 to a maximum of $4.00, depending on the level of services provided, the cost of these services, farmer contributions, and other factors.

The total Federal cost of an expanded program would probably be about $15 million per year, but could range from a low of $7 million to a high of $37 million, dependent upon the acreage covered, and the average subsidy per acre.

It would take from three to five years to expand the program to cover the maximum acreage, because of the need to recruit and train scouting manpower, and to gain acceptance by farmers.

The procedures used in estimating the total acreage that could be covered in an expanded Federal pest information program are illustrated in Table 7. Basically, the approach has been to start with the total acreage in cotton production and to subtract estimates of acreage that would be unlikely to be included in a Federal program. In each case, a low and a high estimate of the acreage likely to be excluded has been given.

For acreage covered by growers, consulting entomologists, and other non-Federal pest information programs, current coverage has been used as a minimum estimate, with a 50 per cent higher figure being used as the maximum. These estimates are based on discussions with pest management personnel. Areas with low infestation levels (such as the Texas Rolling Plains) that make pest information services largely superfluous account for as much as 25 per cent of total U. S. cotton acreage; estimates of this acreage vary from 1.0 to 3.4 million cotton acres.

About one-half to one million cotton acres are farmed in small allotments by growers whose marginal economic situation makes their participation unlikely. Finally, 900,000 acres are already being scouted by Federal pest information programs. The expansion potential therefore varies from 3.8 to 8.3 million cotton acres, corresponding to a total coverage between 4.7 and 9.2 million acres.

Table 7. ALTERNATIVE ASSESSMENTS OF ACREAGE POTENTIAL AND COST FOR FEDERAL INFORMATION SERVICES, COTTON

	Millions of Acres	
	Low Alternative	High Alternative
TOTAL U.S. COTTON ACREAGE	13.5	13.5
Less:		
Acreage Scouted by:		
Growers	1.7	1.1
Consulting Entomologists, Chemical Industry, Gins, Etc.	2.7	1.7
Acreage where scouting uneconomic due to low infestations	3.4	1.0
Acreage in small parcels or farmed by independent farmers	1.0	0.5
Potential acreage to be scouted by federal scouting program:		
Already scouted	.9	.9
Expansion potential	3.8	8.3
POTENTIAL TOTAL ACREAGE IN FEDERAL PROGRAM	4.7	9.2

At present, the data presented in Section IV imply a total subsidization of the Cotton Pest Management Program in 1973 from public sources of $1.82 per acre. This average covers a wide variety of program approaches. Some of the states provided participating farmers with field infestation data only, and not with specific advice (other than general extension pamphlets) on when to spray or what other pest control measures to take. Any improvements in these programs may imply that the $1.82 subsidy would have to increase substantially. If farmers are charged $1.00 per acre scouted or less, the Federal subsidy required could be as high as $4.00 per acre under a more comprehensive program.

However, certain developments are likely to reduce the costs of a scouting program. Many expenditures currently made are investments in the establishment and improvement of the program. A number of scouting programs have been established on an experimental basis to determine whether it is possible to address some problem specific to the given county. In addition, some "learning-by-doing" has taken place -- with concomitant inefficiencies. Finally, the uses of computerized reporting systems and data storage for greater program efficiency are becoming better understood. If services offered were not substantially expanded from the present average, subsidy costs for pest information services might run closer to $1.50 per acre per year.

Table 8 presents estimates of the total annual costs of an expanded Federal pest information program under alternative assumptions about acreage included and subsidy costs per acre. The low-acreage, low-cost combination would cost about $7 million per year to operate at the local level. (The estimates do not include the costs of administering the program at the Federal level.) The costs might go as high as $36.8 million.

If we assume that information subsidies are necessary to widespread participation in information services programs as a means of reducing insecticide use, then the cost of this reduction to the public can be calculated; dividing the required subsidy by the insecticide reduction achieved would yield a cost per pound ranging from $0.15 to $0.40.

Table 8. ESTIMATED COSTS OF EXPANDED FEDERAL PEST INFORMATION PROGRAM

Federal Subsidy Cost Per Acre	Total Acreage in Federal Program	
	4.7 Million	9.2 Million
$1.50	$7.0 million	$13.8 million
$4.00	$18.8 million	$36.8 million

In addition to possible financial limitations, there are of course other constraints on a rapid expansion of a Federal scouting program. Perhaps the most important factor is manpower availability. Thus far, there has been no difficulty in recruiting college students in fields such as biology or agriculture to work as scouts during the summer. However, in the short run, there may be a ceiling level beyond which it would be difficult to locate a sufficient number of qualified recruits. Another limiting factor is the willingness of farmers to participate in the program. The closer participation rates come to the satiation level, the more likely are the remaining non-adopters to resist change. For these reasons, it appears likely that a period of three to five years would be a reasonable expectation for the maximum expansion of a Federally sponsored pest information system.

Program Delivery Systems

Several choices are possible in the institutional structure of the Federal pest information program. These choices concern the role of the Federal government, and the mix of responsibilities among government agencies, organized grower pest control groups or cooperatives, and private sector informations services. There are four major roles that the government could play:

- Directly administer a pest information service through existing agencies or by organizing a new agency for this purpose.

- Contract out the functions of an information service to private sector consulting firms or to grower organizations.

- Offer subsidies to any organization that will operate a pest information service or offer subsidies to farmers who agree to participate in scouting programs.

- Offer informal assistance or encouragement to those who will establish a pest information or scouting program.

Any two or more of these functions can of course be combined. For example, a Federally sponsored pest information service could administer certain functions itself, and either subsidize, contract out, or provide informal technical assistance to other organizations willing to perform complementary functions. Such combinations are common in the current Cotton Pest Management Program, where many states train scouts, make recommendations to farmers, and computerize field data, but leave the hiring and deployment of scouts to farmer groups.

Pest Information Quality

Although high correlations between quality proxies and prices of pest information services precluded an assessment of information program qualitative characteristics on participation patterns, it is reasonable to postulate a positive effect. The following remarks concern the potential for improving these characteristics.

Scout Supervision and Client Contact: The scout supervisor plays an important role in a pest information program. He can perform quality checks on scouting reports, evaluate field data, and formulate recommendations to farmers. A higher supervisor/scout ratio therefore is a potentially important factor in gaining and maintaining the farmer's confidence in the quality of the scouting. In addition, supervisors with fewer scouts are likely to be more accessible to farmers, which increases the chances of the farmers complying with recommendations. In 1972, the number of scouts per supervisor in the nationwide pest management application projects ranged from 3 to 36, for an overall average of 11.5.

However, further research is required to determine the effects of patterns of supervision and quality of supervisors on the effectiveness of pest information programs.

Scout Workload. The reliability of scouting information -- as well as that of resulting recommendations -- is likely to be effected by the total acreage or the number of fields assigned to each scout. Scout workloads should therefore be regarded as a policy variable.

Nature of Recommendations to Farmers. Recommendations to farmer concerning appropriate pest control measures can vary in three major respects:

- they may suggest the application of pesticides when the infestation level is sufficient to predict any reduction, or they may suggest applications only when the cost of yield (or quality) losses because of pest damage would exceed the cost of pesticide applications;
- they may assume different allowances for error and different degrees of risk aversity, and they may or may not make these assumptions explicit to the farmer;
- they may or may not include integrated pest management advice as opposed to pesticide application recommendations alone. For example, recommendations could be made about biological pest control practices, as well as cultural practices related to pest control.

Choices among these variations in the type of recommendations constitute major policy variables.

OUTLOOK

The methodological framework developed in this study offers a flexible approach to evaluate policy alternatives in the field of environmental protection; reduced damages from harmful pesticides used in agriculture. The further development of this methodology can be extremely useful in developing a more differentiated set of policies for a pollution problem that is more difficult to handle than those created by point sources. Applications of the methodology to other types of pesticides and other crops would provide insights into necessary refinements of the current framework.

In addition, perhaps the weakest link of the approach in its present form is the connection between the potential impact of "pure" policy options and the means of realizing this potential. While it is unlikely that the development of a more complex model that attempts to incorporate all aspects of farm operations would be cost-effective, a number of possibilities exist for expanding the conceptual framework and the resulting model. This expansion is perhaps most important with respect to the analysis of insurance options, where differences in coverage (specific-risk vs. all-risk) appear to have a significant effect on the results of the analysis.

SECTION VIII

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APPENDIX A

THE MATHEMATICAL STRUCTURE OF THE SIMULATION MODEL

This appendix describes the mathematical structure of the decision-theoretic model that has been used in the simulation experiments to determine the effects of pest management information and crop insurance programs. The discussion proceeds from the presentation of the general structure of the model to a brief examination of the problems involved in preparing the model for digital-computer simulation.

The core of the decision-theoretic model is the conditional loss expectation function for a given level of pesticide use. Basically, the loss expectation function describes the probabilities that the farmer assigns to a given loss level, expressed as the percentage of maximum yield lost because of the incidence of crop pests. This function is a probability density function (p.d.f.) whose parameters depend on the level of pesticide use. For the first part of the analysis up to Equation (A.8) -- the functional form of this p.d.f. need not be specified.

Expectations of percentage losses affect the pesticide use decision of the farmer only through their relation to expectations concerning the net income associated with alternative pesticide application levels. The functional relationship between the proportion of crop lost and net income per acre is given by:

$$\text{(A.1)} \qquad y = p_y \,(1 - s)\, Y^* - TC - p_X X,$$

where y = net income, \$

p_Y = price per unit of the crop, \$

Y^* = maximum possible yield per acre, lbs.

TC = total cost of production (except pesticide cost) per acre, \$

p_X = price per pound of pesticide, \$

X = pounds of pesticides applied per acre, lbs.

S = fraction of crop lost due to insect damages.

Given the parameters of the loss expectation functions for different levels of pesticide applications, i.e., means (μ_s) and variances (α_s^2), the parameters of the net income expectation functions can be calculated directly from Equation (A.1):*

$$\text{(A.2)}\qquad \begin{aligned} \mu_y &= p_Y (1 - \mu_s)\, Y^* - TC - p_X X, \\ \sigma_y^2 &= (p_Y Y^*)^2\, \sigma_s^2 \end{aligned}$$

The mean and the variance of the net income expectation function, μ_y and σ_y^2, are functions of the amount of pesticides used (X) directly and indirectly, since the mean loss and loss variance also depend on X.

Consistent with established decision theory, the farmer is assumed to choose that action (level of pesticide use) that maximizes his expected utility, which is a function of both the expected net income and the net income variance -- a measure of risk. The expected utility for a given level of pesticide application can be determined from the parameters of the net income expectation function through the mean-variance frontier technique, as described in Halter and Dean [10].

Consider utility as some function of net income, U(y). This function can be written in form of a Taylor series expansion as a function of powers of (y - c), where c is some constant:

$$\text{(A.3)}\qquad U(y) = \sum_{n=0}^{\infty} \frac{(y - c)^n}{n!} \frac{d^{(n)}U(c)}{dy^n}$$

If the arbitrary constant in this expression, c, is set equal to μ_y, the expected net income for the given level of pesticide use, the Taylor series expansion becomes:

$$\text{(A.4)}\qquad U(y) = \sum_{n=0}^{\infty} \frac{(y - \mu_y)^n}{n!} \frac{d^{(n)}U(\mu_y)}{dy^n}$$

Taking expected values on both sides of the equation yields the expected utility as a function of the moments of the net income expectation function and the derivatives of the utility function, evaluated at μ_y:

*The derivation of the mean and variance of a transformation of a random variable is described in work statistics textbooks; for example, W.C. Merill and K.A. Fox, Introduction to Economics Statistics. New York, Wilcy, 1970; p. 135.

$$\text{(A.5)} \qquad E[U(y)] = \sum_{n=0}^{\infty} \frac{E[(y - \mu_y)^n}{n!} \frac{d^{(n)}U(\mu_y)}{dy^n}$$

Frequently, only the first three terms in the right-hand side expression (n = 0, 1, 2) are regarded as significant.

Decision research in agriculture generally is based on the assumption that farmers exhibit <u>risk-averse</u> behavior. This behavior implies that the farmer is willing to give up some expected net income for a reduced risk. A functional form of the utility function that satisfies the assumption of risk aversion is the logarithmic form:

$$\text{(A.6)} \qquad U(y) = \ln (y + a),$$

where the constant *a* is introduced to assure the existence of the natural logarithm; it must be greater than the maximum possible loss (negative net income).

For this specification, the expected utilities for each level of pesticide application can be obtained on the basis of Equation (A.5); dropping all terms in the sum for $n > 2$, we obtain

$$\text{(A.7)} \qquad E[U(y)] = U(\mu_y) + \frac{\sigma_y^2}{2} \frac{d^2U(\mu_y)}{dy^2}$$

$$= U(\mu_y) + \frac{1}{2} \frac{\sigma_y^2}{\mu_y^2}$$

Since both the mean and the variance of the net income expectation function are dependent upon the level of pesticide application, Equation (A.7) can be used directly to determine the expected utility for any given level of pesticide use. The procedure outlined here has the advantage that no estimates of the probability densities for individual loss levels are required. The functional form of the loss expectation p.d.f. therefore does not have to be specified. Alternative estimates of the two parameters of this function can be used directly to assess the potential impact of pest management information programs with a minimum of computational operations.

Unfortunately, this relatively simple technique is incapable of handling the analysis of the impact of alternative insurance schemes. Only "pure" coinsurance schemes can be examined by means of the mean-variance frontier; the coinsurance factor would modify the relationship between percentage loss and net income described in Equation (A.1). However, as soon as a deductible is introduced, the loss expectation function changes from a continuous to a "hybrid" function. Loss expectations over the range of the deductible are defined by the original loss expectation function; beyond the deductible, the farmer is certain of his maximum loss (or minimum net income). Mathematically, this situation can be represented as follows:

$$\text{(A.8)} \qquad \mu_s = \int_0^D s\ f(s)\ ds + (1 - \gamma)\ (1 - D),$$

where D = deductible, defined in terms of the fraction of crop lost;

$\gamma = \int_0^D f(s)\ ds$, the probability that the actual is less than or equal to the deductible.

This "hybrid" probability density function necessitates the specification of f(s), the underlying p.d.f. of the percentage crop loss. The functional specification used in the simulation is based on the assumption that the farmer's loss expectations can be described in terms of a positively skewed p.d.f., i.e. that lower percentage losses are generally more likely than higher ones. The general Γ-type p.d.f. satisfies this requirement, as specified in Hogg and Craig [13]:

$$\text{(A.9)} \qquad f(s) = \frac{1}{\Gamma(\alpha)\beta^{\alpha}}\ s^{\alpha-1}\ e^{-s/\beta},$$

where s = percentage of crop lost because of pest damage;

α, β = parameters,

$\Gamma(\alpha)$ = a constant given by

$$\text{(A.10)} \qquad \Gamma(\alpha) = \int_0^{\infty} z^{\alpha-1}\ e^{-z}\ dz.$$

The relationship between the parameters of the Γ-type p.d.f. and its mean and variance can be determined from its characteristic function:

$$\text{(A.11)} \qquad \phi(t) = E[e^{its}] = \frac{1}{(1 - \beta it)^{\alpha}}$$

Differentiating this expression and evaluating it at t=0 yields the mean and the variance

$$\text{(A.12)} \qquad \begin{aligned} \mu_s &= \alpha\beta, \\ \sigma_s^2 &= \alpha\beta^2. \end{aligned}$$

The parameters of the loss expectation function can therefore be estimated on the basis of estimates of the mean and variance of the function.

The numerical estimation of the Γ-type densities associated with different levels of loss requires the use of approximation formulae; a direct translation of Equations (A.9) and (A.10) into computer program statements would introduce serious inaccuracies. For the densities themselves, the following approximation formula (as given in textbooks on numerical analysis) has been used:*

$$\text{(A.13)} \qquad F(s) = \frac{s^{\alpha}}{\Gamma(\alpha)} \sum_{n=0}^{\infty} \frac{(-s)^{\alpha}}{(\alpha+n)\,n!}$$

where F(s) is the cumulative probability distribution of the percentage loss (s). The $\Gamma(\alpha)$ constant is estimated by means of the expression:

$$\text{(A.14)} \qquad \begin{aligned} \Gamma(\alpha) = 1 &- .57486\ (\alpha-1) + .95123\ (\alpha-1)^2 \\ &- .69985\ (\alpha-1)^3 + .42455\ (\alpha-1)^4 \\ &- .10106\ (\ -1)^5 \end{aligned}$$

This approximation formula implies an error of less than $5 \cdot 10^{-5}$.

This specification of the mathematical approach still implies one source of inaccuracies that may influence the computations. F(s) approaches unity, as s approaches infinity. In the present situation, the evaluation of the integral of Equation (A.9) is limited to the interval [0, 1]. For low expected losses, we have $F(1) \simeq 1$. For higher expected losses, the inaccuracy

* Both approximation formulae have been taken from M. Abromowitz and I.A. Stegun, (eds.), Handbook of Mathematical Functions. New York, Dover, 1965.

may be substantial; for example, for $\mu_s = .5$, we have $F(1) = .865$. The probability densities have therefore been adjusted in the simulation program to yield more accurate estimates.

APPENDIX B

```
                PROGRAM PESTY(OUTPUT,TAPE2)
            C**************************************************************
            C*                                                            *
            C*       THIS PROGRAM ESTIMATES THE EXPECTED UTILITIES OF COTTON *
            C*       FARMERS FOR DIFFERENT QUANTITIES OF PESTICIDES APPLIED AND *
            C*       ALTERNATIVE INSURANCE SCHEMES. THE PRESENT VERSION ASSUMES *
            C*       FARMER BEHAVIOR CONSISTENT WITH WEAK INFORMATION LEVELS.  *
            C*       FARMER BEHAVIOR CONSISTENT WITH HIGH INFORMATION LEVELS.  *
            C*                                                            *
            C*       THE PROGRAM COMPUTES EXPECTED UTILITIES ON THE BASIS OF A *
            C*       LOGARITHMIC UTILITY FUNCTION ASSOCIATED WITH NET INCOMES. *
            C*       EXPECTED UTILITIES ARE COMPUTED FROM THE ORIGINAL LOSS EX- *
            C*       PECTATION -- THROUGH A CHANGE OF VARIABLE TECHNIQUE, AS WELL *
            C*       AS THROUGH THE MEAN-VARIANCE FRONTIER TECHNIQUE.          *
            C*                                                            *
            C**************************************************************
000003          COMMON/EQUA/A(9,7),B(7),PIN5(7)
000003          COMMON/EINS/Y(101,9,7),U(101,9,7)
000003          COMMON/ZWEI/YLOSS(101)
000003          COMMON/DREI/AVY(9,7),SDY(9,7)
000003          COMMON/VIER/AVU(9,7),AVU2(9,7)
000003          COMMON/PARA/AL(9),BE(9),CO(7),DE(7)
000003          COMMON/UNO/P(101),S(101)
000003          COMMON/TRES/AX(9),AS(9),ZX(9),ZS(9)
000003          DIMENSION SUB(5),PANS(7)
000003          DATA AL/.613,.370,.220,.124,.064,.020,.004,.004,.020/
000003          DATA BE/.620,.730,.820,.890,.940,.980,.996,.996,.980/
000003          DATA CO/1.,.5,1.,1.,1.,1.,1./
000003          DATA DE/1.,1.,0.,.1,.2,.25,.4/
000003          DATA PINS/0.,34.,69.,67.,54.,43.,32./
000003          DATA SUB/1.,.9,.75,.5,0./
000003          DO 3 I=1,7
000005        3 PANS(I)=PINS(I)
000010          S(1)=0.
000011          DO 5 I=2,101
000013        5 S(I)=S(I-1)+.01
000020          DO 1 IP=1,2
000021          DO 1 INF=1,3
000022          DO 1 ISUB=1,5
000023          DO 2 I=1,7
000024        2 PINS(I)=PANS(I)*SUB(ISUB)
000031          CALL FCTRL
000032          REWIND 2
000034          DO 4 J=1,9
000036          AX(J)=AL(J)*BE(J)
000040          AS(J)=AL(J)*BE(J)**2
000043          CALL GAMRA(AL(J),BO,IER)
000045          CALL GAMZA(BO,AL(J),BE(J),J,ZX(J),ZS(J))
000052          WRITE(2)P
000057        4 CONTINUE
000061          REWIND 2
000063          CALL INCOME(INF,YMIN,IP)
000066          CALL UTILITY(C,D,INF)
000071          CALL PROBAB(C,D,YMIN)
000074          CALL REPORT(INF,YMIN)
000076        1 CONTINUE
000104          REWIND 2
```

```
000106        PRINT 6,(AX(I),ZX(I),I=1,9),(AS(I),ZS(I),I=1,9)
000132      6 FORMAT(*1       COMPARISON OF MEANS AND STANDARD DEVIATIONS*//9(10X
               ,2E12.5/)/9(10X2E12.5/))
000132        CALL EXIT
000133        END
```

```
              SUBROUTINE INCOME(INF,YMIN,IP)
        C*****************************************************************************
        C*                                                                           *
        C*        THIS SUBROUTINE COMPUTES EXPECTED NET INCOME LEVELS FOR           *
        C*        DIFFERENT LEVELS OF LOSS.                                          *
        C*                                                                           *
        C*****************************************************************************
000006        COMMON/EINS/Y(101,9,7),U(101,9,7)
000006        COMMON/ZWEI/YLOSS(101)
000006        COMMON/PARA/AL(9),BE(9),CO(7),DE(7)
000006        COMMON/EQUA/A(9,7),B(7),PINS(7)
000006        COMMON/UNO/R(101),S(101)
000006        YLOMAX=700.
000007        P=.4
000011        TC=170.+FLOAT(INF-1)*1.5
000015        PI=.8+(IP-1)*.9
000022        DO 1 K=1,7
000023        DEEKK=DE(K)*100.
000026        LIM=IFIX(DEEKK)+1
000030        DO 2 J=1,9
000032        XLBS=5.*FLOAT(J-1)
000035        A(J,K)=P*YLOMAX-TC-PI*XLBS-PINS(K)
000046        B(K)=P*YLOMAX*CO(K)
000052        DO 3 I=1,LIM
000054        Y(I,J,K)=A(J,K)-B(K)*S(I)
000074      3 CONTINUE
000077        BOTTOM=A(J,K)-B(K)*DE(K)
000105        IF(DEEKK.EQ.100.)GO TO 4
000107        LUM=LIM+1
000111        DO 5 I=LUM,101
000112      5 Y(I,J,K)=BOTTOM
000122      4 CONTINUE
000122      2 CONTINUE
000124      1 CONTINUE
000126        IF(INF.GT.1)GO TO 100
000131        YMIN=10.E6
000132        DO 7 K=1,7
000133        DO 7 J=1,9
000134        DO 7 I=1,101
000135        YMIN=AMIN1(Y(I,J,K),YMIN)
000145      7 CONTINUE
000154        YMIN=YMIN-3.
000156        IF(YMIN.GE.1.)GO TO 8
000160        YMIN=YMIN-1.
000161    100 CONTINUE
000161        DO 9 K=1,7
000163        DO 9 J=1,9
000164        DO 9 I=1,101
000165      9 Y(I,J,K)=Y(I,J,K)-YMIN
000202        PRINT 14,YMIN
000207     14 FORMAT(*0LOWEST INCOME OVERALL = *E12.5)
000207      8 CONTINUE
000207        RETURN
000210        END
```

```
                   SUBROUTINE UTILITY(UMIN,D,INF)
             C*****************************************************************
             C*                                                               *
             C*         THIS SUBROUTINE COMPUTES THE UTILITIES ASSOCIATED WITH DIFFERENT   *
             C*         NET INCOME LEVELS.  THE UTILITY FUNCTION IS GIVEN BY THE           *
             C*         NATURAL LOGARITHM OF NET INCOME, STANDARDIZED SUCH THAT U MAX= 100 *
             C*         AND U MIN = 0.                                                     *
             C*                                                               *
             C*****************************************************************
 000006            COMMON/EINS/Y(101,9,7),U(101,9,7)
 000006            FACTOR=1.
 000007            DO 1 K=1,7
 000011            DO 1 J=1,9
 000012            DO 1 I=1,101
 000013            U(I,J,K)=FACTOR*ALOG(Y(I,J,K))
 000030          1 CONTINUE
 000040            IF(INF.GT.1)GO TO 10
 000043            UMIN=10.E6
 000044            UMAX=(-1.)*UMIN
 000045            DO 11 K=1,7
 000047            DO 11 J=1,9
 000050            DO 11 I=1,101
 000051            UMIN=AMIN1(UMIN,U(I,J,K))
 000061            UMAX=AMAX1(UMAX,U(I,J,K))
 000071         11 CONTINUE
 000077         10 CONTINUE
 000077            DO 2 K=1,7
 000101            DO 2 J=1,9
 000102            DO 2 I=1,101
 000103            U(I,J,K)=(U(I,J,K)-UMIN)*100./(UMAX-UMIN)
 000117          2 CONTINUE
 000125            D=(UMAX-UMIN)*.01
 000127            RETURN
 000130            END
```

```
      SUBROUTINE PROBAB(C,D,YMIN)
C*****************************************************************************
C*                                                                           *
C*      THIS SUBROUTINE COMPUTES EXPECTED NET INCOMES AND UTILITIES ON       *
C*      THE BASIS OF A LOSS EXPECTATION FUNCTION DEFINED BY THE GAMMA-       *
C*      DISTRIBUTION. THE SUBROUTINE COMPUTES EXPECTED UTILITIES FIRST       *
C*      THROUGH A TAYLOR SERIES EXPANSION OF THE UTILITY FUNCTION, THEN      *
C*      THROUGH THE CHANGE-OF-VARIABLE TECHNIQUE.                            *
C*                                                                           *
C*****************************************************************************
000006      COMMON/EINS/Y(101,9,7),U(101,9,7)
000006      COMMON/ZWEI/YLOSS(101)
000006      COMMON/DREI/AVY(9,7),SDY(9,7)
000006      COMMON/VIER/AVU(9,7),AVU2(9,7)
000006      COMMON/PARA/AL(9),BE(9),CU( ),DE(7)
000006      COMMON/EQUA/A(9,7),B(7),PINS(7)
000006      COMMON/TRES/AX(9),AS(9),ZX(9),ZS(9)
000006      COMMON/QUATRO/ADM(9),ADS(9)
000006      DIMENSION R(101)
000006      CALL ADJ(YMIN)
000007      DO 100 K=1,7
000013      DEEKK=DE(K)*100.
000016      DO 1 J=1,9
000017      AVY(J,K)=SDY(J,K)=AVU2(J,K)=0.
000027      LIM=IFIX(DEEKK)+1
000031      FACTOR=1.0
000032      CH1=CH2=CHU=0.
000035      READ(2)R
000042      DO 23 I=1,LIM
000046   23 R(I)=R(I)/(B(K)*.01)
000055      DO 20 I=1,LIM
000057      BS=B(K)*.01
000062      Y1=Y(I,J,K)
000070      R1=R(I)
000072      R1=R1*ADM(J)
000075      R2=R1*ADS(J)
000077      CH2=CH2+R1*BS
000101      AVY(J,K)=AVY(J,K)+R1*Y1*BS
000107      SDY(J,K)=SDY(J,K)+R2*Y1**2*BS
000115   20 CONTINUE
000120      LIM=LIM-1
000121      IF(DEEKK.EQ.100.)GO TO 5
000123      IF(CH2.GT.1.)CH2=1.
000126      AVY(J,K)=AVY(J,K)+(1.-CH2)*Y(LIM+1,J,K)
000141      SDY(J,K)=SDY(J,K)+(1.-CH2)*Y(LIM+1,J,K)**2
000154    5 IF(SDY(J,K).LT.AVY(J,K)**2)GO TO 10
000164      SDY(J,K)=SQRT(SDY(J,K)-AVY(J,K)**2)
000174      GO TO 6
000177   10 PRINT 11,J,K
000207   11 FORMAT(*0STANDARD DEVIATION IMAGINARY FOR ACTION*I2*, POLICY*I2)
000207      SDY(J,K)=-0.
000213    6 AVU(J,K)=(FACTOR*ALOG(AVY(J,K))-C)/D
000231      AVU(J,K)=AVU(J,K)-SDY(J,K)**2/(D*2.*AVY(J,K)**2)
000242      G=D/FACTOR
000244      H=C/FACTOR
000245      LUM=LIM+1
000247      DO 30 I=1,LUM
```

```
000250          R(I)=R(I)*G*EXP(U(I,J,K)*G*H)
000265       30 CONTINUE
000271          DO 3 I=1,LIM
000272          PR=(R(I)+R(I+1))/2.
000276          PR=PR*ADM(J)
000300          BS=ABS(U(I,J,K)-U(I+1,J,K))
000313          CHU=CHU+PR*BS
000316          U1=(U(I,J,K)+U(I+1,J,K))/2.
000324        3 AVU2(J,K)=AVU2(J,K)+PR*BS*U1
000336          IF(DEEKK.EQ.100.)GO TO 4
000340          AVU2(J,K)=AVU2(J,K)+(1.-CHU)*U(LIM+1,J,K)
000352        4 CONTINUE
000352        1 CONTINUE
000354          REWIND 2
000356      100 CONTINUE
000360          RETURN
000361          END
```

```
                  SUBROUTINE REPORT(INF,YMIN)
             C*****************************************************************
             C*                                                               *
             C*       THIS SUBROUTINE REPORTS THE RESULTS OF THE ANALYSIS.    *
             C*                                                               *
             C*****************************************************************
000005            COMMON/DREI/AVY(9,7),SDY(9,7)
000005            COMMON/VIER/AVU(9,7),AVU2(9,7)
000005            PRINT 1
000010          1 FORMAT(1H1/10X*SUMMARY REPORT ON THE EFFECTS OF ALTERNATIVE INSURA
                 .NCE SCHEMES. */10X*-- LOSS EXPECTATIONS: INFORMED.*//)
000010            DO 15 K=1,7
000013            DO 15 J=1,9
000014         15 AVY(J,K)=AVY(J,K)+YMIN
000024            GO TO(11,12,13)INF
000033         11 PRINT 21
000037            GO TO 14
000041         12 PRINT 22
000045            GO TO 14
000047         13 PRINT 23
000053         14 CONTINUE
000053            PRINT 10
000057         10 FORMAT(///10X*1. EXPECTED NET INCOMES:*//)
000057            PRINT 2,(I,I=1,9)
000070          2 FORMAT( 1X*--- ACTION*/ 4X*---*5X,9(6XI2,5X)/ 1X*POLICY ---*/)
000070            PRINT 3,(K,(AVY(J,K),J=1,9),K=1,7)
000111          3 FORMAT( 3XI1,8X9(E12.5,1X))
000111            PRINT 4
000115          4 FORMAT(  /// 1X*2. EXPECTED UTILITIES (M-V APPROACH).*//)
000115            PRINT 2,(I,I=1,9)
000126            PRINT 3,(J,(AVU(I,J),I=1,9),J=1,7)
000147            PRINT 5
000153          5 FORMAT(  /// 1X*3. EXPECTED UTILITIES (C-O-V APPROACH).*//)
000153            PRINT 2,(I,I=1,9)
000164            PRINT3,(J,(AVU2(I,J),I=1,9),J=1,7)
000205            PRINT 31
000211         31 FORMAT(////)
000211         21 FORMAT(1H09X*(INFORMATION SERVICES FULLY SUBSIDIZED.)*)
000211         22 FORMAT(1H09X*(INFORMATION SERVICES 50 PER CENT SUBSIDY.)*)
000211         23 FORMAT(1H09X*(INFORMATION SERVICES PROVIDED AT FULL COST.)*)
000211            PRINT 38
000215         38 FORMAT(///10X*4. STANDARD DEVIATIONS:*//)
000215            PRINT 2,(I,I=1,9)
000226            PRINT 3,(K,(SDY(J,K),J=1,9),K=1,7)
000247            RETURN
000250            END
```

```
                SUBROUTINE GAMMA(XX,GX,IER)
             C*************************************************************************
             C*                                                                       *
             C*     THIS SUBROUTINE CALCULATES THE VALUE OF THE GAMMA-CONSTANT        *
             C*                                                                       *
             C*************************************************************************
000006          IF(XX-57.)6,6,4
000010        4 IER=2
000011          GX=1.E75
000012          RETURN
000013        6 X=XX
000014          ERR=1.E-6
000015          IER=0
000016          GX=1.
000017          IF(X-2.)50,50,15
000022       10 IF(X-2.)110,110,15
000025       15 X=X-1.
000027          GX=GX*X
000030          GO TO 10
000031       50 IF(X-1.)60,120,110
000034       60 IF(X-ERR)62,62,80
000037       62 Y=FLOAT(INT(X))-X
000042          IF(ABS(Y)-ERR)130,130,64
000046       64 IF(1.-Y-ERR)130,130,70
000052       70 IF(X-1.)80,80,110
000055       80 GX=GX/X
000056          X=X+1
000060          GO TO 70
000061      110 Y=X-1.
000063          GY=1.+Y*(-.577101+Y*(.9858540+Y*(-.8764218+Y*(.8328212+Y*(-.568472
               .9+Y*(.2548205+Y*(-.0514993))))))
000101          GX=GX*GY
000103      120 RETURN
000104      130 IER=1
000105          RETURN
000106          END
```

```
                  SUBROUTINE GAMZA(BO,A,B,JA,AX,AS)
              C**********************************************************************
              C*                                                                    *
              C*    THIS SUBROUTINE CALCULATES THE VALUES OF THE GAMMA P.D.F.       *
              C*    FOR GIVEN VALUES OF ALPHA AND BETA.                             *
              C*                                                                    *
              C**********************************************************************
000011            COMMON/UNO/P(101),S(101)
000011            COMMON/DUE/NFACT(25)
000011            P(1)=0.
000011            AS=AX=0.
000013            BU=0.
000013            CHK=0.
000015            DO 1 I=2,101
000016            SU=0.
000017            SI=S(I)/B
000021            DO 2 K=1,25
000023            KAP=1
000024            KEP=K-1
000025            KUP=MOD(KEP,2)
000031            IF(KUP.NE.0)KAP=-1
000034            N=KEP
000035            IF(N.EQ.0)GO TO 30
000037            SIGMA=SI**N
000042            GO TO 40
000043         30 SIGMA=1.
000045         40 BUR=KAP*SIGMA/((A+N)*NFACT(K))
000054            SU=SU+BUR
000055          2 CONTINUE
000057            SU=SU*SI**A/BO
000064            SV=SU*B**A
000067            P(I)=SU-BU
000072            BU=SU
000073            CHK=CHK+P(I)
000075            AX=AX+S(I)*P(I)
000101            AS=AS+S(I)**2*P(I)
000106          1 CONTINUE
000107            AS=AS-AX**2
000111            RETURN
000111            END
```

```
                 SUBROUTINE FCTRL
           C****************************************************************************
           C*                                                                         *
           C*        THIS SUBROUTINE CALCULATES THE FACTORIALS REQUIRED IN THE        *
           C*        APPROXIMATION FORMULA FOR THE GAMMA-FUNCTION.                    *
           C*                                                                         *
           C****************************************************************************
000003           COMMON/DUE/NFACT(25)
000002           NFACT(1)=NFACT(2)=1
000005           DO 1 I=3,25
000006         1 NFACT(I)=NFACT(I-1)*(I-1)
000015           RETURN
000016           END
```

```
                SUBROUTINE ADJ(YMIN)
           C*****************************************************************
           C*                                                              *
           C*      THIS SUBROUTINE COMPUTES THE ADJUSTMENT FACTORS USED IN *
           C*      PROBAB TO MODIFY THE PROBABILITIFS.                     *
           C*                                                              *
           C*****************************************************************
000003          COMMON/EINS/Y(101,9,7),U(101,9,7)
000003          COMMON/EQUA/A(9,7),B(7),PINS(7)
000003          COMMON/TRES/AX(9),AS(9),ZX(9),ZS(9)
000003          COMMON/QUATRO/ADM(9),ADS(9)
000003          DIMENSION Z(101)
000003          DO 1 J=1,9
000005          READ(2)Z
000012          YM=A(J,1)-B(1)*AX(J)-YMIN
000021          YS=B(1)**2*AS(J)
000023          YZM=YZS=0.
000025          DO 2 I=1,101
000026          YZM=YZM+Z(I)*Y(I,J,1)
000034        2 YZS=YZS+Z(I)*Y(I,J,1)**2
000044          YS=YS+YM**2
000047          ADS(J)=YS/YZS
000051        4 ADM(J)=YM/YZM
000054        1 CONTINUE
000056          REWIND 2
000060          RETURN
000061          END
```

SUMMARY REPORT ON THE EFFECTS OF ALTERNATIVE INSURANCE SCHEMES.
--- LOSS EXPECTATIONS: INFORMED.

(INFORMATION SERVICES FULLY SUBSIDIZED.)

1. EXPECTED NET INCOMES:

POLICY \ ACTION	1	2	3	4	5	6	7	8	9
1	3.58320E+00	3.03720E+01	5.14880E+01	6.70992E+01	7.71552E+01	8.45120E+01	8.48845E+01	8.08845E+01	7.25120E+01
2	5.60181E+00	2.27669E+01	3.57182E+01	4.47850E+01	5.00644E+01	5.35080E+01	5.23578E+01	4.83541E+01	4.15050E+01
3	4.10000E+01	3.70000E+01	3.30000E+01	2.90000E+01	2.50000E+01	2.10000E+01	1.70000E+01	1.30000E+01	9.00000E+00
4	2.03293E+01	2.05982E+01	2.10577E+01	2.11100E+01	2.03050E+01	1.90578E+01	1.65006E+01	1.25186E+01	7.06004E+00
5	1.64874E+01	2.14573E+01	2.59489E+01	2.92208E+01	3.07497E+01	3.14033E+01	2.99961E+01	2.60060E+01	1.94082E+01
6	2.04292E+01	2.75178E+01	3.37209E+01	3.83104E+01	4.07731E+01	4.21766E+01	4.11741E+01	3.71824E+01	3.01828E+01
7	1.41536E+01	2.66659E+01	3.70902E+01	4.48606E+01	4.95500E+01	5.27286E+01	5.24609E+01	4.84650E+01	4.07387E+01

2. EXPECTED UTILITIES (M-V APPROACH).

POLICY \ ACTION	1	2	3	4	5	6	7	8	9
1	8.65396E+01	9.06261E+01	9.35400E+01	9.55662E+01	9.68502E+01	9.77947E+01	9.79585E+01	9.76391E+01	9.68100E+01
2	8.76734E+01	9.04742E+01	9.24670E+01	9.38337E+01	9.46647E+01	9.52490E+01	9.52523E+01	9.48926E+01	9.41491E+01
3	9.43619E+01	9.39882E+01	9.36084E+01	9.32221E+01	9.28292E+01	9.24294E+01	9.20226E+01	9.16083E+01	9.11864E+01
4	9.20300E+01	9.19979E+01	9.20470E+01	9.20902E+01	9.20557E+01	9.19812E+01	9.17615E+01	9.13460E+01	9.07114E+01
5	9.13862E+01	9.18809E+01	9.23916E+01	9.28047E+01	9.30410E+01	9.31907E+01	9.31364E+01	9.27439E+01	9.19871E+01
6	9.16621E+01	9.23876E+01	9.30820E+01	9.36343E+01	9.39704E+01	9.42018E+01	9.42034E+01	9.38285E+01	9.30508E+01
7	9.05601E+01	9.19698E+01	9.31818E+01	9.41109E+01	9.47056E+01	9.51419E+01	9.52394E+01	9.48805E+01	9.40376E+01

3. EXPECTED UTILITIES (C-O-V APPROACH).

POLICY \ ACTION	1	2	3	4	5	6	7	8	9
1	7.96523E+01	8.55877E+01	9.02463E+01	9.37732E+01	9.62083E+01	9.81365E+01	9.86978E+01	9.83856E+01	9.71557E+01
2	8.08658E+01	8.57297E+01	8.94090E+01	9.22850E+01	9.41709E+01	9.56288E+01	9.59781E+01	9.56259E+01	9.45470E+01
3	9.43619E+01	9.39882E+01	9.36084E+01	9.32221E+01	9.28292E+01	9.24294E+01	9.20226E+01	9.16083E+01	9.11864E+01
4	9.23453E+01	9.23630E+01	9.24061E+01	9.24151E+01	9.23416E+01	9.22257E+01	9.19345E+01	9.15189E+01	9.09712E+01
5	9.18748E+01	9.23577E+01	9.28094E+01	9.31548E+01	9.33358E+01	9.34375E+01	9.32461E+01	9.28543E+01	9.22486E+01
6	9.22186E+01	9.29005E+01	9.35144E+01	9.39881E+01	9.42652E+01	9.44482E+01	9.42997E+01	9.39259E+01	9.33121E+01
7	9.12721E+01	9.25370E+01	9.36137E+01	9.44458E+01	9.49836E+01	9.53841E+01	9.53316E+01	9.49754E+01	9.42939E+01

SELECTED WATER RESOURCES ABSTRACTS

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1. Report No.	
2.	
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4. Title	Crop Insurance and Information Services to Control Use of Pesticides
5. Report Date	
6.	
7. Author(s)	John A. Miranowski, Ulrich F. W. Ernst, Francis H. Cummings
8. Performing Organization	
9. Organization	ABT Associates Inc. 55 Wheeler Street Cambridge, Mass. 02138
10. Project No.	1BA030
11. Contract/Grant No.	68-01-1888
12. Sponsoring Organization	[illegible]
15. Supplementary Notes	Environmental Protection Agency Report Number EPA-600/5-74-018, September 1974

16. *Abstract* This study analyzes the relative effectiveness and efficiency of pest information and crop insurance programs in encouraging farmers to use potentially harmful pesticides more sparingly by eliminating wasteful applications. Possibly excessive applications of pesticides can be attributed to poor timing of applications and to the risk-averse behavior of farmers. Focusing on insecticide use in cotton production as a major policy problem, the study employs a decision-theoretic framework to simulate the farmer's pesticide use decisions under alternative program options and subsidy levels. To the extent possible, empirical data are analyzed to complement the findings of the simulation analysis.

The theoretical and empirical analysis in this study indicate that pest information programs are potentially more effective than crop insurance programs in reducing insecticide usage. These reductions from compliance with pest control recommendations provided by information programs are associated with economic gains by the farmer. Both the simulation experiments and available evaluations of the USDA Pest Management Program indicate that a maximum insecticide use reduction of 30 percent can be achieved through information programs. Subsidies to such programs appear an effective means to encourage adoption by farmers, at least in the initial phases.

17a. *Descriptors*
*Pesticides, *Crop Insurance, *Information Services, Scout Programs, Insecticides, Cotton Production, USDA Pest Management Program, Federal Crop Insurance Corporation

17b. *Identifiers*
*Pest Control, Implementation Strategies

17c. *COWRR Field & Group*

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