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FARM EFFICIENCY AND INSECT INFESTATION FORECASTS: THE CASE OF SOYBEANS IN ILLINOIS

by

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ABSTRACT

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Key words: Insect forecasts, economic impacts, soybeans, economics of pest management.

ACKNOWLEDGMENTS

The authors are extremely grateful to Dr. Katherine H. Reichelderfer for her guidance, support, and encouragement throughout the course of this research. A special thanks is extended to Beverly A. Herath and Violet D. Ortega for typing the preliminary and final manuscript drafts.

AUTHORS

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FARM EFFICIENCY AND INSECT INFESTATION FORECASTS: THE CASE OF SOYBEANS IN ILLINOIS

INTRODUCTION

Following their introduction in the 1940's, chemical pesticides were very effective in suppressing pest populations. Many pesticides remain essential inputs in agricultural pest management. However, widespread use of toxic compounds has created a number of problems. Perhaps most noteworthy is the problem of pest resistance to specific pesticides or classes of pesticides. Resistance requires that pesticide dosage increase, perhaps by a dramatic amount in a relatively short period of time, simply to maintain a given level of pest control. Problems related to pesticide interference with natural biological control (e.g., secondary outbreaks, resurgence) also contribute to farm costs. More recently, society has expressed concern about pesticide residues in air, water, and food.

An alternative pest management approach known as integrated pest management (IPM) has increased in popularity during recent years. IPM emphasizes an array of controls based on an understanding of a pest or pest complex. Typical IPM inputs include pesticides, cultural practices, and biological control methods. The productivity gain achieved through the use of IPM techniques has been documented in a number of cases (see e.g., Hall; Reichelderfer and Bender). The overall feasibility of integrated control was confirmed by the results of a large, multi-university IPM research project, generally referred to as the Huffaker Project, which was completed during the 1970's. Presently, the Consortium for Integrated Pest Management (CIPM), comprised of researchers at fifteen universities, is developing technically and economically feasible IPM programs for a number of different crops.

The focus of the Illinois CIPM soybean project is the development of an insect prediction model to reduce the need for insect scouting and insecticide use. Success of the project is contingent upon the prediction system providing accurate forecasts at reasonable cost. The primary purpose of this report is to quantify the impact of insect forecasts on scouting, insecticide use, and grower profits.

The importance of efficient farm management in soybeans should not be underestimated. An overview of soybean production and uses is contained in the next section. Subsequent sections describe the soybean insect problem in Illinois and the prediction system currently under development, an economic model for analysis of insect forecasts, and results of the economic analysis, respectively.

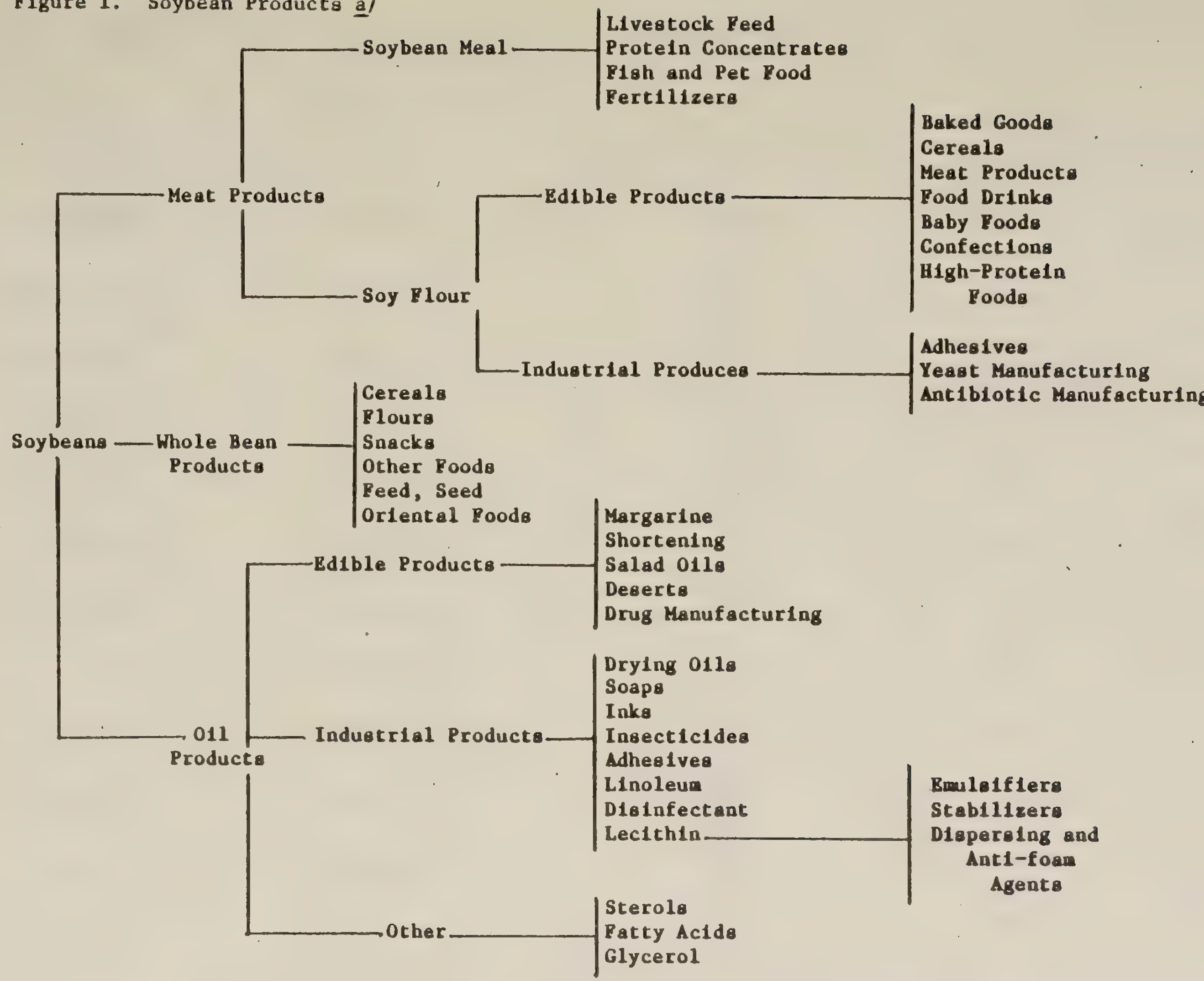
BACKGROUND

An increasingly significant source of protein and other nutrients in the world food supply is derived from soybean cultivation. Soybean products are a popular high protein supplement in livestock and poultry feed and appear as additives in many consumer foods. In addition, soybean oil is used in industrial products and may, in the future, be utilized as a substitute for fossil fuels. Figure 1 illustrates the many products derived from soybeans.

The United States produces more than sixty percent of world soybean output. Using advance production and pest management techniques, domestic firms maintain productivity levels well above world levels, although a trend toward parity is evident (Table 1). Nearly half of the domestic crop is marketed overseas, and hence plays a significant role in total U.S. agricultural exports and the foreign trade balance (Table 2).

Soybean acreage occupied an average of sixteen percent of the nation's cropland throughout the 1970's (Table 3). The largest and most productive

Figure 1. Soybean Products a/



a/ Houck, J.P., M.E. Ryan, and A. Subotnik, Soybeans and Their Products; Markets, Models, and Policy, University of Minnesota Press, Minneapolis (1972).

Table 1. Soybean Production and Yield, United States and the World, Selected Years, 1961-1979[a/]

Year	Production (1000 bushels)		Yield (bushels/acre)	
	United States	World	United States	World
1961-1965	718,687	1,082,600	24.2	18.8
1967	976,439	1,340,764	24.5	19.6
1968	1,106,958	1,454,223	26.7	20.8
1969	1,133,120	1,481,470	27.4	21.1
1970	1,127,100	1,526,554	26.7	21.1
1971	1,176,101	1,600,556	27.5	21.3
1972	1,270,608	1,743,783	27.8	21.5
1973	1,547,543	2,107,546	27.8	22.4
1974	1,216,287	2,450,990	23.7	20.0
1975	1,547,383	2,455,178	28.9	24.4
1976	1,287,560	2,166,997	26.1	22.4
1977	1,761,755	2,741,888	30.6	24.5
1978	1,870,181	2,946,330	29.5	24.4
1979	2,267,647	3,546,796	32.2	27.0

a/ U.S. Department of Agriculture, Agricultural Statistics, various issues.

Table 2. Value of United States' Agricultural and Soybean Exports and Foreign Trade Balance, 1970-1980[a/]

Year	U.S. Agricultural Exports (billion dollars)	U.S. Foreign Trade Balance (billion dollars)	U.S. Soybean Exports (billion dollars)
1970	7.0	+2.2	1.7
1971	8.0	-1.0	2.0
1972	8.2	-7.0	1.9
1973	15.0	-2.5	3.3
1974	21.6	-2.4	5.0
1975	21.9	+5.3	4.1
1976	22.8	-3.2	4.1
1977	24.0	-24.4	5.7
1978	27.3	-33.6	6.4
1979	32.0	-26.0	7.5
1980	40.5	-26.3	8.6

a/ U.S. Department of Agriculture, U.S. Foreign Trade Statistical Report, 1980.

soybean growing region is in the cornbelt including Iowa, Illinois, Indiana, and Ohio. Of these states, Illinois obtains the highest yield per acre and produces approximately one-fifth of total output on sixteen percent of the nation's soybean acreage. Approximately forty percent of Illinois's substantial cropland (Table 4) is planted with soybeans.

A major threat to Illinois soybean production is sporadic outbreaks of insects which feed on various components of the soybean plant. To guard against yield losses, many growers routinely scout their cropland for insects. Unfortunately, extensive scouting also may contribute significantly to production costs. CIPM recognizes the production cost problem and is conducting resarch at the University of Illinois to specify more economically the likelihood of an insect outbreak.

SOYBEAN INSECT PROBLEM, CONTROL PROCEDURE, AND PREDICTION SYSTEM

Detrimental insects such as the bean leaf beetle, green clover worm, and grasshopper, which feed on various components of the soybean plant, can damage the plant sufficiently to adversely affect yield. Insect outbreaks in Illinois are rare and unpredictable with the most recent occurring in 1976. Routine scouting rather than routine spraying for insects is recommended. Chemical control using the carbamate insecticide carbaryl (Sevin®) is generally instituted only when scouting reports indicate an insect outbreak. Scouting is less expensive to growers than calendar spraying and also is more environmentally sound to the extent that air and water quality are related to insecticide application. A survey of insecticide use on soybeans in Illinois conducted by the Illinois Natural History Survey reveals that less than three percent of soybean acreage was sprayed during the period 1973-1978. A description of soybean pest management in Illinois is contained in Kogan and Luckmann.

Table 3. Area Planted in Soybeans and Total Cropland, United States, 1970-1979[a/]

Year	Area Planted in Soybeans (1000 acres)	Total Area Planted (1000 acres)
1970	43,082	293,211
1971	43,472	305,830
1972	46,885	294,609
1973	56,675	318,682
1974	53,507	326,495
1975	54,550	332,366
1976	50,226	336,256
1977	58,760	344,007
1978	64,383	335,031
1979	71,586	345,65[illegible]

a/ U.S. Department of Agriculture, Agricultural Statistics, various issues.

Table 4. Cropland Use and Soybean Production Statistics, Illinois and the United States, 1979[a]

	Illinois (1)	United States (2)	Column (1) as a percentage of column (2)
Total Area Planted (1000 acres)	23,732	345,652	6.87
Total Area Harvested (1000 acres)	23,197	336,643	6.89
Area Planted in Soybeans (1000 acres)	9,800	71,586	13.69
Soybean Area Harvested (1000 acres)	9,720	70,530	13.78
Soybean Production (1000 bushels)	374,220	2,267,647	16.50
Soybean Yield (bushels per acre)	38.5	32.2	119.57

a/ U.S. Department of Agriculture, Agricultural Statistics, 1980.

In order to forecast possible outbreaks of soybean insects, researchers at the University of Illinois and Illinois Natural History Survey are developing a prediction system for soybean insects (Zavaleta and Dixon). Current plans call for a system which utilizes information developed from a reporting network dispersed throughout the state. Data developed from this network will be combined with reports from other regions of the country and other meteorological and entomological information to provide an early season forecast of the likelihood of a major insect infestation during that growing season. The output of this system will be comprised of a binary forecast ("outbreak" or "no outbreak") and a reliability estimate of the forecast.

The information provided by the insect prediction system will be disseminated to growers by county extension agents or via extension publications. It is expected that growers will incorporate these regional forecasts in their pest control decisions. The end result may include a reduction in both scouting and insecticide use.

AN ECONOMIC MODEL FOR ANALYSIS OF INSECT FORECASTS

An objective of the economic analysis is to estimate economic impacts. A grower decision-making under uncertainty or decision theoretic behavioral model is used for simulation to provide estimates of the impact of improved pest management information on expected profit, demand for information furnished by pest management consultants, and insecticide use. The approach used here is described by Winkler. Carlson, Headley, and Miranowski have applied decision analysis to pest control problems. Cammell and Way have evaluated pest forecasts in the case where no other information about the pest population (e.g., prior probabilities) is available.

Characteristics postulated and incorporated in the model include:

(1) Growers maximize expected profit.

(2) Growers apply insecticides according to recommended amounts.

(3) Soybean acreage remains constant.

(4) The possibility of substitution of a productive input for another is limited.

(5) Pest management actions of Illinois growers do not affect the price of soybeans and factor prices.

(6) Growers possess some prior notion of the likelihood that insect damage will exceed the economic threshold during the growing season and pursue insect scouting to refine their notions.

(7) Growers view scouting as a sampling process with a single, terminal conclusion drawn on the basis of the entire sample rather than on a per acre basis.

(8) Growers use both scouting information and the soybean prediction system forecast to assess the chance of an insect forecast.

Under these assumptions, expected grower profit can be calculated before and after implementation of the soybean prediction system. Without the prediction system forecast, growers select scouting intensity and insect control according to expected profit maximization. Following provision of insect forecasts, growers again select scouting and the appropriate insect control strategy. Expected profit, however, is evaluated using information from both the prediction system forecast and scouting.

Expected economic and environmental impacts are determined by comparison of model solutions under these two different information sources. Of course, expected impacts vary according to the reliability of the prediction system forecasts.

The economic decision model is depicted diagrammatically in Figure 2. The mechanical aspects of identifying the efficient (expected-profit-maximizing) grower actions and updating prior probabilities are shown along with specific data used in the model in the Appendix.

ECONOMIC IMPACT OF INSECT FORECASTS AND IMPLICATIONS OF RISK

The model outlined above and completely specified in the Appendix provides estimated economic impacts associated with soybean insect forecasts of varying reliability. The estimated impact of insect forecasts on profit, insecticide use, and scouting intensity for a range of forecast reliabilities are shown in Table 5.

Several interesting observations can be made regarding the impacts shown in Table 5. First, forecasts with less than 90 percent reliability do not change grower actions. Second, expected profit increases as the reliability of the forecast increases. Impacts on profits range from 2 cents per acre for a forecast correctly reflecting the state of nature 91 percent of the time to 67 cents per acre for perfect information. Third, scouting intensity declines as the reliability of the forecast rises.

The most interesting pattern in Table 5 is associated with insecticide use. It is clear from our results that insecticide use can increase or decrease following provision of a forecast. That is, for a range of forecast reliabilities, profit maximizing growers will find it in their best interest to reduce scouting levels and offset their loss of information by increasing insecticide use. The hypothesized negative relationships between information and insecticide use and information and environmental quality do not appear to hold, given two information structures. In the present example, a forecast reliability which ensures environmental improvement should exceed 0.94. Finally, note that the cost of

Figure 2. Flow Diagram of Soybean Economic Decision Model.

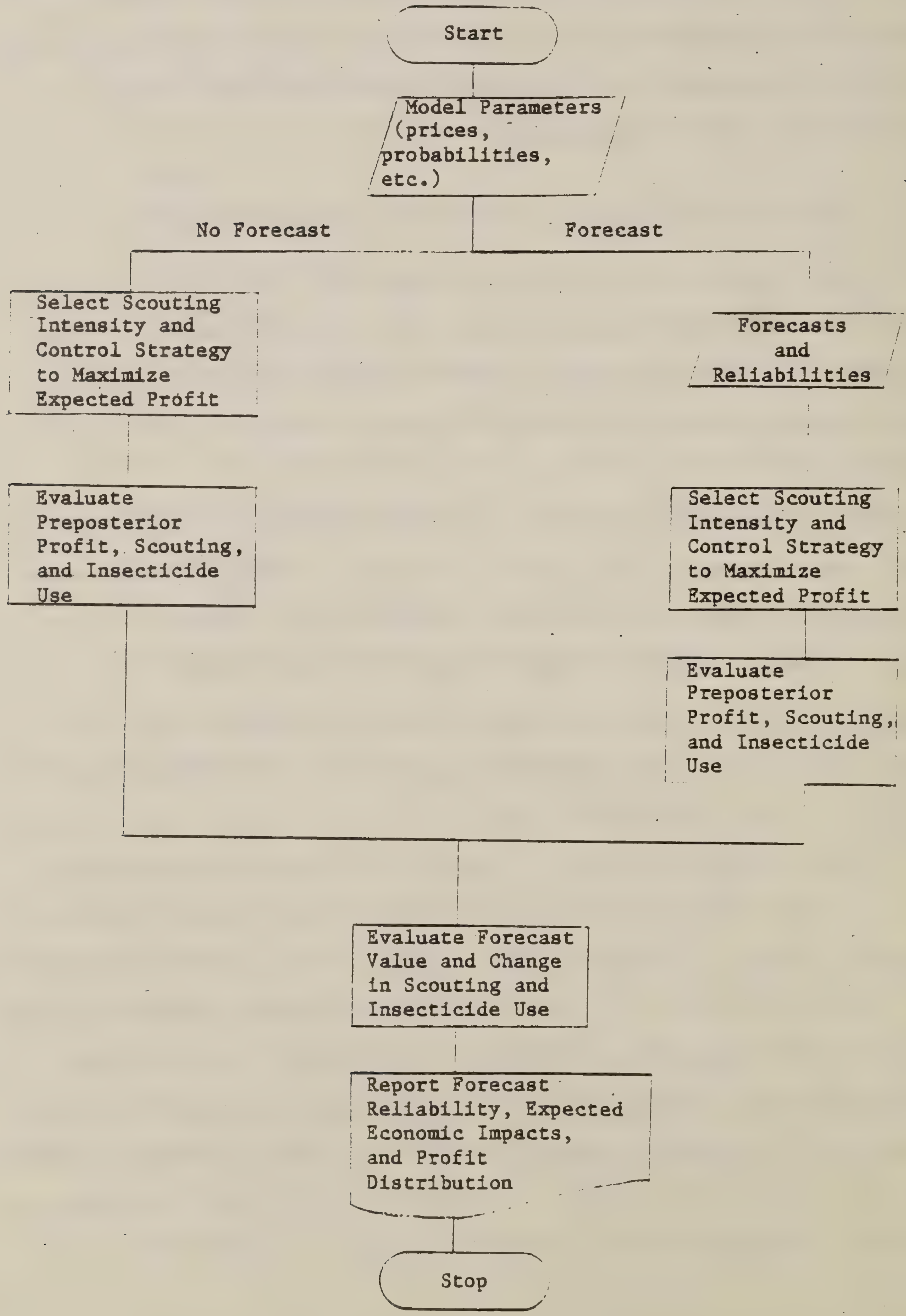


Table 5. Economic Impact of Soybean Insect Forecasts

Reliability of Forecast	Expected change in profit (cents/acre) a/	Expected Percent Change in Insecticide Application	Expected Percent Change in Scouting
< .90	0	0	0
.91	2.2	54	-50
.92	4.8	50	-50
.93	7.5	45	-50
.94	10.8	-16	-92
.95	19.8	-21	-92
.96	28.9	-25	-92
.97	37.9	-30	-92
.98	47.0	-34	-92
.99	56.4	-39	-100
1.00	66.7	-43	-100

a/ "Value" equals the change in soybean grower net returns expected "with" as opposed to "without" a forecast and is a function of changes in the intensity of scouting and insecticide use required to maximize profit.

achieving a specific forecast reliability will have to be used in conjunction with results shown in Table 5 before an optimal prediction system can be identified.

The above estimates are based on the assumption growers exhibit risk neutral behavior (i.e. growers identify optimal strategies by considering only the means of the profit distributions). As an alternative, we now assume growers are averse to risk. Therefore, two stochastic efficiency criteria, mean-variance and stochastic dominance, are used to divide the available pest control strategies into two mutually exclusive sets of efficient and inefficient strategies. In general, the efficient set includes the previously identified risk neutral strategy as well as one or more other strategies. From the efficient set, a range of possible insecticide use and scouting patterns can be constructed to indicate the impact of growers' risk attitudes on forecast valuation.

Before describing the stochastic efficiency criteria used for this purpose, some simple notation is developed for identifying control strategies. There are two possible predictions from both the forecast and scouting, i.e. "no outbreak" and "outbreak". Thus, a grower can receive four sets of information signals (only two without the forecast):

(a) Forecast indicates no outbreak
    Scouting indicates no outbreak

(b) Forecast indicates no outbreak
    Scouting indicates an outbreak

(c) Forecast indicates an outbreak
    Scouting indicates no outbreak

(d) Forecast indicates an outbreak
    Scouting indicates an outbreak

For each signal (a through d) a grower must select one of two control actions:

do not spray = 1 or spray = 2. Sixteen quadruple strategies (2^4) can be constructed using the following notation:

$$(i, j, k, l) \quad i, j, k, l = 1, 2$$

which indicates that action i is taken if signal "a" is received; action j is taken if signal "b" is received, etc. For example, strategy (1,1,1,1) states no insecticide application, regardless of what is indicated by scouting report and the forecast. An alternative strategy is (1,1,2,2), which says to choose chemical control in accordance with the forecast.

The purpose now is to ascertain what other strategies are efficient from the standpoint of a risk averter and to suggest plausible changes in the economic impacts shown in Table 5. The two stochastic efficiency criteria used to identify efficient strategies under risk are described next.

The mean-variance criterion bases choice under uncertainty on the mean and variance of the profit distribution corresponding to each strategy. An efficient strategy must have a larger mean and smaller variance, equal mean and smaller variance, or larger mean and equal variance for profit than another strategy's profit distribution. Stochastic dominance, on the other hand, identifies efficient strategies by comparing actual profit distributions, according to formulas developed from economic research.

The mean-variance and stochastic dominance rules were applied to the four strategies given the two scouting signals and the sixteen strategies given the four joint scouting and forecast signals at fifteen different sample sizes. Efficient strategies are identified in Table 6. The first strategy of each cell is the optimal strategy under risk neutrality. Strategy (2,2,2,2) is efficient under all reliabilities and sample sizes, but is not included in the analysis because it is not a feasible strategy for soybean farmers who currently

Table 6. Mean-Variance and Stochastic Dominance Efficient Strategies for Alternative Scouting Intensities and Forecast Reliabilities

Forecast Reliability Scouting Intensity	Scouting Only	90	91	92	93	94	95	96	97	98	99	100
0	(2,2)	(1,1,2,2)	(1,1,2,2)	(1,1,2,2)	(1,1,2,2)	(1,1,2,2)	(1,1,2,2)	(1,1,2,2)	(1,1,2,2)	(1,1,2,2)	(1,1,2,2)	(1122)
1	(1,2)	(1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	
2	(1,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	
3	(1,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	
4	(1,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	
5	(1,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	
6	(1,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	
7	(1,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	
8	(1,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	
9	(1,2)	(1,2,1,2) (1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	
10	(1,2)	(1,2,1,2) (1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	

Table 6. Cont'd

Forecast Reliability / Scouting Intensity	Scouting Only	90	91	92	93	94	95	96	97	98	99	100
11	(1,2)	(1,2,1,2) (1,2,2,2)	(1,2,1,2) (1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	
12	(1,2)	(1,2,1,2) (1,2,2,2)	(1,2,1,2) (1,2,2,2)	(1,2,1,2) (1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	
13	(1,2)	(1,2,1,2) (1,2,2,2)	(1,2,1,2) (1,2,3,2)	(1,2,1,2) (1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	
14	(1,2)	(1,2,1,2) (1,2,2,2)	(1,2,1,2) (1,2,2,2)	(1,2,1,2) (1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	
15	(1,2)	(1,2,1,2) (1,2,2,2)	(1,2,1,2) (1,2,2,2)	(1,2,1,2) (1,2,2,2)	(1,2,1,2) (1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,2,2,2)	(1,1,2,2) (1,2,2,2)	(1,1,2,2) (1,2,2,2)	

scout before deciding to spray. The extremely strict assumption of zero variance is a major factor for being unable to exclude a strategy which ignores all information and routinely applies insecticides.

Table 6 can be examined from three different viewpoints. First, for each cell, both mean-variance and stochastic dominance rules identify the same efficient strategies. Furthermore, the efficient set is small and composed of a combination of three strategies: (1,1,2,2) (1,2,2,2) and 1,2,1,2). Second, if sample size is fixed and reliability is allowed to vary, efficient strategies associated with a lower reliability are dominated by efficient strategies at a higher reliability. Note that strategy (1,2,1,2), which says to follow scouting information only, is inefficient for forecast reliabilities of 94 or higher. Third, if reliability is fixed and sample size is allowed to vary, the efficiency rules identify different efficient sets. Under mean-variance, sample sizes 2-5 are inefficient. Hence, some growers will base their decisions mainly on forecast information while other growers will supplement the forecast information with scouting. Actual insecticide use will depend upon individual growers' risk preference structures.

Without knowing actual preference structures of soybean growers, both mean-variance and stochastic dominance rules identify the importance of strategy (1,2,2,2), which says to spray if either scouting or the forecast predicts a pest outbreak. Hence, insecticide use is likely to increase and the expected increase in profit due to the forecast decrease if the risk neutral solution is not chosen. In addition, the grower can conceivably scout the entire field because of the negative relationship between insecticide use and scouting intensity.

Limited conclusions can be drawn if scouting is fixed for the risk neutral optimum and insecticide use is calculated using strategy (1,2,2,2). Results

Table 7. Risk impacts on forecast value and insecticide use at risk neutral scouting values

Reliability of Forecast	Expected Change[a/] in Value[b/] of Forecast (cents/acre)	Expected Percent Change[a/] in Insecticide Application
.90	-.53	48
.91	0	0
.92	0	0
.93	0	0
.94	-19.3	119
.95	-24.9	127
.96	-30.5	135
.97	-36.0	145
.98	-41.5	156
.99	-47.5	0
1.00	0	0

a/ Deviation from risk neutral solution, scouting level held constant.

b/ "Value" equals the change in soybean grower net returns expected "with" as opposed to "without" a forecast and is a function of changes in the intensity of scouting and insecticide use required to maximize profit.

are exhibited in Table 7. As expected, the expected profit increase due to the forecast decreases in most instances. From a policy standpoint, state policy-makers should be cognizant of smaller payoffs and reductions in environmental amenities (assuming environmental quality is non-increasing in insecticide use) if risk aversion is the prevalent attitude among soybean producers.

CONCLUSIONS

Initial support for a large area insect prediction system hinged on the belief that collection and dissemination of insect movements could be done more economically on a regional basis. In this paper, we used preposterior decision analysis to identify possible impacts of an early-warning soybean prediction system on grower profits, insecticide use, and acres scouted.

First, if growers are assumed to be profit maximizers, a forecast reliability must exceed 90 percent before the forecast improves grower profits. Furthermore, growers will decrease the number of acres scouted by private consultants as forecast reliability improves. If forecast reliabilities are in the range of 92 to 94 percent, growers would be expected to increase their insecticide use to offset the uncertainty of reducing the number of acres scouted by private consultants. This could lead to negative rather than positive environmental effects as would be ordinarily expected with scouting systems designed to improve predictability of pest populations and improve the efficiency of pesticide use.

Second, if growers are assumed to be risk averse, only limited conclusions can be drawn without further knowledge of individual risk attitudes. Stochastic efficiency criteria suggest that utility-maximizing growers would use more costly insecticide intensive strategies to reduce profit variability. That is, risk aversion most likely reduces the benefits of a forecast system. Thus policy-makers should be aware of the possibility of reduced forecast benefits and lessened environmental improvement if risk aversion is the prevalent attitude among soybean growers.

Third, the decision model assumed growers could hire private consultants on a per acre basis rather than by field, as is commonly done in the agricultural community. If, in the future, scouting practices shift from a field to a per-acre basis, growers likely will benefit from lower costs and consultants will be able to expand their base of operations.

Only the benefits of an insect prediction system are indicated in this paper. When cost data of the forecast system become available, benefits and costs need to be compared to determine the overall desirability of an insect prediction system and to choose an optimal forecast reliability.

Appendix

The soybean economic decision model depicted in the text is made explicit in the following notation:

n = scouting intensity — number of acres scouted for defoliation.

$n = 0, 1, 2 \ldots$;

μ = average percent defoliation in a field;

T = economic threshold expressed in percent defoliation;

θ_j = defoliation indicator; $j = 1\ 2$;

$$= \begin{cases} \theta_1; \text{ if } \mu < T \\ \theta_2; \text{ otherwise} \end{cases} ;$$

$P[\theta_j]$ = probability of θ_j; $j = 1, 2$;

$$= \begin{cases} P[\mu < T] \text{ ; if } \theta_1 \\ P[\mu > T] \text{ ; if } \theta_2 \end{cases} ;$$

A_i = Insecticide application per acre ; $i = 1, 2$;

$$= \begin{cases} A_1; \text{ if } 0 \\ A_2; \text{ if recommended rate} \end{cases} ;$$

$M(A_i, n \mid \theta j)$ = profit per acre if insecticide application is A_i, scouting intensity is n, and state of nature if θ_j; $i, j = 1, 2$;

$\overline{x}$ = sample average percent defoliation;

S_k = sample defoliation indicator ($k = 1, 2$);

$$= \begin{cases} S_1 \text{ ; if } \overline{x} < T \\ S_2 \text{ ; otherwise} \end{cases} ;$$

F_ℓ = prediction system forecast ($\ell = 1,2$);

$$= \begin{cases} F_1; \text{ if prediction is "no outbreak"} \\ F_2; \text{ otherwise} \end{cases} ;$$

In addition $P[\cdot|\cdot]$ denotes the probability of variables to the left of the vertical line conditional on those to the right of this line; e.g.,

$P[\theta_j|S_k,n]$ = probability of θ_j given scouting result S_k and scouting intensity n; (j, k = 1, 2).

In the absence of insect forecasts, the economic simulation model locates the Bayes strategy in the following way. A provisional level of scouting is selected and expected profit is evaluated for all A_i and S_k:

$$E[M(A_i,n|S_k)] = \sum_j M(A_i,n|\theta_j) \cdot P[\theta_j|S_k,n]$$

For each S_k the best control action, $A_{i_k}^*$, dependent upon expected profit is identified (conditional on the provisional scouting intensity) such that

$$\sum_k E[M(A_{i_k}^*,n|S_k)] \cdot P[S_k|n] > \sum_k E[M(A_i,n|S_k)] \cdot P[S_k|n]$$

for all $A_i \neq A_{i_k}^*$. Repetition of this process over a range of values for n determines optimal scouting intensity n*, and expected profit and insecticide application respectively:

$$\pi^* = \sum_k E[M(A_{i_k}^*,n^*|S_k)] \cdot P[S_k|n^*]$$

and

$$A^* = \sum_k A_{i_k}^* \cdot P[S_k|n^*]$$

Similar evaluations provide n*':

$$\pi^{*\prime} = \sum_k\sum_\ell E[M(A_{i_{k\ell}}^*,n^*|F_\ell,S_k|n^*]$$

and

$$A^{*\prime} = \sum_k\sum_\ell A_{i_{k\ell}}^* \cdot P[F_\ell, S_k|n^*]$$

which are correspondingly defined and based on the forecast provided by the insect prediction system as well as on scouting done at the grower level.

The expected profit impact of the insect forecast is given by

$$V = \pi^{*\prime} - \pi^*$$

while expected impacts on insecticide use and scouting are

$$I = A^{*\prime} - A^*$$

and

$$S = n^{*\prime} - n^*$$

respectively. Note that V, I, and S are determined by the reliability of the insect forecasts which are reflected in the posterior probability distributions used in their evaluation.

To specify fully the probability revisions indicated above, first denote the percent defoliation of an acre selected at random from a field by x_i. Further assume x_i is distributed according to a probability density function with positive finite mean and variance:

$$x_i \sim f_{x_i}(x)$$

$$E[x_i] = \mu;\ \mu \in [L,U]$$

$$E[(x_i - \mu)^2] = \sigma_\mu^2\ ;\ \sigma_\mu^2 > 0\ ;\ i = 2,..,n$$

where L and U are lower and upper bounds on mean percent defoliation, respectively. The prior distribution of mean percent defoliation is

$$\mu \sim f_\mu(y)$$

Given a random sample of size n, the sample average percent defoliation, $\overline{x}=(1/n)\sum x_i$, is distributed according to

$$\overline{x} \sim f_{\overline{x}}(x),$$

and the joint density of μ and $\overline{x}$ is

$$f_{\overline{x},\mu}(x,y) = f_{x,\mu}(\overline{x}|y) \cdot f_\mu(y).$$

Recalling that θ_1 implies $\mu < T$ while θ_2 indicates $\mu > T$ and that S_1 indicates $\overline{x} < T$ while S_2 indicates $\overline{x} > T$, the probability that the economic threshold is not exceeded given that this impression was gained from scouting is

$$P[\theta_1 | S_1] = P[\mu < T \mid \overline{x} < T]$$

Similarly, the probability of an insect outbreak given that the sample indicates that the economic threshold is exceeded is

$$P[\theta_2 | S_2] = P[\mu > T | \overline{x} > T]$$

Note that the probability of no outbreak given that the sample indicates an outbreak and the probability of an outbreak given that the sample indicates otherwise are

$$P[\theta_1 | S_2] = 1 - P[\theta_2 | S_2]$$

and

$$P[\theta_2 | S_1] = 1 - P[\theta_1 | S_1]$$

respectively. The required posterior probabilities are

$$P[\theta_1 | S_1] = \frac{\int_{-\infty}^{T} \int_{-\infty}^{T} f_{\overline{x},\mu}(x,y)\,dxdy}{\int_{-\infty}^{T} \int_{-\infty}^{\infty} f_{\overline{x},\mu}(x,y)\,dxdy}$$

and

$$P[\theta_2 | S_2] = \frac{\int_{T}^{\infty} \int_{T}^{\infty} f_{\overline{x},\mu}(x,y)\,dxdy}{1 - \int_{-\infty}^{T} \int_{-\infty}^{\infty} f_{\overline{x},\mu}(x,y)\,dxdy}$$

When insect forecasts are available, posterior probabilities are conditional on both the forecast, F_ℓ, and scouting result, S_k.

The reliability of the forecast, $P[F_\ell|\theta_j]$, indicates the probability that the prediction system forecast correctly reflects the true state of nature. These reliability factors can be used in conjunction with the previously computed posterior probabilities to obtain posterior probabilities conditional on both the forecast and scouting result. Assuming conditional independence between these two sources of information, these are

$$P[\theta_j|F_\ell,S_k] = \frac{P[S_K|\theta_j] \cdot P[\theta_j|F_\ell]}{\sum P[S_K|\theta_j] \cdot P[\theta_j|F_\ell]}; \; j,k,\ell = 1,2.$$

These probabilities are evaluated in a manner similar to that involving $P[\theta_j|S_K]$ shown earlier. The main difference is the density $f_\mu(\cdot)$ which was the prior density previously but which is now modified to reflect the information received from the insect prediction system in evaluating the above. Thus, the posterior density of average percent defoliation, developed from the insect forecast, is the prior density of average percent defoliation from the standpoint of scouting. Given appropriate distributions for the underlying random variables $(x_i, \bar{x}, \mu)$, the posterior probabilities $(P[\theta_j;|\cdot]; \; j=1, 2)$ may be evaluated as above. If the reliability of the prediction system forecast is known, these probabilities may be seen to depend on scouting intensity.

A number of parameters are involved in specification of the economic model and probability revisions described above. Average profit per acre, $M(A_i,n|\theta_j)$, is dependent upon the state of nature, θ_j, and grower decisions with respect to insecticide application, A, and scouting intensity, n. This expression is

$$M(A_i,n|\theta_j) = \text{Soybean Price} \times [\text{Potential Yield} - \text{Yield Loss}\,(A_i,\theta_j)]$$
$$- \text{Production Cost} - \text{Insecticide Cost}(A_i) - \text{Scouting Cost}(n).$$

Variables in the profit equation are:

Soybean Price = \$6.65/acre (source: U.S. Department of Agriculture, 1978 Firm Enterprise Data System Crop Budgets (1980)

Potential Yield = 36.5 bu/acre (source: U.S. Department of Agriculture, 1978 Firm Enterprise Data System Crop Budgets (1980)

$$\text{Yield Loss } (A_i,\theta_j) = \begin{cases} 34\%, \text{ if } A_i = A_1 \text{ and } \theta_j = \theta_2 \\ 0, \text{ otherwise} \end{cases}$$
(source: adapted from Kogan & Luckmann)

Production Cost = \$200/acre (source: U.S. Department of Agriculture, 1978 Firm Enterprise Data System Crop Budgets (1980)

$$\text{Insecticide Cost}(A) = \begin{cases} (\$2.00 \text{ application cost} + \$2.00/\text{pound a.i.})/\text{acre} \\ \$0, \text{ otherwise} \end{cases}$$
(source: U.S. Department of Agriculture, 1978 Firm Enterprise Data System Crop Budgets (1980)

Scouting Cost(n) = (\$3.00/acre x n(acres))/150 acres per field

= \$0.02/acre x n(acres) (source: Zavaleta and Dixon)

$$A_i = \begin{cases} .4375 \text{ pounds of carbaryl per acre, if } A_i = A_2 \\ 0, \text{ otherwise} \end{cases}$$
(source: adapted from Kogan and Luckmann)

The insecticide application is assumed to reduce the pest population below the damage threshold without any loss of yield. The economic threshold is estimated to be T = 20% defoliation (source: adapted from Kogan and Luckmann). This defoliation level was also employed in the analysis of soybean pest control done by Cashman et al.

Insect outbreaks are sporadic in Illinois and occur on average approximately one year in ten. This relative frequency is used to establish the prior probability of an insect outbreak: $P[\theta_1] = .10$ and $P[\theta_2] = .90$. Given these probabilities, it is clear that the prior density of average percent defoliation, $f_\mu(y)$, must satisfy

$$\int_L^T f_\mu(y)dy = .90 \text{ and } \int_T^U f_\mu(y)dy = .10 .$$

The density, $f_\mu(y)$, is only vaguely perceived and is consequently taken as uniform according to

$$f_\mu(y) = \begin{cases} .9/(T-L) , & \text{if } y \varepsilon [L,T] \\ .1/(U-T) , & \text{otherwise} \end{cases}$$

which may be written as

$$f_\mu(y) = (.9/(T-L))I_{[L,T]}(y) + (.1/(U-T))I_{[T,U]}(y)$$

where $I_{(\cdot,\cdot)}(y) = 0$ for y not in the range indicated by the subscripted expression and $_{(\cdot,\cdot)}(y) = 1$ otherwise.

The density of defoliation over the acres in a field, $f_{x_i}(\cdot)$, is unknown, but is assumed to have a positive mean, μ, and variance, σ_μ^2. A relationship between the standard deviation, σ_μ, and the mean was estimated as

$$\sigma_\mu = f(\mu) = 4.453 + 0.549 \mu$$

from the data obtained from Brazilian soybean test plots. The simple linear relationship was selected on the basis of an R^2 criterion. However, alternative functional forms tried for this relationship variably indicated a positive relation between the standard deviation and mean of defoliation.

The distribution of average percent defoliation, $\bar{x}$, is approximated by the normal density. Thus, the joint density of μ and $\bar{x}$ is

$$f_{\bar{x},\mu}(x,y) = [2\pi ((f(y))^2/n)]^{-1/2} \exp[-(1/(2(f(y)^2/n))(x-y)^2]$$
$$\cdot[(.9/(T-L))I_{[L,T]}(y) + (.1/(U-T))I_{(T,U]}(y)] .$$

The required posterior probabilities defined earlier are

$$P[\theta_1|S_1] = \frac{(.9/(T-L))\int_L^T \Phi((t-y)/\overline{n}/f(y))dy}{.9/(T-L)\int_L^T \Phi((T-y)/\overline{n}/f(y))dy + .1/(U-T)\int_T^U \Phi((T-y)/\overline{n}/f(y))dy}$$

$$P[\theta_2|S_2] = \frac{.1/(U-T)\int_T^U \Phi((T-y)/\overline{n}/f(y))dy}{1 - .9/(T-L)\int_L^T \Phi((T-y)/\overline{n}/f(y))dy + .1/(U-T)\int_T^U \Phi((T-y)/\overline{n}/f(y))dy}$$

where

$$\Phi(x) = \int_{-\infty}^{x} [2\pi]^{-1/2} \exp[-\xi^2/2]d\xi^2/2]d\xi$$, is the standard

normal disctibution function, and is evaluated according to the method developed in Dutt. Numerical integration is then employed to complete evaluation of the posterior probabilities. These expressions define the posterior probabilities as a function of scouting intensity.

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[illegible] Historic Survey and Illinois Arch[illegible]

50272-101

REPORT DOCUMENTATION PAGE

1. Report No. Staff Report AGES821013

2.

3. Recipient's Accession No. PB83-128728

4. Title and Subtitle
Farm Efficiency and Insect Infestation Forecasts: The Case of Soybeans in Illinois

5. Report Date October 1982

6.

7. Author(s)
L. Joe Moffitt and others

8. Performing Organization Rept. No. Staff Report AGES821013

9. Performing Organization Name and Address
Natural Resource Economics Division
Economic Research Service
U.S. Department of Agriculture
Washington, D.C. 20250

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G)

12. Sponsoring Organization Name and Address

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

A preposterior decision model and a scouting model are used to estimate the economic benefits of an area-wide soybean insect prediction system in Illinois. Results suggest forecast reliabilities of the insect prediction system must exceed 90 percent accuracy before grower profits increase and acres scouted by consultants decrease. Insecticide use, however, can increase or decrease over a range of forecast reliabilities because of the shift from insect consultants to an area-wide public supported insect prediction system. If risk averse behavior is assumed, growers will likely apply more insecticides and hence reduce forecast prediction benefits.

17. Document Analysis a. Descriptors

Decisions	Insects	Soybean
Economic analysis	Insecticide	
Estimates	Profits	
Forecasts	Risk	

b. Identifiers/Open-Ended Terms

Acre	Farm efficiency	Insect prediction system
Benefits	Growers	Percent
Decision model	Increase	Scouting model
Decrease	Infestation	

Prices as of 1/1/82:
Paper:
Fiche: $4.50
Cost codes are: for Paper and A01 for Fiche

c. COSATI Field/Group 06-F

18. Availability Statement:
National Technical Information Service
5285 Port Royal Road, Springfield, VA 22161

19. Security Class (This Report) Unclassified

20. Security Class (This Page) Unclassified

21. No. of Pages

22. Price See box 17.

(See ANSI–Z39.18) *See Instructions on Reverse*

OPTIONAL FORM 272 (4–77)
(Formerly NTIS–35)
Department of Commerce

55