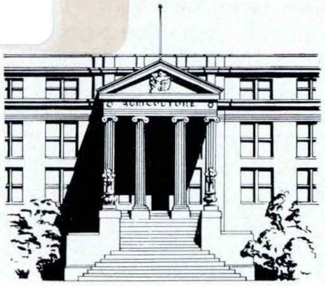

Application of Game Theory Models To Decisions on Farm Practices And Resource Use

by Odell L. Walker, Earl O. Heady,
Luther G. Tweeten and John T. Pesek

Department of Economics and Sociology
Department of Agronomy

AGRICULTURAL AND HOME ECONOMICS EXPERIMENT STATION
IOWA STATE UNIVERSITY of Science and Technology

RESEARCH BULLETIN 488 DECEMBER 1960 AMES, IOWA

CONTENTS

SUMMARY

The use of alternative decision models for farmer decision-making under uncertainty is demonstrated in this study. Particular emphasis is given to game theoretic models. These models have previously had little empirical application to farmer decision problems. This study has shown, however, that the models suggest plans which farmers in various problem settings may wish to follow. Research and extension personnel may want to use the models to derive farmer recommendations.

Farmers must make decisions in their given, uncertain environment. How are these decisions to be made so that the plans resulting will, as nearly as possible, have the outcomes desired by the farmer? This question expresses the problem this study was designed to investigate. Farmers can follow any of several models specifying how to plan under uncertainty. They may apply the models to their own problems directly or follow recommendations based on the models. Research and extension personnel influence choice of decision models through data and recommendations. Research workers must use some choice mechanism to derive recommendations. Published data may influence choice of decision models, by being suitable for use in only one or a few models. Farmers' abilities to plan rationally may be increased by providing a variety of recommendations based on different decision models giving plans with outcomes desired by farmers. Abilities also may be increased by providing data applicable to several decision models.

The objectives of this study were to explain possible applications of game theoretic models to agricultural data of the kind used by farmers to make decisions, or used by research and extension specialists to make recommendations for farmers. Farmers differ in their aversion to uncertainty and in their ability to withstand the consequences of uncertainty and variations in economic outcomes. Given the same data, different farmers may wish to make different plans, depending on their capital and equity position or their family responsibilities. The several decision or game theoretic models applied to agricultural data to determine the choice of practices which might be specified to meet various farmer settings include the Wald, Laplace, Savage regret and Hurwicz criterion models and a conventional probability model.

Of the several models or criteria for decision-making under uncertainty, only the model for maximizing expected utilities, the game theoretic models, the naive or econometric models and various precautions for uncertainty provide an objective rule for obtaining an implicit or explicit goal. They are normative models. Positive models, which describe how individuals may or do choose under uncertainty, have been suggested. These models do not lend themselves to application in a study such as this because they require subjective choices which can only be made by the decision maker. The normative models can be applied to empirical problems by a research worker. The decision maker may then select the recommendation which fits his problem setting.

The game theoretic models have resulted from a special formulation of game theory — games against nature. The knowledge situation assumed in a game against nature is absolute uncertainty. Farmer problems may be thought of as a game against nature if a farmer's alternatives are regarded as his strategies and if possible states of uncontrollable and unpredictable events are treated as nature's strategies. The game theoretic models are techniques for obtaining solutions to the game against nature. The Wald criterion calls for selecting a plan which allows the greatest minimum return, regardless of which state of nature occurs. The Savage regret criterion selects a plan which minimizes the opportunity cost of choosing a less profitable plan, viewed **ex post.** The Hurwicz criterion chooses a plan which has the highest pessimism-optimism index. The Laplace criterion chooses the plan which has the highest average over states of nature. Each of the alternative decision models implies certain goals for the decision maker.

Actual farmer problems were considered to demonstrate techniques of using models and to show the kinds of recommendations which may result. The 17 problems considered were a particular class of within-farm and within-enterprise problems. They included situations requiring choice of crop varieties, kinds and amounts of fertilizer, crop enterprises, pasture mixtures and stocking rates. Data were obtained from annual progress reports on Iowa Experiment Station experimental farms. Thus, this study demonstrated that presently available experimental data may be used in various decision models. A limitation of this study was that the length of data series was relatively short. Therefore, the sets of states of nature considered were small. Ideally, this set should include many states of nature.

Actual problem solutions suggested by the alternative decision models frequently differed. For example, in one problem, farmer alternatives were varieties of oats for planting in northeast Iowa. States of nature were the different years in which oat yields had been observed. The Laplace solution called for planting Clarion oats to maximize long-run yields. The Wald solution suggested planting 56 percent of oat land to Clintland oats and 44 percent to Sauk. This plan assured a minimum oat yield which was 5 bushels higher than any other plan. Regret was minimized by planting 25 percent Clintland, 66 percent Clarion and 9 percent Sauk. Major differences between these plans are evident.

The Wald and Laplace solutions were the same in 8 of 17 problems. Thus, even though a researcher may frequently be required to recommend a number of plans to fit different problem settings, he can sometimes make one recommendation suitable to a range of problem settings. This

result cannot be generalized, however, because the problem setting differs greatly among farmers.

A comparison of the Wald, Savage regret and Laplace problem solutions showed that the Savage criterion plan had the second highest security level in 14 of 17 problems. It had the second highest average in 9 problems and third highest in 8 problems. Thus, for the problems considered, the Savage regret criterion appeared to give plans intermediate between those for maximizing long-run profit and those assuring a minimum return in the short run. This conclusion is given weight by the fact that the Savage regret criterion plan had the second highest possible maximum in 11 of 17 problems.

As expected, the Hurwicz criterion plan, with a range of α including zero, had the highest maximum in all 17 problems. The Laplace tied with the Hurwicz criterion for highest maximum 8 times in 17 problems. The Wald criterion plan had the lowest maximum in 10 of 17 problems. Thus, in the problems considered, use of the Wald plan would require giving up the opportunity for the highest possible return a majority of the time.

Regret was always minimized by using the Savage regret plan. No other criterion even tied with the Savage regret plan in that category. Thus, the Savage regret criterion was demonstrated to be unique among the criteria for obtaining minimum regret. It is theoretically possible to obtain a plan which minimizes regret with other criteria.

This study has demonstrated that application of several decision models to agricultural problems can result in recommendations suited to a wide range of farmer situations. The models are mechanically easy to apply and are relatively easy to understand. The study also demonstrated that data representing the influence of many possible levels of uncontrollable and unpredictable natural variables are needed for application of relevant models for decision-making under uncertainty. Research planners should consider the value of obtaining data of this kind, perhaps as a supplementary product of research designed for another purpose. It should be clear that the publication of data as averages is only one of several data forms that may be useful to farmers in decision-making.

Application of Game Theory Models To Decisions on Farm Practices and Resource Use[1]

BY ODELL L. WALKER, EARL O. HEADY, LUTHER G. TWEETEN AND JOHN T. PESEK[2]

The decision-making function of farmers would be greatly simplified in a world free of risk and uncertainty. Static economic theory provides guides for making decisions when knowledge is complete. Resource-use alternatives and the outcomes of alternative resource combinations are specified by physical scientists. Sociologists and psychologists provide knowledge on the diversity of forces affecting man's activities. Their contributions lead to economic models which are flexible enough to include alternative or multiple goals and various resource situations. Together, the various disciplines of science provide data and principles which would make decision-making a simple process if all price, technical and social quantities were known with certainty.

Obviously, the farmer decision-making environment is more complex than that just described. Uncertainty is introduced by technical and technological change, price variation and unpredictable human action.

Physical scientists cannot predict exactly the amount and quality of a product to be obtained from given resources. The input of factors such as weather and other natural phenomena is not known until production has taken place. Often, resource inputs are only classified quantitatively, and important qualitative properties are not stated. These conditions lead to technical uncertainty in agriculture.

Technological change is a second source of uncertainty. Change in production techniques, development of new products or inputs and introduction of other innovations cannot be accurately predicted, yet they affect the desirability of alternative farm plans.

Price provides a third major source of uncertainty. The complex of interrelated factors which contribute to price variability includes: (a) world and national economic conditions, (b) the general state of uncontrollable, natural phenomena affecting production, (c) commodity and business cycle phenomena, (d) governmental policy and (e) individual values and goals.

A fourth source of farm uncertainty results from relationships among individuals, groups of individuals and institutions. Farmers cannot always predict governmental activities which affect future events and, thus, their own welfare. Man's goals change; therefore, commitments made between a farmer and another person in one time period may not attain goals which exist in another time period.

This study considers uncertainty the usual environment for agricultural production. The term uncertainty has been used initially to describe a general condition of change, imperfect knowledge and lack of foresight. A more technical use of the term is introduced later.

OBJECTIVES OF THE STUDY

Farmers can follow, even though unwittingly, any of several models which specify how to operate under uncertainty. These alternative decision models imply particular psychologies, resource situations and states of knowledge for individuals who use them. Research and extension personnel often use, also perhaps unwittingly, the various models in making recommendations to farmers.

The over-all objective of this study is to examine various game theoretic models which provide a relevant framework for assisting farmers to select plans appropriate to their personal situation. Little attention has previously been given to determining the appropriateness of the relatively new game theoretic techniques for farmer decision-making under uncertainty. Other models, such as those discussed later, are more highly developed and better known. Thus, the game theoretic decision criteria are emphasized in this study. This emphasis is motivated by need for research to determine the usefulness of the game theoretic criteria. A preliminary hypothesis is that the criteria have considerable application to farmer decision-making under uncertainty.

The specific major objectives of this study are:

(1) To review game theoretic criteria relative to farmer decision-making, to demonstrate the

[1] Project 1135 of the Iowa Agricultural and Home Economics Experiment Station.

[2] The authors are, respectively: assistant professor in agricultural economics at Oklahoma State University (formerly graduate assistant at Iowa State University); professor of agricultural economics; research associate in agricultural economics; and professor of soils.

mechanics of their use and to show their relationship to other decision models.

(2) To evaluate the game theoretic criteria for use as decision models under uncertainty by (a) demonstrating the kinds of problem solutions which they suggest and (b) determining the type of problem settings for which they are appropriate.

(3) To demonstrate the wide range of problem settings which farmers logically may have and to show the need for recommendations which are suited to those settings.

(4) To demonstrate techniques for formulating farmer problems clearly and comprehensively.

(5) To use experimental data of conventional types generally used for making recommendations to farmers in a game theoretic framework as a basis for determining how recommendations might best be conditioned to meet the decision-making environment of different farmers.

GAME THEORETIC TECHNIQUES

The decision criteria discussed in this section are for use in a knowledge situation characterized by uncertainty. They are the only models providing an objective rule for obtaining an implied or explicit goal. Such models are normative rather than positive.

Two-Person Zero-Sum Games

Game theoretic techniques are closely related to the two-person zero-sum game. Thus, the latter models are briefly reviewed. Luce and Raiffa[3] and Heady and Candler[4] provide a complete treatment of game theory in this framework.

Two players or persons oppose each other in this type of game; each has a finite number of alternative courses of action called a strategy set. These sets are designated as:

$$S_1 = [a_1, a_2, \dots, a_m] \text{ and}$$
$$S_2 = [b_1, b_2, \dots, b_n] .$$

S_1 is the strategy set for Player 1 and is made up of m strategies. Player 2 has strategy set S_2 composed of n strategies. The rule for the game is that each player has only one move (strategy choice), and the moves must be taken simultaneously or in such a way that neither player knows which strategy choice the other is using. Corresponding to each pair of strategies (one selected by each player), there is a payoff, o_{ij}. All possible pairs of strategies form a matrix of outcomes, (O_{ij}). The O_{ij} $(i = 1, \dots, m \text{ and } j = 1, \dots, n)$ entry in this matrix is the outcome of Player 1 choosing his **ith** strategy and Player 2 choosing his **jth** strategy.

What strategy choice should a player make to achieve the desired game outcome? Game theory does not attempt to say what he should do. It only points out which strategy a player can use to obtain the highest sure return or the lowest sure loss. This is called the "security level." Game theory gives procedures for determining the strategy which obtains the security level. The strategy may be a "pure strategy" requiring the use of only one alternative course of action. A "mixed strategy" calls for using two or more courses of action with given frequencies. This requires repeating the game a large number of times. In some cases, the strategies may not be mutually exclusive, and a mixed strategy may be used in a single game.

Solutions for games with large payoff matrices may be obtained by use of the simplex method. Heady and Candler[5] and others present procedures for converting the game into a linear programming problem to be solved by the simplex method. The simplex procedure is used for solving empirical problems presented in later sections.

Games Against Nature

In this study game theory is applied to "games against nature." The problem visualized in a game against nature has been outlined by Luce and Raiffa[6] as:

> A choice must be made from among acts a_1, a_2, ... a_m but the relative desirability of each act depends upon which "state of nature" prevails, either s_1, s_2, ... s_n.

States of nature may be weather, disease, insects or other natural uncertainties which farmers face. The game against nature differs from true games in that the natural phenomenon is not necessarily a conscious adversary. Nature cannot be said to have specific desires or goals which influence how it plays the game.

Corresponding to each farmer act and state of nature pair there is an outcome, o_{ij}. All possible pairs form a payoff matrix which is the same as that described for true games. The problem is to choose a farmer strategy which will most nearly attain the goals specified for the resources involved. The strategy may be either pure or mixed. The knowledge situation for games against nature is taken to be complete uncertainty as to which state of nature will occur. Several criteria can be suggested for use in resolving the decision problem under uncertainty. Each prescribes an optimal mode of behavior for the decision maker, providing he has the attributes implied by the criterion. The various criteria are used extensively in empirical problems presented later in this study. The criteria are discussed on the following pages with elaboration on the rules for obtaining solutions, the implications of the criteria and the relationship of the criteria to other decision models for imperfect knowledge situations.

WALD MAXIMIN CRITERION

Assume a decision problem under uncertainty with acts $A_1, A_2, \dots A_m$ and states $S_1, S_2, \dots S_n$.

[3] Luce, R. D. and Raiffa, H. Games and decisions: introduction and critical survey. John Wiley and Sons, Inc., New York. 1957.

[4] Heady, Earl O. and Candler, W. V. Linear programming methods. Iowa State University Press, Ames, Iowa. 1958.

[5] Ibid., Ch. 15.

[6] Luce and Raiffa, op. cit., p. 276.

In using the Wald[7] criterion, each act is assigned an index which is its security level. For the following problem, 2 is the security level for A_1 and 1 is the security level for A_2.

$$\begin{array}{c} \\ A_1 \\ A_2 \end{array} \begin{array}{c} \begin{array}{cc} S_1 & S_2 \end{array} \\ \begin{bmatrix} 2 & 3 \\ 4 & 1 \end{bmatrix} \end{array}$$

The Wald criterion rule is to choose the act with the highest index (security level). In the example used, A_1 would be chosen. If a mixed strategy is possible for this example, the security level is 10/4 and the strategy is $(3/4A_1, 1/4A_2)$.[8]

If the A_i are farmer strategies and the S_j are states of nature, the preceding example may be taken as a game in which a farmer is playing against nature. The solution rule corresponds exactly to that for a two-person zero-sum game. It can be shown that the maximin strategy for a two-person zero-sum game is the best strategy against the worst an opponent can do. Nature will not consciously do its worst against the farmer; thus, the Wald criterion is a conservative model for decision-making under uncertainty.

Few farmers believe that nature is trying to do its worst to them. Many farmers, however, may give serious thought to the consequences which could result if the worst possible state of nature were to occur. The characteristics of such farmers are discussed later. It is instructive, however, to mention a few such attributes in this section to show that the Wald criterion may be a useful model for farmer decision-making under uncertainty.

A farmer with severely limiting resources might be forced out of business if a very unfavorable outcome occurs. The payoff which the Wald criterion assures, however, may be sufficient to prevent loss of a magnitude that the farmer cannot continue farming. In this case, the farmer probably would be willing to follow a plan suggested by the Wald criterion. Family responsibilities and dislike for chance-taking also may cause a Wald solution to be preferable.

In a problem requiring choice of alternative crops, a Wald mixed strategy would call for growing several crops to insure the highest security level.[9] This is equivalent to diversification to insure a minimum income level each year. The Wald solution also may call for diversifying practices, such as crop varieties or amounts of fertilizer, rather than using a single variety or fertilization level which might average highest in profit over a series of years. In appropriate problems, the Wald criterion may indicate that a practice such as contracting for purchases or sales allows the highest security level.

SAVAGE REGRET CRITERION

The Savage[10] regret criterion is suggested as a method of analysis for the following decision problem under uncertainty:

$$\begin{array}{c} \\ A_1 \\ A_2 \end{array} \begin{array}{c} \begin{array}{cc} S_1 & S \end{array} \\ \begin{bmatrix} 18 & 21 \\ 17 & 26 \end{bmatrix} \end{array}$$

If S_1 is the true state of nature, the decision maker will have no "regret" if he chooses A_1 but will have regret if he chooses A_2. If S_2 is the true state, he will have regret if he chooses A_1 but will not if he chooses A_2. For this type of problem, we can define a (negative) regret matrix (V_{ij}) by forming the elements:

$$v_{ij} = o_{ij} - \max_{k} o_{kj}$$

That is, form a new matrix (V_{ij}) by subtracting the maximum outcome in each column from each outcome in that column. This matrix, formed by use of the rule and the above example, is as follows:

$$\begin{array}{c} \\ A_1 \\ A_2 \end{array} \begin{array}{c} \begin{array}{cc} S_1 & S_2 \end{array} \\ \begin{bmatrix} 0 & -5 \\ -1 & 0 \end{bmatrix} \end{array}$$

Each entry, v_{ij}, in this matrix measures the difference between the payoff which actually is obtained and the payoff which could have been obtained if the true state of nature had been known. The Wald solution rule is applied to the regret matrix to determine the strategy and the regret security level. For the preceding example, a pure strategy calls for use of A_2, and the security level is 1. If a mixed strategy is allowed, the maximum regret may be reduced to 5/6.

The Savage criterion, like the Hurwicz and Laplace criteria to be discussed, is not entirely suggested by game theory, with which it is associated. Elements of game theory are used only in setting up the problem and in obtaining a solution after the regret matrix is formed. The criterion implies a fundamental assumption about the way individuals plan under uncertainty. It assumes that they actually try to minimize regret. No empirical evidence is available to verify or reject this assumption. Nevertheless, some plans suggested by the

---

[7] Wald, A. Statistical decision functions. John Wiley and Sons, Inc., New York. 1950.

[8] Using the above matrix, a procedure for finding the mixed strategy and the security level L is as follows: Assume that the Ai's are farmer acts and the Sj's are states of nature. The farmer wishes to use a strategy which will assure him at least a gain of L, regardless of the strategy used by nature. Let p be the frequency with which the farmer plays A_1 and (1-p) the frequency with which he plays A_2. If nature plays only S_1, the gain to the farmer is

(a) $2p + 4(1-p)$.

If nature plays only S_2, the gain to the farmer is

(b) $3p + (1-p)$.

Since the farmer wishes to obtain a minimum gain L whether nature plays either S_1 or S_2, we equate (a) and (b) and solve for p. The solution is $p = 3/4$; thus $1-p = 1/4$. The strategy of the farmer is 3/4 A_1 and 1/4 A_2. The security level L may be computed from (a) or (b). From (a) it is $2(3/4) + 4(1/4) = 10/4$. This procedure is practical only in simple games. The principles, however, remain the same when more sophisticated procedures are used.

[9] The security level is the mimimum gain to the farmer (loss to nature). The farmer is assured of this gain even if nature does its worst. If nature does not do its worst, the gain to the farmer may be greater than the security level. The "gain" may be income, yield per acre or pounds per animal, for example.

[10] Savage, L. J. The theory of statistical decision. Jour. Amer. Stat. Assn. 46: 55-57. 1951.

criterion are similar to plans actually followed by farmers.

Examples can be constructed in which farmers would not follow the Savage regret solution. For example, assume that the payoffs in the following example are dollar payoffs above variable costs for alternatives in a farming enterprise.

$$\begin{array}{c} \\ A_1 \\ A_2 \end{array}\begin{array}{cc} S_1 & S_2 \\ \begin{bmatrix} 18 & 21 \\ 17 & 26 \end{bmatrix} \end{array} \longrightarrow \begin{array}{c} \\ A_1 \\ A_2 \end{array}\begin{array}{cc} S_1 & S_2 \\ \begin{bmatrix} 0 & -5 \\ -1 & 0 \end{bmatrix} \end{array}$$

Consider a farmer situation where returns above variable costs must be \$18 or more to pay fixed costs and pay for family living. If these expenses are not paid, the farmer will be in severe difficulty. In such a situation, the possible \$1 regret from choosing A_2 may be more important than the possible \$5 regret from choosing A_1. Thus, the Savage regret criterion would not be appropriate.

Other examples could be constructed where the Savage criterion is quite appropriate. It may give solutions similar to those suggested by a precaution for uncertainty such as insurance. Consider the following insurance problem:

		Barn doesn't burn S_1	Barn does burn S_2			S_1	S_2
Do not insure	A_1	0	–5,000	→	A_1	0	-4,985
Insure	A_2	–15	–15		A_2	–15	0

The minimum payoff in row A_1 of the regret matrix is –4,985 and in row A_2, –15. Thus, the farmer would insure if he follows the Savage regret criterion. Similar examples would show that a Savage solution calls for liquidity and flexibility.

The Savage regret criterion yields a more conservative solution if mixed strategies are allowed. All weight then is not placed on the one highest regret. Some importance is attached to lower possible regret. In the following problem, a strategy of $(1/6A_1, 5/6A_2)$ allows a lower maximum regret and a higher security level in terms of dollar returns than is possible if only A_2 is used.

$$\begin{array}{c} \\ A_1 \\ A_2 \end{array}\begin{array}{cc} S_1 & S_2 \\ \begin{bmatrix} 18 & 21 \\ 17 & 26 \end{bmatrix} \end{array} \longrightarrow \begin{array}{c} \\ A_1 \\ A_2 \end{array}\begin{array}{cc} S_1 & S_2 \\ \begin{bmatrix} 0 & -5 \\ -1 & 0 \end{bmatrix} \end{array}$$

The minimum regret with a mixed strategy is 5/6 compared with a regret of 1 if A_2 is used exclusively. In addition, a payoff level of 17.2, rather than 17, is assured.

HURWICZ CRITERION

The Hurwicz[11] criterion can be used to examine the state of nature having the best consequence and the state having the worst consequence in each row. For act A_i, let m_i be the minimum and M_i the maximum of the outcomes in that row. Let a fixed number, α, $(0 \leqslant \alpha \leqslant 1)$ represent a given individual's pessimism index that the state giving m_i will occur. Let $(1 - \alpha)$ represent his belief that the state giving M_i will occur. An index for each A_i is then computed as follows:

$$\alpha\, m_i + (1 - \alpha)\, M_i = \alpha \text{ index for } A_i\, .$$

The act with the highest α index is the preferred act. It is the strategy chosen by the Hurwicz criterion.

The Hurwicz criterion is an alternative to the more conservative Wald criterion. If $\alpha = 1$, the Hurwicz criterion gives the same solution as the Wald. It places emphasis on both the worst and best consequences which can occur if α is not 0 or 1. The Hurwicz criterion is not as easily applied as the other criteria because the α must be supplied by the decision maker.

The α should not be interpreted as a decision maker's evaluation of the likelihood of various states of nature occurring. Suppose that a farmer has knowledge that S_3, in the following matrix, is likely to occur and that S_2 is unlikely to occur.

$$\begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \end{array}\begin{array}{ccc} S_1 & S_2 & S_3 \\ \begin{bmatrix} 1 & 8 & 0 \\ 1 & 0 & 3 \\ 1 & 0 & 4 \end{bmatrix} \end{array}$$

Assuming $\alpha = 0.3$ for him, he may form the index, (0.3) (0) + (1 – 0.3) 3, for A_2. However, the index for A_1 must be (0.3) (0) + (1 – 0.3) 8. This implies that he is more pessimistic about S_3 occurring than S_2. The α must be independent of states of nature to avoid inconsistency.

Luce and Raiffa[12] suggest a method for deriving α which can be adapted to farm decision-making problems. Suppose this payoff matrix:

$$\begin{array}{c} \\ A_1 \\ A_2 \end{array}\begin{array}{cc} S_1 & S_2 \\ \begin{bmatrix} 0 & 1 \\ x & x \end{bmatrix} \end{array}$$

The α index for A_1 is

$$(0)\ \alpha + 1\ (1 - \alpha) = 1 - \alpha\ .$$

The α index for A_2 is

$$x\ \alpha + x\ (1 - \alpha) = x\ .$$

Luce and Raiffa suggest choosing an x such that A_1 and A_2 are indifferent. The decision maker must specify an x such that $x = 1 - \alpha$. If x, a sure return, must be relatively high, then α will be relatively small. This procedure may indicate a preference for gambling on a higher return. It also may represent the situation of a decision

[11] Hurwicz, L. Optimality criteria for decision making under ignorance. Cowles Commission Discussion Paper, Statistics, No. 350. 1951. (Mimeo.)

[12] Luce and Raiffa, op. cit., pp. 282-283.

maker who must have a high return and who must gamble to "stay in the game." If x is relatively low, the relevant case may be a decision maker who prefers not to gamble. It also may be characteristic of an individual who needs a particular level of return so intensely that he emphasizes it above all else. It has been noted previously that with $\alpha = 1$, the Hurwicz criterion is the same as the Wald pure strategy criterion. This may be interpreted as an extreme case of distaste for gambling or of need for a given level of return. Any of these descriptions of individual psychology or resource situations characterizes some farmers. Thus, the Hurwicz criterion is deemed applicable to farmer problems.

LAPLACE CRITERION

The Laplace[13] criterion is based on the "principle of insufficient reason." In terms of the problem considered here, that principle states that if one is "completely ignorant" as to which state of nature will occur, then one should behave as if all are equally likely. The decision problem under uncertainty is treated essentially as a risk problem with each state being assigned equal probabilities. An expected outcome based on these probabilities is computed for each A_i. The procedure is equivalent to averaging each act across states of nature. The act with the highest average is the strategy chosen by the Laplace criterion.

If enough states of nature are considered, the Laplace criterion is the average "naive" model. Many recommendations made by research and extension workers are based on the average model. Thus, the Laplace criterion is implicitly used in many farming decisions. It is an appropriate model if the decision maker can stay in farming long enough to realize the average expected.

THE FARMER DECISION PROBLEM

The choice models just outlined suggest a number of ways of resolving farming decision problems. Which model should a given farmer select? This question can be answered only after a careful analysis of the setting in which the problem is framed. This section is devoted primarily to further analysis of factors which affect the problem setting.

Analysis of Problem Setting Components

The problem setting for decision-making is provided by these components: (a) the alternative courses of action allowed by a particular farmer's resource situation and known technology, (b) the characteristics of the farmer, including his psychology, family situation and work preference and (c) the knowledge situation with respect to states of nature and other conditions. It is evident that these components are not the same for all farmers.

[13] Thrall, R. M., Coombs, C. H. and Davis, R. L., eds. Decision processes. John Wiley and Sons, Inc., New York 1957.

ALTERNATIVE COURSES OF ACTION AND CHARACTERISTICS OF FARMERS

The alternative courses of action open to a farmer depend on his soil and other physical resources, the amount of capital available to him and his managerial ability in converting these resources into products. These resource situations will differ among farmers. Even for two farmers on the same soil type and faced by the same climatic and natural factors, alternatives in plans can differ depending on the availability of capital and managerial ability. Hence, a common recommendation on resource use or farm practices is not equally applicable to all farmers who are faced with a similar situation with respect to physical resources.

The goal most often attributed to farmers is maximization of returns over a relatively long period of time. This is the goal implied by the average or "naive" model typically used as the basis for recommendations to farmers. But this model is not universally appropriate. Some farmers prefer not to maximize profits, but to consume a part of their resources directly. For example, they may "consume" family labor in the form of leisure or vacations. Farmers who have strong work preferences tend to choose enterprises or practices which involve the tasks they enjoy most. Thus, a farmer may choose dairying even though feeding hogs is more profitable. Some enterprises provide other forms of satisfaction which lead to choice of those enterprises rather than other feasible ones. Thus, decision models designed to maximize money income over time are not appropriate for use of all farmers.

Various psychological traits of farmers also may have considerable influence on decisions. For example, the need for or value placed on financial security is a trait which varies among farmers. This trait affects a farmer's attitude toward chance-taking. Some may enjoy taking chances, and a high-risk enterprise may be selected because of a chance for high profits and for the satisfaction of "playing the game successfully." The psychology of an individual with regard to risk is affected by his age, equity position and family situation. A young farmer may gamble because he has much to gain and few resources to lose. In the event of unfavorable outcomes, his age allows the opportunity to start over in business. A farmer with a large family must provide for their living and often is forced to be conservative. A farmer with a strong equity position can withstand losses in a few years and recover them in other years. He can "take greater chances" than a farmer with a smaller equity ratio who might be forced into bankruptcy with one major setback.

Renters with short-term leases have uncertainty as to how long they will be on the farm. This situation may lead to plans which are not most profitable in the long run. A plan may be followed to assure an acceptable income level each year, rather than an acceptable average income over a period of years. A conservative farmer may follow a plan for his main enterprise which assures a minimum income level each year. He may use a few resources, however, in a risky enterprise because he has little to lose and may make a substantial profit.

A decision required only once or a few times in a lifetime may be made quite differently than one repeated many times. A "one-time" decision is often extremely important. For example, an individual usually purchases a farm only once. Decisions to purchase high-cost machinery or buildings are only made a few times in a lifetime. Some farmers could not base plans on an average expectation if the plans were irrevocable. An unfavorable outcome might force the farmer into severe financial stress or out of business.

We have touched upon only a few of the situations and other attributes which affect the psychology of a farmer in making decisions. The number enumerated is sufficient, however, to indicate that a standard set of recommendations to all farmers, supposing their goal to be profit maximization in the long run, is not equally appropiate or useful to all.

DEGREES OF KNOWLEDGE

Degrees of knowledge relevant in decision-making range from risk through uncertainty. The degree of knowledge varies with enterprises, practices, years, contractual arrangements, locations and the length of time over which decisions must be made. The amount of knowledge possessed by a farmer and the degree of certainty surrounding his predictions will determine the decision-making procedure which is most appropriate. But the degree of knowledge is no less important than the psychology of the farmer in indicating the type of decision model which is most appropriate for the particular situation.

The farmer must predict possible outcomes to make a decision which fits his individual situation and psychological setting. He must predict not only the average outcome but also minimum outcomes, as well as other values of the distribution. The necessity for considering the various possible outcomes (i.e. a probability distribution even though it is held in rough subjective manner) is to estimate the "state of nature" and the "possible strategies which can be used by nature." For example, crop yield data from experiments conducted in different years would be considered outcomes of different states of nature, although they may possibly result from the same course of action (e.g., fertilizers, cultural practices, etc.). The suggested problem formulation indicates that data should reflect the effects of many states of nature.

Once the matrix of outcomes is determined, the farmer may reduce its column magnitude by deciding that his predictive powers are adequate to allow ignoring some possible conditions. That is, he may decide that some states of nature (columns in the payoff matrix) are not important enough to consider. He may be confident enough in his knowledge to attach probabilities to conditions and treat the problem as one of risk. This decision may vary among farmers. It depends on a person's subjective interpretation of the knowledge situation and his ability to withstand the effects of being wrong. Various techniques for handling the set of conditions for particular problems are discussed in later sections.

GAME CRITERIA APPLIED TO AGRICULTURAL DATA

Game theoretical models have been outlined as possible guides for farmer decision-making. Circumstances surrounding the decision-making process of farmers have been reviewed as a basis for indicating that a "standard" recommendation cannot conform equally well to the situation of all farmers. We now turn to applications of game theoretic criteria to choice of various farm practices and resource uses. The objective here is to determine the type of recommendation which may be made to farmers when particular game models are used, to conform with the different degrees of conservatism or risk which farmers with different decision-making environments might employ. The basic data are drawn mainly from experiments conducted over the state by Iowa State University. It is entirely possible that game criteria might be applied to experimental data by research workers before they publish their results and make recommendations to farmers. Under this procedure, alternative recommendations could be made to conform to the decision-making environment of farmers with different situations with respect to capital, equity, aversion to risk or financial responsibilities.

Several typical cropping problems are studied first. The first relates to choice of crop varieties. Next, the problem of choosing the amount and kind of fertilizer to use on a given crop is considered. A problem requiring choice of alternative crops is examined. Finally, problems of pasture mixtures and stocking rates are examined. The problem analysis is designed to achieve several of the objectives of this study: (a) It demonstrates procedures for applying alternative decision models. (b) The analysis provides examples of the kinds of problem solutions that alternative decision models may suggest. Those solutions then may be used to determine the appropriateness of the models to various problem settings. (c) Actual experimental data are used so that the problem solutions obtained may serve for actual recommendations to farmers. They also demonstrate a wider range of possible recommendations than research and extension personnel normally consider. (d) The problem analysis indicates the kinds of data which are needed for decision-making under uncertainty and for application of game theoretic models. It further indicates how data presently available may be adapted to decision-making needs.

CHOICE OF CROP VARIETIES

Farmers must choose crop varieties each production season. Some farmers plant varieties which have had satisfactory yields and have displayed other desirable characteristics in past years. The farmer or his neighbors may have had actual experience with the variety or varieties chosen. Other farmers consult with research and extension personnel and review experiment station and commercial literature before making a choice.

Research and extension specialists spend considerable time and other resources in evaluating crop varieties and presenting variety data and recommendations to farmers. Usually, several varieties are rated as acceptable because their yields, resistance to disease, maturity time, test weight and other characteristics meet certain standards. Other characteristics being equal, varieties which have had the highest average yield over a period of years are usually recommended. Thus, the usual recommendations are based on the Laplace criterion. Previous discussion would suggest that all farmers may not wish to follow plans suggested by this particular criterion.

A variety problem results when one variety does not normally outyield all others every year. The problem may be stated in terms of the general problem formulations presented earlier. Farmer acts or alternatives are the several available varieties. Components of nature—rainfall, insects, disease, temperature—may occur in various combinations to form a state of nature or production condition. Any given year represents such a combination. Thus, each year for which variety data are available represents a state of nature.

Only varieties which are rated as generally acceptable by the Iowa Experiment Station are considered.[14] Characteristics other than yield are partially taken into account. The outcome resulting from a pair of farmer-nature alternatives is measured in bushel yields per acre. All possible pairs of farmer and nature alternatives form a matrix of outcomes. In game theory terminology, the latter is a payoff matrix. Seed costs for various varieties are approximately equal; thus, each of the farmer alternatives requires the same resource input. Therefore, it is appropriate to choose varieties on the basis of bushels produced per acre. The farmer wants to choose varieties which will provide a yield pattern and yield level best suited to his problem setting.

Data used in the variety problems were obtained from annual progress reports on Iowa experimental farms. It is not possible with the data available to determine whether yield differences between varieties in a given year are significant. A 1-bushel yield difference may be shown between two varieties in a given year. That difference may be due to chance alone and not to true differences between the varieties. A refinement of this study might include only varieties which are significantly different in at least 1 year. In years where their yields are statistically equal, equal yields could be used. It can be argued, however, that a difference at a low level of significance should be considered. A farmer may be willing to take advantage of even a 50-percent chance of getting a higher yield from one variety as compared with another, particularly if he has little chance of getting a lower yield.

As previously indicated, each year of yield data is affected by a unique combination of weather, disease and insects. New varieties are continually being developed. Thus, the period of years covered by the variety yield data is relatively short. The newer, superior varieties have been tested for only a few years. The best a farmer can do is use the data he has available in making a choice. Therefore, he has no way of taking account of possible outcomes which could result from other states of nature (years). He can only hope that the relationship between varieties will not change in an unfavorable direction when a different type of year is experienced.

Since one of the objectives of this study is to evaluate the alternative decision criteria, methodological comments are made throughout the following discussion. For the most part, such comments are made at the end of the analysis of each farmer problem. Methodological observations are designed to increase understanding of the decision criteria. They also give further insight into the types of problem solutions which the criteria suggest. Weaknesses of the criteria as decision-making tools are easiest to point out if discussed in connection with the analysis of a particular farmer problem.

CHOICE OF OAT VARIETIES IN NORTHEAST IOWA

Three early maturing, four midseason maturing and one late maturing oat varieties are recommended in Iowa. A farmer may choose from these (i.e., he has eight alternatives). Data are available on four of these varieties grown in Howard County (northeast Iowa) during the period 1953-57. Thus, the farmer knows of five states of nature and has four alternative acts. Table 1 shows the farmer-nature payoff matrix for the northeast Iowa oat variety decision problem. Table 2 shows the Savage regret matrix for the same problem. The Savage regret matrix was obtained by subtracting the highest yield under each year

TABLE 1. FARMER-NATURE PAYOFF MATRIX FOR THE HOWARD COUNTY (NORTHEAST IOWA) OAT VARIETY PROBLEM.[a]

Farmer alternatives (variety)	States of nature (years) 1953 bu./a.	1954 bu./a.	1955 bu./a.	1956 bu./a.	1957 bu./a.
Bonham	46	66	60	110	96
Clintland	49	62	57	97	104
Clarion	45	74	78	111	89
Sauk	61	84	87	0[b]	100

[a] Source of data: Iowa State University. Howard County Experimental Farm. Annual progress report, 1951 through 1957. (Mimeo.) Department of Agronomy, Iowa State University, Ames, Iowa. 1952 through 1958.

[b] Sauk was hailed out in 1956. It might be argued that it is incorrect to count this as a zero yield in comparing this variety with others. However, Sauk is a late-maturing variety and thus is uniquely subjected to hail hazard after the other varieties have already been harvested. Some farmers may exclude hail from consideration as a possible component of states of nature. They may think that hail is too improbable for concern. They must be prepared, however, to accept the consequences of hail if it occurs.

[14] Johnson, I. J. and Bragonier, W. H. Crop varieties for 1958. Iowa Farm Science 12: 13-16. January 1958.

TABLE 2. SAVAGE REGRET MATRIX FOR HOWARD COUNTY (NORTHEAST IOWA) OAT VARIETY PROBLEM.

Farmer alternatives (variety)	States of nature (years) 1953 bu./a.	1954 bu./a.	1955 bu./a.	1956 bu./a.	1957 bu./a.
Bonham	–15	–18	–27	–1	–8
Clintland	–12	–22	–30	–14	0
Clarion	–16	–10	–9	0	–15
Sauk	0	0	0	–111	–4

from each other yield in that same year. All outcomes are in bushels per acre.

Table 3 indicates the strategies (varieties) which result from application of the game theoretic decision models. The average model is replaced by the Laplace criterion in this example. A probability model cannot be used because frequency data for different types of years are not available. The Wald solution, a mixed strategy, was obtained by converting the game against nature into a linear programming problem. It was then solved by the simplex method. According to the assumptions of game theory, nature would never use its 1954, 1955 and 1957 strategies.[15] Yields of every variety were higher in those years than for 1953 and 1956. Thus, assuming that nature is trying to do its worst to the farmer, it would only use its 1953 and 1956 strategies. This assumption must be made to use the Wald criterion. Thus, the size of the game matrix is reduced when the Wald criterion is considered.

The Savage regret solution also calls for a mixed strategy. This solution was obtained by use of the simplex method. All entries were made greater than or equal to zero by adding a constant. This step was necessary to use the most convenient simplex techniques. The solution is not affected by adding a constant, providing the same constant is subtracted from the final minimum regret solution.

[15] This characteristic of many farmer-nature game matrices is discussed later in this section.

The Laplace solution simply indicates the variety that has the highest average. The Hurwicz solution was obtained by forming the optimism-pessimism index discussed in a previous section. Then the resulting equations were solved to determine the range of α over which various varieties are optimum. It should be noted that a different variety is selected for each range of α.

Table 3 also contains four indications of the outcomes which may result from following various strategies. These tend to answer common questions a decision-maker may ask about a course of action. For example, he may ask, "What is the worst and best that can happen?" or "What average outcome might be expected if I follow this course of action over a long period?" The column in table 3 labeled minimum (Min.) shows the worst that can happen. In the case of the Wald criterion, it is the security level derived from the game solution. For pure strategies, it is the worst outcome for a given variety. For the Savage regret criterion, it is the lowest weighted outcome of the given strategy in any year. The maximum column (Max.) is derived in the same manner, except that the best outcomes are considered.

The column labeled average (Av.) is simply the average outcome for each of the four strategies. If each state of nature is equally likely to occur, then over a long period of years the farmer could expect to receive that average yield. If less favorable years are more likely than the better years, then the long-run expectations would be lower. Assuming complete uncertainty, neither of these possibilities can really be verified or rejected. Some farmers, however, may want to consider this long-run average when making a decision.

The regret column is included primarily to aid in demonstrating the characteristics of various solutions. Nevertheless, a farmer who really wants to minimize regret would be interested in

TABLE 3. STRATEGIES AND POSSIBLE OUTCOMES SUGGESTED BY FOUR DECISION MODELS APPLIED TO THE HOWARD COUNTY (NORTHEAST IOWA) OAT-VARIETY PROBLEM.

Decision model: Criterion[a]	Type of strategy[b]	Strategy: Variety[c]	Percent of land[d]	Possible outcome: Min.[e] bu./a.	Av.[f] bu./a.	Max.[g] bu./a.	Max. regret[h] bu./a.
Wald	Mixed	Clintland	56				
		Sauk	44				
			100	54.3	70.5	103.2	56.68
Laplace	Pure	Clarion	100	45 0	79.4	111.0	16.0
Savage regret	Mixed	Clintland	25				
		Clarion	66				
		Sauk	9				
			100	48.0	75.0	97.5	13.44
Hurwicz[i]	Pure						
$0 \leq \alpha \leq 0.5$		Clarion	100	45.0	79.4	111.0	16.0
$0.5 \leq \alpha \leq 0.66$		Bonham	100	46.0	75.6	110.0	27.0
$0.66 \leq \alpha \leq 1$		Clintland	100	49.0	73.8	104.0	30.0

[a] This column gives the decision models used to solve the farmer decision problem.
[b] This column indicates whether the farmer is to use one single course of action or several.
[c] Variety choices resulting from application of alternative decision models.
[d] The percentage of land to be used for each alternative comprising the farmer's strategy.
[e] The worst outcome which can result from following a given strategy.
[f] The long-run average outcome expected, assuming that the states of nature considered include all possible states of nature and that each "state" is equally likely.
[g] The highest outcome possible from following the given strategy.
[h] The maximum outcome foregone as a result of choosing a less profitable alternative, viewed ex post.
[i] The α value reflects the decision-maker's degree of belief that the worst possible outcome will occur for any act (e.g., oat variety) he selects. The strategy for the individual who expects the worst to happen ($\alpha = 1$) is the act containing the highest minimum gain and may be found by the Wald solution described in the text. The strategy for the individual who expects the highest possible income ($\alpha = 0$) for any act he selects is simply the act containing the highest outcome of all acts. Other strategies are specified for individuals with degrees of pessimism between these extremes (i.e., $0 < \alpha < 1$). These strategies are found by weighting the lowest and highest outcomes in each act by the α value as described in the text.

that column. A farmer who does not wish to forego an opportunity for very high yields would at least take note of that column.

APPROPRIATENESS OF THE CRITERIA

One problem setting, which discussion in a previous section indicated should be considered, was a situation in which a farmer wishes to maximize long-run profit. It should be recalled that he must be able and willing to accept short-run unfavorable outcomes. The strategy suggested by the Laplace criterion has the highest average of any alternative.[16] The strategy is to use Clarion oats on all acres. Although yields in some years may be 45 bushels per acre, yields may be 111 bushels per acre in other years. The farmer using the strategy must be confident that the distribution of years which he faces will not result in some other strategy having a higher average over the long run. Clarion oats average about 4 bushels per acre above other varieties; thus, each year does not have to occur exactly the same number of times.

The second problem setting is one in which a farmer must consider short-run outcomes. The setting essentially implies that, for some reason, the farmer must have an outcome above a given level or must have the maximum certain outcome possible. It would only apply to the variety problem if the consequences of yields falling below a minimum income level are very severe. This might be the case where a crop provides the major source of income or where the grain is needed for an inflexible livestock system.

The Wald solution suggests planting 56 percent of oat land to Clintland and 44 percent to Sauk.[17] Using this strategy, a yield of 54.3 bushels per acre would be assured every year.[18] That is the best strategy against the worst that nature can do. Nature's best strategy (worst for the farmer) is to use its 1953 strategy 89 percent of the time and its 1956 strategy 11 percent of the time. The security level of 54.3 bushels is 5 bushels higher than that of the next best strategy. A farmer following this plan would sacrifice in terms of average and maximum possibilities. His regret in some years would be 56.7 bushels. That is, he would find that in some years another plan would have given him an additional 56.7 bushels per acre.

Farmers with problem settings between the two just specified might find another plan more desirable. One farmer might be willing to accept a lower security level to get a higher possible average. The Hurwicz criterion with $0.66 \leqslant \alpha \leqslant 1$ provides such a plan. As α becomes smaller, the security level decreases, and averages increase. Other farmers might follow a plan suggested by the Hurwicz criterion with a smaller α. A farmer who wishes to minimize regret would use Clintland on 25 percent of his oat land, Clarion on 66 percent and Sauk on 9 percent.

Farmers and researchers will be interested in the solutions with regard to the maturity time of the varieties they suggest. The Wald mixed strategy calls for using Clintland, a midseason variety, and Sauk, a late season variety. Thus, a conservative farmer apparently would plant varieties with these two maturity times. A farmer who wants a higher average would plant Clarion, a midseason variety. The Savage regret criterion says to use two midseason varieties and one late variety. The gambling strategy, the Hurwicz criterion with $0 \leqslant \alpha \leqslant 0.5$, calls for using Clarion, also. Only the Hurwicz solution with $0.5 \leqslant \alpha \leqslant 0.66$ says to use the early variety, Bonham. Thus, most of the criteria agree that late or midseason varieties are preferable.

METHODOLOGICAL COMMENTS

The farmer problem represented by table 1 has a characteristic which is quite common to agricultural data. It was pointed out previously that, according to the assumptions of game theory, nature would never use its 1954, 1955 and 1957 strategies. That is, it is assumed that nature is trying to do its worst to the farmer. Thus, it would not use strategies which have a higher payoff for each farmer alternative than another strategy. When the Wald solution is obtained, these years must be excluded from the payoff matrix. Thus, the Wald solution is extremely pessimistic. Nature, however, is not necessarily trying to do its worst to the farmer. Nevertheless, such pessimism may be necessary under certain problem settings.

The regret matrix does not show the characteristic just pointed out. It is unlikely that the regrets for one year will all be less than those for another, so that nature has an inferior strategy. One alternative often yields highest for one state of nature, and another yields highest for a different state of nature. Therefore, a mixed strategy is obtained more often from the Savage regret criterion than from the Wald criterion.

The Savage regret solution for the Howard County oat variety problem has a relatively high security level and average return, but it has the lowest maximum. It actually gives a plan with less yield variation than other plans. Few farmers are likely to select a plan because it has the least variation. They may prefer a plan with great variation, providing the variation arises from extremely high yields rather than extremely low ones. The Savage regret solution for this problem resulted from the nature of the data and the objective implied by the Savage regret criterion. The criterion seeks to minimize regret, thus the solution is affected by the fact that Sauk oats outyield other varieties in all but 2 years. In one of those years, Sauk had the lowest yield, zero bushels . Thus, Sauk is brought into the plan, but at a low level. Clintland and Clarion are in the plan

[16] It is the same as the strategy for the Hurwicz criterion, $0 \leq \alpha \leq 0.5$.

[17] All problems considered in this dissertation have alternative courses of action which are not mutually exclusive. Thus, a mixed strategy will always call for using several courses of action simultaneously. For example, several oat varieties may be used in one year by planting x percent of the land to one variety and perhaps (100 – x) percent of the land to another variety. The strategy-possible outcome table for each problem gives the precentage of the relevant resource (i.e., land, T.D.N., pasture, etc.) to be used for each course of action comprising a strategy.

[18] It is assumed that all possible years are included in the states of nature considered.

because they each had highest yields in one year and relatively low regrets in other years.

CHOICE OF OAT VARIETIES IN SOUTHERN IOWA AND WESTERN IOWA

Applications of game criteria to oat yield data are presented in this section for the Seymour-Shelby soil association area (southern Iowa) and for western Iowa. Data were obtained from progress reports from the Seymour-Shelby Experimental Farm and the Western Iowa Experimental Farm.

Tables A-1 and A-2 of the appendix contain the farmer-nature payoff matrices for these two areas. These tables correspond to table 1. Six oat varieties are included in table A-1 to demonstrate how inferior farmer alternatives may be eliminated. A comparison of yields in table A-1 shows that Clintland outyielded Bonham in each of the 4 years covered by the data. Thus, Bonham is an inferior strategy. Clintland oats also dominate Clinton in each year. Therefore, Clinton is eliminated as a farmer alternative.

Tables A-3 and A-4 in the appendix show the regret matrices for these problems. Those tables correspond to table 2. Bonham and Clinton are again inferior varieties. The regret for Clintland in each year is less than the regret for either of those two varieties.

Tables 4 and 5 show the strategies and possible outcomes suggested by the game theoretic criteria for southern and western Iowa. Appropriate plans for different problem settings can be obtained from tables 4 and 5. The same criteria discussed in the Howard County section are appropriate for these areas. Plans suited to different problem settings are summarized in table 6.

TABLE 4. STRATEGIES AND POSSIBLE OUTCOMES SUGGESTED BY FOUR DECISION MODELS APPLIED TO THE SEYMOUR-SHELBY (SOUTHERN IOWA) OAT-VARIETY PROBLEM.[a]

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Variety	Percent of land	Min. bu./a.	Av. bu./a.	Max. bu./a.	Max. regret bu./a.
Wald	Pure	Sauk	100	52	84.0	133	29
Laplace	Pure	Clintland	100	44	86.2	121	13
Savage	Mixed	Clintland	69				
		Sauk	31				
			100	46.5	85.5	124	9
Hurwicz	Pure						
$0 \leq \alpha \leq 1$		Sauk	100	52	84.0	133	29

[a] See the footnotes of table 3 for an explanation of this table.

TABLE 5. STRATEGIES AND POSSIBLE OUTCOMES SUGGESTED BY FOUR DECISION MODELS APPLIED TO WESTERN IOWA OAT-VARIETY PROBLEM.[a]

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Variety	Percent of land	Min. bu./a.	Av. bu./a.	Max. bu./a.	Max. regret bu./a.
Wald	Pure	Cherokee	100	25	57.8	100	26
Laplace	Pure	Sauk	100	14	66.0	100	11
Savage	Mixed	Cherokee	28				
		Clintland	20				
		Clarion	1				
		Sauk	51				
			100	17.5	62.0	99.8	7.5
Hurwicz	Pure						
$0 \leq \alpha \leq 0.7$		Clintland	100	16	66	121	11
$0.7 \leq \alpha \leq 1$		Cherokee	100	25	57.8	100	26

[a] See the footnotes of table 3 for an explanation of this table.

TABLE 6. ALTERNATIVE RESEARCH OR EXTENSION RECOMMENDATIONS FOR OAT VARIETIES IN THREE AREAS OF IOWA.

Problem setting	Northern Iowa		Southern Iowa		Western Iowa	
	Variety choice	Percent of land	Variety choice	Percent of land	Variety choice	Percent of land
1. The farmer can follow a plan which may lead to highest long-run profits.	Clarion	100	Clintland	100	Sauk	100
1a. The farmer wants to gamble for the highest yield possible. He is in a position to accept the consequences of unfavorable outcomes.	Clarion	100	Sauk	100	Clintland	100
2. The farmer must consider short-run outcomes. He must have assurance of a maximum minimum income or more each year.	Clintland Sauk	56 44 100	Sauk	100	Cherokee	100
2a. The farmer must consider short-run outcomes, but can give some weight to long-run profit advantages of a plan.	Clintland Clarion Sauk or Clintland	25 66 9 100 100	Clintland Sauk or Sauk	69 31 100 100	Cherokee Clintland Clarion Sauk	28 20 1 51 100

ALTERNATIVE RESEARCH AND EXTENSION RECOMMENDATIONS

Four problem settings are visualized in table 6; 1a and 2a are actually less strict statements of settings 1 and 2, respectively. The Laplace criterion solution is used as the recommendation for problem setting 1. The Hurwicz solution with the smallest range of $\propto$ gives the plan for setting 1a. The Wald criterion yields the plan for setting 2. The Savage regret mixed strategy is the plan suggested for setting 2a. In two areas, the Hurwicz criterion with a large $\propto$ is also deemed applicable for problem setting 2a. It gives a higher security level, but a lower average, than the Savage regret criterion. It is clear that all farmers would not wish to follow the Laplace-type recommendation usually made.

The maturity times of the recommended varieties differ between areas. For problem setting 1, midseason varieties are recommended in northern and southern Iowa, and a late variety is suggested for western Iowa. Setting 1a, the gambling setting, calls for a midseason variety in northern Iowa and a late variety in the west and south. The conservative farmer, characterized by problem setting 2, would use a mixture of midseason and late varieties in the north, late in the south and early in western Iowa. For setting 2a, only farmers in western Iowa would include an early variety in their plans.

CHOICE OF BARLEY VARIETIES IN WESTERN IOWA

Farmers with opposite kinds of problem settings need not always have completely different plans. To demonstrate this, barley yields from western Iowa are considered. Two barley varieties, Plains and Mars, outyielded other varieties each year during the period 1953 through 1957. Thus, it is assumed that these two varieties are the farmer's only relevant alternatives. Tables A-5 and A-6 contain the payoff and regret matrices for this problem. The farmer has two alternatives, and nature has five.

Table 7 shows the strategies and outcomes for the game theoretic decision criteria. A farmer can obtain the highest long-run average by planting Plains barley. The farmer wishing the highest possible security level would also plant Plains. Even if a farmer wants to minimize regret, he would plant mostly Plains. The addition of the Mars variety to his plan reduces his security level only slightly. The only farmer who would plant Mars exclusively is one who wants to gamble on the highest yield possible.

The situation just described is significant because it allows a research or extension worker to make simple recommendations with confidence. Assuming that the varieties are equal in other respects, Plains barley could be generally recommended for western Iowa. The researcher might also mention that Mars may outyield Plains in a few years so that the individual operator can consider the alternative of gambling on a maximum yield.

CHOICE OF CORN VARIETIES

Data for this section were obtained from annual Iowa corn yield tests.[19] One set of yields comes from northeast Iowa, Iowa Corn Test Area 3. The other comes from southern Iowa, Iowa Corn Test Area 11. Varieties adapted to the two areas are different because of difference in growing seasons. Varieties were selected which had relatively high yields, in comparison with other varieties tested,

[19] Iowa corn yield test, 1951 through 1957. Iowa Agr. and Home Econ. Exp. Sta. and Coop. Ext. Serv. Bulletins P-112, 115, 116, 118, 120, 123 and 124. 1952 through 1958.

TABLE 7. STRATEGIES AND POSSIBLE OUTCOMES SUGGESTED BY DECISION CRITERIA APPLIED TO WESTERN IOWA BARLEY-VARIETY PROBLEM.[a]

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Variety	Percent of land	Min. bu./a.	Av. bu./a.	Max. bu./a.	Max. regret bu./a.
Wald	Pure	Plains	100	21	48	62	6
Laplace	Pure	Plains	100	21	48	62	6
Savage regret	Mixed	Plains	70				
		Mars	30				
			100	20	47	64	4.2
Hurwicz	Pure						
$0 \leq \alpha \leq 0.54$		Mars	100	16	43	68	14
$0.54 \leq \alpha \leq 1$		Plains	100	21	48	62	6

[a] See the footnotes of table 3 for an explanation of this table.

over several years of testing. Differences in performances of the varieties considered are rather small and perhaps not significant. Even small differences may be important to some farmers, however.

Northeast Iowa. Table A-7 in the appendix contains the farmer-nature payoff matrix for northeast Iowa corn-variety yields. Every variety had a lower yield in 1955 than for any other year. It must be assumed that nature would always use its 1955 strategy, thus no Wald mixed strategy can be obtained. Table A-8 shows the regret matrix for this problem. A Savage mixed strategy can be obtained.

Table 8 shows strategies and outcomes suggested by four decision criteria. A farmer wanting a maximum long-run average yield should use P.A.G. 277. His yields may be 86 bushels per acre in some years and 129 bushels per acre in other years. Over the long run, his average yields should be almost 1 bushel per acre higher than from any other single variety. The most this plan can cost him in terms of opportunity missed (regret) is 8 bushels per acre.

On the basis of the data, a farmer who wants to be sure of the highest possible yield every year should plant Pioneer 371. His security level with that variety is 93 bushels per acre. He must, however, accept a lower long-run expectation. In some years, his regret may be 12 bushels per acre.

From a practical point of view, the Savage regret criterion suggests a desirable plan. It provides a higher security level than the Laplace plan; however, the average is only slightly lower. A farmer following this plan would, of course, be certain that he would never sacrifice more than 4.8 bushels because of choosing the wrong plan.

Southern Iowa. Table A-9 in the appendix shows the farmer-nature payoff matrix for southern Iowa variety yields. In this case, only 1952, 1953, 1956 and 1957 are inferior strategies for nature. However, the Wald solution calls for a pure

TABLE 8. STRATEGIES AND OUTCOMES SUGGESTED BY DECISION CRITERIA APPLIED TO NORTHEAST IOWA CORN-VARIETY PROBLEM.[a]

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Variety	Percent of land	Min. bu./a.	Av. bu./a.	Max. bu./a.	Max. regret bu./a.
Wald	Pure	Pioneer 371	100	93	111.4	122	12
Laplace	Pure	P.A.G. 277	100	86	112.2	129	8
Savage regret	Mixed	Pioneer 347	8				
		Pioneer 371	26				
		Pioneer 352	21				
		P.A.G. 277	45				
			100	88	111.7	124.1	4.8
Hurwicz	Pure						
$0 \leq \alpha \leq 0.5$		P.A.G. 277	100	86	112.2	129	8
$0.5 \leq \alpha \leq 1$		Pioneer 371	100	93	111.4	122	12

[a] See the footnotes of table 3 for an explanation of this table.

strategy because Pioneer 301b has its minimum yield in 1955, and that yield is also the maximum yield of any variety for that year. That is, the minimum in a row is also the maximum in a column. Table A-10 in the appendix contains the regret matrix for this problem. A mixed strategy can be obtained from this matrix.

Table 9 shows that Pioneer 301b will fulfill farmer requirements in both of the problem settings considered in this section. It not only has the highest security level but also has the highest average. The farmer who wants to gamble on the highest possible yield would use P.A.G. 170. The Savage solution requires only a small sacrifice in security level and average to follow a plan which provides the least possible regret.

Choice of Fertilizer Combinations and Amounts

Two fertilizer problems are considered in this section. The first requires choice of nutrient combinations and levels of fertilizer for producing corn. The second is a composite problem requiring choice of varieties, stand level and amount of nitrogen fertilizer for producing corn. The analysis for both of these problems demonstrates that data available from present experiments may be adapted for use with various decision models.

CHOICE OF MANURE, PHOSPHORUS AND POTASSIUM LEVELS

Northeast Iowa. Data for solving this problem were obtained from experimental results at the Howard County Experimental Farm and the Carrington-Clyde Experimental Farm. The Howard County data are considered first. The data are from manure-phosphorus-potassium experiments conducted from 1952 through 1957. The experiment actually included a 3-year corn-oats-meadow rotation, but only the corn data are considered in this problem. The aggregate yields of all crops in the rotation could have been considered. Because only corn is studied, the carryover effects of fertilizer on other crops are not credited to returns from fertilizer.

The experiment provides data which might be considered as eight farmer alternatives. These include no fertilizer (Ck.), manure only (M), phosphorus only (P), potassium only (K), phosphorus and potassium (PK), manure and phosphorus (MP), manure and potassium (MK), and manure, phosphorus and potassium (MPK). Manure was applied at the rate of 6 tons per acre, ahead of corn in the rotation. Phosphorus and potassium were both applied at the rate of 30 lbs. per acre.

It is assumed that these are all the alternatives about which the farmer has knowledge. Actually, he might include other levels or combinations of fertilizer as alternatives. Table A-11 in the appendix shows the farmer-nature fertilizer game when manure is free. The farmer has eight alternative strategies, and nature has six strategies. Each year is regarded as a state of nature. Table A-12 in the appendix shows the regret matrix for this problem.

Payoffs are returns above fertilizer costs and cost of application.[20] A constant, equal to the value of production in the lowest year for corn not fertilized, is subtracted from each payoff to reduce the size of the payoffs. Table A-11 is the payoff matrix for a situation in which a farmer has manure available and need only charge for applying it. It is assumed that he has no alternative use for the manure or that it is most profitably used on corn. Table A-13 shows the payoff

[20] A detailed description of the manner in which payoffs were computed is contained in a footnote of table A-11.

TABLE 9. STRATEGIES AND OUTCOMES SUGGESTED BY DECISION CRITERIA APPLIED TO SOUTHERN IOWA CORN-VARIETY PROBLEM.[a]

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Variety	Percent of land	Min. bu./a.	Av. bu./a.	Max. bu./a.	Max. regret bu./a.
Wald	Pure	Pioneer 301b	100	78	98.7	118	8
Laplace	Pure	Pioneer 301b	100	78	98.7	118	8
Savage regret	Mixed	Pioneer 301b	43				
		P.A.G. 170	34				
		Maygold 47	5				
		Iowa 4565	18				
			100	76.1	97.1	117.8	5.6
Hurwicz	Pure						
$0 \leq \alpha \leq 0.5$		P.A.G. 170	100	75	97.2	121	10
$0.5 \leq \alpha \leq 1$		Pioneer 301b	100	78	98.7	118	8

[a] See the footnotes of table 3 for an explanation of this table.

matrix for this fertilizer problem when manure is not free. A ton of manure is roughly equivalent to 100 pounds of 10-5-10 fertilizer. Thus, rather than apply manure, the farmer can use 600 pounds of 10-5-10. The cost of fertilizer to replace manure is subtracted from payoffs in table A-13. The Savage regret matrix for this problem is contained in table A-14 of the appendix.

The strategies and outcomes suggested by the four-game theoretic decision criteria are shown in tables 10 and 11. A farmer whose planning horizon and resource situation allow him to plan over the long run would use manure and phosphorus on corn. This is the plan given by the Laplace solution. Even though he must buy fertilizer to substitute for manure, he should follow the same plan. This plan also indicates the amount of fertilizer which apparently is most profitable over the long run. The level is roughly 60 pounds of nitrogen, 60 pounds of phosphorus and 60 pounds of potassium. It is assumed that all possible kinds of weather years, with prices constant, are represented in the data available. Thus, caution should be taken in making such a recommendation. The need for data from longer term experiments is made clear in this example.

The farmer who must be sure of the highest possible level of returns each year will use only manure, providing it is free. If he must buy substitutes for manure, he will use phosphorus and

TABLE 10. STRATEGIES AND OUTCOMES SUGGESTED BY FOUR DECISION CRITERIA APPLIED TO HOWARD COUNTY FERTILIZER PROBLEM (NO CHARGE FOR MANURE).[a]

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Alternative	Percent of land	Min. $/a.	Av. $/a.	Max. $/a.	Max. regret $/a.
Wald	Pure	M	100	14.80	37.93	53.74	11.76
Laplace	Pure	MP	100	10.98	38.46	64.84	5.43
Savage regret	Mixed	M	31				
		MP	65				
		MK	4				
			100	12.11	38.00	49.40	4.07
Hurwicz	Pure						
$0 \leq \alpha \leq 0.74$		MP	100	10.98	38.46	64.84	5.43
$0.74 \leq \alpha \leq 1$		M	100	14.80	37.93	53.74	11.76

[a] See the footnotes of table 3 for an explanation of this table.

TABLE 11. STRATEGIES AND OUTCOMES SUGGESTED BY FOUR DECISION CRITERIA APPLIED TO HOWARD COUNTY FERTILIZER PROBLEM (CHARGE FOR MANURE EQUIVALENT).[a]

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Alternative	Percent of land	Min. $/a.	Av. $/a.	Max. $/a.	Max. regret $/a.
Wald	Mixed	PK	77				
		MP	23				
			100	6.77	25.04	37.77	13.87
Laplace	Pure	MP	100	-2.22	25.26	51.64	11.62
Savage regret	Mixed	PK	39				
		MP	61				
			100	1.54	25.15	44.61	7.06
Hurwicz	Pure						
$0 \leq \alpha \leq 0.68$		MP	100	-2.22	25.26	51.64	11.62
$0.68 \leq \alpha \leq 1$		PK	100	5.70	24.98	35.34	18.01

[a] See the footnotes of table 3 for an explanation of this table.

potassium on 77 percent of his land and manure and phosphorus on 23 percent. These plans differ from the long-run profit-maximizing plan in both the level and the kind of fertilizer used. The manure plan includes only 60-30-60, and the PK plan only 0-30-30, as compared with the 60-60-60 plan for the other problem setting. The reason for the plan differences may be seen by reference to table A-13. Additional nitrogen and phosphorus do not result in higher profit in some years. Where manure is not free, the farmer may raise his security level $9 by using less fertilizer. He sacrifices very little in possible long-run average. Thus, even a farmer who can plan to maximize long-run profits might prefer the Wald mixed strategy.

The Savage regret strategy provides a plan which combines characteristics of both the Wald and Laplace plans. Its security level, particularly when manure is free, is not much less than that of the Wald solution. The average for the Savage regret plan is within a few cents of that of the Laplace. In addition, the Savage plan will more nearly be the most profitable one in many years because the maximum regret is considerably lower than the possible regret for other plans. The Hurwicz solution for this problem is very similar or identical to those of other criteria.

Northeast Central Iowa. Tables A-15 and A-17 in the appendix contain the farmer-nature payoff

TABLE 12. STRATEGIES AND OUTCOMES SUGGESTED BY FOUR DECISION CRITERIA APPLIED TO CARRINGTON-CLYDE FERTILIZER PROBLEM (NO CHARGE FOR MANURE).[a]

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Alternative	Percent of land	Min. $/a.	Av. $/a.	Max. $/a.	Max. regret $/a.
Wald	Pure	MP	100	23.80	49.24	72.44	4.58
Laplace	Pure	MP	100	23.80	49.24	72.44	4.58
Savage regret	Mixed	M	32				
		MP	68				
			100	21.80	48.84	69.63	3.10
Hurwicz	Pure						
$0 \leq \alpha \leq 1$		MP	100	23.80	49.24	72.44	4.58

[a] See the footnotes of table 3 for an explanation of this table.

TABLE 13. STRATEGIES AND OUTCOMES SUGGESTED BY FOUR DECISION CRITERIA APPLIED TO CARRINGTON-CLYDE FERTILIZER PROBLEM (CHARGE FOR MANURE EQUIVALENT).[a]

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Alternative	Percent of land	Min. $/a.	Av. $/a.	Max. $/a.	Max. regret $/a.
Wald	Pure	PK	100	12.84	33.62	61.28	16.60
Laplace	Pure	MP	100	10.60	36.05	59.24	5.46
Savage regret	Mixed	M	32				
		PK	18				
		MP	50				
			100	9.00	35.21	57.42	3.86
Hurwicz	Pure						
$0 \leq \alpha \leq 1$		MP	100	12.84	33.62	61.28	16.60

[a] See the footnotes of table 3 for an explanation of this table.

matrices for corn production in the Carrington-Clyde soil area. Tables A-16 and A-18 in the appendix contain the regret matrices for this problem. Tables 12 and 13 show strategies and possible outcomes for farmers who have manure and for those who must buy a manure substitute.

If a farmer wants to maximize long-run profit, he might always apply MP. When manure is free, MP also provides the highest security level. If the farmer must buy a manure substitute, however, PK provides the highest security level. In that case, a farmer would use no nitrogen, and P_2O_5 and K_2O applications would be cut in half. He can raise his security level $2.24 by using a lower level of fertilizer. Evidently, very little additional returns are obtained from nitrogen and heavy amounts of P_2O_5 and K_2O in some years. This may be verified by reference to table A-17.

To minimize regret when manure is free, a farmer must accept a lower security level and average return. If manure substitutes must be purchased, the Savage regret solution results in a lower security level than all other plans. It has a higher average than the Wald plan, however. It seems unlikely that a farmer would follow such a plan unless he does wish to minimize regret.

Choice of Variety, Fertilizer Level and Stand Level

Each crop enterprise requires a number of individual decisions. A farmer must choose varieties, fertilizers and cultural practices. There are a number of possible choices within each decision category. The outcome of each often is affected by the same states of nature. The outcome of each possible choice also is affected by decisions on other aspects of the crop enterprise. All combinations of one variety alternative, one fertilizer alternative and one cultural practice alternative form a set of farmer courses of action. The possible states of nature form nature's strategies. Thus, a problem is formed which is appropriate for game theoretic analysis. A farmer problem of this type is considered in this section.

Data for this problem were obtained from a planting rate and nitrogen experiment conducted at the Seymour-Shelby Experimental Farm in southern Iowa. Two varieties, four stand levels and three nitrogen levels were included in the experiment. Only replication averages are used in the analysis. The following regression equation was fitted to the data for each variety:

$$Y = a + b_1x_1 + b_2x_1^2 + b_3x_3 + b_4x_3^2 + b_5x_1x_2 + b_6x_1x_2x_3 \quad (1)$$

where Y = predicted yield;
x_1 = nitrogen level;
x_2 = stand level; and
x_3 = a rainfall variable.

Table A-19 of the appendix contains the experimental data and the regression equation fitted. Also, each of the variables included in equation 1 is explained in table A-19. The equation was fitted so that levels of the variables could be selected, rather than being limited to the levels involved in the experiment.

Table A-20 of the appendix shows a payoff matrix constructed by use of equation 1. Nitrogen levels of 0, 10, 20, 40 and 60 pounds per acre were used. Stand levels of 12,000, 16,000 and 20,000 were included. Rainfall amounts used were 6, 8, 10 and 12 inches. The two alternative varieties—an early one and an adapted one—also are included. Only farmer alternatives which are not inferior to another alternative at all rainfall levels are included in table A-20. It will be noted that nature has only one noninferior strategy. Thus, the Wald solution must be a pure strategy. Table A-21 of the appendix shows the Savage regret matrix for this problem. Only noninferior nature strategies are included. The 5 years during which the experiment was conducted were not favorable for using high nitrogen and stand levels. Thus, the results shown discourage use of high levels of fertilizer and stand. The rainfall variable used only partially relates yields to weather conditions. Rainfall timeliness, temperatures and maturing conditions are also important. These were generally unfavorable during the period 1953 through 1957. Results for the experiment in 1958 show a much higher yield increase from nitrogen and stand.

The regression equation allows use of two other decision models discussed earlier. These are the average and the probability (risk) approaches. An average weather condition can be estimated and substituted in equation 1. Then, marginal analysis may be used to determine the most profitable long-run alternatives. Probabilities of various levels of rainfall for use in the probability (risk) model may be estimated by use of past weather records. These probabilities may then be used to estimate the long-run average outcome for each alternative. The one with the highest average is the alternative selected.

Only the probability approach is used here. Use of an average would give similar results to that of the Laplace criterion. The problem of selecting discrete levels is similar to the one of specifying activities for linear programming analysis.[21]

Weather records for the period 1925 through 1957 were examined to determine the frequency with which various rainfall levels occurred. The following frequencies for the rainfall variable used in this analysis were found: rainfall $\leqslant$ 7 inches, 0.06; 7 inches $\leqslant$ rainfall $\leqslant$ 9 inches, 0.1; 9 inches $\leqslant$ rainfall $\leqslant$ 11 inches, 0.13; and rainfall $\geqslant$ 11 inches, 0.71. These frequencies were applied to the data in table A-20 to determine the plan with the highest long-run expectation. Table 14 shows the plan suggested by the probability model, as well as those suggested by other decision criteria. It also shows possible results of using the alternative plans.

The first problem setting considered is again that in which a farmer can plan to obtain highest returns over a long period of time. Two plans in

[21] Heady and Candler, op. cit., Chs. 3 and 6.

TABLE 14. STRATEGIES AND OUTCOMES SUGGESTED BY FIVE DECISION MODELS APPLIED TO SEYMOUR-SHELBY NITROGEN-STAND-VARIETY PROBLEM.[a]

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Alternative	Percent of land	Min. \$/a.	Av. \$/a.	Max. \$/a.	Max. regret \$/a.
Probability	Pure	Adapted variety; S=12,000; N=20	100	1.67	49.63	56.54	7.58
Wald	Pure	Early variety; S=12,000; N=0	100	9.25	37.05	52.28	4.71
Laplace	Pure	Early variety; S=12,000; N=0	100	9.25	37.05	52.28	4.71
Savage	Mixed	Early variety; S=12,000; N=0	53				
		Adapted variety; S=12,000; N=0	47				
			100	6.34	36.15	54.03	2.94
Hurwicz	Pure						
$0 \leq \alpha \leq 0.09$		Adapted variety; S=20,000; N=60	100	–4.24	32.13	56.99	13.49
$0.09 \leq \alpha \leq 0.11$		Adapted variety; S=12,000; N=40	100	0.31	33.90	56.58	8.94
$0.11 \leq \alpha \leq 0.2$		Adapted variety; S=12,000; N=20	100	1.67	34.63	56.34	7.58
$0.2 \leq \alpha \leq 0.38$		Adapted variety; S=12,000; N=0	100	3.05	35.14	56.00	6.20
$0.38 \leq \alpha \leq 1$		Adapted variety; S=12,000; N=0	100	9.25	27.05	52.28	4.71

[a] See the footnotes of table 3 for an explanation of this table.

table 14 are suited to this setting. If the farmer is willing to assume that past rainfall records provide a good estimate of the probability that various amounts of rainfall will occur, he may use a probability model. His average expectations over a period of years would be \$49.63. In some years, he can get only \$1.67, while in other years he can get \$56.34 above the cost of fertilizer, seed, transportation and storage. His plan would be to use the adapted variety, 20 pounds of fertilizer and a 12,000-plant-per-acre stand level.

The Laplace plan given in table 14 is also appropriate for this problem setting. The plan given by the Laplace criterion is the early variety with no fertilizer and a 12,000-plant-per-acre stand level. A farmer using this plan would not feel he knows enough about the distribution of weather to use the probability approach. The average of the Laplace plan thus is not strictly comparable to that of the probability plan.

The farmer who must insure himself the highest possible level of income each year would follow a plan identical to that of the Laplace. A farmer with an optimism-pessimism index greater than 0.38 would also follow this plan. Only a farmer willing to gamble or wishing to minimize regret would use another plan. These plans are the Hurwicz solutions with $0 \leqslant \alpha \leqslant 0.38$ and the Savage regret solution.

The preceding analysis indicates many possibilities for using experimental data for decision-making under uncertainty. Because of the low rainfalls experienced during the years this experiment was run, the use of fertilizer does not appear to be very profitable. The rainfall amounts included in the rainfall variable used average more than 12 inches in this section of Iowa. The limits of 6 inches and 12 inches had to be placed on this problem to avoid extrapolating outside the range of the data available. Therefore, it seems advisable to regard this analysis primarily as an example. Real decision-making guides may be derived from this experiment after it has run long enough to include a wider range of weather conditions. At that time, the rainfall variable might be refined to reflect other important weather characteristics.

Choice of Crop Enterprises

The sample problem used is a choice between oat and barley enterprises in western Iowa. The problem matrices for this example are contained in tables A-22 and A-23 of the appendix. Only 5 years of data are considered so that currently recommended varieties can be used in the example. An alternative is to use a long series of oat and barley yields without regard to variety to insure the inclusion of more possible outcomes than are shown in 5 years of data.

Table 15 shows the strategies and outcomes suggested by various decision criteria. Barley was selected by both the Wald and Laplace criteria. Thus, barley is apparently the "safest" crop and the most profitable over the long run. If a farmer wants to gamble on higher returns, he may grow Sauk oats or a combination of Sauk oats and Plains barley. Choice on the basis of profitability assumes that the crops cost the same to produce and offer no particular advantage in other ways, such as use for a nurse crop for legumes.

The prices used for a problem such as this affect the outcome of the analysis. Prices could be included in the problem. Possible oat-barley price situations could be obtained by examining series of past prices. Then all combinations of possible price and yield situations could be regarded as states of nature.

Choice of Pasture Mixtures

Considerable research has been conducted on

TABLE 15. STRATEGIES AND OUTCOMES SUGGESTED BY DECISION CRITERIA APPLIED TO A CROP ENTERPRISE SELECTION PROBLEM.[a]

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Crop	Percent of land	Min. $/a.	Av. $/a.	Max. $/a.	Max. regret $/a.
Wald	Pure	Plains barley	100	17	38.4	50	14
Laplace	Pure	Plains barley	100	17	38.4	50	14
Savage regret	Mixed	Sauk oats	47				
		Plains barley	53				
			100	13	36.8	57	8.5
Hurwicz	Pure						
$0 \leq \alpha \leq 0.68$		Sauk oats	100	8	35	64	16
$0.68 \leq \alpha \leq 1$		Plains barley	100	17	38.4	50	14

[a] See the footnotes of table 3 for an explanation of this table.

pasture mixtures for Iowa. Many of the new grasses and legumes outyield older ones. Research and extension educational efforts have interested many farmers in seeding the new mixtures. An analysis of data available on the newer mixtures, however, indicates that one mixture is not clearly superior to another in every year. Assuming that the mixtures cost about the same and are equal in other respects, which mixture should farmers plant, given variations in their problem setting?

CHOICE OF PASTURE MIXTURES IN NORTHEAST IOWA

The pasture mixtures considered for Howard County are: alfalfa-bromegrass, Ladino-Kentucky bluegrass, Ladino-orchardgrass and alfalfa-timothy. It is assumed that the mixture of grass and legume will remain in such a proportion over the years that the proper balance is maintained to avoid bloat. Data for these mixtures over the years 1954-57 are presented in a payoff matrix in table A-24 of the appendix. Entries are in tons of dry matter per acre. Table A-25 of the appendix contains the regret matrix for the same data.

The plans and possible outcomes suggested by alternative decision criteria are presented in table 16. A farmer with a flexible livestock system may want to follow the Laplace solution given in table 16. It calls for using an alfalfa-bromegrass mixture. Over a period of years, this plan may result

TABLE 16. STRATEGIES AND OUTCOMES SUGGESTED BY DECISION MODELS APPLIED TO THE HOWARD COUNTY PASTURE PROBLEM.[a]

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Pasture mixture	Percent of land	Min. tons/a.	Av. tons/a.	Max. tons/a.	Max. regret tons/a.
Wald	Pure	Alfalfa-timothy	100	1.9	2.4	3.1	1.5
Laplace	Pure	Alfalfa-bromegrass	100	1.7	2.5	3.6	1.4
Savage	Mixed	Alfalfa-bromegrass	53				
		Ladino-Kentucky bluegrass	47				
			100	1.6	2.3	3.0	0.75
Hurwicz	Pure						
$0 \leq \alpha \leq 0.71$		Alfalfa-bromegrass	100	1.7	2.5	3.6	1.4
$0.71 \leq \alpha \leq 1$		Alfalfa-timothy	100	1.9	2.4	3.1	1.5

[a] See the footnotes of table 3 for an explanation of this table.

in an average production of 2.5 tons of dry matter per acre. In some years the production may be only 1.7 tons per acre, but livestock numbers can be adjusted to fit the production in this problem setting. The Hurwicz solution for $0 \leqslant \alpha \leqslant 0.71$ also calls for using alfalfa-bromegrass. The size of the α indicates that this plan is not really a "risky" one. Nevertheless, some farmers may not be able or willing to take the small gamble required.

A farmer with an inflexible livestock system may wish to follow the Wald plan given in table 16. Assume that the profitability of his livestock system depends on the size of the enterprise and that this size is limited by the amount of pasture he can depend on each summer. He wants a pasture mixture that will give him the highest possible assured level of pasture every year. By following the Wald criterion, he can be sure of 1.9 tons of dry pasture matter per year. This would allow him to expand his livestock program to a higher level than is possible with another pasture mixture. Alfalfa-timothy is the pasture mixture suggested. The Hurwicz criterion with $0.71 \leqslant \alpha \leqslant 1$ gives the same plan as the Wald criterion. The Savage plan is particularly inappropriate for this problem setting. An examination of table A-25 of the appendix shows that the year when regret is a maximum for this plan is a year of low yields. This may very well be a year in which the cost of having a nonoptimum plan is highest. Feed costs might be particularly high that year. If a farmer wishes to minimize regret, however, he may plant 53 percent of his land to alfalfa-bromegrass and 47 percent to Ladino-Kentucky bluegrass.

CHOICE OF PASTURE MIXTURES IN SOUTHWEST IOWA

Data from the Soil Conservation Farm in Page County, southwest Iowa, are used for this problem. Two sets of pasture data are used. One includes alfalfa and grass mixtures; the other includes legume-grass mixtures containing a legume other than alfalfa. The alfalfa mixtures outyielded other mixtures in every year, but alfalfa may not be adapted to all land in that region. In addition, some farmers may exclude alfalfa from consideration because of fear of bloat. Thus, less productive mixtures are also considered.

Three alfalfa mixtures are included and are identified as farmer alternatives in table A-26 of the appendix. The years covered by the data are 1952-56. Each year is treated as a state of nature. Table A-27 of the appendix shows the regret matrix for this problem. Table 17 indicates plans and outcomes for the game theoretic criteria.

The Laplace plan is to seed all pasture acres to alfalfa-orchardgrass. This plan may give the highest average pasture production over a period of years. Thus, it is appropriate for a farmer with a flexible livestock system. It is also appropriate for a farmer who must have the highest possible security level every year. The security level (lowest possible yield) is equal to that for the Wald criterion.

The Wald solution shown in table 17 for the alfalfa mixtures resulted from a technicality of the game theoretic procedure. Reference to table A-26 shows that weather would theoretically never use its 1953, 1954 and 1955 strategies. When these columns are eliminated from the payoff matrix, it is seen that alfalfa-Kentucky bluegrass outyields alfalfa-orchardgrass in the remaining payoff matrix. Thus, only alfalfa-Kentucky bluegrass and alfalfa-bromegrass remain as farmer alternatives. The result is a Wald solution which may be either pure or mixed for the same security level. That is, a security level of 2.5 tons per acre may be obtained by using all alfalfa-Kentucky bluegrass or by using a combination including 60 percent al-

TABLE 17. STRATEGIES AND OUTCOMES SUGGESTED BY DECISION CRITERIA APPLIED TO SOIL CONSERVATION FARM PASTURE PROBLEM (ALFALFA MIXTURE).[a]

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Pasture mixture	Percent of land	Min. tons/a.	Av. tons/a.	Max. tons/a.	Max. regret tons/a.
Wald	Mixed	Kentucky bluegrass-alfalfa	60				
		Smooth bromegrass-alfalfa	40				
			100	2.5	3.5	4.4	0.26
Laplace	Pure	Orchardgrass-alfalfa	100	2.5	3.7	4.6	0.1
Savage regret	Mixed	Kentucky bluegrass-alfalfa	25				
		Orchardgrass-alfalfa	75				
			100	2.5	3.6	4.5	0.07
Hurwicz	Pure						
$0 \leq \alpha \leq 1$		Orchardgrass-alfalfa	100	2.5	3.7	4.6	0.1

[a] See the footnotes of table 3 for an explanation of this table.

falfa-Kentucky bluegrass and 40 percent alfalfa-smooth bromegrass. The mixed strategy is shown in table 17. This particular circumstance indicates the importance of analyzing data rather than following purely mechanical steps alone.

CHOICE OF NON-ALFALFA PASTURE MIXTURES IN SOUTHWEST IOWA

The plans suggested for using other pasture mixtures are presented in table 18. The payoff matrix and the regret matrix are found in tables A-28 and A-29, respectively, of the appendix. Both the maximum security level and the highest average are obtained by use of a trefoil-Kentucky bluegrass mixture. Thus, this mixture might be recommended with confidence. Orchardgrass-Ladino might be used by a farmer who is willing to gamble on the highest yield possible. In this case, the Hurwicz criterion, which suggests the orchardgrass-trefoil mixture, allows the same security level as the Wald and the Laplace criteria. The Savage regret mixed strategy allows the lowest regret possible but has other disadvantages. Tables 17 and 18 illustrate that differences may be slight in the possible outcome of the various game criteria. In such instances, a single recommendation is sufficient for a broad range of decision-making settings on farms.

CHOICE OF PASTURE STOCKING RATES

A complex problem which farmers must face is deciding how many animals to have for a given pasture acreage. Normally, the decision must be made before the farmer knows how much forage will be produced.

Heady **et al.**[22] conducted a survey in Iowa to determine what adjustments farmers make in their plans for year-to-year pasture variation. Ninety-one percent of the farmers said they either: (a) plan stocking rates on the basis of average pasture production over a period of years; (b) plan stocking rates for poorer years or (c) plan for the better years and feed hay or rent additional pasture to make up deficits in bad years. The other 9 percent either adjust livestock numbers to pasture conditions or feed grain. The latter measures are mostly actions of farmers who primarily graze stocker or feeder cattle on pasture.

The five alternative courses of action mentioned in the preceding paragraph may be considered as possible farmer strategies in a game against nature. Actually, only the three most prevalent ones are considered in the following problems. Nature's alternatives are different kinds of years. These may be represented by various levels of pasture production measured in animal units which 1 acre will support in that year. Five pasture yield levels are considered here. The cattle system considered is a beef cow-calf enterprise. Cows are bred to calve early in the spring. Calves are sold in October as good-to-choice feeder calves weighing 400 pounds.

Two sets of pasture data are used for the analysis. Both are from experiments at the Grundy-Shelby Experimental Farm in Ringgold County, Iowa, during 1951-57. Table A-30 of the appendix shows the farmer-nature payoff matrix for unimproved Kentucky bluegrass pasture. Table A-31 of the appendix contains the regret matrix for this problem. Tables A-32 and A-33 of the appendix show the payoff and regret matrices for Kentucky bluegrass pasture which has had an application of superphosphate and is overseeded with lespedeza.

In addition to pasture yield uncertainty, the farmer is confronted with price uncertainty. He does not know what the price of calves will be, and he does not know what the price of feed will be if he is forced to supplement the pasture. Price uncertainty also is accounted for in the problem matrices. Three possible price situations are hypothesized. One is that prices will be like 1953 prices, when hay was relatively expensive in comparison to feeder calf prices. The second is that prices will be like those in 1956 when hay was cheaper compared with feeder prices than in 1953. In the third price situation, the hay and feeder calf prices used are the average of 1948-57. Many other price situations could have been considered. At the price levels considered, however, only drastic changes in relative prices would change the plans selected. Such changes would cause shifts in the relative amounts of each alternative entering a mixed strategy plan. All combinations of prices and pasture levels make up the possible states of nature.

The entries in the payoff matrices are per-acre returns. These were computed by determining the value of beef which could be produced by stocking at the rates implied by the farmer alternatives. Rates of gain were obtained from the experimental data. Only the gains of the calves are valued. The cost of hay used to make up pasture deficits is subtracted from the value of total gains. A pasture period of 153 days (May 15 to Oct. 15) is used. For simplicity, it is assumed that alfalfa hay is fed to make up deficits. Value of gains foregone in good years is also subtracted from the value of beef produced. For example, if a farmer stocks for 0.22 animal unit days per acre and gets 0.44, he has an excess carrying capacity of 0.22 animal units per acre. This excess, multiplied by grazing days times daily rate of gain, gives the pounds of gain foregone. This is easily valued by multiplying by the price of feeder calves. The value of gain remaining after subtracting costs of hay and gain foregone is the payoff.

Table 19 gives the strategies and outcomes suggested by alternative decision criteria applied to the unimproved Kentucky bluegrass data. A farmer who can plan for the long run may follow the Laplace solution. This calls for stocking for the next-to-best year. The Hurwicz criterion with $0 \leqslant \alpha \leqslant 0.77$ calls for the same plan. Yearly returns may range from \$7.46 to \$31.07 but should

[22] Heady, Earl O., Olson, R. O. and Scholl, J. M. Economic efficiency in pasture production and improvement in southern Iowa. Iowa Agr. Exp. Sta. Res. Bul. 419. December 1954.

TABLE 18. STRATEGIES AND OUTCOMES SUGGESTED BY DECISION CRITERIA APPLIED TO SOIL CONSERVATION FARM PASTURE PROBLEM (NON-ALFALFA MIXTURES).[a]

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Pasture mixture	Percent of land	Min. tons/a.	Av. tons/a.	Max. tons/a.	Max. regret tons/a.
Wald	Pure	Kentucky bluegrass-trefoil	100	1.0	1.5	2.3	0.9
Laplace	Pure	Kentucky bluegrass-trefoil	100	1.0	1.5	2.3	0.9
Savage regret	Mixed	Kentucky bluegrass-trefoil	16				
		Orchardgrass-trefoil	40				
		Orchardgrass-Ladino	44				
			100	0.78	1.3	1.9	0.51
Hurwicz	Pure						
$0 \leq \alpha \leq 1$		Orchardgrass-trefoil	100	1.0	1.4	2.4	0.9

[a] See the footnotes of table 3 for an explanation of this table.

TABLE 19. STRATEGIES AND OUTCOMES SUGGESTED BY DECISION CRITERIA APPLIED TO GRUNDY-SHELBY UNIMPROVED KENTUCKY BLUEGRASS PASTURE DATA.[a]

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Farmer alternative	Percent of land	Min. \$/a.	Av. \$/a.	Max. \$/a.	Max. regret \$/a.
Wald	Mixed	Average year	88				
		Worst year	12				
			100	8.65	13.38	22.81	15.76
Laplace	Pure	Next-to-best year	100	7.46	19.43	31.07	2.88
Savage regret	Mixed	Next-to-best year	92				
		Worst year	8				
			100	7.69	18.17	28.53	2.65
Hurwicz	Pure						
$0 \leq \alpha \leq 0.77$		Next-to-best year	100	7.46	19.43	31.07	2.88
$0.77 \leq \alpha \leq 1$		Average year	100	8.42	14.70	25.36	13.20

[a] See the footnotes of table 3 for an explanation of this table.

average \$19.43. This plan also has a low regret.

A farmer who must plan with short-run outcomes in mind may use a combination of stocking rates. He may stock 88 percent of his pasture for average yields and 12 percent for the worst possible year. This plan assures the farmer of at least \$8.65 per acre every year, but his average income over the long run may be only \$13.38. In some years, he would miss the opportunity to obtain another \$15.76 (regret).

Plans for intermediate problem settings are given by the Savage regret criterion and Hurwicz criterion with $0.77 \leqslant \alpha \leqslant 1$. The Savage plan is for a farmer who must be slightly more conservative than one using the Laplace solution. The Hurwicz plan calls for stocking for average pasture. It requires only a slight reduction in security level and gives a sizable gain in long-run expectations.

These results do not tell a farmer exactly what stocking rates he should use. They do present him with alternatives and possible consequences of using them. He might then choose the plan which best suits his situation. It should be remembered that many other plans could be devised. The ones presented here are those suggested by decision models which have been advanced for use in decision-making under uncertainty.

TABLE 20. STRATEGIES AND OUTCOMES SUGGESTED BY DECISION CRITERIA APPLIED TO GRUNDY-SHELBY PHOSPHATE-LESPEDEZA PASTURE DATA.[a]

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Farmer alternative	Percent of land	Min. $/a.	Av. $/a.	Max. $/a.	Max. regret $/a.
Wald	Mixed	Worst year	43				
		Next-to-best year	57				
			100	19.49	24.78	31.65	9.05
Laplace	Pure	Next-to-best year	100	18.87	28.83	40.71	1.45
Savage regret	Mixed	Worst year	6				
		Next-to-best year	94				
			100	18.55	28.26	39.45	1.36
Hurwicz	Pure						
$0 \leq \alpha \leq 0.9$		Next-to-best year	100	18.87	28.83	40.71	1.45
$0.9 \leq \alpha \leq 1$		Average year	100	19.45	26.05	35.39	8.60

[a] See the footnotes of table 3 for an explanation of this table.

Why do so many Iowa farmers stock for the worst possible year? This plan was not suggested as a pure strategy by any of the decision criteria used in table 19. Perhaps one reason is that farmers do not evaluate the opportunity cost of unused pasture. Another possibility is that the goals implied by the decision models used are not actually those of farmers. Farmers may use other decision models which suggest very conservative plans. All of these tentative hypotheses might be tested. The result of such testing might lead to development of different decision models or verification of the appropriateness of those available.

One reason for the results obtained may be the price situation and feeding technique assumed. It is profitable to convert hay to beef in each price situation considered. Thus, the heavier stocking rates tend to be most profitable. Cattle may gain at a lower rate when hay makes up a large part of the feed supply. This would reduce the profitability of heavier stocking rates. These factors should be considered when using the analysis to make direct recommendations to farmers. The example presented here has the primary purpose of demonstrating the usefulness of game theoretic criteria for making decisions on pasture stocking rates.

Tables A-32 and A-33 indicate that yields of phosphate-lespedeza-bluegrass pasture are considerably higher than those for unimproved bluegrass pasture. Table 20 shows the strategies and outcomes for phosphate-lespedeza-bluegrass pasture. If a farmer wants the highest average long-run returns, he might stock for the next-to-best year. This stocking rate strategy has the highest average of any strategy considered. The outcomes for this plan are shown in table 20 by the Laplace solution row. The highest possible security level is obtained by stocking 43 percent of the pasture for the worst year and 57 percent for the next-to-best year. This is an appropriate plan for a farmer who must be assured the highest possible income every year. Even though a given farmer wants to minimize regret, he is not likely to follow the Savage plan. It offers little reduction in regret as compared with the Laplace plan. The security level and long-run average are both reduced by using the Savage regret solution.

APPENDIX

TABLE A-1. PAYOFF MATRIX FOR THE FARMER-NATURE, SEYMOUR-SHELBY, OAT-VARIETY PROBLEM.[a]

Farmer alternative (variety)	State of nature (year) 1953 bu./a.	1954 bu./a.	1955 bu./a.	1957[b] bu./a.
Bonham	42	59	117	96
Cherokee	46	60	112	100
Clintland	44	60	120	121
Clinton	40	58	119	62
Clarion	50	66	116	72
Sauk	52	59	133	92

[a] Source of data: Iowa State University. Seymour-Shelby Experimental Farm. Annual progress report, 1952 through 1957. (Mimeo.) Department of Agronomy, Iowa State University, Ames, Iowa. 1953 through 1958.

[b] No oats were harvested on the Seymour-Shelby farm in 1956 because of drouth. Thus, yields in that year were the same for each variety and are not considered in the analysis. The all-zero yields would not affect plans, given that oats are to be grown. They would affect plans, however, if the problem is choosing between two crops such as barley and oats.

TABLE A-2. PAYOFF MATRIX FOR THE FARMER-NATURE, WESTERN IOWA, OAT-VARIETY PROBLEM.[a]

Farmer alternative (variety)	State of nature (year) 1953 bu./a.	1954 bu./a.	1955 bu./a.	1956 bu./a.	1957 bu./a.
Bonham	53	57	80	21	76
Cherokee	53	66	74	25	71
Clintland	49	57	89	16	77
Clarion	67	73	88	17	68
Sauk	63	78	100	14	75

[a] Source of data: Iowa State University. Western Iowa Experimental Farm. Annual progress report, 1951 through 1957. (Mimeo.) Department of Agronomy, Iowa State University, Ames, Iowa. 1952 through 1958.

TABLE A-3. SAVAGE REGRET MATRIX FOR SEYMOUR-SHELBY OAT-VARIETY PROBLEM.

Farmer alternative (variety)	State of nature (year) 1953 bu./a.	1954 bu./a.	1955 bu./a.	1957 bu./a.
Bonham	−10	−7	−16	−25
Cherokee	−6	−6	−21	−21
Clintland	−8	−6	−13	0
Clinton	−12	−8	−14	−59
Clarion	−2	0	−17	−49
Sauk	0	−7	0	−29

TABLE A-4. SAVAGE REGRET MATRIX FOR WESTERN IOWA OAT-VARIETY PROBLEM.

Farmer alternative (variety)	State of nature (year) 1953 bu./a.	1954 bu./a.	1955 bu./a.	1956 bu./a.	1957 bu./a.
Bonham	−14	−21	−20	−4	−1
Cherokee	−14	−12	−26	0	−6
Clintland	−18	−21	−11	−9	0
Clarion	0	−5	−12	−8	−9
Sauk	−4	0	0	−11	−2

TABLE A-5. FARMER-NATURE PAYOFF MATRIX FOR WESTERN IOWA BARLEY-VARIETY PROBLEM.[a]

Farmer alternative (variety)	State of nature (year) 1953 bu./a.	1954 bu./a.	1955 bu./a.	1956 bu./a.	1957 bu./a.
Plains	38	58	61	21	62
Mars	41	44	48	16	68

[a] Source of data: Iowa State University. Western Iowa Experimental Farm. Annual progress report, 1951 through 1957. (Mimeo.) Department of Agronomy, Iowa State University, Ames, Iowa. 1952 through 1958.

TABLE A-6. SAVAGE REGRET MATRIX FOR WESTERN IOWA BARLEY-VARIETY PROBLEM.

Farmer alternative (variety)	State of nature (year) 1953 bu./a.	1954 bu./a.	1955 bu./a.	1956 bu./a.	1957 bu./a.
Plains	−3	0	0	0	−6
Mars	0	−14	−13	−5	0

TABLE A-7. FARMER-NATURE PAYOFF MATRIX FOR NORTHEAST IOWA CORN-VARIETY PROBLEM.[a]

Farmer alternative (variety)	State of nature (year) 1953 bu./a.	1954 bu./a.	1955 bu./a.	1956 bu./a.	1957 bu./a.
Pioneer 347	118	115	87	123	113
Pioneer 371	122	114	93	121	107
Pioneer 352	121	118	87	118	113
Pioneer 349	122	113	86	126	113
P.A.G. 277	117	110	86	129	119

[a] Source of data: Iowa corn yield test, 1951 through 1957. Iowa Agr. and Home Econ. Exp. Sta. and Coop. Ext Serv. Bulletins P-112, 115, 116, 118, 120, 123 and 124. 1952 through 1958.

TABLE A-8. FARMER-NATURE REGRET MATRIX FOR NORTHEAST IOWA CORN-VARIETY PROBLEM.

Farmer alternative (variety)	State of nature (year) 1953 bu./a.	1954 bu./a.	1955 bu./a.	1956 bu./a.	1957 bu./a.
Pioneer 347	−4	−3	−6	−6	−6
Pioneer 371	0	−4	0	−8	−12
Pioneer 352	−1	0	−6	−11	−6
Pioneer 349	0	−5	−7	−3	−6
P.A.G. 277	−5	−8	−7	0	0

TABLE A-9. FARMER-NATURE PAYOFF MATRIX FOR SOUTHERN IOWA CORN-VARIETY PROBLEM.[a]

Farmer alternative (variety)	State of nature (year) 1952 bu./a.	1953 bu./a.	1954 bu./a.	1955 bu./a.	1956 bu./a.	1957 bu./a.
Pioneer 301b	110	118	88	78	84	114
P.A.G. 170	112	121	79	76	91	104
U.S. 13	108	117	75	75	87	110
P.A.G. 381	113	106	79	77	85	106
Pioneer 300	110	117	73	77	86	108
Maygold 47	115	112	69	73	85	110
Maygold 59a	112	115	72	69	84	110
Iowa 4565	118	113	79	73	78	103
P.A.G. 283	111	113	83	75	84	100

[a] Source of data: Iowa corn yield test, 1951 through 1957. Iowa Agr. and Home Econ. Exp. Sta. and Coop. Ext. Serv. Bulletins P-112, 115, 116, 118, 120, 123 and 124. 1952 through 1958.

TABLE A-10. FARMER-NATURE REGRET MATRIX FOR SOUTHERN IOWA CORN-VARIETY PROBLEM.

Farmer alternative (variety)	State of nature (year) 1952 bu./a.	1953 bu./a.	1954 bu./a.	1955 bu./a.	1956 bu./a.	1957 bu./a.
Pioneer 301b	−8	−3	0	0	−7	0
P.A.G. 170	−6	0	−9	−2	0	−10
U.S. 13	−10	−4	−13	−3	−4	−4
P.A.G. 381	−5	−15	−9	−1	−6	−8
Pioneer 300	−8	−4	−15	−1	−5	−6
Maygold 47	−3	−9	−19	−5	−6	−4
Maygold 59a	−6	−6	−16	−9	−7	−4
Iowa 4565	0	−8	−9	−5	−13	−11
P.A.G. 283	−7	−8	−5	−3	−7	−14

TABLE A-11. PAYOFF MATRIX FOR THE FARMER-NATURE, NORTHEAST IOWA, M-P-K PROBLEM (NO CHARGE FOR MANURE).[a]

Farmer alternative	State of nature (year) 1952 $/a.	1953 $/a.	1954 $/a.	1955 $/a.	1956 $/a.	1957 $/a.
(Ck.) No Fertilizer	26.98[b]	0	14.92	4.08	28.78	16.58
(M) 6 tons manure	53.08	17.46	53.74	14.80	45.00	43.48
(P) 30# P_2O_5	28.00	4.64	–0.78	5.30	13.18	18.60
(K) 30# K_2O	36.06	–0.71	27.89	1.76	35.58	32.26
(PK) 30# K_2O 30# P_2O_5	33.63	5.70	32.11	9.40	35.34	33.72
(MP) 6 tons manure 30# P_2O_5	64.84	23.61	49.36	10.98	43.94	38.05
(MK) 6 tons manure 30# K_2O	50.95	18.46	16.48	9.72	48.48	42.88
(MPK) 6 tons manure 30# K_2O 30# P_2O_5	53.94	21.54	51.94	6.34	38.92	37.31

[a] Source of data: Iowa State University. Howard County Experimental Farm. Annual progress report, 1951 through 1957. (Mimeo.) Department of Agronomy, Iowa State University, Ames, Iowa. 1952 through 1958.

[b] The returns-per-acre payoffs only reflect the part of per-acre returns which are influenced by states of nature or fertilizer practices. This was achieved by subtracting the lowest yield in the "no fertilizer" row of the data from all other entries in the yield matrix. This left the portion of yields which varies with years or fertilizer practices. These yields were converted to dollar returns from which fertilizer costs, application costs and other costs which vary with additional yields were subtracted. This is a partial budgeting technique which simplifies the analysis. The corn price used was $1.10. Costs of fertilizer nutrients were: (a) nitrogen, $0.13 per pound; (b) potassium, $0.05 per pound; and (c) phosphorus, $0.10 per pound. A cost of $0.15 per bushel was computed for harvesting, hauling and storing corn. Source of price data: U. S. Dept. Agr., Agricultural Marketing Service. Agricultural prices. Issues 1947 through 1958.

TABLE A-12. SAVAGE REGRET MATRIX FOR NORTHEAST IOWA, M-P-K PROBLEM (NO CHARGE FOR MANURE).

Farmer alternative	State of nature (year) 1952 $/a.	1953 $/a.	1954 $/a.	1955 $/a.	1956 $/a.	1957 $/a.
Ck	–37.86	–23.61	–38.32	–10.72	–19.70	–26.90
M	–11.76	–6.15	0	0	–3.48	0
P	–36.84	–18.97	–54.02	–9.50	–35.30	–24.88
K	–28.78	–24.32	–25.35	–13.04	–12.90	–11.22
PK	–31.21	–17.91	–21.13	–5.40	–13.14	–9.76
MP	0	0	–3.88	–3.82	–4.54	–5.43
MK	–13.89	–5.15	–36.76	–5.08	0	–0.60
MPK	–10.90	–2.07	–1.30	–8.46	–9.56	–6.17

TABLE A-13. PAYOFF MATRIX FOR FARMER-NATURE M-P-K PROBLEM IN NORTHEAST IOWA (CHARGE FOR MANURE).

Farmer alternative	State of nature (year) 1952 $/a.	1953 $/a.	1954 $/a.	1955 $/a.	1956 $/a.	1957 $/a.
Ck	26.98	0	14.92	4.08	28.78	24.70
M	39.88	4.26	40.54	1.60	31.80	30.28
P	28.00	4.64	–0.78	5.30	13.18	18.60
K	36.06	–0.71	27.89	1.76	35.58	32.26
PK	33.63	5.70	32.11	9.40	35.34	33.72
MP	51.64	10.41	36.16	–2.22	30.74	24.85
MK	37.73	5.26	33.28	–3.48	35.28	29.68
MPK	40.74	8.34	38.74	–6.86	25.72	24.11

TABLE A-14. SAVAGE REGRET MATRIX FOR FARMER-NATURE M-P-K PROBLEM IN NORTHEAST IOWA (CHARGE FOR MANURE).

Farmer alternative	State of nature (year) 1952 $/a.	1953 $/a.	1954 $/a.	1955 $/a.	1956 $/a.	1957 $/a.
Ck.	–24.66	–10.41	–25.62	–5.32	–6.80	–9.02
M	–11.76	–6.15	0	–7.80	–3.78	–3.44
P	–23.64	–5.77	–41.32	–4.10	–22.40	–15.12
K	–15.58	–11.12	–12.65	–7.64	0	–1.46
PK	–18.01	–4.71	–8.43	0	–0.24	0
MP	0	0	–4.38	–11.62	–4.84	–8.87
MK	–13.91	–5.15	–7.26	–12.88	–0.30	–4.04
MPK	–10.90	–2.07	–1.80	–16.26	–9.86	–9.61

TABLE A-15. PAYOFF MATRIX FOR FARMER-NATURE M-P-K PROBLEM IN NORTHEAST-CENTRAL IOWA (NO CHARGE FOR MANURE).[a]

Farmer alternative	State of nature (year) 1952 $/a.	1953 $/a.	1954 $/a.	1955 $/a.	1956 $/a.	1957 $/a.
Ck.	0	26.03	40.56	8.93	10.64	31.73
M	47.38	58.59	70.94	30.76	17.55	62.86
P	–0.97	22.30	48.24	0.84	10.62	34.08
K	10.70	18.39	30.27	8.60	–0.99	23.52
PK	23.66	29.36	61.28	16.82	12.84	57.76
MP	46.32	57.72	69.02	26.18	23.80	72.44
MK	43.35	57.22	66.82	27.86	19.41	59.88
MPK	44.24	59.16	66.28	24.01	23.06	64.20

[a] Source of data: Iowa State University. Carrington-Clyde Experimental Farm. Annual progress report, 1952 through 1957. (Mimeo.) Department of Agronomy, Iowa State University, Ames, Iowa. 1953 through 1958.

TABLE A-16. SAVAGE REGRET MATRIX FOR NORTHEAST-CENTRAL IOWA M-P-K PROBLEM (NO CHARGE FOR MANURE).

Farmer alternative	State of nature (year) 1952 $/a.	1953 $/a.	1954 $/a.	1955 $/a.	1956 $/a.	1957 $/a.
Ck.	–47.38	–33.13	–30.38	–21.83	–13.16	–40.71
M	0	–0.57	0	0	–6.25	–9.58
P	–48.35	–36.86	–22.70	–29.92	–13.18	–38.36
K	–36.68	–40.77	–40.67	–22.16	–24.79	–48.92
PK	–23.72	–29.80	–9.66	–13.94	–10.96	–14.68
MP	–1.06	–1.44	–1.92	–4.58	0	0
MK	–4.03	–1.94	–4.12	–2.90	–4.39	–12.56
MPK	–3.14	0	–4.66	–6.75	–0.74	–8.24

TABLE A-17. PAYOFF MATRIX FOR FARMER-NATURE M-P-K PROBLEM IN NORTHEAST-CENTRAL IOWA (CHARGE FOR MANURE).

Farmer alternative	State of nature (year) 1952 $/a.	1953 $/a.	1954 $/a.	1955 $/a.	1956 $/a.	1957 $/a.
Ck.	0	26.03	40.56	8.93	10.64	31.73
M	34.18	45.39	57.74	17.56	4.35	49.66
P	–0.97	22.30	48.24	0.84	10.62	34.08
K	10.70	18.39	30.27	8.60	–0.99	23.52
PK	23.66	29.36	61.28	16.82	12.84	57.76
MP	33.12	44.52	55.82	12.98	10.60	59.24
MK	30.15	44.02	53.62	14.66	6.21	46.68
MPK	31.04	45.96	53.08	10.81	9.86	51.00

TABLE A-18. SAVAGE REGRET MATRIX FOR NORTHEAST-CENTRAL IOWA M-P-K PROBLEM (CHARGE FOR MANURE).

Farmer alternative	State of nature (year) 1952 $/a.	1953 $/a.	1954 $/a.	1955 $/a.	1956 $/a.	1957 $/a.
Ck.	–34.18	–19.93	–20.72	–8.63	–2.20	–27.51
M	0	–0.57	–3.54	0	–8.49	–9.58
P	–35.15	–23.66	–13.04	–16.72	–2.22	–25.16
K	–23.48	–27.57	–31.01	–8.96	–13.83	–35.72
PK	–10.52	–16.60	0	–0.74	0	–1.48
MP	–1.06	–1.44	–5.46	–4.58	–2.24	0
MK	–4.03	–1.94	–7.66	–2.90	–6.63	–12.56
MPK	–3.14	0	–8.20	–6.75	–2.98	–8.24

TABLE A-19. DATA AND REGRESSION EQUATIONS FOR THE NITROGEN-STAND-VARIETY EXPERIMENT ON THE SEYMOUR-SHELBY EXPERIMENTAL FARM.[a]

		Early variety — Iowa 4297					Adapted variety — A.E.S. 801				
Lbs. N per a.	Plants per a.	1953 bu.	1954 bu.	1955 bu.	1956 bu.	1957 bu.	1953 bu.	1954 bu.	1955 bu.	1956 bu.	1957 bu.
0	8,000	55.2	26.6	26.6	50.5	47.3	52.5	21.9	24.4	49.8	55.7
	12,000	56.9	8.1	23.3	56.8	50.3	47.2	9.1	13.2	60.3	52.1
	16,000	54.2	6.6	11.3	63.9	58.4	43.6	3.2	3.4	65.7	64.7
	20,000	43.4	3.7	10.3	53.0	55.2	38.0	2.6	2.4	64.1	61.5
80	8,000	59.5	28.2	30.0	55.5	58.4	53.0	21.5	23.4	53.6	66.2
	12,000	60.9	11.9	24.5	58.3	66.2	54.3	9.2	13.7	59.0	70.9
	16,000	71.1	6.5	18.0	71.1	81.6	58.0	3.8	8.8	71.6	89.8
	20,000	58.8	3.0	11.0	63.4	83.5	44.1	3.5	6.6	70.7	86.6
160	8,000	63.8	19.6	41.4	48.2	54.9	58.0	18.0	30.0	48.8	65.5
	12,000	65.5	13.0	27.5	54.0	69.2	61.8	11.6	20.0	57.6	69.1
	16,000	67.9	5.5	16.7	61.1	83.2	59.8	7.9	6.7	68.9	96.9
	20,000	66.4	5.2	9.8	56.3	88.4	55.5	4.1	4.2	60.7	88.4

Regression equation for the early variety:[b]

$$\hat{Y} = -144.8603 + \underset{(1.3)}{0.5268X_1} - \underset{(1.03)}{0.0639X_1^2} + \underset{(4.35)}{35.3228X_3} - \underset{(3.6)}{1.5640X_3^2} - \underset{(1.4)}{0.1063X_1X_2} + \underset{(1.6)}{0.0114X_1X_2X_3};\ R^2 = 0.69;\ d.f. = 53$$

Regression equation for the adapted variety:

$$\hat{Y} = -149.7796 + \underset{(1.09)}{1.1635X_1} - \underset{(0.75)}{0.0421X_1^2} + \underset{(4.6)}{34.1749X_3} - \underset{(3.6)}{1.4083X_3^2} - \underset{(1.5)}{0.1059X_1X_2} + \underset{(1.7)}{0.0115X_1X_2X_3};\ R^2 = 0.79$$

X_1 = nitrogen; X_2 = stand; X_3 = current year rainfall [June rainfall ($\leq$ 4 inches) + July rainfall ($\leq$ 5 inches) + August rainfall ($\leq$ 6 inches)] + carryover (previous year rainfall − 21 inches).

[a] Source of data: Iowa State University. Seymour-Shelby Experimental Farm. Annual progress report, 1952 through 1957. (Mimeo.) Department of Agronomy, Iowa State University, Ames, Iowa. 1953 through 1958. United States Weather Bureau. Iowa Weather and Crop Service. Climatological data. Des Moines, Iowa. 1925 through 1957.
[b] The t's for each b appear in parentheses below coefficients.

TABLE A-20. PAYOFF MATRIX FOR FARMER-NATURE NITROGEN-STAND-VARIETY PROBLEM.[a]

Farmer alternative	Weather (rainfall in inches)			
	6 in. $/a.	8 in. $/a.	10 in. $/a.	12 in. $/a.
Early variety, stand = 12,000, N = 0	9.25[b]	35.84	50.85	52.28
Adapted variety, stand = 12,000, N = 0	3.05	31.87	49.62	56.00
Adapted variety, stand = 12,000, N = 10	2.32	31.41	49.44	56.10
Adapted variety, stand = 12,000, N = 20	1.67	31.10	49.41	56.34
Adapted variety, stand = 12,000, N = 40	0.31	30.23	49.09	56.58
Adapted variety, stand = 16,000, N = 40	-0.78	29.51	48.73	56.59
Adapted variety, stand = 16,000, N = 60	-2.85	28.18	48.14	56.73
Adapted variety, stand = 20,000, N = 60	-4.24	27.93	47.85	56.99

[a] Source of data: Iowa State University. Seymour-Shelby Experimental Farm. Annual progress report, 1952 through 1957. (Mimeo.) Department of Agronomy, Iowa State University, Ames, Iowa. 1953 through 1958.

[b] Returns shown equal bushels times $0.95 a bushel for corn, less seed and fertilizer costs. Fertilizer costs include application expenses. Corn price used is $1.10 minus $0.15 per bushel for harvesting, hauling and storage costs.

TABLE A-21. SAVAGE REGRET MATRIX FOR FARMER-NATURE NITROGEN-STAND-VARIETY PROBLEM.

Farmer alternative	Rainfall	
	6 in. $/a.	12 in. $/a.
Early variety, stand = 12,000, N = 0	0	-4.71
Adapted variety, stand = 12,000, N = 0	-6.20	-0.99
Adapted variety, stand = 12,000, N = 10	-6.93	-0.89
Adapted variety, stand = 12,000, N = 20	-7.58	-0.65
Adapted variety, stand = 12,000, N = 40	-8.94	-0.41
Adapted variety, stand = 16,000, N = 40	-10.03	-0.40
Adapted variety, stand = 16,000, N = 60	-12.10	-0.26
Adapted variety, stand = 20,000, N = 60	-13.49	0

TABLE A-22. PAYOFF MATRIX FOR FARMER-NATURE CROP ENTERPRISE SELECTION PROBLEM.[a]

Farmer alternative	State of nature (year)				
	1953 $/a.	1954 $/a.	1955 $/a.	1956 $/a.	1957 $/a.
Sauk oats	26[b]	30	47	8	64
Clintland oats	33	41	53	7	49
Plains barley	30	46	49	17	50
Cherokee oats	28	35	39	13	53

[a] Source of data: Iowa State University. Western Iowa Experimental Farm. Annual progress report, 1951 through 1957. (Mimeo.) Department of Agronomy, Iowa State University, Ames, Iowa. 1952 through 1958.

[b] Payoffs are the gross value of the production from 1 acre. The oat price used was $0.53 per bushel, and the barley price was $0.80 per bushel.

TABLE A-23. SAVAGE REGRET MATRIX FOR THE CROP-ENTERPRISE SELECTION PROBLEM.

Farmer alternative	State of nature (year)				
	1953 $/a.	1954 $/a.	1955 $/a.	1956 $/a.	1957 $/a.
Sauk oats	-7	-16	-6	-9	0
Clintland oats	0	-5	0	-10	-15
Plains barley	-3	0	-4	0	-14
Cherokee oats	-5	-11	-14	-4	-11

TABLE A-24. PAYOFF MATRIX FOR FARMER-NATURE PASTURE MIXTURE PROBLEM IN HOWARD COUNTY.[a]

Farmer alternative	State of nature (year)			
	1954 tons/a.	1955 tons/a.	1956 tons/a.	1957 tons/a.
Alfalfa-bromegrass	2.0[b]	1.7	2.8	3.6
Trefoil-bromegrass	1.7	1.8	2.3	2.4
Ladino-Kentucky bluegrass	3.4	1.5	1.2	2.3
Ladino-orchardgrass	3.2	1.5	1.4	1.6
Alfalfa-timothy	1.9	1.9	2.8	3.1

[a] Source of data: Iowa State University. Howard County Experimental Farm. Annual progress report, 1951 through 1957. (Mimeo.) Department of Agronomy, Iowa State University, Ames, Iowa. 1952 through 1958.

[b] Yields are in tons of weed-free dry matter per acre per year. These may be converted to pounds of T.D.N. by multiplying 1.14 x tons per acre x percent T.D.N. for the pasture. The factor, 1.14, converts yields to pounds of 12-percent moisture hay.

TABLE A-25. SAVAGE REGRET MATRIX FOR HOWARD COUNTY PASTURE MIXTURE PROBLEM.

Farmer alternative	State of nature (year)			
	1954 tons/a.	1955 tons/a.	1956 tons/a.	1957 tons/a.
Alfalfa-bromegrass	-1.4	-0.2	0	0
Trefoil-bromegrass	-1.7	-0.1	-0.5	-1.2
Ladino-Kentucky bluegrass	0	-0.4	-1.6	-1.3
Ladino-orchardgrass	-0.2	-0.4	-1.4	-2.0
Alfalfa-timothy	-1.5	0	0	-0.5

TABLE A-26. FARMER-NATURE PAYOFF MATRIX FOR SOIL CONSERVATION FARM, ALFALFA-GRASS PASTURE PROBLEM.[a]

Farmer alternative	State of nature (year)				
	1952 tons/a.	1953 tons/a.	1954 tons/a.	1955 tons/a.	1956 tons/a.
Alfalfa-Kentucky bluegrass	2.5[b]	4.1	4.3	4.3	2.7
Alfalfa-smooth bromegrass	2.5	4.2	4.5	3.7	2.2
Alfalfa-orchardgrass	2.5	4.3	4.6	4.4	2.6

[a] Source of data: Iowa State University. Soil Conservation Experimental Farm. Annual progress report, 1952 through 1957. (Mimeo.) Department of Agronomy, Iowa State University, Ames, Iowa. 1953 through 1958.
[b] Yields of pasture in tons of weed-free dry matter per acre per year.

TABLE A-27. SAVAGE REGRET MATRIX FOR SOIL CONSERVATION FARM, ALFALFA-GRASS PASTURE PROBLEM.

Farmer alternative	State of nature (year)				
	1952 tons/a.	1953 tons/a.	1954 tons/a.	1955 tons/a.	1956 tons/a.
Alfalfa-Kentucky bluegrass	0	–0.2	–0.3	–0.1	0
Alfalfa-smooth bromegrass	0	–0.1	–0.1	–0.7	–0.5
Alfalfa-orchardgrass	0	0	0	0	–0.1

TABLE A-28. FARMER-NATURE PAYOFF MATRIX FOR THE SOIL CONSERVATION FARM, NON-ALFALFA LEGUME-GRASS PASTURE PROBLEM.[a]

Farmer alternative	State of nature (year)				
	1952 tons/a.	1953 tons/a.	1954 tons/a.	1955 tons/a.	1956 tons/a.
Trefoil-Kentucky bluegrass	1.0[b]	2.3	2.0	1.1	1.0
Trefoil-smooth bromegrass	0.7	2.1	2.2	1.0	1.1
Trefoil-orchardgrass	1.0	1.8	2.4	1.0	1.0
Ladino-orchardgrass	1.9	1.6	1.4	0.6	0.5

[a] Source of data: Iowa State University. Soil Conservation Experimental Farm. Annual progress report, 1952 through 1957. (Mimeo.) Department of Agronomy, Iowa State University, Ames, Iowa. 1953 through 1958.
[b] Yields are in tons of weed-free dry matter per acre per year.

TABLE A-29. SAVAGE REGRET MATRIX FOR THE SOIL CONSERVATION FARM, NON-ALFALFA PASTURE PROBLEM.

Farmer alternative	State of nature (year)				
	1952 tons/a.	1953 tons/a.	1954 tons/a.	1955 tons/a.	1956 tons/a.
Trefoil-Kentucky bluegrass	–0.9	0	–0.4	0	–0.1
Trefoil-smooth bromegrass	–1.2	–0.2	–0.2	–0.1	0
Trefoil-orchardgrass	–0.9	–0.5	0	–0.1	–0.1
Ladino-orchardgrass	0	–0.7	–1.0	–0.5	–0.6

TABLE A-30. FARMER-NATURE PASTURE STOCKING RATE PROBLEM FOR UNIMPROVED PASTURE IN GRUNDY-SHELBY SOIL AREA ($/a.).[a]

Cow and calf carrying capacity per acre	Farmer alternatives		
	Plan for av. pasture –0.39[c]	Plan for worst year –0.23	Plan for next-to-best year and feed hay –0.47
0.23			
1953 prices	8.42[d]	10.34	7.46
Av. prices[b]	17.15	15.35	17.04
1956 prices	10.89	11.79	10.43
0.31			
1953 prices	12.98	6.74	12.01
Av. prices	21.59	10.01	22.49
1956 prices	15.44	7.69	14.98
0.40			
1953 prices	17.08	2.70	17.14
Av. prices	25.30	4.01	27.48
1956 prices	19.48	3.09	20.10
0.47			
1953 prices	13.93	–0.44	21.12
Av. prices	20.69	–0.66	31.07
1956 prices	15.89	–0.50	24.08
0.55			
1953 prices	10.34	–4.04	17.52
Av. prices	15.36	–5.99	28.56
1956 prices	11.80	–4.59	19.98

[a] Source of data: Heady, Earl O., Olson, R. O. and Scholl, J. M. Economic efficiency in pasture production and improvement in southern Iowa. Iowa Agr. Exp. Sta. Res. Bul. 419. December 1954. Iowa State University Grundy-Shelby Experimental Farm. Annual progress report, 1952 through 1957. (Mimeo.) Department of Agronomy, Iowa State University, Ames, Iowa. 1953 through 1958. McKee, D. E., Heady, E. O. and Scholl, J. M. Optimum allocation of resources between pasture improvement and other opportunities on southern Iowa farms. Iowa Agr. Exp. Sta. Res. Bul. 435. January 1956.
[b] Average prices of hay and grain, 1948-57.
[c] Stocking rate in animal units per acre.
[d] Payoffs are returns per acre from the given stocking rate minus hay costs and value of gains foregone.

TABLE A-31. SAVAGE REGRET MATRIX FOR UNIMPROVED PASTURE STOCKING RATE PROBLEM ($/a.).

Cow and calf carrying capacity per acre	Farmer alternatives		
	Plan for av. pasture –0.39	Plan for worst year –0.23	Plan for next-to-best year –0.47
0.23			
1953 prices	–1.92	0	–2.88
Av. prices	0	–1.80	–0.11
1956 prices	–0.90	0	–1.36
0.31			
1953 prices	0	–6.24	–0.97
Av. prices	–0.90	–12.48	0
1956 prices	0	–7.75	–0.46
0.40			
1953 prices	–0.06	–14.44	0
Av. prices	–2.18	–23.47	0
1956 prices	–0.62	–17.01	0
0.47			
1953 prices	–7.19	–21.56	0
Av. prices	–10.38	–31.73	0
1956 prices	–8.19	–24.58	0
0.55			
1953 prices	–7.18	–21.56	0
Av. prices	–13.20	–34.55	0
1956 prices	–8.18	–24.57	0

TABLE A-32.[a] FARMER-NATURE PASTURE STOCKING RATE PROBLEM FOR PHOSPHATE-LESPEDEZA PASTURE IN THE GRUNDY-SHELBY SOIL AREA ($/a.).[b]

Cow and calf carrying capacity per acre	Farmer alternatives		
	Plan for av. pasture –0.52	Plan for worst year –0.43	Plan for next-to-best year and feed hay –0.58
0.43			
1953 prices	19.45	20.32	18.87
Av. prices	31.50	30.18	32.38
1956 prices	22.91	23.18	22.73
0.47			
1953 prices	21.72	18.43	21.15
Av. prices	33.72	27.37	34.60
1956 prices	25.19	21.02	25.00
0.50			
1953 prices	23.43	17.01	22.86
Av. prices	35.39	25.27	36.27
1956 prices	26.89	19.41	26.71
0.58			
1953 prices	21.73	13.23	27.41
Av. prices	32.29	19.65	40.71
1956 prices	24.80	15.10	31.26
0.62			
1953 prices	19.84	11.34	25.52
Av. prices	29.30	16.84	37.90
1956 prices	22.64	12.94	29.10

[a] See footnotes in table A-30 for an explanation of this table.
[b] Source of data: Iowa State University. Grundy-Shelby Experimental Farm. Annual progress report, 1952 through 1957. (Mimeo.) Department of Agronomy, Iowa State University, Ames, Iowa. 1953 through 1958.

TABLE A-33. SAVAGE REGRET MATRIX FOR PHOSPHATE-LESPEDEZA-BLUEGRASS PASTURE STOCKING RATE PROBLEM ($/a.).

Cow and calf carrying capacity per acre	Farmer alternatives		
	Plan for av. pasture –0.52	Plan for worst year –0.43	Plan for next-to-best year –0.58
0.43			
1953 prices	–0.87	0	–1.45
Av. prices	–0.88	–2.20	0
1956 prices	–0.27	0	–0.45
0.47			
1953 prices	0	–3.29	–0.57
Av. prices	–0.88	–7.23	0
1956 prices	0	–4.17	–0.19
0.50			
1953 prices	0	–6.42	–0.57
Av. prices	–0.88	–11.00	0
1956 prices	0	–7.48	–0.18
0.58			
1953 prices	–5.68	–14.18	0
Av. prices	–8.42	–21.06	0
1956 prices	–6.46	–16.16	0
0.62			
1953 prices	–5.68	–14.18	0
Av. prices	–8.60	–21.06	0
1956 prices	–6.46	–16.16	0