GAME THEORY APPLICATIONS IN AGRICULTURAL DECISIONS

by

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I. INTRODUCTION

A. The General Problem

In a world free of risk and uncertainty, the decision making function of farmers would be greatly simplified. A farmer could make plans for obtaining feasible goals and then simply carry out the plans. Static economic theory provides guides for making decisions when knowledge is complete. These choice guides bring together data and concepts from several sources. Resource use alternatives and the outcomes of alternative resource employment 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.

Obviously, the farmer decision making environment is not as described above. 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. In most production processes, 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 ignored. 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. Such developments may affect the desirability of alternative plans which farmers can make.

Price uncertainty is a third major problem of farmers. The static economic models rely heavily on knowledge of prices for making choices. Thus, the usefulness of those models is sharply reduced by the existence of price uncertainty. The complex of interrelated factors which contribute to price variability include: (a) world and national economic conditions, (b) the general state of uncontrollable, natural phenomena affecting production, and (c) the commodity cycle phenomena.

A fourth source of uncertainty to farmers results from their relationships with other individuals, groups of individuals and institutions. It is difficult to anticipate actions of other individuals or groups which may affect the farmer's plans. Farmers cannot predict governmental activities which affect future events and, thus, their own welfare. Man's goals change; therefore, plans made in one time period may not attain goals which exist in another time period. These factors increase farmer uncertainty.

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 in later chapters.

B. The Specific Problem

Farmers must make decisions in their given, uncertain environment. How are those decisions to be made? Lack of knowledge of production conditions does not lessen farmers' desires to maximize the attainment of certain ends through use of available resources. They must observe, conceive ideas, make a decision, implement their plan and accept the consequences. How nearly they attain the desired results depends on managerial skill and "luck". This study suggests ways of increasing managerial skill. However, "luck" is courted through attention to mathematical probabilities and provision to benefit from various eventualities.

C. Objectives of the Study

Farmers can follow any of several models which specify how to operate under uncertainty. Most such schemes are discussed in Chapters II and III. These alternative decision models imply particular psychologies, resource situations and states of knowledge for individuals who use them. Research and extension personnel often use the various models in making recommendations to farmers.

The overall objective of this study is to provide a relevant framework for assisting farmers to select plans which are appropriate for their personal situation. One way to achieve this objective is to provide them with recommendations which are appropriate for their problem setting. Thus, the models used to derive recommendations must be suited to several problem settings. Alternatively, different models may be used for different problem settings. Decision models must be analyzed to determine their implication with respect to goals, knowledge and resource position. Then, research and extension specialists may select choice models which are suited to the farmers whom they counsel.

Little attention has previously been given to determining the appropriateness of the relatively new game theoretic techniques for decision making under uncertainty. Other models, such as those discussed in Chapter II, 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 explain the game theoretic decision criteria, to demonstrate the 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 solution 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.

Other objectives are:

(1) To review traditional approaches to decision making under uncertainty.

(2) To demonstrate methods of processing and using available experimental data in various decision models.

(3) To provide possible solutions to actual decision problems of Iowa farmers.

D. Presentation Outline

Ideas in this dissertation are arranged in the order of their use in the problem solving process. The dissertation problem is stated in this introductory chapter. Chapter II is largely a summary of important contributions to the theory of choice in an uncertain environment. It provides a review of ideas which have been advanced for classifying states of knowledge. Theories about the way people may or do react to uncertainty are also included. Thus, Chapter II provides an important background for analytical work and discussion presented in following chapters.

An introduction to the theory of games is presented in Chapter III. That section provides many of the concepts necessary for understanding and using the related game theoretic criteria discussed in the remainder of the chapter. The mathematical rules and techniques for using game criteria are presented and the criteria are further analyzed to determine their implications and to formulate ideas about their usefulness as tools for agricultural decision making.

A general farmer decision problem is formulated in Chapter IV. The problem statement introduced there helps to delineate important components of farmer problems. Each component is then examined to determine its effect on the final decision. Particular emphasis is given to the influence of the problem setting on decisions. The role of professional agricultural workers in providing data and other assistance to farmers is discussed in Chapter IV. Suggestions are made for modifying some current research and extension activities to increase their contributions to decision making under uncertainty.

The presentation up to Chapter V contains the necessary concepts and techniques for attacking actual farmer uncertainty problems. These are drawn together in Chapter V to form a method for deriving solutions to farmer problems considered in later empirical chapters. The class of farmer problems considered in empirical chapters are specified in Chapter V.

Chapters VI and VII are devoted to various crop and livestock problems. The solutions obtained for those problems allow evaluation of the alternative decision criteria. Possible outcomes for the solutions suggested by each criteria are also computed. The criterion appropriate for a given problem setting is determined by examining possible outcomes. The empirical chapters demonstrate techniques of using the criteria on a variety of farmer problems.

II. UNCERTAINTY THEORY

The body of theory discussed in this chapter has grown out of various attempts to improve man's ability to deal with his uncertain environment. Contributors to the theory have included mathematicians, psychologists, economists, statisticians and representatives from other disciplines. The theory provides models for classifying knowledge situations and predicting choice under various states of knowledge. It also provides alternative normative models for making decisions under different knowledge situations. Thus, a review of ideas relating to uncertainty provides an important background for the analysis undertaken in this dissertation.

Uncertainty theory is reviewed in two parts. First, schemes for classifying knowledge situations are presented. Second, theories concerning the way individuals may or do choose in an uncertain environment are examined. This division is useful for presentation; however, the two topics are not entirely separable. The nature of the uncertainty is determined subjectively by an individual and its classification is influenced by his psychology (2, p. 405). His psychology also influences decisions.

A. Classification of Knowledge Situations

Arrow (2, p. 410) designates two categories of descriptions of uncertain consequences. One utilizes the language of probability distributions. The other calls for other principles which may supplement or replace probability concepts. Probability descriptions may be regarded as originating from several sources (2, p. 410). They may: (a) be subjectively given to individuals, (b) come from limited numbers of *a priori* probabilities or (c) be derived by bringing degree of belief and frequency theories together by use of the law of large numbers (1, p. 71). As is seen later, probabilities are used in computing expected values of outcomes. Outcomes are usually referred to conceptually as utility units (6, p. 391). The use of various ideas on probability is evident from the discussion which follows.

One well known classification of knowledge in an uncertain situation is by Knight (28). Knight's classification is based on whether or not *a priori* or statistical probabilities can be specified for events of interest. If they can be, the situation is one of risk, and if they cannot, uncertainty prevails. His knowledge situations include: (a) perfect certainty, (b) risk, and (c) uncertainty. Certainty is the state of knowledge in which static economic theory applies.

Knight's classification is convenient for setting up decision models. Some decision models may be specified for use in risk situations and others for use under uncertainty. However, Knight's formulation has been criticized on other grounds. For example, it has been pointed out that a manager may have a risk situation but may prefer to act as though uncertainty prevails in order to allow time to pass in waiting for additional information (25). Knight's criterion for defining risk and uncertainty tends to neglect the possibility that knowledge situations are evaluated differently by individuals. One individual may regard an event as certain, another may attach a probability and a third may regard the event as completely uncertain.

Tintner (40, 41, 42) has also made contributions to uncertainty theory. His "certainty" classification is the same as Knight's. The remainder of Tintner's classification falls in the realm of dynamic economic theory. The three knowledge situations under this category are: (a) single valued anticipations, (b) subjective risk, and (c) subjective uncertainty. Single valued anticipations may be used in the same manner as perfect knowledge, or they may be discounted. With subjective risk, there is a known probability distribution for the event of interest. In the use of subjective uncertainty, the decision maker has a subjective probability distribution of probability distributions. Tintner's classification has the advantage of including subjective as well as objective descriptive elements.

Johnson and Haver (26) and Johnson (25) have defined five knowledge situations. These incorporate statistical evidence and experience with subjective individual considerations. Johnson's first class, subjective certainty, corresponds to Knight's certainty but allows for an individual's conviction that knowledge may be regarded as perfect. His second class, subjective uncertainty, is divided into the following four cases: (a) "Risk action" is similar to Tintner's subjective risk. The farmer has sufficient information to take action if action is deemed appropriate. The plan may include precautions for risk. (b) The "learning" case occurs when a farmer thinks he has insufficient knowledge for action and decides to await additional knowledge. (c) An "inactive" situation exists when a farmer has inadequate information for action but declines to continue learning. (d) "Forced action" is a case where knowledge is insufficient but a decision must be made and action taken. Most of the problems considered in this dissertation are characterized by the fourth case.

Shackle (36, 37) proposes another formulation of states of knowledge. He rejects all probability elements, particularly those applied to important, unique decisions. Shackle says that "actuarial general principles and particular facts will only help if . . ." (36, pp. 607): (a) one is sure that the system observed now and in the past will remain the same so that inferences can be made for the future, (b) an individual is interested in the average result of many decisions on the same problem, and (c) there is assurance of having an opportunity to make the same decision many times.

For each outcome of a decision made in an uncertain situation, Shackle assumes there is a degree of potential surprise that this outcome will occur instead of some other. Each outcome-potential surprise pair is ranked in accordance with its ability to stimulate the mind. The highest and lowest ranking pairs of outcome-potential surprise are the ones determining what an individual will do. They are the only ones powerful enough to command the decision maker's attention.

The preceding review of knowledge classification schemes helps to define the class of farmer decision problems considered in this dissertation. They are characterized by subjective risk and subjective uncertainty. Most of the problems require action based on the knowledge available. In some cases, farmers may make decisions as though their anticipations are single valued. However, this situation may not result from confidence in available information but from lack of knowledge of other decision techniques.

B. Models for Choice Under Uncertainty

Literature describing the way individuals may or do make decisions in an uncertain environment includes: (1) attempts to explain the psychology of individuals with regard to uncertainty, (2) evaluation of models or proposals for models for decision making under uncertainty, and (3) enumeration of managerial steps which may be taken to avoid unfavorable contingencies. The first two are discussed in following paragraphs. The third is discussed later in this chapter under the heading of "Measures for living with uncertainty".

Maximization of expected utilities is the model most commonly suggested for decision making under uncertainty. Criticisms of this model are directed at the difficulty of objectively measuring utility and the necessity of indefinite repetition of decisions under similar circumstances. Tintner's suggestions for consideration of other parameters of distributions in addition to expected values reduces the importance of these objections. Empirical applications of the model are often only concerned with maximizing money income over time. The discussion in Chapter IV shows that this procedure misrepresents the goals and situation of some decision makers.

Shackle says that:

> We decide on one particular course of action out of a number of rival courses of action because this one gives us, as an immediately present experience, the most enjoyment by anticipation of its outcome. (36, p. 10)

He believes that choice is made between two rival courses of action by informal use of what he calls the "gambler indifference map" (36, p. 30). Although the Shackle choice model cannot be used in this dissertation, the Hurwicz game theoretic criterion incorporates part of Shackle's ideas.

Simon (38, pp. 241-256) offers ideas which are of particular interest to those who are disturbed by the assumptions about the human organism required by other decision models. Assumptions regarding man's goals, abilities, knowledge and other attributes picture a very unreal individual. Simon tries to construct a decision model which is more consistent with actual human attributes and real life situations. He thinks that actual human rationality striving can only be an approximation of the kind of rationality implied by present models.

Simon introduces modifications in choice rules which he thinks correspond to actual human behavior processes. His model provides for defining a rough set of alternative courses of action. The individual then examines each alternative sequentially to determine its implied outcome. This theory differs from others in that it assumes that individuals simply try to find alternatives with acceptable outcomes, rather than alternatives which maximize expected payoffs. An alternative is acceptable if it satisfies the decision maker's "aspiration level". The aspiration level may change in the course of examining alternatives. On the other hand, the first alternative action examined which allows a satisfactory payoff may be selected.

In addition to game theoretic models, the model for maximizing expected utilities is the only other model actually applied in this dissertation. However, elements of the Shackle model and the Simon model are present in the game theoretic criteria. The problem of quantifying utility is handled by holding other sources of utility constant and working with money income.

The book, Decision Processes (39), contains reports on recent experimental work on individual psychology with respect to uncertainty. Edwards (6) reports on similar activities. Dillon (5) has made a recent contribution in that area. Friedman and Savage (7) have attempted to explain a few aspects of individual psychology in an uncertain environment. Such investigations help to increase understanding of individual reactions to uncertainty and provide a basis for making recommendations for actions under uncertainty.

C. Alternative Approaches to Agricultural Uncertainty Problems

This section is devoted to ideas closely associated with agricultural problems. However, the various approaches to uncertainty problems discussed are not unique to agriculture. Three approaches to uncertainty problems discussed are: (a) research to reduce uncertainty, (b) measures to "live with uncertainty", and (c) education to improve managerial abilities.

1. Research to reduce uncertainty

Considerable resources are allocated to research designed to extend knowledge and understanding of natural phenomena. Technological developments in plant and animal breeding, mechanization, irrigation and fertilization are part of the results of this research. These developments have increased man's ability to control nature directly or to compensate for its uncontrollable variation. As a result, uncertainty has been reduced.

Some attempts have been made to reduce uncertainty resulting from sociological and institutional factors. Such attempts require research to determine the relationships of these factors to farm uncertainty and to devise ways of reducing their effects. Notable proposals have been made for reducing price uncertainty through governmental action (10, 24). These include proposals for forward prices, storage, cooperatives and credit institutions. Many of the laws of the land are designed to set bounds on business relationships between individuals and groups of individuals. Governmental agencies attempt to reduce uncertainty through stabilizing the national economy. The various models behind these activities have come from research and experience of social and physical scientists.

Basic research has added to man's understanding of physiological relationships. The concept of a production function, where output is a function of various inputs, has increased ability to predict the outcome of production. However, most production function work only includes controllable variables. Thus, yield predictions may differ from yields observed because of variation in inputs such as weather. Inclusion of weather, insect, and disease variables in production functions would increase the predictive power of the function, providing that these variables can themselves be roughly predicted.

The idea of statistical prediction of uncertain outcomes is prevalent in agricultural uncertainty literature (4, 10). The predictive models include "naive" models and complex econometric models. The "naive" models usually imply simple relationships between the event to be predicted and variables affecting it. Thus, they assume other than complete uncertainty. Typical "naive" models include use of averages, random outcomes, projections of the present, modes, linear trends, parallel periods, normal periods, outlook material and regression estimates for prediction (10, pp. 478-496). The econometric models are used to determine the interrelated effects of several variables on the object of prediction. An econometric model is considered useful for prediction if it has a high probability of success. The discussion in

Chapter IV shows that such a model has limited usefulness to some farmers. The "average" model is the only one considered in empirical work in this dissertation. Knowledge of states of nature for the problems considered does not justify use of other models. However, the state of knowledge is subjective with individuals. Thus, some farmers may prefer to regard the problems as in the area of certainty or subjective risk rather than uncertainty. Other decision guides then become appropriate.

2. Measures for "living with uncertainty"

In addition to attempts to deal with uncertainty by improving the basis of expectations, suggestions are found in the literature (10, 24, 28) for adjusting plans to "live with uncertainty". These measures may be used to: (1) reduce income variability, (2) prevent returns from falling below some minimum level, or (3) increase the firm's ability to withstand unfavorable economic outcomes (10, p. 505). Hart (8, p. 553) would add that in certain cases the level of returns may be raised when certain precautions are used.

Some farmers are in a position to follow plans which maximize returns over the long run. Precautions presented in this section are not necessarily used by them. The farmers may follow the scheme of selecting plans which have the highest expected income over a period of years. The expected values may be based on long run averages or be derived from weighing possible outcomes by _a priori_ or statistical probabilities. Annual plans may be based on a prediction scheme, such as one of the "naive" models, in which the farmer has confidence. He may select enterprises such as cattle feeding or invest in heavy fertilization or extensive mechanization. Even though returns are low in some years, they may be quite high in others. He can stay in business over the long run and expect to "come out ahead". Characteristics of such farmers are examined in Chapter IV.

Other farmers may choose plans which offer income stability between years. Enterprises may be selected which are regarded as "safe" because they nearly always return some minimum profit. This is the traditional explanation for farmers choosing dairying, beef breeding herds and poultry enterprises. Characteristics of such farmers are also discussed in Chapter IV.

Another precaution for uncertainty is discounting. Even though the farmer has formulated expectations about the future, he may not treat them as if they are "single valued". In this case the discounting is not for time but for uncertainty. The farmer discounts by reducing the value of his expectations by an amount which reflects his "degree of belief" in the expectations or protects him from serious losses. Plans are then geared to the discounted expectation. The effect is that more resources are required for a given output than original expectations imply or that the output expected for a given amount of resources is lower. Price discounting reduces the level of production which is planned. Discounting implies a conservative bias on the part of a farmer.

Insurance and contracts of various kinds represent attempts to reduce adverse effects which may occur under uncertainty. These devices are means of avoiding possible large losses by sacrificing returns in most years. In the case of insurance, a nearly certain small loss is substituted for a small chance of a large loss. However, all types of uncertainty in agriculture are not formally insurable. Contracts offer a means of shifting the risk of unfavorable events to other individuals willing or able to bear the consequences. Thus, it is similar to insurance. The cost is giving up a chance to profit from favorable events.

Diversification is one of the better known methods of meeting uncertainty. The diversification of interest here is not practiced to take advantage of complimentary production relationships but to reduce income variability. The idea is to: (a) combine enterprises whose production is not highly correlated (*i.e.*, with correlation coefficients ≤ 0); (b) combine enterprises with low variance with more profitable ones having higher variances; (c) increase resource employment by adding enterprises with lower variance than present enterprises or low correlation with present enterprises.

Heady (10, pp. 510-522) has outlined the conditions under which income variability will be decreased by diversification. In addition he and associates have provided estimates of variances and correlations of various enterprises in Iowa (3, 12). The estimates provided are useful if the sample of yields or prices on which they are based are representative of future yields and prices.

Flexibility may be defined as the ability of a manager to adjust his plans as time passes to take advantage of additional information. Such changes can be made in most plans at some cost, thus the definition must be qualified by adding that the changes should not result in prohibitive costs. For example, a change from Grade A dairying is quite costly if the facilities are highly specialized. The plan would be more flexible if the operation were Grade C with low cost or multiple use facilities. The cost of flexibility is low efficiency in "normal" or "average" years.

Liquidity is another uncertainty precaution. It may be regarded as a form of flexibility in that liquidity exists when assets can be transferred quickly, at low cost, into another asset form. Liquidity reserves for the farmer the opportunity to change his plan to take advantage of unexpected profitable alternatives. It also enables the farmer to "live through" unfavorable developments by converting liquid assets into funds to be used for family living and to pay annual fixed outlays. An individual with a high equity ratio has greater liquidity, other things equal, than one with a low equity ratio. Legal or institutional equity restrictions are not so limiting. Thus, he has security for additional borrowed funds.

3. Education to improve managerial abilities

Another activity of agricultural economists and other professional agricultural workers is education to improve managerial abilities. This activity is complimentary with others discussed in the two preceding sections. Farmers must know about precautions for uncertainty and have the data and knowledge necessary to predict outcomes. The required knowledge comes through education designed to increase abilities to formulate problems and solve them. This requires training in techniques and concepts, and involves learning to reason both inductively and deductively. Another form of education comes from provision of data in forms which farmers can use.

The latter is emphasized in later sections of this dissertation.

III. GAME THEORETIC TECHNIQUES

The decision criteria discussed in this chapter are for use in a knowledge situation characterized by complete uncertainty. Thus, they supplement the models adapted to risk and uncertainty situations presented in Chapter II. These criteria, along with the model for maximizing utility, are the only decision models which can be meaningfully applied to empirical problems by an individual other than the decision maker. That is, they are the only models providing an objective rule for obtaining an implied or explicit goal. Such models are normative rather than positive.

A. Two-Person Zero-Sum Games

The game theoretic techniques are closely related to the two-person zero-sum game. Thus, the concepts involved in that problem are briefly reviewed. Luce and Raiffa (29) and other authors (33) provide a very complete treatment of game theory.

The two players, opposing each other in this type of game, each have a finite number of alternative courses of action called a strategy set. These sets are designated as follows:

$$S_1 = \{ a_1, a_2, \ldots, a_m \} \text{ and}$$

$$S_2 = \{ b_1, b_2, \ldots, b_n \} .$$

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} ($i = 1, \ldots, m$ and $j = 1, \ldots, n$) entry in this matrix is the outcome of Player 1 choosing his ith strategy and Player 2 choosing his jth strategy. A payoff matrix appears as follows:

Player 1	Player 2: b_1	b_2	b_3
a_1	3	5	1
a_2	6	-3	0

In the above game, choice of strategy a_2 by Player 1 and b_2 by Player 2 results in an outcome of -3. The outcomes may take on a wide variety of interpretations (29, pp. 57-58). For simplicity, they are simply regarded as dollars in this chapter. A minus sign means that Player 2 gains dollars and

Player 1 loses and conversely for a positive sign. This characterizes a "strictly competitive" game in which the players have "strictly opposing" preference patterns for the outcome of the game (29, p. 59). The outcomes are defined so that the gain of one player is the loss of the other. Thus, the game is zero sum. This relationship is apparent in the following section.

1. The game solution

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 the 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 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.

2. Games with equilibrum pairs

Consider the following game matrix:

Player 2

		b_1	b_2
Player 1	a_1	3	4
	a_2	2	8

Assume that each player knows all the payoffs in this matrix and is trying to obtain the highest one possible. Each player must select his strategy not only by the outcome which it implies but also by what reasoning tells him his opponent may do. Player 1 can see that the highest sure payoff which he can receive is $3.00. This comes from using a_1. Player 2 can never lose more than $3.00 if he uses b_1. In this game, $3.00 is the minimum in its row and the maximum in its column. The row and column represent a pair of strategies called an "equilibrum pair". The term, equilibrum, is applied because neither player has an incentive to change his strategy choice if the other does not. This is the solution to a game with a "saddle point", (*i.e.*, $\underset{j}{\text{Min.}}\ O_{ij} = \underset{i}{\text{Max.}}\ O_{ij}$; $i = 1, \ldots m$ and $j = 1, \ldots n$). The solution for a game with a saddle point is obtained by writing the minimum in each row beside the row and the maximum in each column below the column. The saddle point occurs where the minimum in a row is also the maximum in a column. The equilibrum pair of strategies is given by the row and column in which the saddle point occurs. The solution is a pure strategy in this case. A player does not have to use the strategy specified by the solution; however, it is the only one assuring him a payoff of $3.00 or more,* regardless of what the other player does. A_1 assures Player 1 a maximum minimum payoff of $3.00 and is called his "maximin" strategy; b_2 is Player 2's "minimax" strategy. Player 2 can do his worst to Player 1 by following the minimax strategy. The maximin strategy is the best strategy against the worst Player 2 can do.

3. Games without an equilibrum pair

All games do not have equilibrum pairs. For example, the following matrix has no equilibrum pair.

		Player 2 b_1	Player 2 b_2
Player 1	a_1	4	2
	a_2	1	3

Game problems such as the one above have led to the formulation of a game solution which calls for a mixed strategy. The mixed strategy for a small matrix may be derived by use

*"More", in the case of Player 2, is actually a lower level of loss.

of simple algebraic techniques. In the above game problem, Player 1 wants to maximize the outcome, V. To achieve this he must use his alternatives, a_1 and a_2, in such proportions, p_1 and p_2, that if Player 2 uses b_1,

$$V = 4\ p_1 + 1\ p_2 \ . \qquad (1)$$

He also wants to use a_1 and a_2 in such proportions, p_1 and p_2, that,

$$V = 2\ p_1 + 3\ p_2 \ . \qquad (2)$$

p_1 and p_2 are proportions; thus,

$$p_1 + p_2 = 1 \ . \qquad (3)$$

These three equations may be solved simultaneously to obtain:

$$V = \frac{5}{2} = 4p_1 + 1p_2 = (4)(1/2) + (1)(1/2) \ , \text{ and} \qquad (4)$$

$$V = \frac{5}{2} = 2p_1 + 3p_2 = (2)(1/2) + (3)(1/2) \ . \qquad (5)$$

Equations 4 and 5 say that regardless of which strategy Player 2 uses, Player 1 can always receive 5/2 by playing $(1/2a_1,\ 1/2a_2)$. Actually 5/2 is the minimum payoff which Player 1 can expect; however, the payoff may be greater than V. Thus, equations 1 and 2 can be written:

$$V \leq 4p_1 + 1p_2 \ , \text{ and} \qquad (6)$$

$$V \leq 2p_1 + 3p_2 \ . \qquad (7)$$

A similar procedure yields the mixed strategy, $(q_1\ b_1,\ q_2\ b_2)$, for Player 2. Player 2 wants to select a strategy that minimizes V because Player 1's gains are his losses. Thus, he can minimize losses by minimizing V. The relation to be fulfilled is as follows:

$$V \geq 4q_1 + 2q_2 \tag{8}$$

$$V \geq 1q_1 + 3q_2 \ . \tag{9}$$

Player 2's strategy is ($1/4b_1$, $3/4b_2$) and the security level is 5/2. This is the same as the security level for Player 1 because the game is zero-sum.

Solutions for games with large payoff matrices may be obtained by use of the simplex method (11). Heady (9) and others (29, pp. 408-419) have presented procedures for converting the game to a linear programming problem to be solved by use of the simplex method. The simplex procedure is used for solving empirical problems presented in later chapters.

B. Games Against Nature

The application of game theory in this study is to "games against nature" (29, pp. 275-318). The problem visualized in a game against nature is that:

> 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_m. (29, p. 276)

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 each state of nature pair there is an outcome, O_{ij}. All possible pairs form a payoff matrix which is the same as 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. Most of the problems considered in this dissertation will allow a mixed strategy to be used in the playing of a single game.

The knowledge situation for games against nature is taken to be complete uncertainty as to which state of nature will occur. Several criteria have been 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 in this dissertation. The criteria are discussed in the following pages. Emphasis is placed on the rules for obtaining solutions, the implications of the criteria and the relationship of the criteria with other decision models for imperfect knowledge situations.

1. <u>Wald maximin criterion</u> (15, 29, 39, 44) .

Assume a decision problem under uncertainty with acts $A_1, A_2, \ldots A_m$ and States $S_1, S_2, \ldots S_n$. In using the Wald criterion, each act is assigned an index which is its security level. For the problem below, 2 is the security level for A_1 and 1 is the security level for A_2.

$$\begin{array}{c} \\ A_1 \\ A_2 \end{array} \begin{array}{cc} S_1 & S_2 \\ \end{array}$$

$$\begin{matrix} & S_1 & S_2 \\ A_1 & 2 & 3 \\ A_2 & 4 & 1 \end{matrix}$$

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 if 10/4 and the strategy is $(3/4A_1, 1/4A_2)$.

If the A_i are farmer strategies and the S_j are states of nature, the above 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 was shown in previous discussion that the maximin strategy 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. However, many farmers 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 in Chapter IV; however, it is instructive to mention a few such attributes in this section to show that the Wald criterion is a useful model for decision making under uncertainty.

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

The Wald criterion may suggest a farming plan similar to those suggested by various precautions for uncertainty discussed in Chapter II. In a problem requiring choice of alternative crops, a Wald mixed strategy would call for growing several crops to insure the highest security level. This is equivalent to diversification to insure a minimum income level each year. The Wald solution may also call for diversifying inputs such as crop varieties or amounts of fertilizer. In appropriate problems, the Wald criterion may indicate that a practice such as contracting for purchases or sales allows the highest security level. Thus, it appears that use of the

Wald criterion has actually been advocated by farm management specialists for several years.

2. Savage regret criterion (29, 35, 39)

The Savage regret criterion is suggested by an analysis of the following decision problem under uncertainty.

	S_1	S_2
A_1	18	21
A_2	17	26

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. Savage (35) suggests defining the (negative) regret matrix, (V_{ij}), by

$$V_{ij} = O_{ij} - \underset{k}{\text{Max}}\, O_{kj} \ .$$

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:

	S_1	S_2
A_1	0	-5
A_2	-1	0

Each entry, r_{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 above 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 only used 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. However, some plans suggested by the 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.

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

Consider a farmer situation where returns above variable costs must be \$18.00 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 \$1.00 regret from choosing A_2 may be more important than the possible \$5.00 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	Barn does burn
		S_1	S_2
Do not insure	A_1	0	-5000
Insure	A_2	-15	-15

$$\longrightarrow \begin{array}{c|cc} & S_1 & S_2 \\ A_1 & 0 & -4985 \\ A_2 & -15 & 0 \end{array}$$

The minimum payoff in row A_1 of the regret matrix is -4985 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 is then not placed on the one regret which is the highest. Some importance is attached to lower possible regret. In the following problem a strategy of (1/6 A_1, 5/6 A_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.

	S_1	S_2
A_1	18	21
A_2	17	26

	S_1	S_2
A_1	0	-5
A_2	-1	0

The minimum regret with a mixed strategy is 5/6 compared to a regret of 1 if A_2 is used exclusively. In addition, a payoff level of 17.2, rather than 17, is assured. This property of the Savage regret criterion is further discussed in a later chapter.

3. Hurwicz criterion (16, 29, 39)

Hurwicz (16) proposes to look at the state 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, $(0 \leq \alpha \leq 1)$ 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.

Hurwicz suggested his criterion as 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. This criterion is similar to Shackle's decision model in that the best and worst that can happen are assumed to be the only values important enough to warrant the decision maker's attention. 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.

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

He may form the index, $(.3)\ (0) + (1 - .3)3$, for A_2. However, the index for A_1 must be $(.3)\ (0) + (1 - .3)8$. 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 (29, pp. 282-283) suggest deriving the α by a simple empirical problem.

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

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 may indicate a preference for gambling on a higher return. It may also represent the situation of a decision maker who must have a high return to stay in the game and who must gamble. If the x is relatively low, the relevant case may be a decision maker who prefers not to gamble. It may also 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 need for a given level of return. Any of these descriptions of individual psychology or resource situations could characterize some farmers. Thus, the Hurwicz criterion is deemed applicable to farmer problems.

4. <u>Laplace criterion</u> (29, 39)

The Laplace criterion is based on the "principle of insufficient reason" (29, p. 284). 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 essentially treated 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.

IV. THE FARMER DECISION PROBLEM

The choice models outlined in Chapters II and III suggest a number of ways of resolving farming decision problems. Which model should a given farmer select? This question can only be answered authoritatively after a careful analysis of the setting in which the problem is framed. Some indication was given in preceding chapters of the circumstances under which particular decision models are most appropriate. This chapter is devoted primarily to further analysis of factors which affect the problem setting. The nature of the factors' effects on uncertainty are given particular emphasis.

A. General Formulation of a Farmer Decision Problem

A general statement of a farmer decision problem helps to point out important components of the problem. In order for a decision to be required, the farmer must have alternative courses of action. These courses of action may be thought of as a set; A_1, A_2, . . . A_m. The size of the set, m, is limited by known and available technology. It is also limited by the resources which the farmer will devote to the particular activity in question. Thus, the set of courses of action may be different for every farmer.

For a given problem, a set of conditions, S_1, S_2, . . . S_n, which could prevail during the period of interest, can be specified. Conditions of interest may be thought of as states or levels of variables which may influence the outcome of alternative farmer acts. They may be states of nature such as were referred to in the game theoretic chapter. Alternatively, they may be possible courses of action of other individuals with whom the farmer is competing. Most of these conditions are not predictable or controllable by the farmer. The degree to which they are determines whether certainty, risk or uncertainty prevails. The conditions that may exist during the period in which a plan is carried out are further discussed in a later section of this chapter.

For each alternative course of action, there is an outcome which is determined by the condition that prevails during the period the action is effective. The game theory discussion showed how a matrix of possible outcomes may be constructed by considering all possible pairs of A_i and S_i. In order to reach this stage in problem formulation, the farmer must gather and organize available knowledge and specify alternative courses of action. Finally, he must estimate possible outcomes of alternative plans. Problem solving steps remaining are selecting a course of action and putting the plan in action. Obviously, a farmer must accept the consequences of his choice.

The following analysis of factors affecting decisions help to explain or anticipate the decision which a farmer makes. Professional agricultural workers must be cognizant of possible problem settings if they are to provide data and recommendations which are of maximum use for farmers. The following setting analysis is designed to broaden their understanding of farmer circumstances.

B. Analysis of Problem Setting Components

A problem setting may be described by analysis of the following variables: (a) alternative courses of action allowed by a particular farmer's resource situation and known technology; (b) 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 a description of these variables would not be the same for all farmers.

1. Alternative courses of action

Most farmers are aware of crops adapted to their locality. They also know which classes of livestock can utilize available feed. Research and extension workers are generally proficient in listing physical possibilities for using resources and are familiar with existing technology. Thus, they are able to specify alternative cultural practices, feeding practices, machinery combinations, varieties, breeds and construction techniques. Any of the above may be the subject of choice in a farmer decision problem. In general, a farmer, and advisors working with him, should have no difficulty in specifying alternative courses of action. The critical point is whether sufficient effort is actually devoted to listing relevant, technically possible alternatives. From technically possible alternatives, a farmer must choose those which his resources allow. The resource position may affect decisions in other ways discussed in the following section.

2. Characteristics of individual farmers

The theory of choice attempts to explain or predict human behavior by combining preference structures and physical possibilities into one model. Preference structures are reflected by ends or goals. Resource limitations and technology determine physical possibilities and may be thought of as means of obtaining goals or ends. The resource situation may also affect the goals which farmers make known. This section is devoted to an examination of goals which farmers may have and to an analysis of factors which influence selection of those goals. This section has considerable influence on choice of relevant decision models in this dissertation.

a. Farmer goals. The goal most often attributed to farmers is to maximize returns over a relatively long period of time. This is the goal implied by the average "naive" model and the probability (risk) model discussed in Chapter II. As was indicated there, the concept is to maximize utility, but in empirical applications, utility is usually considered to be a function of money. The goal of maximizing dollar returns is an intermediate one which is necessary for the end of obtaining consumable goods and services. Discussion in this section shows that farmers cannot always act as though profit maximization over time is their objective.

Some farmers prefer 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.

A particular value system is often attributed to farmers. For example, it is sometimes suggested that the goal of farm ownership is motivated not only by a desire for security but also by a sincere belief that an individual should be a "steward of the soil". Debt may be avoided because it is thought to be an unfavorable reflection on character. Farmers with this type of value system may follow quite inflexible farming systems because vacilation in farming is "bad". These value judgments may result in plans which are clearly inconsistent with profit maximization.

The possible farmer characteristics discussed above may be appropriate to various decision models if outcomes are properly defined. Thus, even though the practical difficulties are great, various farmer problems can conceptually be resolved by the techniques discussed in this dissertation. A different situation exists if outcomes cannot be modified so that given decision models are relevant as a guide to choice. The problem then is not in defining outcomes but in choosing models which are consistent with the desired goals. The following farmer situations lead to farmer goals which may be obtained by following only one or a few of the decision models discussed in this study.

b. Farmer situations affecting choice of decision models. Various psychological traits may have considerable influence on decisions. For example, the need for financial security is a trait which varies between farmers. This trait affects a farmer's attitude toward chance-taking. To some, taking a chance is a source of satisfaction. In that case, high risk enterprises may be selected because of a chance for high profits and for the satisfaction of gambling. Most farmers probably have some degree of "risk aversion" (10, pp. 550-557). This indicates a distaste for gambling or an inability to gamble due to resource restrictions.

The psychology of an individual with regard to risk is affected by his age, equity position and family situation. A young farmer may gamble in farming 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 family must provide for their living (if it suits his value system) and is often forced to be conservative.

A farmer with a strong equity position can withstand losses in a few years and recover them in other years. Severe capital restrictions may prevent a farmer from adopting plans which would be most profitable in the long run. He would not be willing to risk the short run chance of resource depletion and severe financial hardship.

A farmer's tenure arrangement is part of his general resource situation. He may be an owner with various amounts of equity, an owner-renter, or a cash, share or partnership renter. 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. Such a plan is followed to assure an acceptable income level each year rather than an acceptable average income over a period of years. The annual payment of a cash renter may necessitate a plan which assures payment of the required rent. Share tenants must sometimes take landlord preferences into account. The landlord may prefer a stable income each year rather than a higher, variable income over several years.

The importance of a decision in terms of possible magnitudes of desirable or undesirable consequences may also affect choice. A farmer may be classified as conservative because he follows a plan for his main enterprise which assures a minimum income level each year. However, he may use a few resources in a risky enterprise because he has little to lose and may make a substantial profit. Thus, it is important to determine the criticalness of a decision when suggesting solutions to farmer problems.

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 quite 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 plan is irrevocable. An unfavorable outcome might force the farmer into severe financial stress or out of business.

The situations affecting farmer goals (and thus his decisions) are highly interrelated. The effect of one situation is conditioned by the state of another. Thus, the preceding discussion has resulted in overlapping ideas in several places. Present understanding of farmer goals is relatively limited. Extension or research personnel can probably discover additional important farmer characteristics affecting decisions. However, the presentation here should broaden the basis for making farmer recommendations. In Chapter V, the various farmer situations discussed are used in specifying relevant choice models for the farmer problems considered in empirical chapters.

3. <u>The knowledge situation</u>

It is well known that decisions are made with various amounts of information. Data relevant to a particular problem may come from several sources. It comes from other farmers, a wide assortment of publications and professional agricultural workers with various amounts of technical training. The data which a given farmer has is a function of the sources he uses and the amount each can supply. It is assumed in this study that the farmer is very thorough in gathering information or that extension personnel take the initiative in supplying data. Thus, the problem of obtaining data is not considered in this section.

The problem faced is that of analyzing available data and determining its adequacy for use in planning future actions. Even when other aspects of the problem are identical, the knowledge situation may differ between farmers because of the subjective nature of its evaluation. Thus, it is important to analyze the knowledge situation for individual farmers or groups of farmers when choosing decision models on which to base recommendations.

The very infrequent case of perfect knowledge of production processes and the future is only briefly treated. In the case of "certainty", the set of future conditions is reduced to one unique condition. The farmer can simply compare alternative actions on the basis of how nearly they obtain his goal and select the optimum one. If a farmer thinks he knows enough about the future to have "single valued expectations", the same procedure is applicable. However, expectations may be discounted before applying choice criteria.

Other degrees of knowledge range from risk through uncertainty. This implies that there is a set composed of more than one possible condition which can prevail. The conditions which must be considered vary between problems. In production problems, they are unpredictable and uncontrollable variables which affect output or profit. For example, crop production is affected by weather variables, insects and disease. Weather influences livestock production directly by affecting the feed efficiency and indirectly by affecting feed production. In addition, feed efficiencies and rates of gain vary because of unobservable and unpredictable differences in animals fed in different years. Thus, the farmer is not always able to predict feed requirements or the date animals will reach a given market grade or weight. It is also well known that exact prices cannot be predicted accurately. In a risk or uncertainty situation, several price levels may be regarded as possible. All possible combinations of prices and natural factors form the set of conditions. The outcome of investment decisions is affected by prices and technological change. Thus, all combinations of these form the future possible conditions.

Some farmer problems involve competition with another individual such as a landlord, a salesman or a buyer. In that case, the outcome of a course of action is affected by a set composed of alternative actions of a competitor. This is a true two-person game situation. The game criterion is strictly applicable because the competitor can be assumed to be trying to do his best for himself and his worst to the farmer. This involves implied assumptions that the farmer knows alternative courses of action of his competitor and that the competitor will act rationally. Some might argue that the farmer competes with all other farmers in markets. However, Dillon (5) has shown that, since farming is largely pure competition, the farmer may regard the price situation as a "state of nature". All other farmers are not actively trying to do their worst to one farmer.

Specification of a set of possible conditions is important for a number of reasons. For one thing, the farmer must know possible outcomes in order to make a decision which fits his individual situation. That is, he must not only know averages but minimum outcomes as well. The set of conditions is also helpful in stratifying available data. The procedure of considering alternative "states of nature" discourages combination of data generated from very different conditions. For example, crop yield data from experiments conducted in different years would be considered outcomes of different states of nature but possibly 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 it 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) 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 between farmers. It depends on his 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 is discussed in later chapters.

C. Role of Research and Extension in the Problem Solving Process

The problem statement and analysis of factors affecting its solution could provide a useful guide to research and extension workers. The discussion gives a broad perspective of the problem which may influence the activities of professional agricultural workers. This section includes a brief summary of present and past work in the area of providing assistance to decision makers. Suggestions are also made for possible adjustments in the future.

Agricultural workers have devoted considerable effort to providing data and recommendations to farmers. Most important farmer decision problems have been given some attention. Data provided are usually averages or point estimates. For example, estimates of average yields, average input requirements and average prices are available for a wide range of activities. Although there are notable exceptions, little attention has been given to other parameters of yield or price distributions such as variance, range or skewness.

Good reasons exist for the kinds of data and recommendations which have been provided to farmers in the past. For many years (and even now in some areas) agricultural technical knowledge was very limited. Farmer technical knowledge was even more meager. Emphasis was logically placed on providing data of some kind, even if it represented point estimates of input-ouput coefficients relating to one year. Very little data were available which reflected the effects of uncontrollable variables. However, careful researchers described the exact situation being reported so that farmers could recognize data limitations. Technological development in agriculture has been so rapid that a shortage of data representing replication over time still exists. With each innovation, old research is often discontinued and new started. Research staff turnover and other administrative problems often limit the length of a particular research project. Difficulties of the above kind are virtually unpreventable and inadequate data naturally result.

Very often a decision has been made to derive data for other purposes than farmer decision making. For example, basic research has been conducted to advance knowledge of plant and animal physiology. Presumably, the results of such research are then used in more applied work which is directly useful to farmers. Such decisions have probably been sound. Agricultural research in these areas has made a great contribution to national and agricultural productivity. Basic research will and should be continued. However, at some point, the marginal value of research resources in that area may be less than the marginal returns from resources used to provide specialized data for particular farmer situations.

In some instances, the limitation of data to be used for farmer planning is the result of a narrow perspective of farmer problems and goals. The farmer is often assumed to be trying to maximize profit over time. This leads to the conclusion that averages over time are adequate as farmer expectations. On the other hand, over-zealous suggestions for diversification tend to emphasize the desire for income stability. Emphasis on mechanization to reduce average costs overlooks the value of liquidity and in some cases flexibility. The treatment of the problem in the preceding section should broaden appreciation of differences in farmer goals and, thus, the plans they wish to follow.

In the present agricultural research and education setting, data and recommendations can be improved. One way is to make several recommendations, each implying a different goal or resource situation. In that way, farmers may choose recommendations which suit their own situation. Research plans may include consideration of the value of the data for planning in addition to its specific scientific purpose. In many cases, adjustments may be made in experiments which cost little but provide additional data for decision making. Data which were generated for one purpose are often adaptable for other purposes. This requires that the researcher know the kinds of information needed.

The actual farmer decision problems treated in this dissertation demonstrate ways of using available data and improving recommendations. Techniques are shown for adapting data to farmer needs. The plans resulting from application of alternative decision criteria are shown. These plans may be published as a variety of recommendations which are applicable in various farmer situations. In addition, the problems considered are ones about which research and extension personnel are frequently counseled. The techniques demonstrated may thus be directly adopted by such workers.

V. PROCEDURE FOR APPLICATION AND EVALUATION OF ALTERNATIVE DECISION MODELS

Preceding chapters provide the background and technical knowledge required for assisting farmers with decision problems. The knowledge situations which may characterize decision models have been discussed. Various models which may be used in making the required decision have been presented. Of these, only the game theoretic models, the "naive" models and the probability (risk) model can be used normatively. The others either only attempt to explain how decisions are made (positive models) or are subsumed by the normative models mentioned above. Chapter IV has shown that several factors may affect the desired outcome of a decision. The procedure used in examining empirical problems in Chapters VI and VII is reviewed in this chapter. However, the importance of this chapter is in demonstrating a technique for bringing problem setting components and alternative decision models together to form a systematic procedure for deriving solutions to actual farmer problems.

A. Farmer Problems Considered

The farmer decision problems treated in the following chapters are limited to individual ones within the whole farm plan. For example, they include choice of crop varieties, fertilizer rates, pasture mixtures and stocking rates.

Obviously, such problems imply that a decision has already been made to devote some level of resources to a particular farming alternative. Such within farm or within enterprise decision problems are emphasized because they are convenient for demonstrating problem formulation and techniques of applying criteria.

It is not entirely unrealistic to consider farmer problems which are a part of the overall farm management task. Extension and research personnel are often asked for advice concerning enterprises and other within farm problems. In fact, very little of their time and effort is spent on whole farm problems. In some geographical areas, a few enterprises are clearly most profitable. In that case the management task is simply choice of input levels and technology. As was seen in Chapter IV, personal preferences and the resource situation often dictate which enterprises are selected. Decisions are then only required for how much, when and how.

Most of the problems considered deal with technical uncertainty. In most cases prices are assumed known. This assumption is good for crops for which price supports exist. However, livestock prices can not be predicted very accurately. In that case price uncertainty is probably a larger problem to the farmer than technical uncertainty. Time and other resources available for this study limited the number of problems studied and the choice was made to study technical aspects of uncertainty problems. Dillon (5) has demonstrated the application of game theoretic methods to price uncertainty problems in livestock production.

B. Problem Settings Hypothesized and Decision Models Applied

In order to analyze the appropriateness of alternative decision criteria, it is necessary to compare the outcomes which may result from using the criteria with the outcomes desired by farmers. It has been shown that the outcomes desired by a farmer depend on his particular problem setting. Thus, it is necessary to specify the problem setting in order to arrive at relevant farmer goals.

The many factors which affect decisions can occur in a number of combinations. Each combination can technically be called a unique problem setting. Thus, a large number of problem settings could be considered. In order to keep this study within manageable size, it is necessary to hypothesize a limited number of problem settings. Actually only two are considered. However, these are general enough to encompass a number of combinations of factors which affect goals.

The first problem setting is characterized by a situation in which a farmer can act as though he is to maximize income over a long period of time. This setting may imply a multitude of farmer characteristics. For example, the farmer's goal may be to maximize income over time. That goal may not be feasible unless his resource situation allows him to absorb losses in some years and regain them in others. That is, he must be able to survive over a period long enough that observed values approach expected values. Intertemporal substitution of funds may be achieved by borrowing on equity or using cash reserves. However, this requires the managerial and personal characteristics necessary to plan and carry out such substitution. In the past many farmers have essentially followed a plan to maximize income over time. The recurrence of farmer stress in unfavorable periods and opulence in favorable years indicates that farmers have some difficulty in achieving intertemporal transfer of income.

Other factors leading to this problem setting were discussed in Chapter IV. The farmer must have a particular psychology with regard to risk. He should not receive lower satisfaction from experiencing losses in some years compared with the satisfaction he obtains from stable, though lower, income every year. This problem setting may occur when an unfavorable outcome has unimportant negative effects on the farmer's economic well being. It may also occur when one farmer course of action clearly dominates all others.

Several decision criteria may be appropriate for planning long run profit maximization. If the knowledge situation is one of complete uncertainty the Laplace criterion may be used. This criterion says to average outcomes for each farmer alternative over states of nature. The course of action with the highest average is chosen. This criterion is applied to each problem in the empirical analysis.

The average model mentioned previously is also applicable to this problem setting. It calls for following a plan which maximizes the expected value of a probability distribution of outcomes. The outcomes are assumed to have equal probabilities. Thus, the expected value is the average (arithmetic mean) of past outcomes which have resulted from various states of uncertain, uncontrollable inputs and constant levels of known, controllable inputs. The inference is that past, observed outcomes are a random sample from a population of possible outcomes. The sample average is assumed to be an unbiased estimate of the population mean. If the assumption is true, a farmer can maximize long run profits by choosing the alternative plan which has the preferred (highest, least costly, etc.) outcome. He must be able to continue in farming long enough to experience a sample of outcomes which averages out to the expected value.

It can be seen that the average model described above is similar to the Laplace criterion. Theoretically, the Laplace criterion calls for considering all possible states of nature. However, in practice, the states of nature included must be limited to those for which data are available. For the empirical problems studied later, this is equivalent to considering only the outcomes which have been observed in the past. Few identical states of nature occur, thus no weighting problem arises which might cause the average model and the Laplace criterion to differ.

If used in a slightly different manner than outlined above, the average model may give a different solution than the Laplace. The average model may be used to formulate expectations of states of nature on which to base plans. For example, expectations for rainfall may be formed by averaging past rainfall. The average rainfall might be regarded as certain ("single valued expectation") and a plan devised to fulfill all the marginal conditions (14) for maximizing profits. The plan resulting may call for resource uses not previously visualized as alternatives. However, if care is taken in specifying alternatives this difficulty will not occur. It will also not occur in a problem for which resource use alternatives are not continuously variable. That is, when there is a finite set of discrete alternatives.

In practice, the difference between the models would seldom be great. Frequently, data are available for only a few farmer alternatives; thus, both models would consider the same courses of action. If empirically derived production functions are available which include uncertain variables, the average may suggest a different plan. The Laplace model is regarded as a substitute for the average model in this dissertation.

If the knowledge situation permits, a farmer in a problem setting which allows long run profit maximization may wish to treat the problem as one of risk. Estimates of the probability of uncontrollable conditions occurring are necessary if the probability (risk) model is to be used. In addition, the farmer must have enough confidence in the probabilities to use them for planning. The probability model uses the concept of maximizing expected values (income). The average model is actually a special case of the probability model in which the weights applied to past outcomes are $1/n$.* The probabilities used in obtaining expected values for the probability model may be any value, $0 \leq P \leq 1$. The alternative with the highest expected value is the one chosen.

Probabilities of various natural factors which affect outcomes of farmer decisions can often be estimated. For example, a frequency distribution can be constructed for rainfall by using available weather records. The assumption

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*n is the number of past outcomes used to estimate the mean of a population of possible outcomes.

is required that future weather will be like the past. In the following example, rainfall is grouped into three categories:

		Weather		
		Good	Average	Bad
Farmer alternatives	A	50	30	15
	B	45	35	20
	C	35	35	25

Assume that the probabilty of good weather is .2; average weather, .55; and, bad, .25. The expected outcomes for each alternative are as follows:

$$A: \quad 50(.2) + 30(.55) + 15(.25) = 30.25$$

$$B: \quad 45(.2) + 35(.55) + 20(.25) = 33.25$$

$$C: \quad 35(.2) + 35(.55) + 25(.25) = 32.5$$

Alternative B is the one selected by the probability model. That is, it would be expected that alternative B would be the most profitable over the long run. This model is applied to only one empirical problem. It is the only problem for which probabilities can be computed. In most problems a state of nature is simply identified by a year. The year is a composite state of nature which expresses the state of many natural uncertain variables. A joint probability distribution of all those variables would be nearly impossible to construct.

The second general problem setting considered in empirical chapters is one in which farmers must consider the short run level of returns. As was true with the preceding problem setting, several individual and problem characteristics lead to this setting. The farmer under consideration may be a very conservative individual. He may feel great dissatisfaction from experiencing losses or may get little satisfaction from gambling on a high return. The farm family may have goals which require a minimum income level each year. For example, they may wish to buy appliances, improve the home or have a vacation each year. They would not be willing to follow a farming plan which leaves a chance of foregoing those items. The amount of resources available may offset the pressure of family needs. If resources are unlimited, income floors can be set at any level. Family responsibilities differ between farmers so that two farmers having the same resources may select different plans. One may plan for long run profit maximization and the other for a minimum income level. A "one time" decision may also lead to this problem setting. However, no one time decisions are considered in this study. Some types of rental arrangements cause this setting.

The most severe problem setting requiring attention to income variability between years might include all the factors mentioned - psychology, resource position, family responsibility and rental arrangement. In other cases only a few of the factors may be important. Since the degree to which each restricts planning varies, one would expect to find farmers who take income variability into account in different ways. Thus, the decision problems appropriate to this problem setting may be used in conjunction with decision models appropriate for long run profit maximization. That is, one model may be used on one problem and another on a different problem.

The Wald criterion is appropriate for choosing a plan which assures a minimum income level each year. It may or may not reduce income variability but is sure to skew the direction of variation toward higher incomes. A very conservative farmer might follow the Wald criterion regardless of his resource position. However, a farmer would not necessarily follow it because of acute resource restrictions. He might be willing to gamble and accept the consequences. The Wald criterion is applied to each of the farmer problems in following chapters.

It is not deemed necessary to consider other more traditional models for behavior under uncertainty. The Wald criterion subsumes such actions as diversifying, choosing low risk activities and providing for flexibility. It might also suggest liquidity in an appropriate problem. Thus, the Wald criterion, with both pure and mixed strategies, is the only choice model used explicitly for this problem setting. In the following section, situations in which the Hurwicz and Savage regret criteria are applicable to this problem setting are indicated.

C. Other Decision Models and Their Application

The Hurwicz and Savage regret criteria are not uniquely applicable to either of the problem settings discussed in this chapter. It is shown here that they have properties which may suit them to either setting. The outcome of using the criteria depends primarily on the characteristics of the problem and the farmer.

As was shown in Chapter III, the pessimism-optimism index, α, reflects the willingness or ability of a particular farmer to take chances. A low α causes the farmer to weigh favorable outcomes heavily. A plan results which may subject the farmer to a low income in some years. This requires a problem setting allowing long run profit maximization. However, the plan may not be the same as that suggested by the Laplace criterion. The Hurwicz criterion with a relatively small α may not select the plan with the highest average. Thus, the inference is that a farmer using the Hurwicz with an α very near zero is gambling on a distribution of states of nature other than one in which states are equally likely. In empirical work, the Hurwicz solution, using a very small α, is called the "gambling plan".

The Hurwicz solution with a range of α including 0 calls for an alternative which allows a maximum minimum income level each year. It places emphasis on the possible adverse effects of a highly unfavorable outcome. It gives the same plan as the Wald pure strategy. If the range of α does not include 0, some emphasis is placed on the possibility of obtaining a high return. In that case the Hurwicz plan may be less conservative than that of the Wald. It fits a problem setting between the two extremes considered in this chapter. In the discussion of empirical problems, this non-extreme plan is frequently indicated.

The Hurwicz criterion has a property which suits it to dynamic planning. It is possible to change the α each year to suit the farmer situation. A farmer may start with an α which fits his problem setting. If he experiences favorable outcomes, he may change the α to allow more gambling. If a series of unfavorable outcomes occur, he may change to a large α until he gets to a better resource position. The other criteria do not allow the farmer such flexibility; however, he may change criteria between years.

The Savage regret criterion does not necessarily fall into either problem setting. It gives no indication of the psychology or resource situation of the farmer. It only implies that the farmer wants to minimize the regret he might have from choosing a less profitable plan. The regret may be of two kinds. It may result from having missed an opportunity for a very high return or from having fallen below a minimum sure income. Nothing about the criterion says which will be the greatest. In the case of a mixed strategy, the two regrets may both be given weight. This may result in a solution which fits a problem setting between the two hypothesized. It is necessary to examine the problem to determine which problem setting the Savage regret solution implies. Various possible outcomes besides regret are computed for the Savage regret plan to facilitate examination of the appropriateness of the plan.

D. Analytical Format for Empirical Chapters

Empirical work is presented in two chapters. Various crop problems are examined in Chapter VI and pasture and livestock problems are presented in Chapter VII. The technique of using various decision models and the solution resulting from their use are both emphasized. The procedure for each problem is as follows:

(a) The farmer problem being considered is discussed.

(b) The source and treatment of data is reviewed and the problem is formulated in the manner suggested in Chapter IV.

(c) The problem solution and possible outcomes are presented in table form.

(d) The applicability of plans to problem settings hypothesized is determined. Various possible outcomes are examined to show the possible results of using the plan over a period of years.

VI. PLANNING CROP ENTERPRISES UNDER IMPERFECT KNOWLEDGE

Three typical crop problems are studied in this chapter. The first problem discussed is choice of crop varieties. Next, the problem of choosing the amount and kind of fertilizer to use on a given crop is considered. Finally, a problem requiring choice of alternative crops is examined. The problem analysis is designed to achieve several 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 may then 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 be used as actual recommendations. 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. It further indicates how data presently available may be adapted to decision making needs.

A. Choice of Crop Varieties

Farmers must choose crop varieties each production season. Some farmers do not spend much time in making this choice. They 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, disease resistance, maturity time, test weight and other characteristics meet certain standards. Other characteristics equal, varieties are usually recommended which have had the highest average yield over a period of years. Thus, the usual recommendations are based on the Laplace criterion. The discussion in Chapters IV and V has shown that all farmers may not wish to follow plans suggested by that criterion.

The variety problem results because one variety does not normally outyield all others every year. The problem may be stated in terms of the general problem formulation presented in Chapter IV. 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.

The variety analysis takes only the yield characteristic into consideration. This is probably the most important characteristic to farmers. An index could have been constructed attaching weight to other characteristics such as quality. For simplicity, this procedure was not followed. Only varieties are considered which are rated as generally acceptable by the Iowa Experiment Station (27). Characteristics other than yield are partially taken account of in that way.

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 one 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 one year. In years where their yields are statistically equal, equal yields could be used. However, it can be argued 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 indicated above, each year of yield data is affected by a unique combination of weather, disease and insects. New varieties are continuously being developed. Thus, the period of years covered by the variety yield data is relatively short. The newer, superior varieties have been used in tests only a few years. The best a farmer can do is use the data he has available to make 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.

1. Choice of oat varieties in northeast Iowa

What oat variety or combination of varieties should a farmer plant in northeast Iowa? This section provides answers useful to farmers in various problem settings. 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 1953-1957. 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 (column) from each other yield in that same year (column). 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. The probability model can not 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.* 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

*This characteristic of many farmer-nature game matrices is discussed in a later section of this chapter.

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: (20).

[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 is thus 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. However, they must be prepared to accept the consequences of hail if it occurs.

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

Table 3. Strategies and possible outcomes suggested by four decision models applied to the Howard county (northeast Iowa) oat variety problem

Decision model		Strategy		Possible outcome			
Criterion[e]	Type of strategy[f]	Variety[g]	Percent of land[h]	Min.[a] bu./a.	Av.[b] bu./a.	Max.[c] bu./a.	Max. regret[d] 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

[a]The worst outcome which can result from following a given strategy.

[b]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.

[c]The highest outcome possible from following the given strategy.

[d]The maximum outcome forgone as a result of choosing a less profitable alternative, viewed *ex post*.

[e]This column gives the decision models used to solve the farmer decision problem.

[f]This column indicates whether the farmer is to use one single course of action or several.

[g]Variety choices resulting from application of alternative decision models.

[h]The percent of land to be used for each alternative comprising the farmer's strategy.

Table 3. (Continued)

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.
Savage regret	Mixed	Clintland	25				
		Clarion	66				
		Sauk	9				
			100	48.0	75.0	97.5	13.44
Hurwicz	Pure						
$0 \leq \alpha \leq .5$		Clarion	100	45.0	79.4	111.0	16.0
$.5 \leq \alpha \leq .66$		Bonham	100	46.0	75.6	110.0	27.0
$.66 \leq \alpha \leq 1$		Clintland	100	49.0	73.8	104.0	30.0

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 in order to use the most convenient simplex techniques. The solution is not affected by adding a constant, providing the same constant is substracted from the final minimum regret solution.

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 Chapter III. The resulting equations were then 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. However, some farmers 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. However, a farmer who really wants to minimize regret would be interested in that column. A farmer who does not wish to forego an opportunity for very high yields would at least take note of that column.

a. <u>Appropriateness of the criteria</u>. One problem setting, which the discussion in Chapter V indicated should be considered, was one 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

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*It is the same as the strategy for the Hurwicz criterion, $0 \leq \alpha \leq .5$.

average of any alternative. The strategy is to use Clarion oats on all acres. Although yields in some years may be 45.0 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 four 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 factors leading to such a problem setting were discussed in Chapter V. The setting essentially implies that for some reason, the farmer must have an outcome above a given level or must have the maximum sure 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.* Using this strat-

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*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% of the land to one variety and (continued on next page)

egy, a yield of 54.3 bushels per acre would be assured every year.* 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 five 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 specified above might find another plan more desirable. One farmer might be willing to accept a lower security level in order to get a higher possible average. The Hurwicz criterion with $.66 \leq \alpha \leq 1$ 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

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(footnote continued from previous page) perhaps (100-x)% of the land to another variety. The strategy-possible outcome table for each problem gives the percentage of the relevant resource (i.e., land, T.D.N., pasture, etc.) to be used for each course of action comprising a strategy.

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

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 would apparently 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. The gambling strategy, Hurwicz with $0 \leq \alpha \leq .5$, calls for using Clarion also. Only the Hurwicz solution with $.5 \leq \alpha \leq .66$ says to use the early variety, Bonham. Thus, most of the criteria agree that late or midseason varieties are preferable.

2. 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. The Wald solution is thus extremely pessimistic. Nature is not necessarily trying to do its worst to the farmer. However, the fact remains that such pessimism may be necessary under certain problem settings. Agricultural data often show this characteristic because most farmer alternatives result in highest returns when the state of nature is most favorable.

The regret matrix does not show the characteristic pointed out above. 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 but 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 years but two. In one of those years, Sauk had the lowest yield, zero bushels. Thus, Sauk is brought in the plan, but at a low level. Clintland and Clarion are in the plan because they each had highest yields in one year and relatively low regrets in other years.

3. Choice of oat varieties in southern Iowa and western Iowa

It is instructive to note the differences in oat variety choices which may be made in various sections of Iowa. Thus, oat yield data are presented 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 22 and 23 contain the farmer-nature payoff matrices for these two areas. These tables correspond to Table 1 of this chapter. Six oat varieties are included in Table 22 to demonstrate how inferior farmer alternative may be eliminated. A comparison of yields in Table 22 shows that Clintland outyielded Bonham in each of the four 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 24 and 25 show the regret matrices for the above problems. Those tables correspond to Table 2 in the text. 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. Plans appropriate for different problem settings can be obtained from Tables 4 and 5. The same criteria appropriate for problem settings discussed in the Howard county section are appropriate for these areas. Plans suited to different problem settings are summarized in Table 6, and discussed in the next section; thus, a discussion of Tables 4 and 5 is not necessary here.

a. Alternative research or extension recommendations. How may research and extension personnel use the results of the oat variety analysis? One possibility is shown in Table 6. There, four problem settings are visualized; 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 α 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 α is also deemed applicable for problem setting 2a. It

Table 4.[a] Strategies and possible outcomes suggested by four decision models applied to the Seymour-Shelby oat variety problem

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 31 100	46.5	85.5	124	9
Hurwicz $0 \leq \alpha \leq 1$	Pure	Sauk	100	52	84.0	133	29

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

Table 5.[a] Strategies and possible outcomes suggested by four decision models applied to western Iowa oat variety problem

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						
$0 \leq \alpha \leq .7$		Clintland	100	16	66	121	11
$.7 \leq \alpha \leq 1$		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	Sauk	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

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.

Recommendations could be published in a form similar to Table 6. Discussion explaining the problem settings should accompany the recommendations. Alternatively, an extension specialist could make the appropriate recommendation after counseling with a farmer to determine his goals and resource situation. He could simply point out the alternatives and discuss possible outcomes. The final choice in any case is left to the farmer.

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 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.

A researcher might react to this distribution of maturity dates in various ways. For example, he might concentrate research on varieties with maturity dates best suited to different areas. On the other hand, he may try to improve varieties with other maturity dates. The factors causing them to be less desirable might be eliminated by careful breeding and selection.

4. 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 to 1957. Thus, it is assumed that these two varieties are the farmer's only relevant alternatives. Tables 26 and 27 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 Mars 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 described above is significant because it

Table 7.[a] Strategies and possible outcomes suggested by decision criteria applied to western Iowa barley problem

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						
$0 \leq \alpha \leq .54$		Mars	100	16	43	68	14
$.54 \leq \alpha \leq 1$		Plains	100	21	48	62	6

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

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 out-yield Plains in a few years so that the farmer can consider the alternative of gambling on a maximum yield.

5. Choice of corn varieties

Corn is a major source of income to Iowa farmers; thus, it is important to select corn varieties which yield in accordance with a farmer's requirements. His requirements may include consistency and high, long-term averages. This decision problem is suited to the analysis in this dissertation.

Data for this section were obtained from annual Iowa corn yield tests (17). 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 differences in growing seasons. Varieties were selected which had relatively high yields, in comparison to other varieties tested, over several years of testing. Differences in performances of the varieties considered are rather small, and perhaps not significant. However, even small differences may be important to some farmers.

a. Northeast Iowa. Table 28 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 29 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.

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 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 very 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

Table 8.[a] Strategies and outcomes suggested by decision criteria applied to northeast Iowa corn variety problem

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						
$0 \le \alpha \le .5$		P.A.G. 277	100	86	112.2	129	8
$.5 \le \alpha \le 1$		Pioneer 371	100	93	111.4	122	12

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

4.8 bushels because of choosing the wrong plan.

b. Southern Iowa. Table 30 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 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 31 contains the regret matrix for this problem. A mixed strategy can be obtained from this matrix.

A brief glance at Table 9 shows that Pioneer 301b will fulfill farmer requirements in both of the problem settings considered in this chapter. It not only has the highest security level but also 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 in order to follow a plan which provides the least possible regret.

B. 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

Table 9.[a] Strategies and outcomes suggested by decision criteria applied to southern Iowa corn variety problem

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						
$0 \leq \alpha \leq .5$		P.A.G. 170	100	75	97.2	121	10
$.5 \leq \alpha \leq 1$		Pioneer 301b	100	78	98.7	118	8

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

both of these problems demonstrates that data available from present experiments may be adapted for use of various decision models.

1. Choice of manure, phosphorus and potassium levels

Should a farmer fertilize corn? If he should fertilize, which nutrients should he apply? How much of the various nutrients should be applied? These are the questions facing a farmer in the following decision problem. The locales of the problem are northeast and north eastcentral Iowa.

a. 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 to 1957. The experiment actually included a three year corn-oats-meadow rotation. 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 carry-over 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 pounds 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 32 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 33 shows the regret matrix for this problem.

Payoffs are returns above fertilizer costs and cost of application.* A constant, equal to the value of production in the lowest year for corn not fertilized, is subtracted from each payoff in order to reduce the size of the payoffs. Table 32 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 34 shows the payoff matrix for this fertilizer problem when manure is not free. A ton of manure is roughly equivalent

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*A detailed description of the manner in which payoffs were computed is contained in a footnote of Table 32.

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 34. The Savage regret matrix for this problem is contained in Table 35.

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 will 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 will follow the same plan. This plan also indicates the amount of fertilizer which is apparently 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 years are represented in the data available. Thus, caution should be taken in making such a recommendation. The need for data from long 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 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 level and kind of

Table 10.[a] Strategies and outcomes suggested by four decision criteria applied to Howard county fertilizer problem (no charge for manure)

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Alter-native	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						
$0 \leq \alpha \leq .74$		MP	100	10.98	38.46	64.84	5.43
$.74 \leq \alpha \leq 1$		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)

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						
$0 \leq \alpha \leq .68$		MP	100	-2.22	25.26	51.64	11.62
$.68 \leq \alpha \leq 1$		PK	100	5.70	24.98	35.34	18.01

fertilizer used. The manure plan includes only 60-30-60 and the PK plan only 0-30-30 as compared to the 60-60-60 plan for the other problem setting. The reason for the plan differences may be seen by reference to Table 34. 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 $9.00 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.

b. North eastcentral Iowa. Tables 36 and 38 contain the farmer-nature payoff matrices for corn production in the Carrington-Clyde soil area. Tables 37 and 39 contain the regret matrices for this problem. Tables 12 and 13 show strategies and possible outcomes for farmers who have manure

Table 12. Strategies and outcomes suggested by four decision criteria applied to Carrington-Clyde fertilizer problem (no charge for manure)

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Alter-native	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 $0 \leq \alpha \leq 1$	Pure	MP	100	23.80	49.24	72.44	4.58

Table 13. Strategies and outcomes suggested by four decision criteria applied to Carrington-Clyde fertilizer problem (charge for manure equivalent)

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Alter- native	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 $0 \leq \alpha \leq 1$	Pure	MP	100	12.84	33.62	61.28	16.60

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. However, if the farmer must buy a manure substitute, 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 38.

In order 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. However, it has a higher average than the Wald plan. It seems unlikely that a farmer would follow such a plan unless he does wish to minimize regret.

An extension or research specialist who advises farmers on fertilizer application could make extensive use of the analytical techniques discussed in this section. In doing so, he could be sure his recommendations are consistent with the problem setting and goals of different farmers. Considerable data of the nature used in the fertilizer example are available at experiment stations. Thus, opportunities exist for extensive work on decision making under uncertainty.

C. Choice of Variety, Fertilizer Level and Stand Level

Each crop enterprise requires a number of individual decisions. For example, a farmer must choose varieties, fertilizers and cultural practices. There are a number of possible choices within each decision category. The outcome of each is often affected by the same states of nature. The outcome of each possible choice is also 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 40 contains the experimental data and the regression equation fitted. That table also explains each of the variables included in equation 1. The equation was fitted in order that levels of the variable could be selected, rather than be limited to the levels involved in the experiment.

Table 41 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, are also included. Only farmer alternatives which are not inferior to another alternative at all rainfall levels are included in Table 41. It will be noted that nature has only one non-inferior strategy. Thus, the Wald solution must be a pure strategy. Table 42 shows the Savage regret matrix for this problem. Only non-inferior nature strategies are included. The five years during which the experiment was conducted were not favorable ones 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 1953 to 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 in Chapter V. 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 Laplace criterion. The marginal analysis involved has been presented in much agricultural research and is well known (14). It might offer the advantage of choosing a unique level of stand and nitrogen which is most profitable. The levels picked in this analysis are somewhat arbitrary. The problem of selecting levels is similar to the one of picking activities for linear programming analysis.

Weather records for the period 1925 to 1957 were examined to determine the frequency with which various rainfall levels occur. The following frequencies for the rainfall variable used in this analysis were found: rainfall <7 inches, .06; 7 inches $\leq$ rainfall $\leq$ 9 inches, .1; 9 inches $\leq$ rainfall $\leq$ 11 inches, .13; and rainfall $\geq$ 11 inches, .71. These frequencies were applied to the data in Table 41 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 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 the probability model. His average expectations over a period of years would be $49.63. In some years he can get only $1.67 and in other years $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

Table 14. Strategies and outcomes suggested by five decision models applied to Seymour-Shelby nitrogen-stand-variety problem

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						
$0 \leq \alpha \leq .09$		Adapted variety; S=20,000; N=60	100	-4.24	32.13	56.99	13.49
$.09 \leq \alpha \leq .11$		Adapted variety; S=12,000; N=40	100	.31	33.90	56.58	8.94
$.11 \leq \alpha \leq .2$		Adapted variety; S=12,000; N=20	100	1.67	34.63	56.34	7.58
$.2 \leq \alpha \leq .38$		Adapted variety; S=12,000; N=0	100	3.05	35.14	56.00	6.20
$.38 \leq \alpha \leq 1$		Adapted variety; S=12,000; N=0	100	9.25	27.05	52.28	4.71

per acre stand level.

The Laplace plan given in Table 14 is also appropriate for the above 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 is thus not strictly comparable with 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 .38 would also follow this plan. Only a farmer willing to gamble or who wishes to minimize regret would use another plan. These plans are the Hurwicz solutions with $0 \leq \alpha \leq .38$ and the Savage regret solution.

1. Methodological comments

The analysis presented above 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, 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.

D. Choice of Crop Enterprises

This section demonstrates the application of game theoretic criteria to the problem of choosing between alternative crop enterprises. The most common techniques for solving this problem are budgeting and linear programming. The usual procedure is to compute the average return per acre or per bushel for a particular crop. This return is usually the value of production above variable costs. It is an average return because average yields, average prices and average input coefficients are usually used. The problem is to choose a crop or combination of crops which allow the greatest return to given amounts of fixed resources. Both budgeting and linear programming lead to choice of a crop or combination of crops which give the highest average expected return for a "bundle" of fixed resources. It can be seen that these techniques are closely related to the Laplace criterion. The plans they suggest are appropriate for a farmer who can stay in business long enough to realize the expected return.

Another criterion for choice of crop enterprises was referred to in Chapter II. There it was suggested that a farmer might choose an enterprise which gives the highest sure return every year. Enterprises with high variability, including variation below minimum return levels of other alternatives, are avoided under this criterion. This choice criterion is very much like the Wald criterion. If emphasis on the security level is allowed to vary, it is also similar to the Hurwicz criterion. These criteria are appropriate for reasons which have been discussed in this dissertation.

The preceding paragraphs indicate that game theoretic techniques are useful for choosing between crop enterprises. The sample problem used is choice between oat and barley enterprises in western Iowa. The problem matrices for this example are contained in Tables 43 and 44. Only five years of data are considered so that currently recommended varieties can be used. 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 five years of data. The example given here should be used cautiously as a basis for recommendations because it includes so few of the many possible returns from oats and barley.

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.

Table 15. Strategies and outcomes suggested by decision criteria applied to a crop enterprise selection problem

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						
$0 \leq \alpha \leq .68$		Sauk oats	100	8	33	64	16
$.68 \leq \alpha \leq 1$		Plains barley	100	17	38.4	50	15

VII. PLANNING PASTURE AND LIVESTOCK ENTERPRISES UNDER IMPERFECT KNOWLEDGE

The analysis in this chapter is similar to that of Chapter VI. Three pasture and livestock problems are considered. First, methods of choosing pasture mixtures under uncertain weather conditions are presented. Second, the complex problem of planning pasture stocking rates is considered. Finally, an example is given of the way alternative choice criteria may be used to choose between competitive livestock enterprises. In addition, suggestions are made for solving other livestock problems which are applicable to the analysis presented in this dissertation.

Like the preceding one, this chapter demonstrates the application of decision models to real farmer problems. It also allows further analysis of the appropriateness of the decision models for farmer uncertainty problems. The results may be used as actual recommendations for farmers in a few Iowa areas.

A. Choice of Pasture Mixtures

Considerable research has been conducted on pasture mixtures for Iowa. Many of the new grass and legume species outyield older ones. Research and extension educational efforts have interested many farmers in seeding the new mixtures. However, an analysis of data available on the newer mixtures 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 a farmer plant? This is a problem well suited to analysis in this dissertation.

What does a farmer want from his pasture? Some farmer's livestock programs are flexible enough that livestock numbers can be adjusted to the available pasture. Farmers in that position want to seed a pasture which has the highest average yield over a period of years. This assumes that profits from grazing livestock on pasture are highly positively correlated with pasture production. A farmer in this situation could presumably adjust livestock numbers down in bad years and up in good years. After a period of years, he will have obtained a higher total value of beef than if he had pasture with a less variable and lower average yield.

Other farmers have an inflexible livestock system. For example, a beef cow herd, a dairy herd or a rigid deferred feeding beef program require a fairly constant number of animals each year. It may be quite uneconomical to vary numbers in such enterprises because of their interrelationship with the whole farm operation, and not just to pasture. Some minimum amount of pasture is required during some period of each year. At these times pasture is a vital link in the whole year plan. In this situation, a farmer would probably prefer to choose a pasture mixture which always provides the amount of pasture needed at the critical period.

The two preceding paragraphs describe two problem settings for the pasture seeding problem. Other problem settings may be specified which are intermediate to these. For example one farmer may have a livestock enterprise which is inflexible and requires a minimum level of pasture each year. However, he may have flexibility in another part of his livestock plans. His pasture requirements would include a minimum level, but he would also give weight to having a high average. A mixed strategy may be appropriate which would involve planting several mixtures on different plots of land. Plans which are consistent with various problem settings are specified in the following analysis.

1. 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 prevent bloat. Data for these mixtures over the years 1954-1957 are presented in Table 45. There, the data are presented in the form of a payoff matrix. Entries are in tons of dry matter per acre.

Table 46 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. This calls for using an alfalfa-bromegrass mixture. Over a period of years, this plan may result 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 $0 \leq \alpha \leq .71$ also calls for using alfalfa-bromegrass. The size of the α indicates that this plan is not really a "risky" one. However, 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 assures him the highest possible sure 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 cri-

Table 16. Strategies and outcomes suggested by decision models applied to the Howard county pasture problem

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	.75
Hurwicz	Pure						
$0 \leq \alpha \leq .71$		Alfalfa-bromegrass	100	1.7	2.5	3.6	1.4
$.71 \leq \alpha \leq 1$		Alfalfa-timothy	100	1.9	2.4	3.1	1.5

terion with $.71 \leq \alpha \leq 1$ gives the same plan as the Wald criterion. The Savage plan is particularly inappropriate for this problem setting. An examination of Table 46 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 non-optimum plan is highest. Feed costs might be particularly high that year. However, if a farmer really wishes to minimize regret he may plant 53 percent of his land to alfalfa-bromegrass and 47 percent to Ladino-Kentucky bluegrass.

2. <u>Choice of pasture mixtures in southwest Iowa</u>

Data from the Soil Conservation Farm in Page county, southwest Iowa are used for this problem. Considerable pasture research has been performed in that area. Two sets of pasture data are used. One includes alfalfa and grass mixtures. The other is made up of other legume-grass mixtures. The alfalfa mixtures outyielded other mixtures in every year. However, 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, other less productive mixtures are also considered.

Three alfalfa mixtures are included and are identified as farmer alternatives in Table 47. The years covered by the data are 1952-1956. Each year is treated as a state of nature. Table 48 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.

A research worker making recommendations for pasture mixtures in southwest Iowa can be quite confident that his recommendations are acceptable to a wide range of possible problem settings. He can simply recommend alfalfa-orchardgrass mixtures. It is again assumed that the years covered by the data are representative of all possible years.

3. Methodological comment

The Wald solution shown in Table 17 for the alfalfa mixtures resulted from a technicality of the game theoretic procedure. Reference to Table 47 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-

Table 17. Strategies and outcomes suggested by decision criteria applied to Soil Conservation Farm pasture problem (alfalfa mixture)

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	.26
Laplace	Pure	Orchardgrass-alfalfa	100	2.5	3.7	4.6	.1
Savage regret	Mixed	Kentucky bluegrass-alfalfa	25				
		Orchardgrass-alfalfa	75				
			100	2.5	3.6	4.5	.07
Hurwicz $0 \leq \alpha \leq 1$	Pure	Orchardgrass-alfalfa	100	2.5	3.7	4.6	.1

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 a combination including 60 percent alfalfa-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.

4. 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 49 and 50, respectively. Both the maximum security level and the highest average are obtained by use of a trefoil-Kentucky bluegrass mixture. Thus, a research worker may recommend this mixture with confidence, assuming it has other desirable characteristics. 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-Ladino mixture, allows the same security level as the Wald criterion.

Table 18. Strategies and outcomes suggested by decision criteria applied to Soil Conservation Farm pasture problem (non-alfalfa mixtures)

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	.9
Laplace	Pure	Kentucky bluegrass-trefoil	100	1.0	1.5	2.3	.9
Savage regret	Mixed	Kentucky bluegrass-trefoil	16				
		Orchardgrass-trefoil	40				
		Orchardgrass-Ladino	44				
			100	.78	1.3	1.9	.51
Hurwicz $0 \leq \alpha \leq 1$	Pure	Orchardgrass-trefoil	100	1.0	1.4	2.4	.9

The Savage regret mixed strategy allows the lowest regret possible but has other disadvantages.

B. Choice of Pasture Stocking Rates

A very complex problem which farmers must face is deciding how many animals to have for a given pasture acreage. The decision must normally be made before the farmer knows how much forage will be produced. Once the decision on numbers is made, it often must hold for a number of seasons. For example, a farmer with a dairy herd or a beef cow-calf enterprise cannot vary cattle numbers very much once the herd is built up. Losses often result because of between year variation in pasture yields.

Heady _et al_. (13, pp. 204-206) 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 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 one 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. A cow and calf require about 20 pounds of total digestible nutrients (T.D.N.) per day (32). Per acre annual yields are converted to T.D.N. by multiplying them by their T.D.N. percentage (32). Acre requirements of a cow and calf are determined by dividing pounds of T.D.N. produced per year by 20 times the number of days grazing is required. It is implicitly assumed that within year variation of pasture yields can be handled by rotation grazing and various other cattle management schemes.

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 1951-1957. Table 51 shows the farmer-nature payoff matrix for unimproved Kentucky bluegrass pasture. Table 52 contains the regret matrix for this problem. Tables 53 and 54 show the payoff and regret matrices for Kentucky bluegrass pasture which has had an application of superphosphate and is over seeded 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 is also 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 chaper compared to feeder prices than in 1953. In the third price situation the hay and feeder calf prices used are the average of 1948-1957. Many other price situations could have been considered. However, at the price levels considered, 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 October 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 .22 animal unit days per acre and gets .44, he has an excess carrying capacity of .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 $0 \leq \alpha \leq .77$ calls for the same plan. Yearly returns may range from $7.46 to $31.07 but should average to $19.43. This plan also has a very low regret associated with it.

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

Table 19. Strategies and outcomes suggested by decision criteria applied to Grundy-Shelby unimproved Kentucky bluegrass pasture data

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 Worst year	88 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 Worst year	92 8 100	7.69	18.17	28.53	2.65
Hurwicz $0 \leq \alpha \leq .77$	Pure	Next to best year	100	7.46	19.43	31.07	2.88
$.77 \leq \alpha \leq 1$		Average year	100	8.42	14.70	25.36	13.20

the worst possible year. This plan assures the farmer of at least $8.65 per acre every year. However, 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 $.77 \leq \alpha \leq 1$. 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 sizeable gain in long run expectations.

The results discussed above 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 may 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.

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. This dissertation does not include such tests; however, testing of the hypotheses appears to be a worthwhile research activity to be considered for the future.

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 stocking rates.

Tables 53 and 54 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

Table 20. Strategies and outcomes suggested by decision criteria applied to Grundy-Shelby phosphate-lespedeza pasture data

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	19.55	28.26	39.45	1.36
Hurwicz	Pure						
$0 \leq \alpha \leq .9$		Next to best year	100	18.87	28.85	40.71	1.45
$.9 \leq \alpha \leq 1$		Average year	100	19.45	26.05	35.39	8.60

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 by Table 20 in 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.

C. Choice of Livestock Enterprises

The game theoretic criteria are useful in choosing between alternative livestock enterprises such as cattle or hogs. Prices are the major source of uncertainty in this problem. Thus, prices are the states of nature used in the following analysis. Once a choice has been made to produce hogs, beef or a combination of the two, the farming operation is not perfectly flexible. Housing, feeding equipment and breeding animals must be accumulated. These can not be economically purchased and sold as prices vary. Fixed assets for hog production can not all be used for producing beef and conversely. Thus, rigidity is introduced into the farming operation. In view of these restrictions, which enterprise or combination of enterprises should farmers in various problem settings adopt? The following example is designed to show one way of resolving the problem.

Table 55 shows the payoff matrix for a farmer-nature enterprise problem. The farmer has two alternatives - hogs and beef. Nature has eight alternatives (hog and beef prices which occurred during 1950-1957). The payoffs are the value of beef or pork produced with 100 pounds of T.D.N. Costs other than those for feed are assumed equal (30, p. 27). Table 56 contains the regret matrix for this problem.

The strategies and outcomes resulting from the game theoretic criteria are shown in Table 21. Hogs are both the safest and the most profitable enterprise over the long run. Thus, both a conservative farmer and a long run profit maximizer may raise hogs. Regret is minimized by a combination of hogs and cattle. Cattle have the highest possible outcome in the payoff matrix. Thus, the solutions obtained tend to agree with common farmer evaluations of the enterprises.

This problem could have included consideration of other sources of uncertainty in livestock enterprises. For example, the coefficients implied for rates of gain or efficiency are simply averages. These may vary from year to year. In addition, numbers of pigs saved vary between years. Death loss varies between years. All of these uncertainties result from

Table 21. Strategies and outcomes suggested by decision criteria applied to the hog-cattle enterprise choice problem

Decision model		Strategy		Possible outcome			
Criterion	Type of strategy	Enterprise	Percent of TDN	Min. \$/100# of TDN	Av. \$/100# of TDN	Max. \$/100# of TDN	Max. regret \$/100# of TDN
Wald	Pure	Hogs	100	3.55	4.49	5.26	.56
Laplace	Pure	Hogs	100	3.55	4.49	5.26	.56
Savage regret	Mixed	Hogs	72				
		Cattle	28				
			100	3.47	4.36	5.11	.49
Hurwicz	Pure						
$0 \leq \alpha \leq .54$		Cattle	100	3.26	4.04	5.60	1.79
$.54 \leq \alpha \leq 1$		Hogs	100	3.55	4.49	5.26	.56

uncontrollable and unpredictable natural conditions. Possible states of nature could include all combinations of these conditions and weather. Alternatively, the other sources of uncertainty could be used as the primary uncertainty in other farmer-nature games. The problems presented in this chapter are only some of the few to which game theoretic techniques are applicable.

VIII. SUMMARY AND CONCLUSIONS

This study demonstrated the use of alternative decision models for farmer decision making under uncertainty. Particular emphasis was given to game theoretic models. These models have previously had little empirical application to farmer decision problems. However, this study has shown that they 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.

Uncertainty is the usual environment for agricultural decisions. Uncertainty is introduced by technical and technological change, price variation and unpredictable human action. Technical uncertainty results from inability to predict relationships between agricultural inputs and outputs with a probability of one. Prediction is complicated by inability to control natural inputs such as weather, insects and disease. Technological changes such as development of new products, production techniques and inputs may drastically affect the profitableness of farmer plans. Price variation results from varying world and national economic conditions, the state of natural factors affecting production and inflexible production processes. The actions of other individuals may also affect the outcome of farmers' plans. Obviously, these actions are not controllable or predictable.

Uncertainty is used to describe a general condition of change, imperfect knowledge, and lack of foresight. However, more technical descriptions of these conditions were reviewed in this study. Most classifications of knowledge situations use the language of probability distributions. Individuals evaluate objective probability measures in different ways, partly because of differences in experience. In addition, they may allow their personal situation and intuition to influence their classification of the knowledge situation. Thus, the more satisfactory classifications include subjective as well as objective elements of knowledge. Classes of knowledge for problems considered in this study were assumed to be subjective risk and subjective uncertainty. The knowledge situation affects the choice of models for decision making under uncertainty.

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 may also be increased by providing data applicable to several decision models.

Of the several models 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 by Simon and Shackle. 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 model for maximizing expected utility was called the probability (risk) model in this study. It may be used in a knowledge situation where the decision maker thinks he knows the probabilities of unpredictable events occurring (subjective risk). The probabilities are used in computing expected outcomes for farmer alternatives. The alternative plan with the highest expected outcome is chosen by this model. Money income rather than utility is maximized.

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 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 game theoretic criteria include the Wald, Savage regret, Hurwicz and Laplace. The Wald criterion calls for selecting a plan which allows a maximum 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,

$$\alpha m_i + (1 - \alpha) M_i ,$$

where α is an individual's pessimism index that the worst outcome, m_i, will occur and $(1 - \alpha)$ is his optimism index that the highest outcome, M_i, will occur. M_i is the highest outcome for the ith farmer alternative and m_i is the lowest outcome for the ith farmer alternative. The Laplace criterion chooses the plan which has the highest average over states of nature. These models subsume the naive models and the precautions for uncertainty.

Each of the alternative decision models implies certain goals for the decision maker. Thus, one way of evaluating the appropriateness of the criteria is comparing the goals they imply with actual farmer goals. Farmer goals may be inferred from his problem setting. This study has shown that (a) alternative courses of action, (b) characteristics of the farmer, and (c) the knowledge situation with respect to states of nature may affect goals and thus the appropriateness of alternative decision criteria. Characteristics of a given farmer such as psychology with regard to risk, resource position, family situation, work preference and rental arrangement are particularly influential on goals. Thus, they must be taken into account in making recommendations. Models used to derive recommendations should imply actual farmer goals if recommendations are to represent rational farmer alternatives.

Decision models and problem setting components were brought together in this study to form a systematic procedure for deriving recommended solutions to farmer decision problems under uncertainty. Two problem settings were hypothesized. One setting is a long run profit maximizing setting which characterizes a farmer having the resource position and personal attributes allowing long run planning. The other setting characterizes a farmer who must consider the level of possible short run outcomes because of limited resources, risk aversion or family responsibilities.

The Laplace criterion is appropriate for the long run problem setting. The average (naive) model is also appropriate for this setting but is subsumed by the Laplace criterion in most cases. The Wald criterion is appropriate for the short run setting. The Hurwicz criterion with a range of α including 1 is also appropriate for the short run setting. However, a Wald mixed strategy allows a higher security level than the Hurwicz. The Hurwicz criterion with an α of 0 is a gambling alternative. It emphasizes obtaining the highest outcome possible. The Savage regret criterion is not easily classified in either problem setting. It may suggest a plan appropriate for either, depending on the nature of the outcome matrix. One can only be sure that the Savage regret plan will minimize regret.

Actual farmer problems were considered to demonstrate techniques of using models and to show the kinds of recommendations which may result. The problems considered were a particular class of within farm and within enterprise problems. They included problems requiring choice of crop varieties, kinds and amounts of fertilizer, crop enterprises, pasture mixtures, stocking rates and livestock enterprises. 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. Theoretically, it should include all possible. In the absence of all possible states of nature, a decision maker can only use the data available.

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 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 eight of 18 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. However, this result cannot be generalized because problem characteristics differ greatly. Thus, the appropriateness of recommendations can only be determined by applying several choice models to each farmer problem.

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 18 problems. It had the second highest average in nine problems and third highest in nine problems. Thus, for the problems considered, the Savage regret criterion appeared to give plans intermediate between those for maximizing long run profit and 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 18 problems.

As expected, the Hurwicz criterion plan, with a range of α including 0, had the highest maximum in all 18 problems. The Laplace tied with the Hurwicz criterion for highest maximum eight times in 18 problems. The Wald criterion plan had the lowest maximum in 10 of 18 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. The Savage regret criterion was thus 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 data published in the form of averages is only one of several data forms that may be useful.

Game theoretic techniques may have considerable use in whole farm planning. Usually, input-output coefficients used in linear programming or budgeting are simply averages. They are subject to variation. This variation may affect the profitableness of the whole farm plan. Some farmers may want to be sure that income levels will not fall below some minimum, feasible level. Thus, a whole farm plan based on average input-output coefficients may not be acceptable. However, farmers might accept a plan which assures a maximum minimum level each year. Such a plan may be based on input-output coefficients derived from a game against nature by application of the Wald criterion. The Wald solution for a crop enterprise problem would suggest a plan which assures a minimum return. The minimum return may be regarded as the output coefficient. The input coefficient is given by the combination of variety, fertilizer and cultural practices required for the crop plan selected. The particular crop is an activity to be included in linear programming analysis designed to plan the whole farm operation.

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XI. APPENDIX

Table 22. 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: (21).

[b]No oats were harvested on the Seymour-Shelby farm in 1956 because of drought. 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. However, they would affect plans if the problem is choosing between two crops such as barley and oats.

Table 23. Payoff matrix for 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	96
Cherokee	53	66	74	25	100
Clintland	49	57	89	16	121
Clarion	67	73	88	17	72
Sauk	63	78	100	14	92

[a]Source of data: (23).

Table 24. 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 25. Savage regret matrix for western Iowa, oat variety problem

Farmer alternative (variety)	State of nature (years)				
	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 26. 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: (23).

Table 27. 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 28. Farmer-nature payoff matrix for northeast Iowa, corn variety problem[a]

Farmer alternative (variety)	State of nature (years)				
	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: (17).

Table 29. Farmer-nature regret matrix for northeast Iowa, corn variety problem

Farmer alternative (variety)	State of nature (years)				
	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 30. Farmer-nature payoff matrix for southern Iowa, corn variety problem[a]

Farmer alternative (variety)	State of nature (years)					
	1952 bu./a.	1953 bu./a.	1954 bu./a.	1955 bu./a.	1956 bu./a.	1957 bu./a.
Pioneer 301b	110	118	88	78	94	114
P.A.G. 170	112	121	75	76	91	104
U.S. 13	108	117	75	75	87	110
P.A.G. 381	113	108	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: (17).

Table 31. Farmer-nature regret matrix for southern Iowa, corn variety problem

Farmer alternative (variety)	State of nature (years)					
	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 32. Payoff matrix for the farmer-nature, northeast Iowa, M-P-K problem[a] (no charge for manure)

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	53.24	14.80	45.00	43.48
(P) 30# P_2O_5	28.00	4.64	-.78	5.30	13.18	18.60
(K) 30# K_2O	36.06	-.71	27.89	1.76	35.59	32.26
(PK) 30# K_2O and P_2O_5 30# P_2O_5	33.65	5.70	32.11	9.40	35.34	33.72
(MP) 6 tons manure 30# K_2O	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: (20).

[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 vary 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, 13¢ per lb.; (b) potassium, 5¢ per lb.; and (c) phosphorus, 10¢ per lb. A cost of 15¢ per bu. was computed for harvesting, hauling and storing corn. Source of price data: (43).

Table 33. 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	-38.82	-10.72	-19.70	-18.78
M	-11.76	-6.15	0	0	-3.48	0
P	-36.84	-18.97	-54.52	-9.50	-35.30	-24.88
K	-28.78	-24.52	-25.85	-13.04	-12.90	-11.22
PK	-31.21	-17.91	-21.63	-5.40	-13.14	-9.76
MP	0	0	-4.38	-3.82	-4.54	-5.43
MK	-13.89	-5.15	-37.26	-5.08	0	-.60
MPK	-10.90	-2.07	-1.80	-8.46	-9.56	-6.17

Table 34. 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	22.78	24.70
M	39.88	4.26	40.54	1.60	31.80	30.28
P	28.00	4.64	-.78	5.30	13.18	18.60
K	36.06	-.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 35. 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	-.24	0
MP	0	0	-4.39	-11.62	-4.84	-8.87
MK	-13.89	-5.15	-7.26	-12.88	-.30	-4.04
MPK	-10.90	-2.07	-1.80	-16.26	-9.86	-9.61

Table 36. Payoff matrix for farmer-nature M-P-K problem in north eastcentral Iowa[a] (no 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	47.38	58.59	70.94	30.76	17.55	62.86
P	-.97	22.30	48.24	.84	10.62	34.08
K	10.70	18.39	30.27	8.60	-.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: (18).

Table 37. Savage regret matrix for north eastcentral 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	-.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	-.74	-8.24

Table 38. Payoff matrix for farmer-nature M-P-K problem in north eastcentral 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	-.97	22.30	48.24	.84	10.62	34.08
K	10.70	18.39	30.27	8.60	-.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 39. Savage regret matrix for north eastcentral 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	-.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	-.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 40. Data and regression equations for the nitrogen-stand-variety experiment in Wayne county[a]

Lbs. N per a.	Plants per a.	Early variety - Iowa 4297 1953 bu.	1954 bu.	1955 bu.	1956 bu.	1957 bu.	Adapted variety - A.E.S. 801 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]

$$Y = -144{,}8603 + \underset{(1.3)}{.5268X_1} - \underset{(1.03)}{.0639X_1^2} + \underset{(4.35)}{35.3228X_3} - \underset{(3.6)}{1.5640X_3^2} - \underset{(1.4)}{.1063X_1X_2}$$

$$+ \underset{(1.6)}{.0114X_1X_2X_3} \; ; \; R^2 = .69 \; ; \; d.f. = 53$$

[a]Source of data: (21).

[b]t's for each b appear in parenthesis below coefficients.

Table 40. (Continued)

Lbs. N per a.	Plants per a.	Early variety - Iowa 4297 1953 bu.	1954 bu.	1955 bu.	1956 bu.	1957 bu.	Adapted variety - A.E.S. 801 1953 bu.	1954 bu.	1955 bu.	1956 bu.	1957 bu.

Regression equation for the adapted variety:

$$Y = -149.7796 + \underset{(1.09)}{1.1635X_1} - \underset{(.75)}{.0421X_1^2} + \underset{(4.6)}{34.1749X_3} - \underset{(3.6)}{1.4083X_3^2} - \underset{(1.5)}{.1059X_1X_2}$$

$$+ \underset{(1.7)}{.0115X_1X_2X_3} \; ; \; R^2 = .79$$

X_1 = nitrogen ; X_2 = stand ; X_3 = current year rainfall [June rainfall (≤ 4 inches) + July rainfall (≤ 5 inches) + August rainfall (≤ 6 inches)] + carry-over (previous year rainfall - 21 inches)

Table 41. 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	.31	30.23	49.09	56.58
Adapted variety, stand = 16,000, N = 40	-.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: (21).

[b]Returns shown equal bushels times $.95 a bushel for corn less seed and fertilizer costs. Fertilizer costs include application expenses. Corn price used is $1.10 - .15 per bushel harvesting, hauling and storage costs. Source of price data: (43).

Table 42. Savage regret matrix for farmer-nature nitrogen-stand-variety problem

Farmer alternative	Rainfall 6 in. $/a.	Rainfall 12 in. $/a.
Early variety, stand = 12,000, N = 0	0	-4.71
Adapted variety, stand = 12,000, N = 0	-6.20	-.99
Adapted variety, stand = 12,000, N = 10	-6.93	-.89
Adapted variety, stand = 12,000, N = 20	-7.58	-.65
Adapted variety, stand = 12,000, N = 40	-8.94	-.41
Adapted variety, stand = 16,000, N = 40	-10.03	-.40
Adapted variety, stand = 16,000, N = 60	-12.10	-.26
Adapted variety, stand = 20,000, N = 60	-13.49	0

Table 43. 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	41	7	49
Plains barley	30	46	46	17	50
Cherokee oats	28	35	35	13	53

[a]Source of data: (23).

[b]Payoffs are the gross value of the production from one acre. The oat price used was $.53 per bushel and the barley price was $.80 per bushel (43).

Table 44. 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	-4	-10	-15
Plains barley	-3	-0	0	0	-14
Cherokee oats	-5	-11	-10	-4	-11

Table 45. 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: (20).

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

Table 46. 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	-.2	0	0
Trefoil-bromegrass	-1.7	-.1	-.5	-1.2
Ladino-Kentucky bluegrass	0	-.4	-1.6	-1.3
Ladino-orchardgrass	-.2	-.4	-1.4	-2.0
Alfalfa-timothy	-1.5	0	0	-.5

Table 47. 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: (22).

[b]Yields of pasture in tons of weed-free dry matter per acre per year.

Table 48. 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	-.2	-.3	-.1	0
Alfalfa-smooth bromegrass	0	-.1	-.1	-.5	-.5
Alfalfa-orchardgrass	0	0	0	0	-.1

Table 49. 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	.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	.6	.5

[a]Source of data: (22).

[b]Yields are in tons of weed-free dry matter per acre per year.

Table 50. 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	-.9	0	-.4	0	-.1
Trefoil-smooth bromegrass	-1.9	-.2	-.2	-.1	0
Trefoil-orchardgrass	-.9	-.5	0	-.1	-.1
Ladino-orchardgrass	0	-.7	-1.0	-.5	-.5

Table 51. Farmer-nature pasture stocking rate problem for unimproved pasture in Grundy-Shelby soil area[a] ($/a.)

Farmer alternatives	Cow and calf carrying capacity per acre								
	.23			.31			.40		
	Prices			Prices			Prices		
	1953	Av.[b]	1956	1953	Av.	1956	1953	Av.	1956
Plan for average pasture - .39[c]	8.42[d]	17.15	10.89	12.98	21.59	15.44	17.08	25.30	19.48
Plan for worst year - .23	10.34	15.35	11.79	6.74	10.01	7.69	2.70	4.01	3.09
Plan for next to best year and feed hay - .47	7.46	17.04	10.43	12.01	22.49	14.98	17.14	27.48	20.10

Farmer alternatives	Cow and calf carrying capacity per acre					
	.47			.55		
	Prices			Prices		
	1953	Av.	1956	1953	Av.	1956
Plan for average pasture - .39	13.93	20.69	15.89	10.34	15.36	11.80
Plan for worst year - .23	-.44	-.66	-.50	-4.04	-5.99	-4.59
Plan for next to best year and feed hay - .47	21.12	31.07	24.08	17.52	22.56	19.98

[a]Source of data: (13, 19, 31).

[b]Average prices of hay and grain, 1948-1957 (34, 43).

[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 52. Savage regret matrix for unimproved pasture stocking rate problem ($/a.)

Farmer alternatives	Cow and calf carrying capacity per acre								
	.23			.31			.40		
	Prices			Prices			Prices		
	1953	Av.	1956	1953	Av.	1956	1953	Av.	1956
Plan for average pasture - .39	-1.92	0	-.90	0	-.90	0	-.06	-2.12	-.62
Plan for worst year - .23	0	-1.80	0	-6.24	-12.48	-7.75	-14.44	-23.47	-17.01
Plan for next to best year - .47	-2.88	-.11	-1.36	-.97	0	-.46	0	0	0

Farmer alternatives	Cow and calf carrying capacity per acre					
	.47			.55		
	Prices			Prices		
	1953	Av.	1956	1953	Av.	1956
Plan for average pasture - .39	-7.19	-10.38	-8.19	-7.18	-13.20	-8.18
Plan for worst year - .23	-21.56	-31.73	-24.58	-21.56	-34.85	-24.57
Plan for next to best year - .47	0	0	0	0	0	0

Table 53.[a] Farmer-nature pasture stocking rate problem for phosphate-lespedeza pasture in the Grundy-Shelby soil area[b] ($/a.)

Farmer alternatives	Cow and calf carrying capacity per acre								
	.43			.47			.50		
	Prices			Prices			Prices		
	1953	Av.	1956	1953	Av.	1956	1953	Av.	1956
Plan for average pasture - .52	19.45	31.50	22.91	21.72	33.72	25.19	23.43	35.39	26.89
Plan for worst year - .43	20.32	30.18	23.18	18.43	27.37	21.02	17.01	25.27	19.41
Plan for next to best year and feed hay - .58	18.87	32.38	22.73	21.15	34.60	25.00	22.86	36.27	26.71

Farmer alternatives	Cow and calf carrying capacity per acre					
	.58			.62		
	Prices			Prices		
	1953	Av.	1956	1953	Av.	1956
Plan for average pasture - .52	21.73	32.29	24.80	19.84	29.30	22.64
Plan for worst year - .43	13.23	19.65	15.10	11.34	16.84	12.94
Plan for next to best year and feed hay - .58	27.41	40.71	31.26	25.52	37.90	29.10

[a]See footnotes in Table 51 for an explanation of this table.

[b]Source of data: (19).

Table 54. Savage regret matrix for phosphate-lespedeza-bluegrass pasture stocking rate problem ($/a.)

Farmer alternatives	Cow and calf carrying capacity per acre								
	.43			.47			.50		
	Prices			Prices			Prices		
	1953	Av.	1956	1953	Av.	1956	1953	Av.	1956
Plan for average pasture - .52	-.87	-.88	-.27	0	-.88	0	0	-.88	0
Plan for worst year - .43	0	-2.20	0	-3.29	-7.23	-4.17	-6.42	-11.00	-7.48
Plan for next to best year - .58	-1.45	0	-.45	-.57	0	-.19	-.57	0	-.18

Farmer alternatives	Cow and calf carrying capacity per acre					
	.58			.62		
	Prices			Prices		
	1953	Av.	1956	1953	Av.	1956
Plan for average pasture - .52	-5.68	-8.42	-6.46	-5.68	-8.60	-6.46
Plan for worst year - .43	-14.80	-21.06	-16.16	-14.18	-21.06	-16.16
Plan for next to best year - .58	0	0	0	0	0	0

Table 55. Farmer-nature payoff matrix for hog-cattle choice problem ($/100# T.D.N.)

Farmer alternative		State of nature (Prices of hogs and cattle 1956-1957)							
	Year	1950	1951	1952	1953	1954	1955	1956	1957
	Price of hogs	17.70	19.70	17.40	21.10	21.00	15.00	14.20	17.60
	Price of cattle	25.30	31.10	27.30	19.30	19.60	19.00	18.40	20.10
Produce hogs		4.42[a]	4.92	4.35	5.26	5.25	3.75	3.55	4.40
Produce cattle		4.55	5.60	4.91	3.47	3.53	3.42	3.26	3.62

[a]Payoffs are the value of 100 pounds of T.D.N. per acre. One hundred pounds of T.D.N. will produce 18 pounds of beef or 25 pounds of pork with feed requirements of breeding animals included (30). Other costs associated with the two enterprises are assumed to be about equal.

Table 56. Savage regret matrix for hog-cattle choice problem

Farmer alternative	State of nature (Prices of hogs and cattle, 1950-1957)							
	1950	1951	1952	1953	1954	1955	1956	1957
Produce hogs	-.13	-.68	-.56	0	0	0	0	0
Produce cattle	0	0	0	-1.79	-1.72	-.33	-.29	-.78