DECISION STRATEGIES FOR THE MULTIPLE USE OF WINTER WHEAT IN OKLAHOMA

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CHAPTER I

INTRODUCTION

In the past ten years there has been a marked increase in the number of calves kept for beef purposes on farms in Oklahoma. The factors which have contributed to this increase relate both to the supply of cattle at particular points in the marketing channel and to the demand for these cattle. The demand for red meats in the United States, particularly beef, has been continuously increasing for a number of years and Oklahoma livestock producers have responded with greater output.[1]

The increased supply has been made possible in part by more intensive use of available land resources. More intensive use of grazing lands has been made possible by such factors as increased fertilization and improved varieties and species of grasses. Another important contributor has been the greater use of small grains as a forage crop. Increased grazing of small grains has increased the production of livestock per unit area of land and has made more local cattle available for the feedlots in the southern plains region.

Among the concerns of both agriculturalists and government officials is the growth potential of particular agricultural sectors of the economy and the possibilities of sustaining existing growth trends. The expansion of the livestock production sector is constrained chiefly by the price and availability of inputs and by the market price of the output. The major input of any livestock enterprise other than the cost of the animals is feedstuffs. Protein and energy sources typically have been dried or grazed grasses and legumes, grains, grain by-products, and other industrial by-products.

The forage portion of winter cereal grains is similar to traditional forage crops in nutritive value. Further it has been found that removal of the forage portion prior to the emergence of the growth point of the plant does not impair or diminish the potential yield of grain.

The production of forage is a supplemental crop up to the critical emergence stage as its use does not increase or decrease the amount of grain that is subsequently produced. This implies the economic decision dictates use of the forage during the supplemental grazing period if the added returns are greater than the added costs. The added costs include the cost of additional fertilization if the crop is to be utilized as a forage, and costs involved in tending and maintaining cattle such as fencing costs.

The utilization of small grain forage as a supplementary product presents producers with an opportunity to achieve a comparative advantage in livestock production.

If winter season grazing is climatically feasible, the comparative advantage is achieved mainly by reducing or eliminating the need for expensive protein concentrates during the winter period. Inclement weather can negate the potential advantage in two ways. First, the producer's costs may be increased by feed purchases and veterinary expenses. And second, returns may be reduced by death losses.

The Problematic Situation

The problems relating to the multiple use of the wheat plant can be subdivided into two groups. The first is the cultural aspects of crop production. The growth of the plant is related to such cultural practices as seeding date, fertilization rate, variety and the control of grazing to avoid such things as tramping damage and over-grazing. In this study, it is assumed that the cultural practices and the coefficients selected such as the seeding rate are representative of the practices followed in the area. The second problem area relates to the economic use of the crop. In addition to winter grazing, the crop may be fully utilized as a forage crop by grazing cattle on through the spring rather than removing and producing a grain crop. The stocking rate or number of animals grazed per unit area is a basic decision that must be made by the farm operator.

After emergence of the growth point, the two crops, grazing and grain, become directly competitive and the economic problem becomes more difficult to solve than during the winter period when grazing is supplementary. To link these two problems, the growing characteristics of the wheat plant throughout the season from planting until harvest must be determined. The plant as a growing organism reacts to the environmental inputs while it is regularly being depleted through grazing, rather than simply accumulating nutrients until maturation.

From time to time the operator receives inputs of information to use in the decision making or management process. These include soil moisture, temperature and plant growth conditions as well as prices of livestock and wheat. The management process has both a long run and a short run time perspective. In the long run the operator considers the probabilities of various climatic phenomena occurring and makes a determination of the optimal general or long run strategy to follow. In the short run, knowing what has already happened in a particular season, the decision maker can reassess the probabilities and modify his plans. Expectations which are based on historical series of occurrences, can then be used to estimate seasonal outcomes by measuring the deviation of the most recent information from the norm.

The decision maker is faced with both controllable and uncontrollable variables. The major variables over which control is possible include the method and time of purchasing cattle and the number purchased or the number that will be grazed per unit area of wheat. The uncontrollable variables include the climatic variables such as rainfall and temperature and the prices that will be faced by the individual operator.

The calendar of events for the producer is given in Table 1. In terms of this time sequence, decisions regarding the major controllable variables occur on or before November 1 and on March 1. It can be noted that some action occurs at each identified date but the actions that occur in September, May and June are actions that are conditioned on previous decisions. If the original decision is made to grow wheat, the crop will be planted about September 1; if a graze out decision is made in March, cattle will be sold in May; and if a produce wheat decision is made in March, grain will be harvested about mid-June.

The problem may be summarized into the following points:

1. Wheat plants produce two products, forage and grain. In the fall and winter, grazing is a supplementary crop and in the spring the two products become competitive.
2. The decision maker is faced with uncontrollable as well as controllable variables creating an environment of decision making with imperfect knowledge.

TABLE I

CALENDAR OF ANNUAL EVENTS FOR WINTER WHEAT-STOCKER OPERATION

Approximate Date	Event
September 1	Grain is planted
November 1	Stockers are placed on wheat pasture
March 1	Decision is made to produce wheat or graze out livestock
May 15	Cattle are sold or removed from wheat grazing if graze out decision was made in March
June 15	Wheat is harvested if produce wheat decision was made in March

3. To economically assess the variability of yields and prices, a decision model must be developed that considers the information available to operators.

Objectives

The general objective is to construct a decision model to enhance the economic use of wheat for grazing and grain considering information on expected production levels as well as expected livestock and grain prices.

The specific objectives are:

1. To construct a winter small grain production submodel to predict the yield of grazing and grain and to convert forage production into livestock weight gain.
2. To investigate the effects of varying the stocking rate, buying and selling strategies and price ratios on the expected net returns and the distribution of net returns.
3. To construct forecasting models for price and production variables using phenomena observable during the production year.
4. To determine the expected net returns and distribution of net returns using the forecasting models and to construct empirical decision models using these predictions.

Model Construction

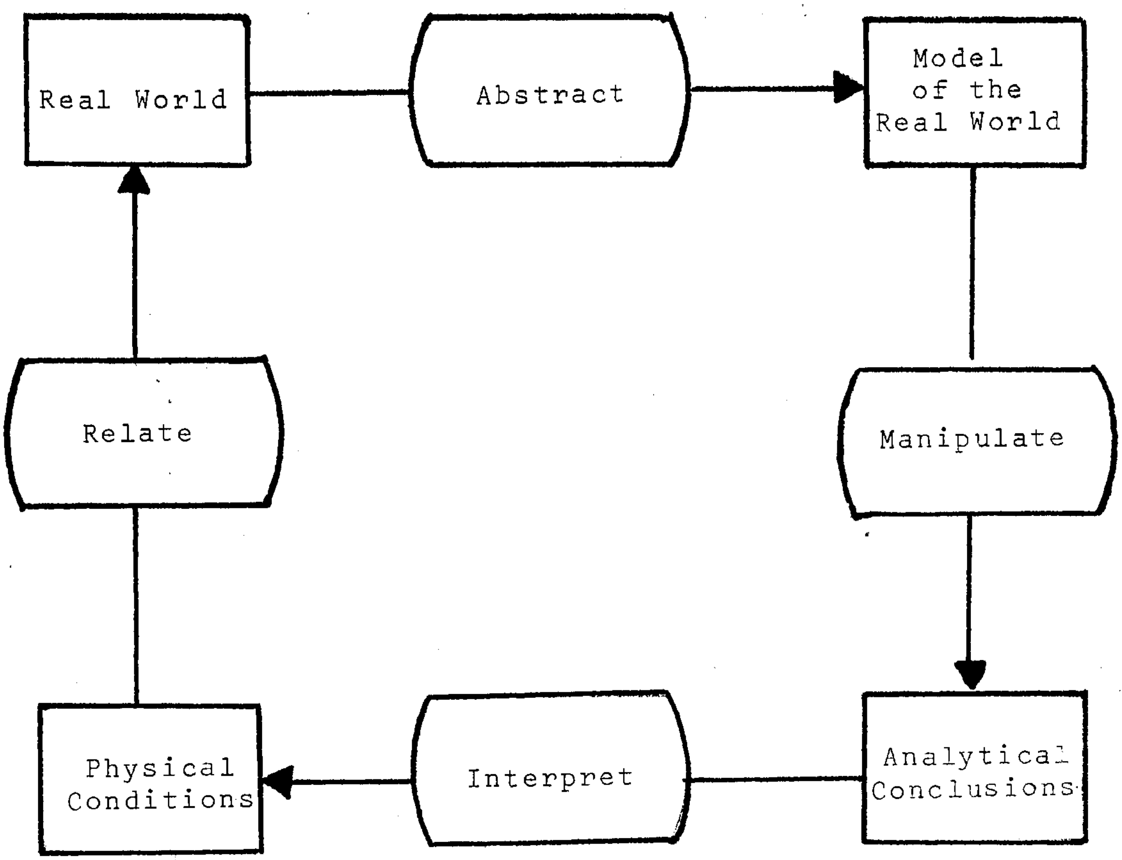
The discussion of the problem indicates a number of significant variables affect the outcome. Such a situation can only be understood and studied by constructing a model to represent the actual system of relationships.

A model is an abstract representation of a system that incorporates enough detail to allow accurate assessment of the real world but not necessarily complete detail of the actual system. Figure 1 illustrates how problems from the real world can be abstracted in a form suitable for analysis and evaluation. The real world is abstracted and modelled which then allows manipulation of the relationships to produce analytical conclusions. The results are in turn interpreted with regard to the physical conditions and the interpretation related to the real world conditions.

The key term in Figure 1 is manipulate. An appropriate model permits experimentation among various strategies. In fact, the whole justification as Figure 1 implies, for constructing a model is to make experimentation more feasible than in the real world.[2] This is particularly true of the problem investigated in this thesis. The time and cost to conduct similar experimentation in the real world would be prohibitive.

A model may be small or large. A particular set of equations, for example which are designed to estimate a particular portion of a model, may be thought of as a model.[3] Models may be used to represent economic, psychological, physical, political, or biological systems.

The problem investigated in this study can be thought of as a wheat production and utilization system composed of two subsystems. These are: 1. The biological or production subsystem including the growth of the wheat plant, the production of forage and grain and the conversion of digestible nutrients into pounds of beef;



Source: Johnson et al., *The Theory of Management of Systems*.

Figure 1. Modeling and the Decision Process

and 2. The economic subsystem of the computation of expected costs and returns.

A model of this system will allow the manipulation of controllable factors to be studied. A detailed discussion of the use and analysis of systems models is included in the next chapter.

It is acknowledged that the production subsystem is the first requirement of the system but it is emphasized that the ultimate goal is a decision making model. Use of this model will suggest methods of increasing the effectiveness of decisions and the efficiency of management. Insight into how this may be achieved in the context of the problem investigated in this study is presented in the following section.

The Management Process

In general terms, the management process involves integrating resources in a manner such that the primary goals and objectives can be achieved. In this context, management is an intermediary between goals and accomplishments. Management can also be defined as the planning, organizing and controlling functions needed to achieve the goals of the firm or organization.[4]

The planning stage involves determining and specifying the objectives or any desirable changes in the objectives and then selecting the necessary actions to achieve these objectives.

The operating or organizing phase involves acquiring and utilizing the required resources and implementing the previously determined course of action.

The third critical stage is the control phase. Following execution of the plan, feedback of achievement levels allows a comparison to be made between actual performance and the specified goals and objectives indicating what, if any corrective action is necessary. Control has been defined as the function which provides adjustments in conformance to the plan and the maintenance of variations from system objectives within allowable limits.[5]

The control phase involves two key aspects. First, a means of making a comparative measurement must be provided or be available and second, a means of carrying out the indicated changes must be a functional part of the plan. Control is not an isolated process but must take account of the objectives and be directly incorporated with the feedback mechanism.

Management has traditionally been viewed as a problem solving exercise, which in the context of the above discussion involves the feedback-control phases of the planning process. A problem can be specified by comparing what is or what has been achieved with what ought to be or what should have been achieved.

The decision model that is developed here relates to both the planning and the control stages. The planning stage is a long run type of exercise such as that done by a producer in the summer and fall period when planning his operations for the next production year. In the decision model various objectives that might be followed by the operator are discussed. In addition, an analysis of long run type strategies is constructed to indicate the decision maker actions that will achieve the objectives.

The decision model also relates to the control stage. As the production year approaches the spring period, the operator can assess the prevailing situation in comparison with what was expected when fall plans were made. A decision can then be made to continue pursuing the original plan or make a change if that action appears more desirable.

Problems of Control

In the operation of agricultural firms all of the steps in the planning process are not always isolated or explicitly identified. Even though goals as well as controls are at least implied if not exactly specified, the goals are often not achieved. It is useful to investigate some of the problems of control and possible reasons for the apparent breakdown of control systems. Four of the possible explanations are discussed below.

1. The "Ceteris Paribus" Problem

The number of factors involved in a production process is essentially infinite. In addition, some of the factors work in a random rather than a completely predictable manner. With an infinite number of factors, there are an even greater number of interactions between variables. In most physical and biological systems, comprehension and accurate prediction of the interaction is not feasible. To make economic analyses possible and useful, it is necessary to isolate the effects of a limited number of variables. This may exclude some relatively important interactions and therefore result in biased or even inaccurate results.

In the prediction of forage growth for example, a simple model might include only the amount of fertilizer or rainfall as the determinants of the amount of grazing grown in a particular year. One of the objectives of this study is to construct a model detailed enough to include most of the important variables and to allow interactions between variables to occur.

2. Ineffective Communication Systems

Researchers and extension agents who develop management aids and techniques inherently have a deeper understanding and appreciation of the data requirements, ramifications and limitations than an individual operator. In addition, managers vary in their ability to recognize and implement the course of action suggested by an enterprise or firm business analysis. Thus there are differential rates of transformation of technical information between individual farmers and between extension agents and farm operators. A discussion of information theory is not attempted here as numerous good references are available. It is helpful however to point out some of the requisites of an effective communication system as discussed by Purcell.[6]

a. The source must understand the needs of the receivers and make the relationship a dynamic rather than a static one.

b. Feedback facilities must be present and functioning.

c. Actions must be calculated and designed rather than habitual.

Optimizing models such as linear programming or enterprise budgets compare enterprises on a net return basis but do not indicate the variability of the expected income. Enterprise budgets, for example may indicate that the expected income of one enterprise is greater than for another but it may also carry a much higher probability of negative returns--a risk that the operator may not be willing to accept. This is designed to rectify the problem for one type of operator and in the process demonstrate the general applicability of the approach.

3. Imperfect Data

In terms of the theoretical approaches of information theory and cybernetics, information is regarded as the measure of the amount of organization as opposed to randomness.[7] The amount of information has a quantity and a quality dimension. If the amount of information is measured by the reduction of uncertainity, the information a farm manager receives may be inadequate in terms of the quantity available pertaining to the specific problem, or inadequate in terms of the quality or accuracy. An example in farm management studies is the problem of using generalized budgets and areal data and coefficients. These of course may deviate significantly from the farm situation in question due to such factors as managerial capabilities, soil type and amount of annual precipitation.

Related to the quality aspect is the use of inaccurate price and production forecasts. Forecasts are based on a very specific set of conditions and assumptions and if not utilized in such a manner, the predicted results will be meaningless. The decision model developed in this study is designed to show how current available information can be utilized to update expectations and thereby allow managers to be more adaptive to changing conditions.

In addition, forecasting models are developed which an individual Oklahoma operator can adapt to the observed conditions.

4. Misconceived Goals and Objectives

Operators may misinterpret their true goals. For example, maximizing net worth will dictate a significantly different control plan than maintaining a minimum level of annual income. A recent study suggests many farm operators may not accurately evaluate their goals and objectives.[8]

In most economic endeavors, some form of profit maximization has long been assumed to be the top priority objective. Extension and planning agents as well as researchers may not accurately identify the goals stated by an operator resulting in ill-conceived control plans. The goals and objectives problem has been investigated extensively by other studies.[9] In this study some modified profit maximization decision rules to demonstrate how this might be done by a producer and the effects of such criteria will de discussed.

Types of Decisions

A further insight into the breakdown of control plans can be gained by categorizing the types of decisions made by a manager. A brief explanation of the classification is given below:

1. Allocative

   The allocation of available resources among alternative uses or enterprises is a basic decision that must be made by all operators. A complete inventory of resources must be available as well as an understanding of all feasible alternatives.

2. Quantitative

   An operator usually has the possibility of increasing (or decreasing) the number of units of a resource under his control. Often, due to capital constraints or the nature of the input, all inputs cannot be increased at the same rate. Excess capacities may occur at a given point in time but should only occur as intermediate stages in a growth path over time.

3. Technological

   Available technology can be viewed as an everchanging input. The technology utilized involves determining the specific process desired and when to change levels of that technology or when to substitute an entirely new technology.

4. Temporal

Good management is not always making the correct decisions but making them at the critical time. The manager can have the best information, such as completely accurate price information but may still not make a decision or at least may not decide to take action at the appropriate time.

In terms of the problem being investigated in this study, the allocative, quantitative and temporal types of decisions are the most important. For example, a decision maker must decide how much of the area in wheat will be used for graze out and how much for grain. The possibility of expansion in terms of additional land exists for an operator but in this problem the quantitative type of decision has direct reference to the number of animals to be purchased and what stocking rate will be followed.

In the situation being studied the temporal aspect of decision making is of the utmost importance in placing cattle on and removing them from pasture at the critical times. In the model, specified criteria are imposed on the system to insure that these actions are completed at the correct times. In this study the technological decision is not considered as it is assumed that new enterprises are not considered and technology is constant.

Description of the Study Area

The study area, referred to as North Central Oklahoma is a major wheat producing area of the state. It includes the counties of Grant, Garfield, Alfalfa, Major and the eastern portion of Woods county.

The selection of the study area is based on the agricultural production characteristics of the region. A large acreage of winter cereals is grown in the area and the potential for utilizing the forage portion of these cereals is greater than any other area of the state. Many of the producers in this area have already adopted the practice of grazing at least a portion of their winter cereal acreage. However, many acres are not grazed and a significant potential for increased livestock output still exists. For these reasons the specified problem to be studied is of major significance in this area, more so than any other four or five county area in the state.

Wheat is by far the most prominent crop in each of the counties. In 1971 there were 1,088,500 acres of wheat in the five county area. Barley, the next most prevelant crop was grown on 172,100 acres, followed by alfalfa hay with 61,000 acres.[10]

The specification of study area boundries is based upon the uniformity of cropland capability and climatic factors. Two climatic features for the area are shown on

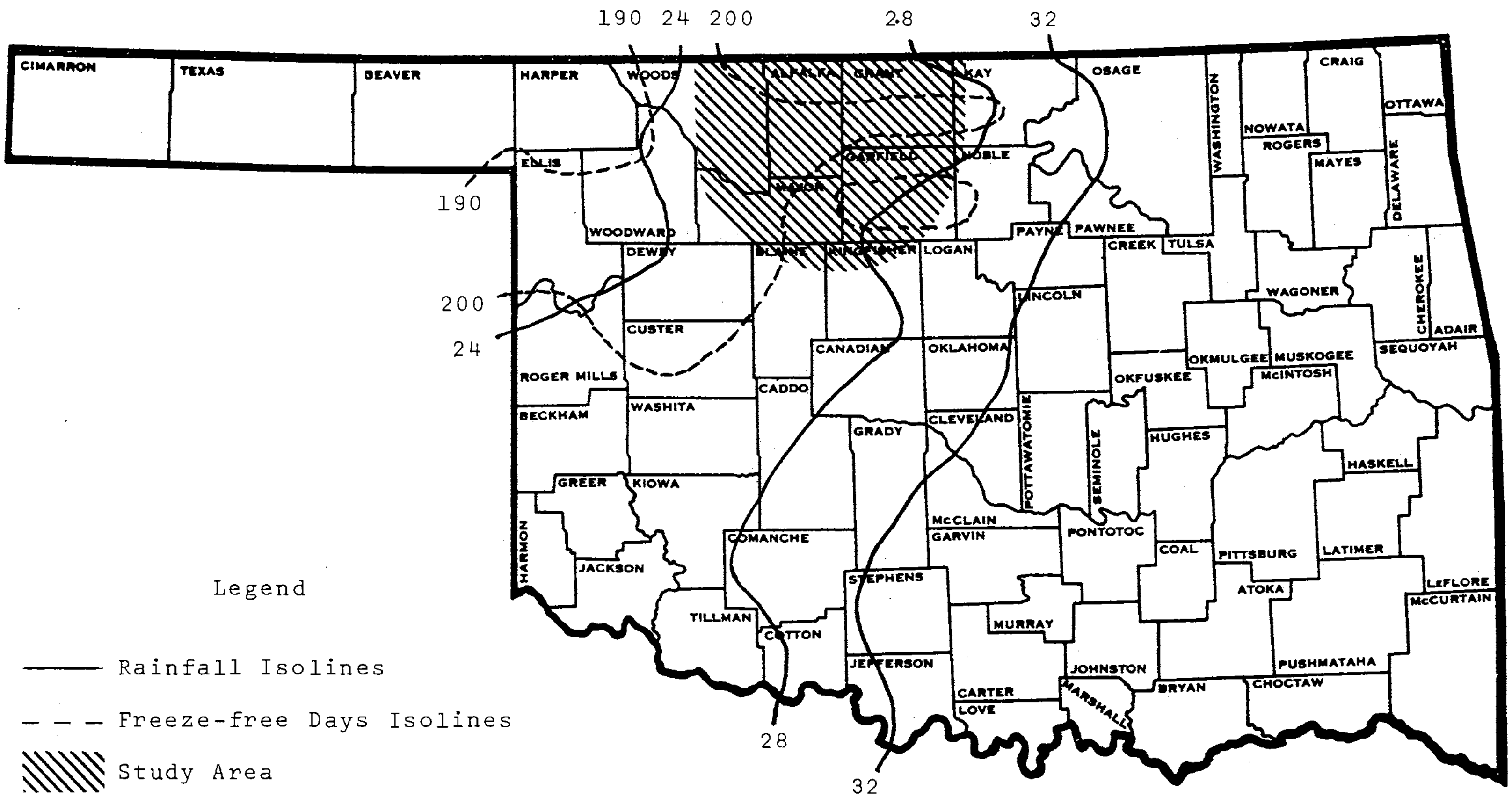


Figure 2. The Study Area

Figure 2; namely, the inches of annual rainfall and the number of freeze-free days. With respect to rainfall, a majority of the area falls between the 24 inch and 26 inch annual rainfall isolines. The normal for Alva is 25.64 inches. The freeze-free isoline for 200 days covers most of the region with the southeast portion of the area having a slightly higher number of freeze-free days.

It should also be noted that the area has a significant position in relation to the other areas of the state in total agricultural production. The five counties have approximately 13 percent of the total cropland of the state and have about one quarter of the state's wheat grain acreage.[11]

Format of the Thesis

The objectives stated that the two subsystems composing the system of wheat production and economic utilization were to be constructed. In Chapter II, some models of crop production systems will be discussed followed by a discussion of some of the basic concepts of systems analysis including the components and classification of systems. This is followed by an examination of decision theory as it relates to the decision model used in the systems analysis.

To construct the production subsystem many physical and biological relationships must be developed. A detailed explanation of these components are presented in Chapter

III. This includes the simulation of random events, forage growth and forage utilization.

The representative farm situation and the crop and livestock budgets that are necessary to compute net returns are described in Chapter IV. Also included in this chapter is a delineation of the analysis procedures used to evaluate the strategy alternatives.

The details of the analyses are presented in Chapter V including price expectations and net returns distributions for various strategies.

Chapter VI summarizes the analyses, draws conclusions and offers suggestions for improvement of the model. It also includes suggestions for analytic procedures and further research to facilitate these improvements.

FOOTNOTES

[1]From January 1, 1964 to January 1, 1973, the number of calves under 500 pounds, kept for beef purposes increased steadily from 1,136,000 head to 1,760,000 or a 55 percent increase. Source: U.S. Department of Agriculture, *Livestock and Meat Statistics*, Statistical Reporting Service, Economic Research Service (Washington).

[2]R. S. Johnson, F. E. Kast and J. E. Rosenzweig, *The Theory and Management of Systems* (New York, 1973), p.131 ff. and J. B. Dent and J. R. Anderson, eds., *Systems Analysis in Agricultural Management* (New York, 1971).

[3]Ibid.

[4]Johnson, Kast, and Rosenzweig.

[5]Ibid.

[6]Wayne D. Purcell, *An Appraisal of the Information System in Beef Marketing*, Michigan State University, Agricultural Economics Report No. 151 (East Lansing, 1969). Other references on information theory include the following: T. C. Helvey, *The Age of Information* (Englewood Cliffs, 1971). ch. 3; J. C. Emery, *Organizational Planning and Control Systems* (London, 1972), ch. 4; and Jiri Klir Miroslav Valach, *Cybernetics Modelling* (London, 1966), ch. 13.

[7]Norbert Weiner, *Cybernetics or Control and Communication in the Animal and the Machine*, 2nd edition (Cambridge, Massachusetts, 1961), pp. 1-10.

[8]W. L. Harman, R. E. Hatch, V. R. Eidman and P. L. Claypool, *An Evaluation of Factors Affecting the Hierarchy of Multiple Goals*, Oklahoma State University , Technical Bulletin, T-134 (Stillwater, 1972).

[9]Ibid.

[10]The averages are reported as "acreage planted, 1971", by the Oklahoma Crop and Livestock Reporting Service.

[11]By 1969 census definition of cropland there were

15,658,206 acres in the state and 2,022,365 acres of cropland in the 5 counties. Also, the "wheat for grain" reported for the whole state, totalled 4,253,753 acres with 1,030,676 acres being grown in the study area.

CHAPTER II

THEORETICAL FUNDAMENTALS

As with most production processes the problem studied in this research involves both controllable and uncontrollable factors. The presence of the latter and the existence of interactions between these and the controllable factors places the decision maker in an environment of risk or uncertainity, depending upon his knowledge of the nature and distribution of possible outcomes. One way to increase the knowledge available regarding the interaction between controllable and uncontrollable variables is to pursue a program of extensive grazing trials with large numbers of cattle carried out over many years. The time and costs of this approach are immediately evident. An alternative to field trials is to construct a detailed mathematical model of the real world relationships.

The functional model can be referred to as a model of the wheat growth and utilization system and with such a model, an analysis of the interactions between uncontrollable and management strategies can be made. Systems analysis is summarized in the first section of this chapter to provide a framework for the construction and use of the model in the following chapters. Decision theory is presented to provide a background for the methodology of decision analyses and the criteria for decision selection.

Systems Analysis

There are a number of ways the steps in the decision making process may be specified. Hutton[1] says that a manager or decision maker (1) senses (that is, obtains information on) the state of the environment in which he operates; (2) analyzes this information for its possible consequences to the unit he manages; and (3) develops a plan of control that is calculated to cause his firm to survive and if possible, prosper and grow.

Simon looks at the decision making stage a little differently.[2] The stages he outlines are:

1. Intelligence or searching the environment for conditions calling for decisions,
2. Design or inventing, developing and analyzing the possible courses of action, and
3. Choice or selecting a particular course of action from the available alternatives.

Regardless of the approach taken, alternatives are selected and since a rational economic man is assumed, an economic evaluation of alternatives is imperative. To perform the necessary economic analyses, a number of formal techniques,[3] or "models" are available. These include the following:

1. Budgeting,
2. Functional analyses such as regression models,
3. Activity analysis or linear programming, and
4. Simulation and systems analysis.

Simulation concepts have been developed more recently than the three previous techniques, in part to tackle new and different problems.

Although simulation and systems analysis are given as one technique, they are not strictly equivalent concepts. Simulation can be defined as a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models that describe the behavior of business, economic, social, biological or chemical systems over extended periods of time.[4,5] A more simplistic approach defines simulation as a general approach to the study and use of models and an individual simulation run is an individual experiment performed on a model.[6]

Simulation can also be defined as the feasibility to do the following with a model:

1. Introduce probability events,
2. Deal with sequential time,
3. Interact the capital and operating problems.[7]

Simulation then is the use of models for the study of the dynamics of a real system necessitating the construction of the model as the first stage followed by the experimental phase.

The problem studied fits Maisel and Gnugnoli's definition of simulation as it involves a physical system, the water-soil interaction, a biological system, the growth and utilization of wheat, and an economic system, the economic evaluation of different ways of using the wheat crop.

Budgeting, functional analyses and linear programming all have limitations that are critical to this study and that can be overcome by simulation. These include the use of probability distributions and the introduction of time in the model. In computing a distribution of net returns it is necessary to consider the whole distribution of the random events which determine the net returns. It was previously indicated that time is also a necessary element to be included to assess alternative strategies. It is necessary to account for the passage of time in estimating forage growth through the year and in specifying the decision actions.

Naylor incorporates the idea of a model and a system in explaining that the scientific method follows a four-step procedure when applied to an economic system.[8] The four stages are:

1. The observation of a mathematical system,
2. The formulation of a mathematical model that attempts to explain the observation of the system,
3. The prediction of the behavior of the system on the basis of the model by using mathematical or

logical deduction, that is, to validate by comparing the model with the real system, and

4. The performance of experiments with the model.

The simulation of the wheat production-utilization system presented in this study follows these four steps. The outline of the system is presented later in this chapter and the development and validation of the model is presented in the next chapter.

A key word both in discussing modelling in the previous chapter and in discussing simulation has been "experimentation". In comparing simulation and system analysis, the latter can be defined simply as the study of systems.[9] Systems analysis is, therefore, a broader, more encompassing term. The complexity of the systems makes it difficult to handle problems directly in the context of the models. In the context of this study, the sequential occurrence of random and controllable events through the production year is a simulation of the wheat system. When different limitations and constraints are placed on the system, a comparison of simulation results or a comparison of experiments with the system constitutes an analysis of the system.

Systems and Components

A system must involve at least two elements and a relation that holds between each of its elements and at least one other element in the set.[10] The elements include components and variables or can be thought of simply as inputs and outputs and can be concrete and measureable or abstract in nature.[11] In terms of a mathematical model, all these concepts are encompassed; that is, components, variables, parameters and functional relationships are included.[12] The functional relationship is:

$$Y = \phi(X_1, X_2, \ldots, X_k) \ , \ i = 1, \ldots, k \qquad (2\text{-}1)$$

where:

Y = the ouptut or endogenous variable, and

X_i = the k variables which influence Y and are made up of exogenous and policy variables.

The variables relate in one way or another to the components. A three-category classification of variables into output, status and input variables is convenient.[13]

Status variables describe the state of a system or one of its components either at the beginning, during, or at the end of a time period.

It was indicated above that output and endogenous variables are synonymous terms. These are generated by the components or denote characteristics internal to the system.

Exogenous inputs are those elements which affect but are not affected by the system or they are said to provide the environment for the system.[14] The term "policy variable" was used above. Rather than referring to variables as exogenous and policy variables, these elements may be classified as uncontrollable exogenous and controllable or instrumental exogenous variables, respectively.

These concepts can now be placed in the context of the system developed in this study. The following are the basic functional relationships of the production system:

$$SM = \phi_1(RA, ET, RN, DR) \qquad (2\text{-}2)$$

$$YF = \phi_2(SD, SF, T, SM) \qquad (2\text{-}3)$$

$$YG = \phi_3(YF) \qquad (2\text{-}4)$$

$$WT = \phi_4(SR) \qquad (2\text{-}5)$$

$$HR = \phi_5(SR, YF) \qquad (2\text{-}6)$$

$$NR_1 = \phi_6(HR, WT) \qquad (2\text{-}7)$$

$$NR_2 = \phi_7(YG) \qquad (2\text{-}8)$$

where:

SM = the soil moisture level,

YF = the yield of forage per acre,

YG = the yield of grain per acre,

WT = the weight gain per acre,

HR = the hay required for supplemental feeding per acre,

NR_1 = the net returns per acre for grazing,

NR_2 = the net returns per acre for grain production,

RA = rainfall,

ET = evapotranspiration,

RN = runoff,

DR = drainage,

SD = seeding date,

SF = soil fertility,

T = air temperature, and

SR = stocking rate per acre.

Following the above classifications of components, NR_1 and NR_2 are output or endogenous variables while SM, YF, YG and HR are status variables and RA and ET are input variables. On the other hand, SR, SD and SF are controllable exogenous variables and T and SM are uncontrollable exogenous variables.

A final word on functional relationships. These can be thought of chiefly as one of two types, namely; accounting statements or identities and operating characteristics.[15] For example, equation (2-2) is an identity while the other functional relationships specified are operating relationships.

Systems Classifications

There are a number of ways of classifying systems and only a few are discussed here.

A system can be defined as stochastic or deterministic. In a deterministic system, the output can be predicted completely if the input and the initial state of the system are known. Conversely, in a stochastic system, for a production state of the system, a given input does not always produce the same output. Only the range of the expected output can be predicted. The stochastic nature of systems can arise from the existence of truly random elements in the system or from a lack of completeness with respect to the conceptualization of the system.[16] Johnson and Rausser point out that often the parameters define the relations and error terms are specified as elements resulting in a stochastic model of a non-stochastic system.

The system utilized in this study is stochastic in that daily temperature and rainfall are randomly generated and the interaction of these two events affects daily production of forage. It should be emphasized that the relationships given in equations (2-2) through (2-8) are exactly defined and in this sense, they are deterministic. For example, rainfall is stochastically generated, but the amount of moisture added to the soil profile by a given amount of rainfall is precisely defined according to the existing soil moisture conditions and is not a function of an externally generated random factor.

A second classification is based on the state of the system, i.e., either static or dynamic.[17] It was previously pointed out that the time dimension is an important part of simulation and accounts for some of the main techniques, especially in the system used in this study. The system developed in this study can therefore be classified as dynamic.

Applicable Decision Theory

The problem described in the previous chapter indicated that the decisions to be studied are made under conditions of uncertainity. Decision theory therefore can be applied to the production and price data to assess the alternatives. Each decision considered has a number of possible outcomes depending on the state of nature that occurs, where a state of nature is the occurrence of a particular phenomena or event over which the decision maker has no control. Each combination of decision maker action and state of nature produces a payoff which may be positive or negative. A schematic concept is presented in Table II where the "Actions" (a_j) can be considered actions to be taken on March 1 in the context of this problem. The states of nature (θ_i) represent possible combinations of crop yields and livestock prices. These random variables are not an inclusive list of the variables that could be considered. In addition, a more detailed classification of the variable values than that given in the table could be considered. The table can be completed by entering the gains or net incomes for each action for each state of nature (R_{ij}).

A table such as Table II can be used to select an optimum strategy according to a number of criteria or

TABLE II

SCHEMATIC CONCEPT OF PAYOFFS OF ALTERNATIVE ACTIONS UNDER VARIOUS STATES OF NATURE

Values of Random Variables		States of Nature	Actions			$P(\theta_i)$
Crop Yields	Livestock Prices		a_1	a_2	a_3	
Low	Low	θ_1	R_{11}	R_{12}	R_{13}	P_1
Low	High	θ_2	R_{21}	R_{22}	R_{23}	P_2
Medium	Low	θ_3	R_{31}	R_{32}	R_{33}	P_3
Medium	High	θ_4	R_{41}	R_{42}	R_{43}	P_4
High	Low	θ_5	R_{51}	R_{52}	R_{53}	P_5
High	High	θ_6	R_{61}	R_{62}	R_{63}	P_6

decision rules.

The _maximin criterion_ is a pessimistic rule. It requires that the minimum payoff for each state of nature be found. The optimum action is that which gives the maximum of these minimum payoffs. The _minimax criterion_ is similarly conservative. It requires that the maximum gain be selected assuming the worst state of nature occurs. The _maximax criterion_ is conversely an optimistic criterion.

It firstly assumes the most favorable state of nature will occur and then optimizes by selecting the maximum payoff. All of these three criteria assume that the particular state of nature selected, either the most or least favorable will occur with a probability of 1.0.

The <u>principle of insufficient reason</u>, on the other hand assumes all the possible states of nature are equally likely. The optimum strategy is then the action which has the highest expected return.

All decision strategies such as those described above or similar criteria are based on the premise that the decision maker has neither objective nor subjective information regarding the probabilities of the states of nature. This can be described as one side of a dichotomy of decision theory. On the other side is the Bayesian approach which allows the use of available information to establish expected outcomes. In reference to Table II, the basic Bayes approach establishes the probabilities of the θ_i either from empirical data or subjectively by the decision maker. The optimal strategy is the action which maximizes the product, the payoffs and the $P(\theta_i)$. That is

$$\max_j \sum_{i=1}^{n} NR_{ij} \cdot P(\theta_i)$$

where:

n = the number of states of nature, and

NR_{ij} = the payoff for the i^{th} state of nature and the

j^{th} action.

This usually is referred to as the "no data" solution and the $P(\theta_i)$ are the a priori probabilities. Outside or additional information may be utilized to estimate the probabilities of θ_i for a particular decision period. This is done by observing a factor Z_k as a predictor of θ and constructing a conditional probability distribution or posterior probabilities, $P(\theta/Z)$ by the use of the Bayes' formula

$$P(\theta_i/Z_k) = \frac{P(Z_k/\theta_i) \cdot P(\theta_i)}{P(Z_k)}$$

The expected income using the posterior distribution for the data solution is given by the following equation:

$$ENR = \Sigma \left[\max_k \sum_{i=1}^{n} P(\theta_i/Z_k) \cdot NR_j \right] P(Z_k)$$

The above discussion concentrates on strategy selection by the use of the expected income parameter only. This approach disregards the distribution of income and the producer's utility preferences. If a function is derived which relates the level and distribution of money income to utility, utility values can be substituted for monetary values in Table II.[18] The optimal Bayes criterion in this situation maximizes expected utility. However, attempting to maximize expected utility creates a significant problem. A utility function must be derived for each producer and the difficulties and time required to perform such an operation are prohibitive.

The customary approach is to assume that utility is a linear function of money income which then implies that the Bayes criterion will select the strategy which maximizes expected returns. An alternative is a multi-dimensional utility model.[19] This concept is based on the principle of the irreducability of wants which states that an individual has a hierachy of wants and the lesser wants are not regarded until the higher wants have been satisfied. The objective then is to maximize the number of wants that reach the satisficing level given that all previous wants have reached the satisficing level. For example, assume a producer has two goals of maximizing money income and leisure time. The first objective is to reach a satisficing level of income and then try to achieve the satisficing level of leisure time. The analyses of the achievement of wants under these objectives is called lexiographic utility analysis. With this type of utility model, a modified Bayes criteria is possible for this study. For exsmple, the strategy which maximizes expected returns subject to the restriction that net returns exceed a specified amount with a specified probability could be selected. Another possibility is to select the strategy which maximizes expected returns subject to the restriction that expected hay requirements not exceed a specified level. A producer may not wish to feed a large amount of hay either because he doesn't want to store a large amount of hay as an insurance factor or because a large amount of hay may not be readily available in the area when it is needed.

In this study both fall and spring decisions are considered. The analyses of fall decisions are viewed as long run types of analyses. The main emphasis for Bayesian analysis is placed on the spring decision and posterior distributions are devised only for the decisions that are made on March 1.

The actions at each decision point, i.e., fall and March 1 are fully specified later but are defined as the stocking rate or the number of head grazed per acre. In an initial analysis three stocking rates are considered for the fall-winter period, the middle of which is considered the normal stocking rate in the study area. These three stocking rates are combined with three actions in the spring, namely sell all cattle winter grazed, retain the same number for graze out and reduce the acreage grazed and purchase enough animals to graze out the total acreage at the accepted stocking rate for the spring period.

In a second "no data" analysis, the medium stocking rate for the winter is utilized to reconsider decisions in March including different stocking rates for the spring period.

A data analysis for this spring period is conducted in a third analysis utilizing predictors for the uncontrollable variables faced by the operators.

For each of these analyses, net returns distributions for the various combinations of states of nature and decision maker actions are computed. The Bayes criterion and the modified Bayes criteria suggested above are applied to these distributions to determine superior strategies.

In this chapter, the concepts of systems analysis and simulation were presented with special emphasis on the role of simulation procedures in solving the problem presented in Chapter I. An outline of decision theory was also presented with an indication of how the concepts can be especially applied to the problem being studied. In the next chapter, details of the production subsystem are presented including the conceptual relationships, the establishment of mathematical formulation for these relationships and lastly the role of these relationships in the simulation of the total system.

FOOTNOTES

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[13] Orcutt and Naylor, et al.

[14] Ackoff.

[15] Orcutt.

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CHAPTER III

THE PRODUCTION SUBSYSTEM

The system of wheat production and economic utilization is divided into two subsystems which were previously referred to as the biological or production subsystem and the economic analysis subsystem. The outcome of the production subsystem is dependent upon a number of uncontrollable variables. Components of the subsystem are developed in this chapter to simulate these uncontrollable variables. Detailed relationships between these variables and the production of forage and grain are also explained.

While a number of components or submodels are described separately, the simulation of the total system is the ultimate goal. As the models are discussed it should be apparent that they are designed to fit together rather than being entities in themselves. The union of the components into the subsystems allows the simulation of probabilistic events over time. This union also allows the model to be used to achieve the second objective, experimentation with the controllable variables such as the stocking rate.

The general production relationships are presented in the first section of this chapter. This is followed by a detailed description of the development, specification and validation of the relationships concerning weather phenomena. In the next section, the production relationships used to predict forage growth are described along with the model to convert forage into equivalent grain yield. The specification of the steps involved in the procedure to simulate production and grazing are presented in the last section.

General Production Relationships

As indicated above, this study is concerned with one crop, wheat producing two products in variable proportions; namely, wheat forage and wheat grain. Identification of the stages of plant growth from emergence to maturity[1] provides a means to start modelling production of wheat. From emergence until late spring, the plant has the potential to increase in dry matter weight at an increasing rate. Then the accumulation of forage matter essentially stops and accumulation of reproductive matter begins. When nutrients begin to be utilized for head development, the forage portion increases at a decreasing rate. Two production relationships are used to model the rate of forage growth during these two periods. Both relationships assume the amount of forage produced in a day depends on the amount of previously accumulated growth. To compute corresponding wheat grain yields, the accumulated forage is converted to equivalent grain yield.

Factors Affecting Yield

In an earlier study, Mapp was only concerned with grain yield.[2] His approach was to establish a maximum potential yield and subsequently make deductions from that yield according to the daily atmospheric and soil moisture stress placed upon the plant. The first concern in this study is to estimate the amount of forage production on a daily basis rather than to estimate grain production. The prediction of forage growth presents a slightly different situation than predicting grain production. The basic concept of cell growth in a plant dictates that the amount of plant material on day t is directly a function of the amount of plant material on day t-1. Therefore an additive or accumulative approach is used in this study. The amount of forage accumulates over time rather than being reduced from a specified potential maximum. Even with this additive approach the potential yield is not infinite and it can be conceptualized as a function of the seeding date, the variety and the fertility level in addition to soil moisture and temperature conditions. The functional relationship is given in equation (3-1).

$$YF_a = f(SD, SF, T, SM, V) \qquad (3\text{-}1)$$

where:

YF_a = the actual yield of forage,

SD = the seeding date,

SF = the soil fertility,

T = the air temperature,

SM = the soil moisture, and

V = the variety.

The general approach is not to specify a maximum potential yield. However, factors used in the production model, which implicitly do limit the potential yield, are discussed later.

The relationship presented in equation (3-1) is not implied to be comprehensive. It is acknowledged that a number of other variables such as soil temperature, soil compaction and tramping damage by livestock could be included.

The seeding date and the soil fertility are considered as constants and are discussed in a later section. The means of incorporating air temperature and soil moisture into the system are discussed extensively in the following sections.

Air Temperature

The atmospheric temperature is an important variable in the growth of the wheat plant for two reasons. First, the air temperature is correlated with daily pan evaporation and hence with the daily evapotranspiration rate. Second, since the winter wheat plant grows during all four seasons of the year, temperature has a significant effect on the growth pattern of the plant.

Estimating Daily Temperature

The simulation of daily air temperature in this study is based on the works of Bingham[3,4] which utilize harmonic regression as the fundamental tool for modelling diurnal temperature events. When these harmonic functions are estimated, they can be used to predict a temperature measurement, i.e., the high, the low, or the range for any particular day in the year.[5]

Any set of data $x_1, x_2, \ldots, x_n$ at equally spaced times $t_1, t_2, \ldots, t_n$ may be exactly fitted by a series of the form:

$$y = a_o + \sum_{p=1}^{n} A_p \cos(pt - \phi_p) \qquad (3\text{-}2)$$

where:

t and ϕ_p are measured in the number of days after March 1[6] transformed to units of angular measure, and

p is the number of terms in the Fourier equation. This is the sum of cosine curves each with semi-amplitude A_p and time of maximum $t = \phi_p/p$. Equation (3-2) can also be written in the form:

$$y = a_o + \sum_{p=1}^{n} (a_p \cos pt + b_p \sin pt) \qquad (3\text{-}3)$$

where:

$$a_p = A_p \cos \phi_p,$$

$$b_p = A_p \sin \phi_p,$$

$$a_p^2 + b_p^2 = A_p^2, \text{ and}$$

$$p = 1, \ldots, n.$$

Such a sum is called an n-termed Fourier series. Bingham points out that the expected value $\mu(t)$ and the common logarithm of the standard deviation $\sigma(t)$ for the maximum, minimum or range can be expressed by an equation of the form of equation (3-3) where y can represent either $\mu(t)$ or $\log \sigma(t)$.[7]

Equation (3-2) can be written in the following form:

$$y = \alpha_o + \Sigma \alpha_p \cos \frac{360^o}{k} (t-\phi) \qquad (3-4)$$

and

$$\alpha_p \cos \frac{360^o}{k} (t-\phi) = A \sin \frac{360t^o}{k} + B \cos \frac{360t^o}{k} \qquad (3-5)$$

where:

$$A = \alpha \sin \frac{360^o}{k},$$

$$B = \beta \cos \frac{360^o}{k},$$

$$\phi = \frac{k}{360^o} \arctan \frac{B}{A} = \text{phase angle},$$

k = period, and

t = weeks.

Temperature observations can then be analyzed to determine the value of k for the cyclical and seasonal type of components.

Temperature Data

To utilize the above model the value of various parameters must be determined for the particular area under study. In this study, historical data from the Alva weather station was used for this purpose. A spectral analysis in the frequency domain permits study of the pattern of the historical data to ascertain the appropriate number of terms and hence the values of the parameters.[8]

Forty years of daily maximum and minimum temperature observations were available for all days of the year for the Alva weather station. To make this volume of data more manageable and adaptable to analytic algorithms, weekly average maximum and minimum temperatures were computed starting with March 1, 1932, as day 1 of week 1.

Power Spectral Analysis

The power spectral analysis routine used could not handle more than 1,000 discrete points. Therefore, 19 years was the maximum number of full years of data that could be analyzed in one run.[9] To account for this constraint, a spectral density function was estimated over the periods 1932-1950 and 1952-1971 for both the maximum and minimum weekly average temperatures.

The spectral analyses revealed only one distinct peak, that due to annual cycle of temperatures. The functions were further characterized by rapidly decreasing power immediately after the yearly cycle and then steadily declining power estimates with no distinctive peaks. Thus, except for the distinctive yearly cycle, all other frequencies contributed noise and obvious discernable cycles could not be identified.

In terms of equation (3-5):

$k = 52$, and

$$\frac{360}{k} = 6.923077^{\circ} \text{ or } .1208305 \text{ radians.}$$

A function was then estimated for both maximum and minimum temperatures using one trigonmetric term. The following equations were estimated:

$$T_{xt} = 73.48996 - \underset{(-82.93)}{19.98888} \cos(.1208305t) + \underset{(60.27)}{14.52597} \sin(.1208305t) \qquad (3\text{-}6)$$

$$R^2 = .84$$

$$T_{nt} = 46.53097 - \underset{(-110.63)}{19.1683} \cos(.1208305t) + \underset{(81.40)}{14.10404} \sin(.1208705t) \qquad (3\text{-}7)$$

$$R^2 = .90$$

where:

T_{xt} = maximum daily temperature for the t^{th} week,

T_{nt} = minimum daily temperature for the t^{th} week, and

t = the number of weeks after March 1.

The numbers in parenthesis are the "t" statistics.

A spectral density analysis was also conducted on the standard deviations of the average weekly temperatures. The resulting power spectral estimates were similar to those discussed above for the maximum and minimum temperatures. Thus yearly variation was the only cycle discernable and functions similar to those used to predict maximum and minimum temperatures can be estimated for the standard deviations.

The following functions were estimated to describe the standard deviations.

$$D_{xt} = .83860 + \underset{[.006]}{\underset{(21.16)}{.12759}} \cos(.1208305t) - \underset{[.006]}{\underset{(-11.17)}{.06737}} \sin(.120805t) \qquad (3\text{-}8)$$

$$D_{nt} = .74782 + \underset{[.006]}{\underset{(17.955)}{.10781}} \cos(.1208305t) - \underset{[.006]}{\underset{(-10.252)}{.06156}} \sin(.1208305t) \qquad (3\text{-}9)$$

where:

D_{xt} = Log_{10} (Standard deviation of average weekly maximum temperature),

D_{nt} = Log_{10} (Standard deviation of average weekly minimum temperature, and

[ ] = standard error of coefficient.

The standard errors of the estimates are 7.773, 5.588, .1945, and .1936 for equations (3-6), (3-7), (3-8) and (3-9) respectively.

Temperature Simulation

Having developed the previous equations, the following steps are used to generate daily maximum and minimum temperatures.

1. Compute the estimated maximum and minimum temperature using equations (3-6) and (3-7).
2. Compute the estimated standard deviation of maximum and minimum temperature using equations (3-8) and (3-9).
3. Generate a random normal deviate using an on-line subroutine called GAUSS which selects random variates from discrete probability density functions.
4. Multiply the random normal deviate by the standard deviations and add to the respective estimated temperatures. The result is a simulated maximum and minimum daily temperature.

Note that the same deviate is used in computing both the maximum and minimum temperature for day t.

The results of simulating temperatures for a twenty-year period are presented in Table III. To avoid a few unrealistically high daily temperatures during the summer period, all random normal deviates greater than 1.7 were rejected for all months of the year. Thus the averages in Table III are somewhat below the normal values shown. This does not create a problem for simulation as the deviations are relativley small and the months which show the greatest deviation between the normal and the predicted tend to be during the winter when growth is usually limited. This is also after the critical fall establishment period and it can be noted that during this period (October-November) the predicted temperatures are very close to the normal temperatures.

Soil Moisture

The factors which effect the amount of water in the soil profile on any given day include the soil moisture level on the prevoius day, the soil type, the precipitation, the evapotranspiration, the runoff and the drainage.

When the additions and deletions are known for a given day a soil moisture budget or balance can be made. The soil moisture balance is calculated in a different

TABLE III

COMPUTED AND NORMAL MONTHLY AVERAGE TEMPERATURES IN DEGREES FAHRENHEIT

Year of Sim.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
						Normal						
	47.8	58.9	68.0	78.6	83.9	83.4	74.6	63.1	47.9	39.1	36.3	40.2
						Computed						
1	44.6	55.1	68.4	76.7	83.4	80.0	70.1	59.9	48.8	41.7	35.9	33.8
2	47.6	55.6	67.3	75.4	83.8	83.2	73.4	58.3	45.5	37.9	33.8	37.7
3	45.2	53.5	65.8	79.2	84.6	81.3	70.3	59.9	48.3	39.4	36.0	33.9
4	41.0	55.3	67.9	77.4	80.7	78.9	73.1	61.7	46.1	37.6	32.1	36.4
5	44.5	54.8	66.9	77.5	81.9	82.8	70.7	61.8	50.3	37.2	35.4	36.9
6	46.3	56.7	66.8	76.6	81.9	83.0	71.5	63.7	50.3	40.9	32.7	34.0
7	41.5	53.7	69.3	77.6	84.0	80.4	72.7	60.8	50.6	39.4	34.7	37.4
8	46.8	56.0	66.8	76.9	81.6	81.2	72.0	62.5	48.1	41.6	36.2	35.7
9	42.8	55.5	65.0	78.7	81.7	81.8	70.9	61.5	46.0	39.0	35.4	35.4

TABLE III (Continued)

Year of Sim.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
10	46.6	55.1	65.9	77.8	83.4	82.7	73.3	63.8	47.1	40.8	35.9	36.9
11	43.2	57.6	68.0	77.6	82.6	82.1	73.3	62.5	50.7	40.0	35.5	31.6
12	43.8	58.2	70.4	76.6	83.4	80.7	73.8	61.9	51.8	40.3	36.1	34.8
13	39.5	57.8	70.3	76.9	81.0	81.8	73.0	59.5	48.0	44.1	30.8	34.9
14	47.4	56.2	66.0	78.3	84.3	78.9	74.5	62.6	45.6	41.5	32.3	34.7
15	42.2	54.2	66.2	78.5	84.2	82.0	70.7	58.8	47.6	42.0	34.1	37.5
16	45.9	57.8	70.0	75.9	82.3	80.3	73.0	63.0	50.4	36.0	35.3	36.1
17	41.0	56.2	68.6	77.7	82.9	80.6	73.3	60.6	48.2	40.0	33.1	40.2
18	46.2	55.5	68.4	77.7	83.2	78.8	71.7	63.7	48.5	38.0	32.4	37.4
19	42.2	55.7	69.0	79.2	82.6	80.3	72.6	62.7	45.2	40.3	32.9	36.4
20	44.6	55.6	70.7	77.6	83.2	79.7	75.0	60.9	49.0	36.6	31.6	37.4
Ave.	44.2	55.8	67.9	77.5	82.8	81.0	72.4	61.5	48.3	40.2	34.1	36.0

way depending on the time of the year and the stage of plant growth. Each of these soil moisture models includes the effect of the six factors delineated above. The first soil moisture balance is for the period from July 1 through September 30. This is the summer soil moisture balance for the period when the ground is fallow or bare. The second is for the period from October 1 through February 14 and is referred to as the fall and winter soil moisture balance. This is designed to carry the plant through until rapid spring growth begins. The third or spring soil moisture balance extends from February 15 through June 30. During this period a majority of the plant growth occurs and the demand for water is the greatest.

Each of the soil moisture factors are discussed in detail in the following sections.

Soil Characteristics

The wheat-producing soils of the study area were characterized as one of four types. A 48-inch soil profile was utilized as the soil unit of interest for the soil moisture balance. The cropland soils for the study area were divided into the following four groups: medium texture composed of Grant and Pond Creek soil types, coarse texture corresponding to Nash soil type, fine texture which included Kirkland, Bethany and Tabler soil types and eroded fine texture corresponding to Renfrow soil type. Soil moisture coefficients were determined for these soils from published data.[10] For the purposes of this research, the analysis was restricted to the first soil classification, the medium textured soil. The Grant and Pond Creek soils are the most prevalent soil types of the land used for crop production in the study area. In addition the soil types for the experimental plot results used in the validation process were mainly of these two soil types.

With suitable validation of the coefficients, the model could be applied to the other soil types. The wilting points for the medium textured classification are 1.17 and 5.78 and the field capacities are 2.375 and 9.25 inches both for the upper and lower zones respectively.

Rainfall and Evaporation Data

A long historical series of weather data is available for the Alva, Oklahoma, reporting station. To estimate the form and the parameters of the rainfall probability distribution, forty years (1932-1971) of data were used. This is a relatively complete series with very few days of missing rainfall observations.

Pan evaporation readings, however, are not taken at Alva. Therefore, the pan evaporation readings taken at the Great Salt Plains Dam were utilized. There are several problems in estimating probability distribution for evaporation from this series. First, no readings are available for the "cool" season when pan evaporation is very low, namely the period from November 1 to February 28. Second, within the March 1 to October 31 period there are many days when readings were missing, especially in the months of March and October. Third, the data series is only available for a relatively short period as readings began only in 1948. The twenty-five year series (1948-1972) was utilized. In analyzing the data, days of missing observations and days of accumulated observations were removed from the data set. The daily observations were taken from the monthly Climatological Data Reports for Oklahoma and punched on cards in Weather Bureau Deck 486 format.

Rainfall Probability Distributions

In estimating the probability of rainfall events with historical data, there are a large number of days on which no rainfall occurred. Inclusion of these zero event days in the estimating procedure proves cumbersome and inaccurate. The probability of no rainfall on any given day is high and the probability of a specific amount of rainfall on that day is very small making the estimation procedure for the latter very inprecise.

To avoid this problem two separate distributions were used in estimating the probability of rainfall events. These are:

1. The probability of any amount of rainfall on a

given day, and

2. Given that a rainy day occurs, the probability of alternative amounts occurring.

These probabilities are represented by P_{1i} and P_{2jk} respectively where:

i = the period of the year,

j = the amount interval of rainfall, and

k = the period of the year.

P_{1i} is then a zero-one distribution where the probability of a one (a rainy day) is a function of the time of year.

If it is assumed that P_{1i} and P_{2jk} are independent then the probability of an alternative amount of rainfall on any given day is the product of these two probabilities.

The parameters for i, the P_1 periods, were determined using the Alva rainfall data. The parameters for k, the P_2 periods were taken from Duffin[11].

Duffin found that computing the probability of rainfall for individual days on a strictly daily basis results in an irregular pattern of probabilities for consecutive days. For example, assume daily rainfall observations are taken for any historical period such as a twenty-year period. Then compute the number of times in twenty years that rainfall occurred on each day of the year. If the probabilities are plotted for any period of consecutive days, the resulting pattern will have an irregular sawtooth shape rather than a smooth oscillating curve. If a moving average of probabilities over some number of days is used rather than the probabilities of individual days, the smooth curve can be produced. Duffin states that some method of smoothing the plotted data is justified. This justification is based on the assumption that the general shape of the low frequency component of the plotted data is meaningful, but the short-term or high frequency component or "noise" irregularities are not. It is hypothesized that if a very large number of observations were used such as 200 years of observations rather than the twenty or forty years of data, the plotted probabilities would have a relatively smooth curve.

Various lengths of periods can be used to compute moving averages. Greater detail is maintained with a relatively short period such as 3-, 5-, or 15-day period. But high frequency "noise" of rainfall frequencies still occurs and for this reason a 29-day equally weighted moving average was chosen to compute P_{1i}.

In assessing these probabilities to simulate the occurrence of rainfall events, the following steps were followed:

1. Rainfall events were selected. These were arbitrarily selected to be .1-inch increments from 0.01 inch to 2 inches and one event for rainfalls of greater than or equal to 2.00 inches. These are the parameters referred to by the subscript j in the P_{2jk} above. A trace is assumed to be zero.
2. Forty years of daily observations for the Alva,

Oklahoma, station were available. Included in this data set were a few days for which no observation was recorded. The data set was revised by eliminating all days on which measurable precipitation was not recorded.

3. On this revised data set, a frequency count was made by day of the year for each specific rainfall event. For example, assume that for day t, rainfall observations were recorded for 38 years out of 40 and that rainfall of between 0 and .09 inches occurred on two of the 38 years on day t. A similar frequency count was made for all the specified rainfall events.
4. On this revised data set, a frequency count was made by day of the year and by specific rainfall event.
5. The occurrences of all rainfall events were totaled for each day of the year. This gives the number of times a measurable amount of rainfall occurred for day t in 40 years.
6. A 29-day moving average was computed on the number of days of rainfall for each day computed in Step 5.
7. The periods identified by Duffin and referenced by the subscript k in P_{2jk} are given below where the week numbers are the climatological weeks.

   Weeks 51, 52, and 1 to 8,

Weeks 9-36, and

Weeks 37-50.

He found that within these periods the probability distributions for the amount of rain that occurs on a rainy day, could be held constant.[12]

8. The frequency of each rainfall event for these three periods was tabulated. The frequencies are presented in Table IV.

9. The moving averages computed in Step 6 were plotted for each day of the year. The year was divided, by visual inspection, into periods during which the number of days in forty years that rainfall occurred, remained relatively constant. These periods are referenced by the subscript i in P_{1i}. Since the week is used as a unit of measurement for defining P_{1i} periods, the year could not be divided into periods of shorter length than seven days. Therefore, during periods when the number of rainy days was steadily increasing and rapidly declining, 1-week periods were isolated. The year was divided into the eleven periods. The average number of rainy days for each period was computed and divided by 40 to give the probability of a day with rain within the period. The periods and the probabilities are presented in Table V.

TABLE IV

CONTINGENCY TABLE OF FREQUENCY DISTRIBUTION OF RAINFALL EVENTS BY P_2 PERIODS, ALVA, OKLAHOMA, 1932-1971

Rainfall Event	P_2 Periods		
	I Wks. 51-08	II Wks. 09-36	III Wks. 37-50
(inches)			
0.01-0.09	197	638	240
0.10-0.19	91	264	70
0.20-0.29	56	163	37
0.30-0.39	33	123	26
0.40-0.49	28	86	18
0.50-0.59	21	92	18
0.60-0.69	15	65	19
0.70-0.79	10	47	9
0.80-0.89	5	41	10
0.90-0.99	11	31	3
1.00-1.09	8	42	4
1.10-1.19	9	21	3
1.20-1.29	1	21	1
1.30-1.39	5	11	2
1.40-1.49	2	14	1
1.50-1.59	3	16	4
1.60-1.69	4	7	1
1.70-1.79	1	7	1
1.80-1.89	1	6	1
1.90-1.99	0	5	0
$\geq$2.00	3	54	0
Total No. of Rainy Days	504	1754	468

TABLE V

P_1 PERIOD LENGTHS AND THE PROBABILITY OF A RAINY DAY BY PERIOD NUMBER

P_1 Period Number (i)	P_1 Period Length by Climat. Week	Ave. No. of Rainy Days for a Given Day in 40 Years	Probability of a Rainy Day
1	51-05	6.4	.1600
2	06	8.0	.2000
3	07	9.0	.2250
4	08	9.75	.2436
5	09-11	11.2	.2800
6	12-15	11.95	.2986
7	16	10.86	.2715
8	17	9.46	.2365
9	18-29	8.4	.2100
10	30-36	7.8	.1950
11	37-50	5.2	.1300

The rainfall probability distributions may now be more fully defined as follows:

P_{1i} = the probability of a rainy day in period i, i = 1, 11, and

P_{2jk} = the probability of the rainfall being in the

j^{th} interval in period k, given that a rainy day occurs, j = 1, 21 and k = 1, 3.

It should be noted that in reality, $P_{1i,n}$ and $P_{1i,n+1}$ are not independent where $P_{1i,n}$ is the probability of a rainy day on the n^{th} day of the i^{th} period. The procedure described above implicitly assumes this independence and accordingly is insensitive to the order of events over a few days period. However, it will be noted later that plant growth is an integrating process and this assumption of independence of daily events is not considered to create a significant bias in predicting plant growth over the whole growing season.

Simulation of Rainfall

The frequencies presented in Table V were converted to cumulative probabilities. These probabilities were multiplied by the appropriate P_1 probability to compute discrete probability intervals for P_2, given a rainy day occurs. A random number is then generated for each day and is checked against the P_1 and P_2 probabilities for that day to determine if it was a rainy day and if so how much it rained. The simulated annual rainfall for each of twenty-two years is presented in Table VI.

In simulating rainfall, the mid-point of each respective rainfall interval was used for the actual rainfall event. For example, if the random selection of a rainfall event determined the rainfall to be between .50

TABLE VI

PREDICTED ANNUAL RAINFALL BY YEAR OF SIMULATION

Year of Simulation	Predicted Total Annual Rainfall in Inches
1	23.90
2	26.10
3	23.75
4	25.75
5	18.10
6	29.70
7	26.20
8	30.60
9	26.65
10	21.85
11	23.20
12	21.80
13	16.65
14	27.85
15	24.95
16	26.25
17	33.20
18	23.45
19	25.80
20	29.50
21	29.65
22	21.45
Predicted Mean	25.74
Normal	25.64

and .54 inches, the simulated rainfall was .55 inches. It is acknowledged that this rule may introduce some upward bias into the rainfall simulator as there tends to be more events in the lower intervals. A comparison of the figures presented in Table VI indicated that this was not a significant problem and therefore was not considered further.

Equivalent Rainfall

Under dry soil conditions where rainfall has not occurred in a number of days, a high proportion of the rain that falls enters the soil profile. If rainfall occurs on concurrent days or there is an elapsed time of only a few days (two to six) without rainfall, the profile is essentially wet and the amount of runoff is a function of the antecedent moisture conditions or the antecedent rainfall as well as the amount and the intensity of the rainfall. Runoff then is a function on a particular day plus a portion of the rain that fell on the immediately preceeding days.[13]

$$EQR_t = R_t + f(R_{t-n}), \quad n = 1,6 \qquad (3\text{-}10)$$

where:

EQR_t = equivalent rainfall on day t, and

R_t = actual rainfall on day t.

Runoff is assumed to be a function of equivalent rainfall only, as rainfall intensity is dependent on the season of the year (see Tables IV and V).

$$Q_t = f(EQR_t), \quad R_t > 0 \tag{3-11}$$

where:

Q_t = the runoff on day t.

Points were plotted to determine the relationship between Q and EQR. Data was taken from measurements made at the Cherokee experimental station. From the hand drawn smooth curve (shown in Figure 3) it was determined that a function of the following form would be appropriate for equivalent rainfall of less than 2 inches:

$$Q = Ae^{-bEQR} \tag{3-12}$$

or

$$\ln Q = \ln A - bEQR$$

The following equation was estimated:

$$\ln Q = -8.5607 - (-2.939\ EQR) \tag{3-13}$$

$$(.1214) \qquad (.0778)$$

or

$$Q_t = .00019e^{2.939EQR_t}, \quad EQR < 2.0 \tag{3-14}$$

where the numbers in parenthesis are the standard errors of the coefficients.

If rainfall is greater than two inches, from the

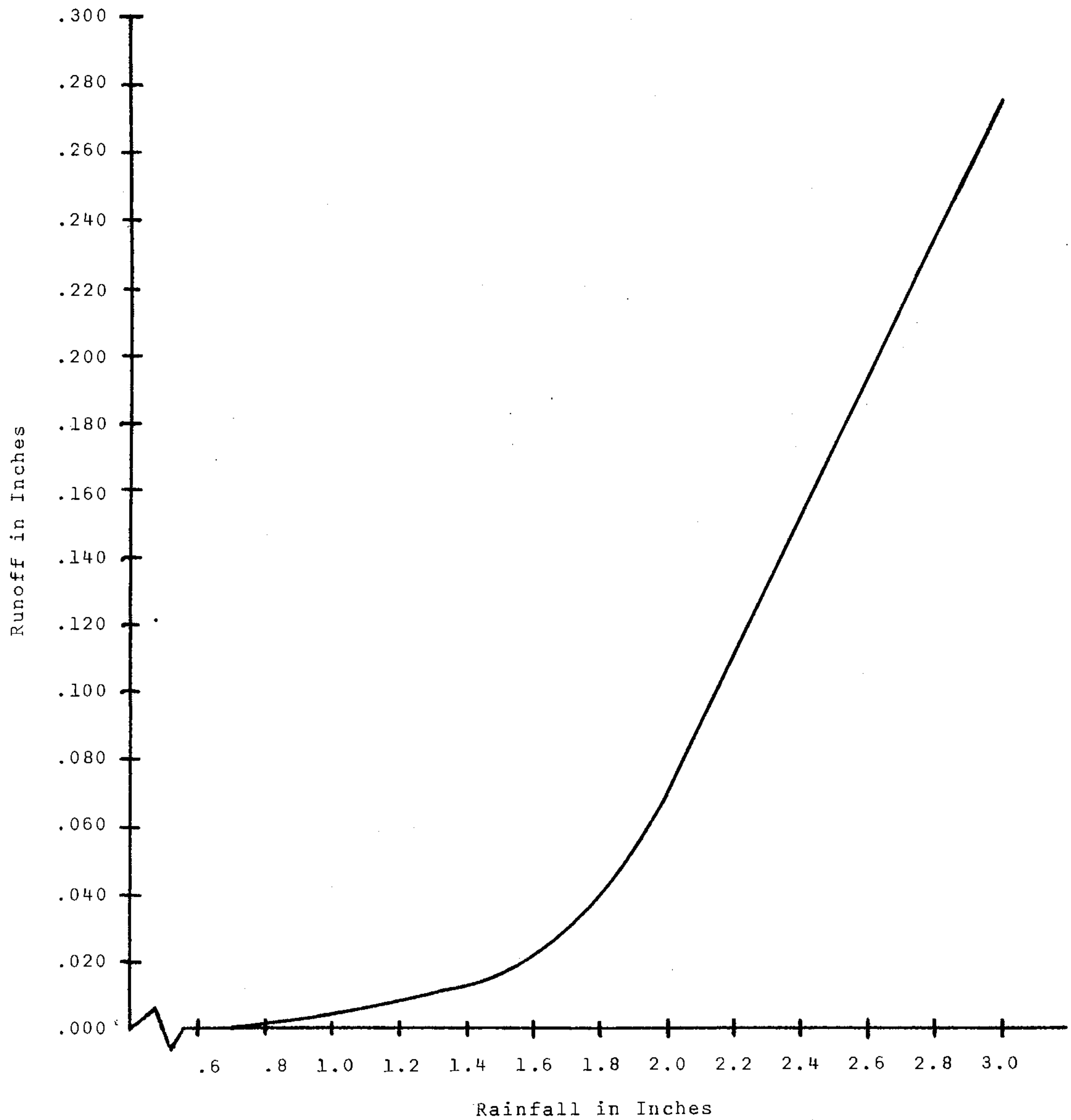

Figure 3. The Relationship Between Daily Rainfall and Runoff

graphical analysis it was determined that runoff is a linear function of rainfall. The estimated equation is given in equation (3-15):

$$Q_t = .3395 + .20365EQR_t, \quad EQR > 2.0 \qquad (3\text{-}15)$$

If equivalent rainfall is less then .7 inch per day, runoff was assumed to be zero.

$$Q_t = 0, \quad EQR \leq .7 \qquad (3\text{-}16)$$

<u>Computation of Equivalent Rainfall</u>

1. If day t is a rainy day

$$EQR_t = R_t + EQR_{t-1} \qquad (3\text{-}17)$$

where:

EQR_t = the equivalent rainfall on day t,

R_t = the actual rainfall on day t, and

EQR_{t-1} = the equivalent rainfall at the end of day t-1.

If $EQR_{t-1} = 0$ and $R_t < .7$ then the equivalent rainfall remains at zero.

$$EQR_t = 0, \quad EQR_{t-1} = 0 \text{ and } R_t \leq .7 \qquad (3\text{-}18)$$

$$EQR_t = R_t, \quad EQR_t - 1 = 0 \text{ and } R_t > .7 \qquad (3\text{-}19)$$

2. If day t is a dry day

$$EQR_t = .5EQR_{t-1} \tag{3-20}$$

If the equivalent rainfall is positive on day t followed by a number of rainless days, the equivalent rainfall is reduced by half each day and on the seventh day, assuming no intervening rainy days, is set at zero.

<u>Pan Evaporation Probability Distributions</u>

The general relationships presented in a previous section specified pan evaporation as an independent variable in the simulation of daily soil moisture readings.

The beta distribution was selected to describe pan evaporation. It was deemed appropriate for two reasons.[14] First, all of the probability mass occurs between zero and one. The curve of the probability density function can have any shape depending on the two parameters of the distribution. This essentially allows for different seasons or periods of the growing season.[15] The expression for the beta density function is:

$$\frac{1}{B(\alpha,\beta)} X^{\alpha-1}(1 - X)^{\beta-1}, \quad 0 \leq x \leq 1 \tag{3-21}$$

where:

$$B(\alpha,\beta) = \frac{\Gamma(\alpha+1)(\beta+1)}{\Gamma(\alpha + \beta + 2)}$$

and

$$\text{Mean} = \frac{\alpha + 1}{\alpha + \beta + 2} \tag{3-22}$$

$$\text{Variance} = \frac{(\alpha + 1)(\beta + 1)}{(\alpha + \beta + 2)^2 (\alpha + \beta + 3)} \tag{3-23}$$

In determining the parameters for the beta distribution using the data available, i.e., relative humidity or daily wind velocities are not available, two basic approaches are feasible. The first is to have a different distribution for each calendar period of one or two weeks in length. The second, and the one chosen is to compute the beta parameters according to the daily temperature because this allows the simulated pan evaporation readings to be correlated with the simulated daily temperature readings. For example, assume a different distribution was established for each two week period and that a cold front moved through the state during the first week of July dropping the maximum temperature to 75°F. If the calendar date distribution was used to generate a pan evaporation reading, the predicted value would implicitly assume the temperature on that date was the normal or about 95°F. However, the temperature was in fact much lower and allowance for this should be made in the pan evaporation readings. The parameters for the beta distributions were computed by ten degree increments in daily maximum temperature, using the Cherokee and Alva data. The results are presented in Table VII.

TABLE VII

PAN EVAPORATION AND BETA PARAMETERS BY TEMPERATURE RANGE ALVA-CHEROKEE, OKLAHOMA, MARCH-OCTOBER, 1948-1972

Temp. Range in °F Daily Maximum	Number of Obs.	Pan Evaporation		Beta Parameters	
		Mean	Std. Dev.	α	β
40- 49	52	.09596	.06372	2.40448	22.65264
50- 59	164	.16512	.09919	2.96654	14.99941
60- 69	477	.20551	.11947	3.18596	12.31674
70- 79	869	.23790	.12720	3.80880	12.20130
80- 89	1326	.28934	.13724	7.87395	11.97111
90- 99	1362	.36971	.13712	7.88852	13.44854
100-109	592	.48849	.15435	9.26516	9.70178
110+	23	.50087	.14219	11.38554	11.34598

For the period from mid to end October until approximately the beginning of March, pan evaporation readings are not available. However, in modeling winter wheat it is important to carry the plant on through the winter and to take account of the water loss even though the daily consumptive-use is small. To simulate water loss during this period, the Blaney-Criddle consumptive-use formula was selected. This formula relates consumptive-use to percentage of daytime hours of the year and the mean temperatures. The relationship is given in equation (3-24).[16]

$$U = \frac{ktp}{100} \qquad (3\text{-}24)$$

where:

U = the consumptive-use for a given period and is equivalent to evapotranspiration,

k = empirical coefficient for the consumptive-use period,

t = mean temperature for the consumptive-use period in degrees Fahrenheit, and

p = percentage of daytime hours of the year for the consumptive-use period.

Values for the k coefficient are available by months from empirical trials with irrigated winter wheat at Garden City, Kansas. The values for the coefficient p are determined by the latitude location. For this study $36^{\circ}30'$N was selected and the coefficients were computed on a daily basis.[17] The value of t is computed on a daily basis using the temperature simulation procedure described previously. The values of k and p are presented in Table VIII.

It is emphasized that this formula was used only for the winter months, the period for which evaporation readings were not available.

TABLE VIII

COEFFICIENTS FOR THE BLANEY-CRIDDLE FORMULA FOR STUDY AREA BY MONTH

Month	Daily Daytime Hours in Percent (p)	Consumptive-Use Coefficient (k)
October (10-31)	.2524	.57
November	.2297	.32
December	.2177	.33
January	.2245	.36
February	.2443	.34
March	.2694	.40

Evapotranspiration

A major problem predicting plant growth is the estimation of how much water a plant can get from the soil. Ritchie put forth the concept of extractable water which is defined as the water which can be readily taken up by the plant.[18] Water loss measurements are developed in this section to utilize this definition of extractable water.

Potential evapotranspiration is set at 50 percent of pan evaporation in all seasons of the year.

1. Summer Period, July 1 through September 30

This is the fallow and planting period. By approximately October 1, the plants will be up and effectively cover the soil surface. The water loss from the soil surface by evaporation during this period is computed from equation (3-21).[19]

$$ET_t = E_t(e^{-.183*KT}) \qquad (3\text{-}21)$$

where:

ET_t = actual evapotranspiration loss on day t,

E_t = potential evapotranspiration and is equal to 50 percent of pan evaporation, and

KT = the number of days which EQR $\geq$ .7.

The day EQR becomes greater or remains greater than .7, KT is set equal to one.

2. Fall and Winter Period, October 1 through February 15

During this period the simulated pan evaporation readings are small. If the average daily temperature is above 40°F, the actual evapotranspiration is assumed to be equal to the potential evapotranspiration; if less than 40°F the water loss is assumed to be zero.[20]

It has been observed that wheat plant roots penetrate quite deep into the soil profile during the fall period and that some upward movement of deep water does occur. Therefore, it was assumed that if the extractable water in the upper zone exceeded 60 percent of the potential extractable water in that zone all water demand would be taken from the upper zone. If however, the upper zone extractable water was reduced to less than 60 percent, half the daily water demand would be taken from each zone.[21]

On the first day of the fall period (October 1) the evapotranspiration is assumed to be equal to one percent of pan evaporation and the evapotranspiration rate increases at the rate of one percentage point per day up to 50 days after which the rate remains at 50 percent of pan evaporation.[22]

$$ET_t = .1ND\ (PAN_t) \qquad (3\text{-}22)$$

where:

ND = the number of days after September 30, and

PAN_t = the pan evaporation reading for day t.

3. Spring Period, February 16 through June 30

The concept of extractable water is used in this period to compute the relationship between actual evapotranspiration and potential evapotranspiration.

$$ET_t = pE_t, \quad 0 < p \leq 1 \tag{3-23}$$

$$p = f(EXT_t) \tag{3-24}$$

$$EXT_t = \sum_{i=1}^{2} (SM_{it} - WP_i) \tag{3-25}$$

where:

ET_t = actual evapotranspiration on day t,

E_t = potential evapotranspiration on day t,

EXT_t = extractable water on day t,

SM_{it} = inches of soil moisture in zone i on day t, and

WP_i = wilting point in inches of water for zone i.

The relationship to determine p is shown graphically in Figure 4 and functionally in the following set of equations:

$$p = 3.3\ (\%\ EXT_t), \quad 0 < (\%\ EXT_t) < .3 \tag{3-26}$$

$$p = 1, \quad .3 \leq (\%\ EXT_t) \leq 1.0 \tag{3-27}$$

$$p = 0, \quad EXT_t = 0 \tag{3-28}$$

In the model, the total water demand during

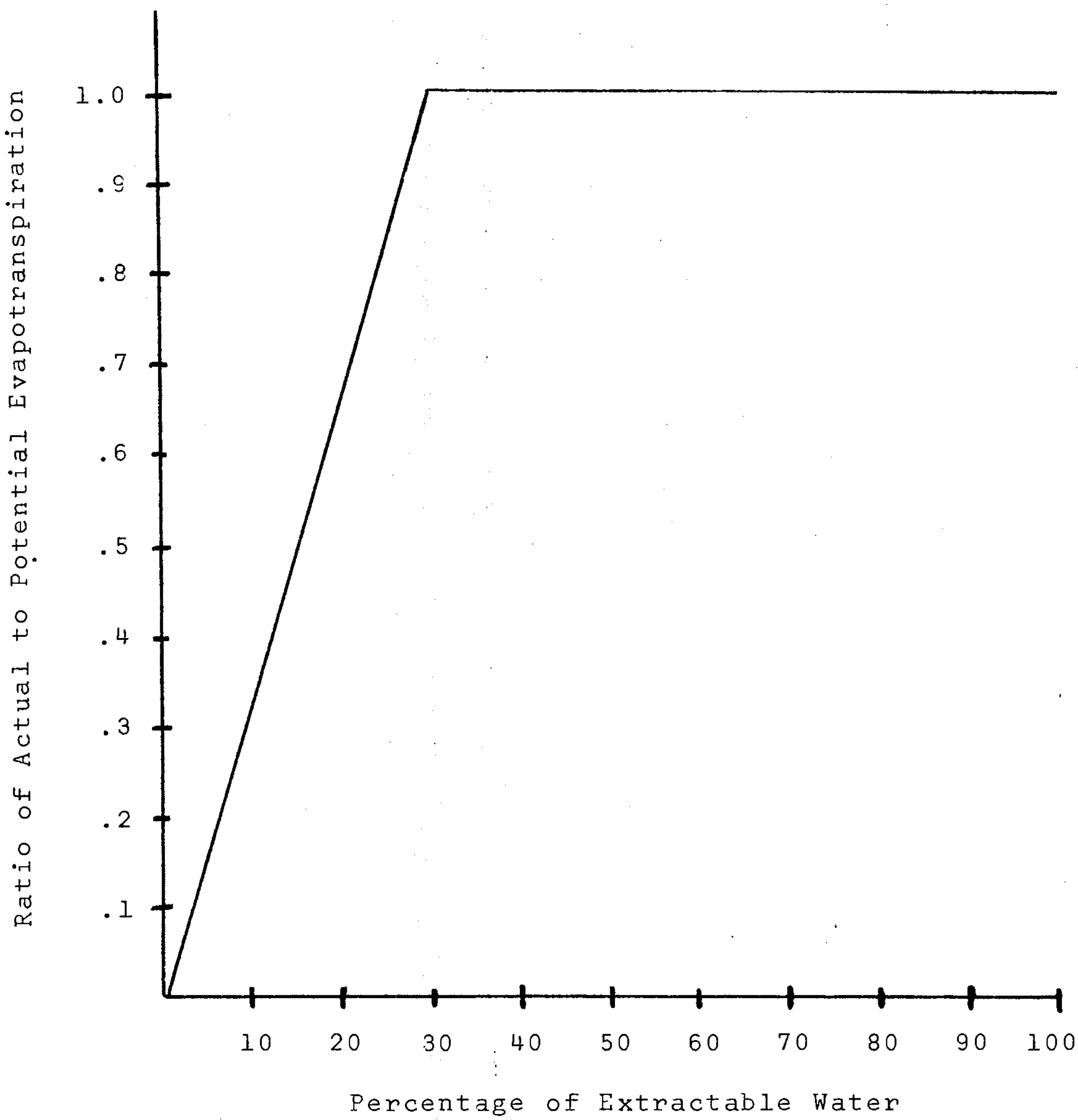

Figure 4. The Relationship Between Evapotranspiration Ratio and the Percentage of Extractable Water in the Soil Profile

the period is first removed from the upper zone until the permanent wilting point is reached. Further demand is taken from the lower zone until it reaches permanent wilting point (PWP). If both zones reach PWP no further water loss occurs until some recharge takes place.

If any day is a rainy day, the evapotranspiration is assumed to be equal to the pan evaporation.

Deep Drainage

In addition to water loss upward in soil due to the evapotranspiration demand there is drainage downward. The amount of drainage is a function of such factors as the soil type and the amount of water in the soil profile. The following functional relationship and the estimated equation are given in equations (3-29) and (3-30) respectively.[23]

$$DR_t = f(SML_t) \tag{3-29}$$

$$DR_t = .1e^{(2(SML_t - FCL))} \tag{3-30}$$

where:

DR_t = the drainage in inches from the lower horizon on day t,

SML_t = the soil moisture present in the lower horizon on day t, and

FCL = the field capacity of the lower horizon in inches.

The above relationship is utilized for all seasons of the year. The only restriction is made during the winter period where it is assumed that if an evapotranspiration demand is made on the lower horizon, no drainage occurs that day.

Soil Moisture Balance

The soil moisture balance is made on a forward basis. That is, the rainfall that occurs on day t does not enter the profile until the beginning of day t+1. Similarly, the evapotranspiration and drainage losses for day t are made at the end of day t or the beginning of day t+1. In functional form the balance is given in equation (3-31).

$$SM_{it} = SM_{it-1} + RN_{it-1} - ET_{it-1} - DR_{t-1}, \quad i = 1,2 \qquad (3\text{-}31)$$

where:

SM_{it} = soil moisture in horizon i on day t,

RN_{it-1} = net rainfall (actual minus runoff) on day t-1 entering horizon i,

ET_{it-1} = evapotranspiration loss on day t-1 from horizon i, and

DR_{t-1} = drainage loss from horizon 2 on day t-1; if i = 1, $DR_{t-1} = 0$.

If the net rainfall is greater than the available capacity of the first zone, the remainder enters the second zone. If the net rainfall is greater than the available capacity of both zones, both are filled to field capacity and the remainder is assumed to be further runoff. Of course, the soil moisture in either level cannot decrease to less than the PWP for that horizon.

It is assumed there is no percolation of water from the upper to the lower horizon.

Soil Moisture Balance Validation

Soil moisture measurements taken at the Wheatland Conservation Experiment Station three times a year were available for the crop years 1957-1958 through 1966-1967.[24] Data is presented in percentage of water by weight. It was converted to inches of water in the 12 inch and 36 inch zones using the following relationships:

$$\% \text{ by Volume} = \% \text{ by Weight} \times \text{Bulk Density}$$

$$\text{Inches Water} = \text{Depth} \times \frac{\% \text{ by Volume}}{100}$$

The bulk density for the first six inches was assumed to be 1.5 and the bulk density of all lower depths was assumed to be 1.38. The computed soil moisture measurements are presented in Table IX.

The soil moisture balance was initialized by setting

TABLE IX

COMPARISON OF MEASURED AND ESTIMATED SOIL WATER, CHEROKEE, OKLAHOMA, 1958-1967

Date		Measured 12 Inch	Measured 36 Inch	Measured Total	Estimated 12 Inch	Estimated 36 Inch	Estimated Total
				Inches			
1958-1959							
10-20-58	(234)	2.34	6.89	9.23	1.80	8.17	9.97
3-19-59	(19)	1.70	5.98	7.68	1.57	5.78	7.35
6-25-59	(117)	1.92	5.00	6.92	1.40	6.10	7.50
1959-1960							
11-09-59	(254)	2.84	7.88	10.72	1.96	8.04	10.00
4-05-60	(36)	2.69	7.90	10.59	1.22	7.56	8.78
6-22-60	(114)	2.38	4.83	7.21	1.17	7.91	9.08
1960-1961							
9-28-60	(193)	2.82	7.20	10.02	1.81	8.59	10.40
3-14-61	(14)	1.66	6.45	8.11	1.17	6.50	7.67
6-26-61	(118)	2.49	4.70	7.19	1.17	8.07	9.24
1961-1962							
9-28-61	(212)	2.92	6.13	9.05	2.33	8.41	10.74
3-15-62	(19)	2.32	7.14	9.46	1.17	6.39	7.56
6-19-62	(111)	2.17	4.60	6.77	1.50	8.26	9.24

TABLE IX (Continued)

Date		Measured 12 Inch	Measured 36 Inch	Measured Total	Estimated 12 Inch	Estimated 36 Inch	Estimated Total
				Inches			
1962-1963							
10-05-62	(219)	2.77	7.02	9.79	2.32	8.63	10.95
3-21-63	(21)	2.28	6.49	8.77	1.17	6.15	7.32
6-11-63	(103)	2.27	3.77	6.04	2.22	7.33	9.55
1963-1964							
9-30-63	(214)	2.47	6.80	9.27	2.09	8.45	10.54
3-11-64	(21)	1.66	5.06	6.72	1.80	5.81	7.61
6-12-64	(104)	1.40	3.61	4.01	1.68	6.31	7.99
1964-1965							
9-28-64	(212)	2.33	5.52	7.85	2.07	7.67	9.74
3-26-65	(26)	2.62	7.44	10.06	1.17	7.22	8.39
6-11-65	(102)	1.50	3.25	4.75	1.80	6.31	8.11
1965-1966							
10-04-65	(218)	2.68	6.52	9.20	2.24	8.59	10.83
4-06-66	(35)	2.16	5.80	7.96	1.17	5.92	7.09
6-14-66	(102)	.71	3.11	3.82	1.32	5.81	7.13
1966-1967							
10-11-66	(225)	1.95	4.73	6.68	1.93	8.17	10.10
3-14-67	(14)	1.28	4.30	5.58	1.25	5.78	7.03
6-19-67	(111)	1.61	3.37	4.98	1.54	5.95	7.49

the soil moisture at the measured levels of June 17, 1958 (day 109) and simulating the balance for the next nine years.

The weather data used to validate the model was from the Alva station, the same data used in other parts of the model described previously. A couple of problems are raised by using daily readings directly to simulate the soil moisture balance. First, there are a number of days of missing data in the historical series for temperatures. In the 1958 to 1968 period there were no long periods of missing data. Where there were missing days, it was assumed the temperature was the same as the previous day. Gaps in the pan evaporation readings taken at Cherokee were filled using the pan evaporation simulator described prevoiusly.

The second problem relates to the location of the experimental plots and weather stations. For the basic climatological data, temperatures and rainfall, the Alva station was selected because of the length and the completeness of the records. However, pan evaporation readings were not available for Alva but were available for the Great Salt Plains Dam near Cherokee. Thus there could be significant differences in climatological events at the three locations on any given day.

The data presented in Table IX were inspected by agronomists and soil physicists who were involved in the studies conducted at the Wheatland Conservation Experiment

Station. In thier opinion, in addition to the problems of soil moisture measurement discussed above there is question regarding the suitability of the dates on which some of the field measurements were made. It was felt that many of the measurements were taken immediately after rains when field work was not possible. In this situation the estimated measurements would be greater than the measured readings as the model assumes water enters the soil profile in an instantaneous fashion.

The evaluation of these scientists was that the model displayed satisfactory predictive powers.

Forage Growth Production Functions

Review of Crop Production Models

There are a number of different mathematical forms that can be used for crop production functions. The simplest form is similar to that given in equation (3-32).[25]

$$Y = -6.37 + 2.09\ X \qquad (3\text{-}32)$$

where:

Y = yield of wheat in bushels per acre, and

X = inches of rainfall for October through June period.

The form given in equation (3-33) is more detailed as it contains more variables but still uses a linear regression model to predict yield.[26]

$$Y = f(N, M_p, M_i, NM_i) \tag{3-33}$$

where:

Y = yield of grain per acre,

N = nitrogen fertilizer per acre,

M_p = soil moisture at time of planting,

M_i = amount of rainfall during growth stage i, i = 1,9, and

NM_i = the interaction of nitrogen and soil moisture.

The production of a crop is a function of more than one input and with output a function of more than one input numerous types of production surfaces result. These can be described algebraically by many different types of functions. Common forms used are the Cobb-Douglas or power function, the Spillman function and various polynomial forms.[27]

It should be noted that all three of the above models are static in that they are designed to predict a final yield or total response to specific levels of inputs. In this sense they might be more properly referred to simply as yield predictors rather than plant growth models.

In contrast to these relatively simple production functions used in many economic analyses, models which can be referred to as detailed physical and biological science models have the characteristic of considering a large number of independent variables. A second difference is that the above models are one equation models while the detailed models of plant growth are multiple equation models. A third feature is the inclusion of a time dimension as growth is integrated with time rather than being a one input-one response relationship. A fourth feature is that there is an objective, implicit or explicit, to understand interactions through some type of feedback mechanism. An example of the type of model referred to is that presented by Curry.[28] Independent submodels were developed for the rate of photosynthesis, the rate of respiration and evapotranspiration. These included such variables as concentration of carbon dioxide, incident radiation above the crop, soil heat flux and atmospheric diffusion resistance.

It is obvious such a model requires a myriad of detailed data. While neither the accuracy of the predictability of such a model nor the theoretical basis of the physical relationship involved is questioned, the data problem is very significant. It is significant for a number of reasons. First, the time and expense involved in data collection would be enormous. Second, because of the large number of variables for which data must be available, the model would not be generally applicable. Third, a long range view toward model utilization and application must be considered. The ultimate objective is to produce models that are readily understood by practitioners and employ variables or proxies thereof that can be observed or easily estimated. These types of models do not have these qualities.

The models referred to as general physical models are not as detailed as those referred to above. The objective is to reduce complexity but consider the environment as rigorously as possible using data from observable phenomena. They have the following general requirements.

1. They include enough of the relevant aspects of agronomic, soil and meteorological theory to produce a meaningful solution,
2. They require relatively accessible data, and
3. The computations be feasible and relatively easy to perform.

The model developed by Flinn centers on the soil-plant-water relations.[29] He delineates the following three major components:

1. Those factors determining the level of atmospheric demand for moisture,
2. Those concerned with the availability of moisture for the crop, and
3. The interaction between supply of and demand for water on economic yield.

These three general components were used to simulate crop growth by time periods as a function of the incidence and severity of moisture stress in that period.

Production Models of Small Grain Grazing

In the simulation model of small grain grazing, yields or production of forage must be estimated in a continuous fashion as opposed to predicting a final year-end yield for a crop due to the physiology of plant growth and to interaction with the grazing. When evaluating the grazing, the time dimension is important as grazing can be utilized, of course, only after it is produced. Thus, the production relationships used must include a time dimension as well as taking into account the other variables such as temperature that are considered. The accumulation of forage for winter cereals follows the general trend shown in Figure 5.[30] A number of characteristics of this growth curve can be observed.

1. The growth in the fall period is low. During the initial stages of growth following germination a root system must be developed before nutrients and moisture can be directed to aerial growth. The onset of cool temperatures in the fall limits the amount of forage that can be produced in this period. To counteract this problem, seeding dates have been moved ahead compared to the date adhered to when winter wheat was grown solely as a grain crop.

2. Growth in the spring is rapid. By the time warmer temperatures encourage growth, an extensive root system has been developed. Soil moisture conditions can also be expected to be good in the spring. With little runoff during the winter due

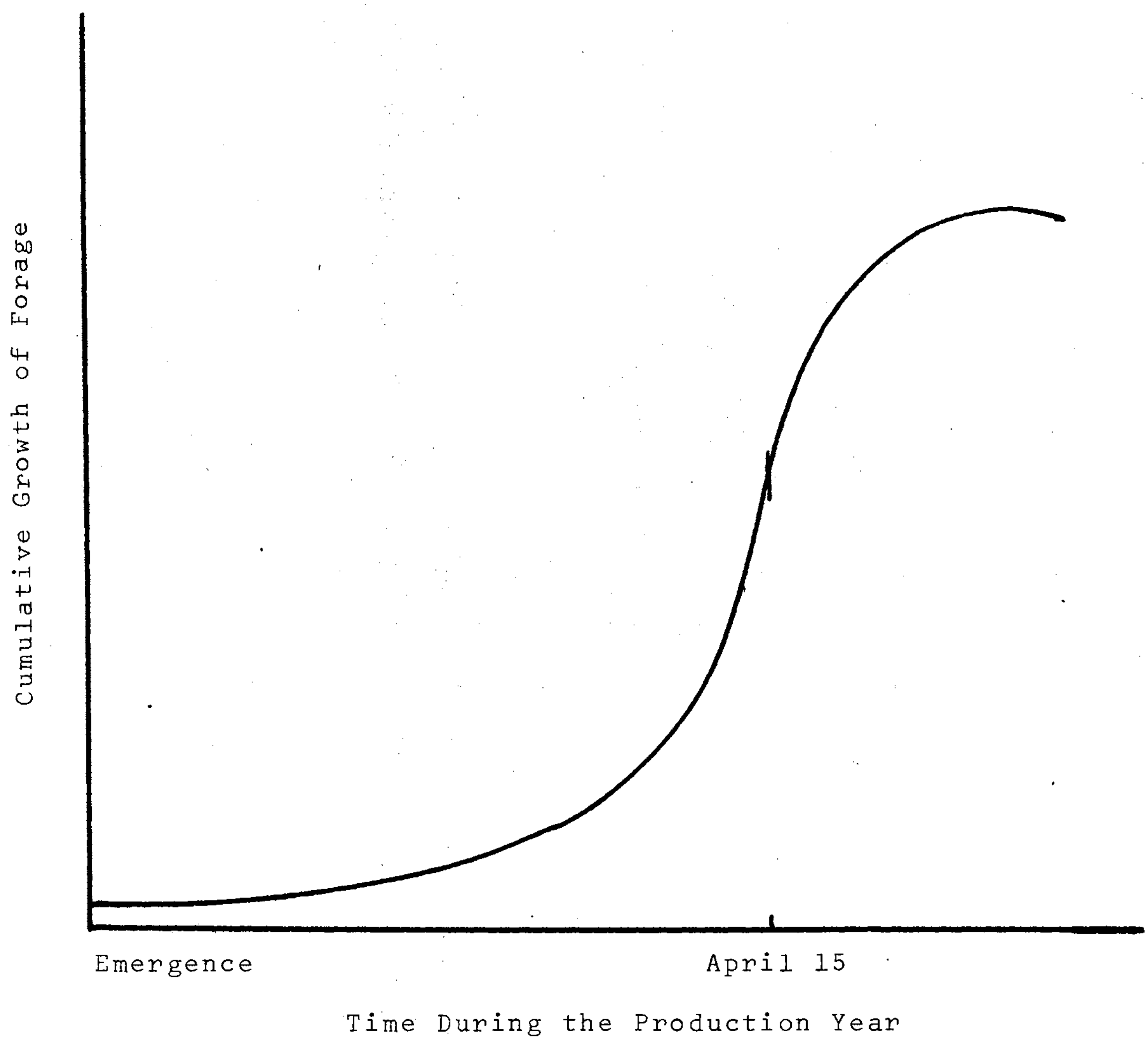

Figure 5. Theoretical Growth Curve for Winter Wheat in Oklahoma

to an unfrozen penetrable profile and low water loss rates, sufficient water is available to support rapid growth.

3. When nutrients are used for reproduction by the plant, the accumulation of dry matter in forage increases at a decreasing rate until it reaches a maximum and remains constant.

The growth curve shown in Figure 5 can be described mathematically by two functions. From emergence until the reproductive stage begins the growth is characteristic of the natural exponential function, $Y = Ae^{rt}$. The second portion also can be described by an exponential-type function of the form, $Y = M - AR^{x}$, commonly referred to as the Spillman function.[31] The inflection point in the growth curve is therefore determined by the juxtaposition of the two production functions.

Natural Exponential Function

$$Y = Ae^{rt} \qquad (3\text{-}34)$$

where:

A = the principal when used in interest compounding or the initial amount,

e = the base of natural logarithms,

r = the instantaneous rate of growth per unit of time,

t = the time period, and

Y = the growth.

In the above form Y is equal to the accumulated growth at time t, a stock rather than a flow concept.

In the daily simulation of forage growth and grazing, the incremental growth must be computed in order to calculate the forage balance. The forage growth at the end of the first period is defined by equation (3-35) and the change or incremental growth by equation (3-36).

$$Y_1 = Ae^r \qquad (3\text{-}35)$$

$$\frac{dY}{dt} = rAe^r \qquad (3\text{-}36)$$

The variable r indicates that if Y has a rate of growth r at the instant $t = t_o$ and this rate of growth continues for the whole unit of time, Y will have increased by the amount rY at the end of the period.[32] The period in this case is one day. Therefore,

$$Y_2 = Y_1 + rY_1$$

$$Y_2 - Y_1 = rY_1 \qquad (3\text{-}37)$$

$$\Delta Y_t = rY_{t-1} \qquad (3\text{-}38)$$

where:

ΔY_t = the incremental growth from period t-1 to period t, and

Y_{t-1} = the accumulated growth at the end of period t-1.

Similarily, the following identities hold:

$$Y_2 = Y_1 + rY_1$$

$$= Ae^r + rAe^r$$

$$= Ae^r (1 + r)$$

$$= Y_1 (r + 1) \qquad (3-39)$$

Spillman Function

A Spillman type function is used to describe the growth function after April 15. The general Spillman function with one variable input is defined as shown in equation (3-40).[33]

$$Y = M - AR^x \qquad (3-40)$$

where:

M = the total maximum yield, which can be attained by use of the variable input,

X = the variable input,

A = the total increase in output which can be attained by increasing X,

R = the constant which defines the ratio of successive increments to total product, and

Y = the total product.

To describe the production of forage by the wheat plant after April 15, the variable M is defined as the maximum growth in pounds of dry matter per acre that can be achieved from April 16 to May 30, a period of 45 days, which now also becomes equal to the variable A. In addition, the variable input X is redefined as t, the days after April 15. The function can now be revised to the form given in equation (3-41).

$$Y = M\,(1-R^{t}) \tag{3-41}$$

where Y is still total output.

Again, it is necessary to have measurement of daily incremental growth. The equations in set (3-42) derive the function for incremental growth.

$$\begin{aligned} \Delta Y &= Y_{t} - Y_{t-1} \\ &= M - MR^{t} - M + MR^{t-1} \\ &= MR^{t-1} - MR^{t} \\ &= MR^{t}\,(R^{-1} - 1) \\ &= MR^{t}\,(1/R - 1) \end{aligned} \tag{3-42}$$

It is important to note at this point that two production functions have been developed to simulate plant growth on a daily basis. But, both functions define daily growth given that temperature and soil moisture conditions are optimal for growth. The functions then can be expressed in the forms given in equations (3-43) and (3-44).

$$PY_{t1} = R_1 Y_{t-1} \qquad (3\text{-}43)$$

$$PY_{t2} = MR_2^t \ (R_2^{-1} - 1) \qquad (3\text{-}44)$$

where:

PY_{t1} = the potential growth on day t during period 1,

PY_{t2} = the potential growth on day t during period 2,

R_1 = the rate of growth coefficient for the compounding function, and

R_2 = the rate of growth coefficient for the Spillman function.

It has previously been noted that temperature and soil moisture are isolated as the main variables effecting growth. The daily potential growth defined above then must be adjusted for soil moisture and temperature conditions.

Soil Moisture and Temperature Coefficients

If soil moisture and temperature conditions were optimal for growth, the actual or net growth would be equal to the potential growth. However, if either or both were less than optimal, net growth would be only a fraction of potential. The value of the coefficient for each of the two variables is defined as that portion of potential growth that will occur according to the conditions existing for that variable. Equations (3-43) and (3-44) are redefined as equations (3-45) and (3-46).

$$NY_{t1} \doteq \sigma\ \tau\ R_1\ Y_{t-1} \qquad (3\text{-}45)$$

$$NY_{t2} = \sigma\ \tau\ MR_2^t\ (R_2^{-1} - 1) \qquad (3\text{-}46)$$

where:

NY_{t1} = the net growth on day t during period 1,

NY_{t2} = the growth on day t during period 2,

σ = the soil moisture - growth coefficient, $0 \leq \sigma \leq 1$, and

τ = the temperature - growth coefficient, $0 \leq \tau \leq 1$.

A soil moisture - growth relationship has been defined by Ritchie[34] where soil moisture is defined in terms of the percentage of extractable water. In terms of the previously defined soil moisture parameters, extractable water is defined as the difference between the field capacity and the permanent wilting point. The relationship is shown graphically in Figure 6. For the period from planting to March 1, extractable water is defined as the extractable water in the top 12 inches of the profile and for the period from March 1 to May 31, the extractable water is the amount available in the total profile. The relationships are expressed mathematically in equations (3-47) through (3-51).

$$EXPC1 = (SMU - WPU)\ /\ (FCU - WPU) \qquad (3\text{-}47)$$

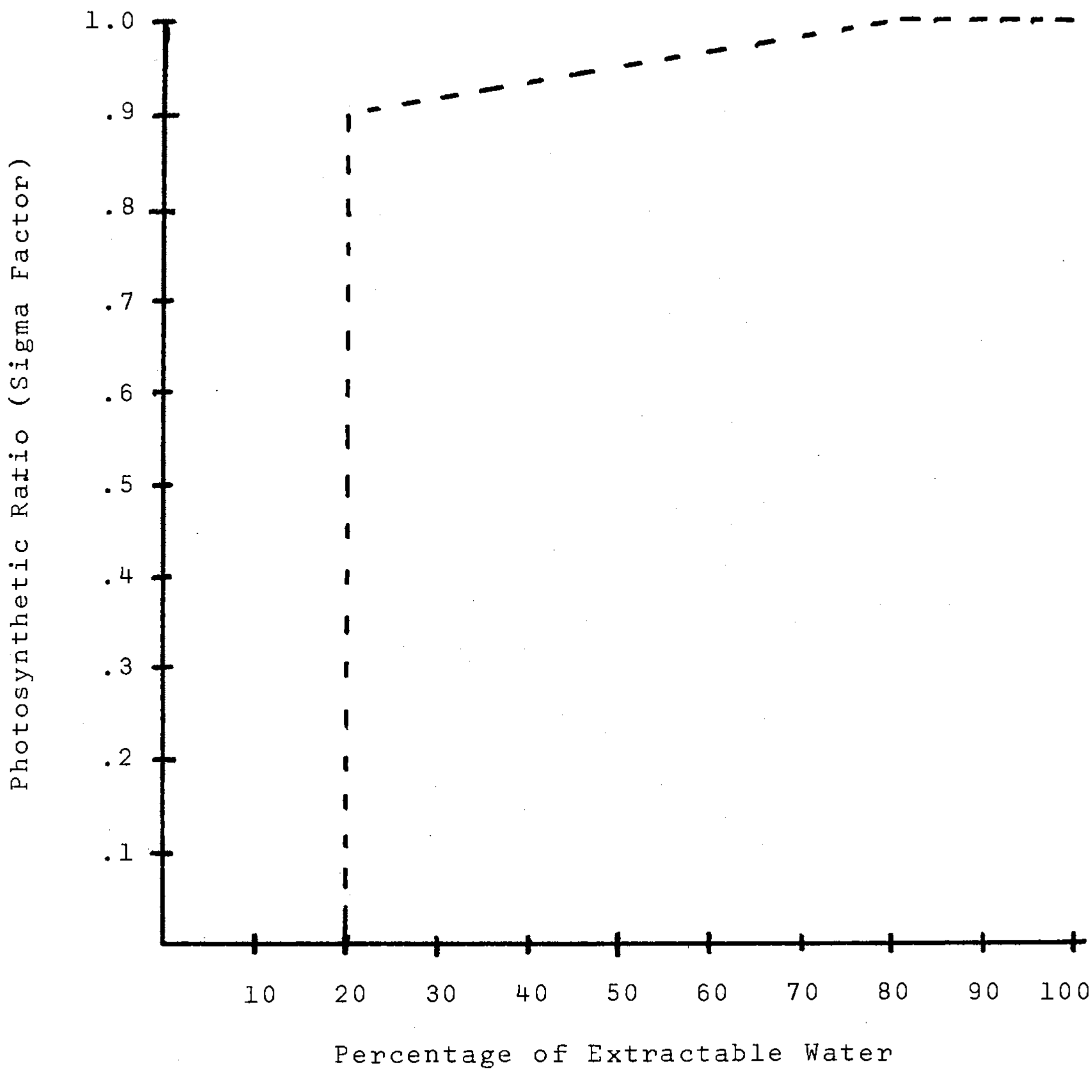

Figure 6. The Relationship Between the Ratio of Net Photosynthesis to Potential Photosynthesis and the Percentage of Extractable Water in the Soil Profile

$$EXPC2 = ((SMU - WPU) + (SML - WPL)) / ((FCU - WPU) + (FCL - WPL)) \quad (3\text{-}48)$$

$$\sigma = .8667 + .16667\ EXPC, \quad .2 \leq EXPC \leq .8 \quad (3\text{-}49)$$

$$\sigma = 1, \quad EXPC > .8 \quad (3\text{-}50)$$

$$\sigma = 0, \quad EXPC < .2 \quad (3\text{-}51)$$

where:

EXPC = the percentage of extractable water,

EXPC1 = the percentage of extractable water, planting to March,

EXPC2 = the percentage of extractable water, March to May,

SMU = the soil moisture level in the upper 12 inches,

SML = the soil moisture level in the lower 36 inches,

WPU = the permanent wilting point of the upper profile,

WPL = the permanent wilting point of the lower profile,

FCU = the field capacity of the upper profile, and

FCL = the field capacity of the lower profile.

A similar approach was used to determine the temperature-growth relationship. The graphical relationship is shown in Figure 7. The relationship is really a meas-

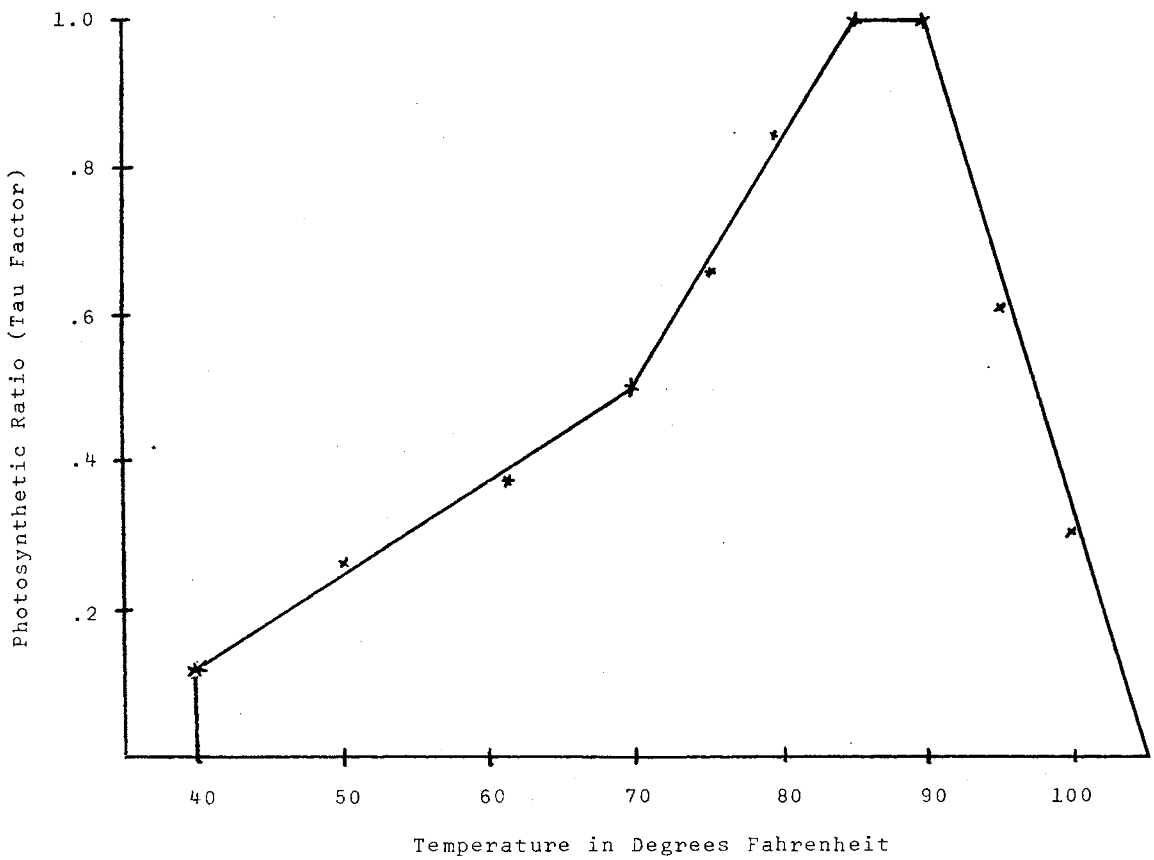

Figure 7. The Relationship Between Photosynthetic Ratio and the Daily Maximum Temperature

urement of "Q_{10}" for the wheat plant or the photosynthetic activity for each 10°F. rise in temperature. From the plotted points, the curve was divided into segments and the relationships estimated with linear functions.[35]

The linear functions are given in equations (3-52) through (3-56).

$$\tau = 7.3 - .07TP \quad , 90^\circ < TP \leq 104^\circ \qquad (3\text{-}52)$$

$$\tau = -.3868 + .01267TP \quad , 40^\circ \leq TP < 70^\circ \qquad (3\text{-}53)$$

$$\tau = -1.833 + .0333TP \quad , 70^\circ \leq TP < 85^\circ \qquad (3\text{-}54)$$

$$\tau = 1 \quad , 85^\circ \leq TP < 90^\circ \qquad (3\text{-}55)$$

$$\tau = 0 \quad , 40^\circ > TP > 104^\circ \qquad (3\text{-}56)$$

where:

TP = daily maximum temperature in °F.

<u>Measurement and Interpretation of R Factors</u>

The exponential factors for the two production curves referred to as R_1 and R_2 represent the slope of the total growth function over time. These factors are constant but the value of each is actually dependent upon the variety, the total nutrient condition of the soil, climate and longitudinal location.

To determine the appropriate value of R_1, data was taken from forage clipping trials for 1971-1972 and 1972-1973[36] for the fall period. Using actual temperatures that occurred but assuming soil moisture was optimal, i.e., ($\sigma = 1$) trial runs using the fall-winter growth function indicated that the value of R_1 was between .06 and .12.

Equation (3-44) was used to determine the value of R_2 where the parameter M was set at 1500 and t went from one to 45. This means that for the 45 day period from April 16 to May 30, the maximum forage that can be produced under ideal temperature and soil moisture conditions is 1500 pounds dry matter. Through a process of recursive approximations, the value of R_2 was determined to be .93.

Conversion From Forage To Grain

The results of an experiment conducted at the Wheatland Conservation Experiment Station were utilized to determine the relationship between forage and grain production. Data was taken from a study which investigated the "Effect of Cropping Systems, Tillage and Nitrogen Treatments and Wheat and Straw Yields".[37] The experiment was conducted on both Pond Creek and Grant soil types. Using least squares regression the relationship given in equation (3-57) was estimated.

$$WHT = \underset{(3.4406)}{11.44295} + \underset{(.000716)}{.005015}\ FG \qquad (3\text{-}57)$$

$$R^2 = .77$$

where:

WHT = bushels of wheat per acre, and

FG = the total accumulated forage per acre at the end of the production year.

The numbers in parenthesis are the standard errors of the coefficients.

The standard error of estimate = 4.80.

Data was used for the crop years 1957-1958 through 1966-1967 for both soil treatments except for the crop year 1959-1960 for which no straw yields were reported.

Forage Production Validation

A number of measurements were used to validate the forage production. Using actual temperature and pan evaporation readings, predicted yields were compared with straw yields from the Cherokee experimental station for the years 1957-1958 to 1966-1967. The criteria used was to select the set of R factors which minimized the deviations between the predicted forage yields and the actual straw yields. The extreme values, i.e., the highest and lowest predicted values also were subjectively appraised to ensure that the model predicted satisfactorily under the full range of climatic and moisture conditions to be used in the analyses.

Actual forage clippings trials for the year 1972-1973 were taken for four locations in Oklahoma.[38] The predicted forage yields were compared with the clippings taken at various times during the year, particularily those taken in the fall. This of course offers only one observation for comparison. Also, the model generates forage production for two situations, with no grazing and with a grazing balance made every week. Thus clipping data with two or three measurements taken during the year are not ideally suited for direct comparison. However, they represent the best data on the real system available during the time frame of this study.

One other measurement was used as a validation procedure. It is recommended that grazing not begin until about 800 pounds of dry matter have been produced. This normally occurs about November 1.[39] The subjective criterion imposed during vaildation was that this minimum forage be available on November 1 at least one-half of the years.

Model validation is an important phase of systems analysis. In the case of the model developed for this research, validation proved rather troublesome, primarily due to the lack of data and verified relationships of physical and biological phenomena.

Dent and Anderson distinguish between validation and verification. The latter is concerned with determining whether the model truly represents reality. This is applied where the objective is to discover facts about a system in order to explain system structure and operation.[40] Validation, on the other hand is concerned with how effective or suitable a model is for a specific purpose. This is comparison with a purpose whereas verification can be thought of as a comparison with truth.

It is therefore argued that validation is more important than verification for this bio-economic model and that given the state of knowledge and the objectives of this study, the model was satisfactorily validated.

Procedure For The Simulation Of Forage Production And Grazing

1. The seeding date has a calendar day and a rainfall determinant. Both a "date threshold" and a "rainfall threshold" must be specified.[41] The date threshold designates the earliest possible date that seeding can begin. The specified threshold date must be after August 1. The rainfall threshold delays the beginning of seeding after the threshold date until a rain of at least the specified magnitude occurs.[42]
2. Following the threshold rainfall event it is assumed that 12 days are required to seed the whole farm and that the acre being modelled or simulated is seeded at the midpoint of the seeding period or on the 6th day.
3. Wheat is seeded at the rate of 120 pounds per acre.
4. Eight days after the wheat is seeded or 14 days

after the threshold rainfall occurs, simulation of forage production begins. On this day it is assumed the crop has emerged and the accumulated forage is equal to the specified "initial growth level".

5. If the threshold amount of rainfall has not occurred by October 1, the crop is assumed to be "dusted in" and the specified initial growth level will be produced in the normal 14 days. It should be noted that under these circumstances soil moisture will probably have been depleted and no further growth will be produced until adequate rainfall occurs.
6. Grazing can begin on November 1 if the accumulated forage is greater than the specified "minimum forage to start grazing". If cattle are available November 1 but insufficient grazing is available, alfalfa hay must be fed to replace the forage.
7. The grazing consumption rate is dependent upon the calendar date rather than the date cattle were placed on forage.
8. After grazing has begun the stock of forage in the field must always be at least equal to the apecified "minimum to be maintained". If grazing demands are greater than available forage, alfalfa hay is fed to replace the deficit.
9. Once grazing has begun, a grazing-forage balance

is computed every seven days. Note that forage additions are made on a daily basis but deletions are made only every seventh day.

10. If the specified "minimum forage to start grazing" has not been produced by February 28, it is assumed that cattle on hand are sold and no grazing occurs during that production year, regardless of the designed plan of action for the March to June period. Wheat grain is produced on all 930 acres.

11. If a full seven-day week does not end on February 28, the forage balance is computed for the portion of a week which ends on February 28 and a new week always begins on March 1 after the March transactions have taken place.

12. It is assumed the graze-out period ends on May 15. The simulation of forage production closes on May 31 (day 92) but the simulation of soil moisture continues on throughout the year.

13. It is assumed the grain crop is harvested about the middle of June.

14. Whenever alfalfa hay is used to replace forage, the substitution rate is one pound of hay for one pound of oven-dry forage.[43]

Summary

The details of the production subsystem were presented in this chapter including the development, estimation and validation of the specific components. A summary of the procedure to use the production model components to simulate forage production and grazing was presented in the last section.

The other major subsystem, the economic analysis subsystem, is discussed in the next chapter. The chapter also discusses how these two subsystems can be used in combination to simulate the production and economic utilization of winter wheat.

FOOTNOTES

[1] R. H. Griffin, "A Yield Model for Dryland Wheat Production", (unpublished Ph.D. dissertation, Texas A & M University, 1971), p. 14 and R. F. Peterson, Wheat, Botany, Cultivation and Utilization (New York, 1965), p. 22.

[2] H. P. Mapp, "An Economic Analysis of Water-Use Regulation in the Central Ogallala Formation", (unpublished Ph.D. dissertation, Agricultural Economics Department, Oklahoma State University, 1972), pp. 49-51.

[3] C. Bingham, "Distributions of Weekly Averages of Diurnal Temperature Means and Ranges About Harmonic Curves", Monthly Weather Review, 89(1961), pp. 357-367.

[4] C. Bingham, Probabilities of Weekly Averages of the Daily Temperature Maximum, Minimum and Range, Connecticut Agricultural Experiment Station, Bulletin 659 (New Haven, 1963).

[5] Ibid., p. 3.

[6] March 1 is day 1 of the climatological year. Throughout this study any reference to the number of the day of the year will be based on March 1 as dav 1 unless otherwise specified. See Table XXXVIII in Appendix A for dates and the corresponding day number.

[7] Bingham, Probabilities of Weekly Averages of the Daily Temperature Maximum, Minimum and Range, p. 4.

[8] A good spectral density analysis reference is W. M. Meyers, Combining Statistical Techniques with Economic Theory for Commodity Forecasting, American Agricultural Economics Meetings (Gainesville, 1972). Other references are: G. S. Fishman, Spectral Methods in Econometrics (Cambridge, Massachusetts, 1969); T. W. Anderson, The Statistical Analysis of Time Series (New York, 1971); M. Nerlove, "Spectral Analysis of Seasonal Adjustment Procedures", Econometrica, 23(1964),pp. 241-286; and T. H. Naylor, Computer Simulation Experiments with Models of Economic Systems (New York, 1971).

[9] The computer routine used was "BMD02T Autocovariance

and Power Spectral Analysis". A description of the routine is found in the BMD Manual, pp. 459-470.

[10]Original data were taken from Eck and Stewart. Local data (Chin Choy and Stone) on Bethany soil were compared to Eck and Stewart's Bethany. Eck and Stewart reported 15 atmosphere percentage which approximates wilting point and moisture equivalent which approximates field capacity. The tendency is for moisture equivalent to overestimate field experience of highest water content noted in a given zone of the profile (overestimate field capacity). The several years of data Chin Choy and Stone suggested that moisture equivalent as obtained by Eck and Stewart to a "corrected value". The 15 atmospheric data of Eck and Stewart were close to the lowest field experience of Chin Choy and Stone and were accepted as published. Eck and Stewart reported data from 0 to 6 inches and 6 to 12 inches. These were commonly different from the rest of the profile and were averaged together. The next 3 feet of the profile were averaged for the lower depth. In general, the C horizon was not encountered until the fourth foot.

Nash soil was not reported in the Eck and Stewart bulletin so the assumption was that the Nash profile would look like the Pratt data of Eck and Stewart but ignoring the clay at 2 feet in the Pratt horizon. The data sources were: H. V. Eck and D. A. Stewart, Water Retension Properties of 17 Oklahoma Soils, Oklahoma State University, Bulletin B-526 (Stillwater, 1959) and E. W. Chin Choy, Jr. and J. F. Stone, Soil Moisture Record, Stillwater, 1963-1965, Oklahoma State University, Progress Report P-613 (Stillwater, 1969).

[11]R. B. Duffin, "An Approach to Rainfall Probability Analyses of Selected Central Oklahoma Stations", (unpublished Ph.D. dissertation, Oklahoma State University, 1967), p. 5.

[12]Ibid., p. 52.

[13]The equivalent rainfall concept developed here follows the concept of antecedent moisture conditions put forth in: R. H. Shaw, "Prediction of Soil Moisture Under Meadow", Agronomy Journal, 56(1964), pp. 320-324. See also the method utilized in: U. S. Department of Agriculture, Hydrology, Part IV, SCS National Engineering Handbook, Soil Conservation Service (Washington, 1964).

[14]In the previously referenced study by Mapp, a log normal distribution was used to describe pan evaporation. Experimentation with this distribution found it unsatisfactory as it produced many daily readings in excess of one inch of evaporation. Inspection of the data of Great

Salt Plains Dam revealed no daily observation in 25 years in excess of one inch.

[15]References for Beta distribution include: V. R. Eidman, ed., Agricultural Production Systems Simulation (Stillwater, 1971) and B. Ostle, Statistics in Research, 2nd ed. (Ames, 1963).

[16]J. T. Musick, D. W. Grimes and G. M. Herron, Water Management, Consumptive Use and Nitrogen Fertilization of Irrigated Winter Wheat in Western Kansas, Agricultural Research Service and Kansas State University, Production Research Report No. 75 (Washington, 1963), pp. 9-10; and H. F. Blaney and W. D. Criddle, Determining Consumptive Use and Irrigation Water Requirements, U. S. Department of Agriculture, Agriculture Technical Bulletin 1275 (Washington, 1962).

[17]J. E. Garton and W. D. Criddle, Estimates of Consumptive Use and Irrigation Water Requirements of Crops in Oklahoma, Oklahoma State University, Technical Bulletin T-57 (Stillwater, 1955). The use of the Blaney-Criddle consumptive use idea on a daily basis may be questioned. It is more appropriate for use on an average or monthly basis but was used here because of the lack of alternatives.

[18]J. T. Ritchie, "Atmospheric and Soil Water Influence on the Plant Water", Plant Modification for More Efficient Water Use, Proceedings of a Symposium (Stillwater, forthcoming). This definition of extractable water has two implications. First water is held at less than 15 bars soil water pressure and second, absorbing roots are near the water. The extractability of water then depends upon root development and distribution and upon the distribution of water at various tensions throughout the soil profile.

[19]The data to estimate the function was extrapolated from data published in: J. M. Davidson, L. R. Stone, D. R. Neilsen and M. E. Larue, "Field Measurement and Use of Soil-Water Properties", Water Resources Research, 5(1969), pp. 1312-1321.

[20]M. Y. Nuttanson, Wheat-Climate Relationships and the Use of Phenology in Ascertaining the Thermal and Photo-Thermal Requirements of Wheat (Washington, 1955), p. 322.

[21]H. G. Kmoch, R. E. Ramig, R. L. Fox and F. E. Koehler, "Root Development of Winter Wheat as Influenced by Soil Moisture and Nitrogen Fertilization", Agronomy Journal, 49(1957), pp. 20-25.

[22]When the crop emerges, the ground cover provided by

the young plant is negligible as is the water loss through soil evaporation from the soil. The evapotranspiration is then determined primarily by the rate of plant growth. It is estimated that about 50 days after emergence, the wheat plant has produced a complete ground cover and evapotranspiration has increased to its full potential rate.

[23]See footnote 19.

[24]"Annual Reports, Wheatland Conservation Experiment Station, Cherokee, Oklahoma", (unpublished mimeos, Oklahoma State University).

[25]T. J. Army, J. J. Bond and C. E. Van Doren, "Precipitation-Yield Relationships in Dryland Wheat Production On Medium to Fine Textured Soils of the Southern High Plains", Agronomy Journal, 51(1959), pp. 721-724.

[26]Griffin.

[27]E. O. Heady and J. L. Dillon, Agricultural Production Functions (Ames, 1961), p. 75.

[28]R. B. Curry, Dynamic Modelling of Plant Growth, American Society of Agricultural Engineering, Paper 69-939 (St. Joseph, 1969).

[29]J. C. Flinn, "The Simulation of Crop-Irrigation Systems", Systems Analysis in Agricultural Management, J. B. Dent and J. R. Anderson, eds. (New York, 1971).

[30]The growth curve presented is only a generalized representation of winter wheat plant growth. The principal references are: L. Schlehuber and B. B. Tucker, "Wheat Culture", Wheat and Wheat Improvement, K. S. Quinsberry and L. P. Reitz, eds. (Madison, 1967), and D. J. Watson, "Variation in Net Assimilation Rate and Leaf Area Between Species and Varieties, and Within and Between Years", Annals of Botany N. S., 11(1947), pp. 41-76.

[31]E. O. Heady and J. L. Dillon, p. 77. See also R. E. Buchanan "Some Elementary Mathematics of Plant Growth", Growth and Differentiation in Plants, N. E. Loomis, ed. (Ames, 1965) and W. J. Spillman, Use of the Exponential Yield Curve in Fertilizer Experiments, U. S. Department of Agriculture , Technical Bulletin No. 348 (Washington, 1933).

[32]A. C. Chaing, Fundamental Methods of Mathematical Economics (New York, 1967), p. 278.

[33]See footnote 31.

[34]The general shape of the curve and the relationship

so described is substantiated by: A. C. Trouse, "Effects of Soil Moisture on Plant Activities", Compaction of Agricultural Soils, K. K. Barnes et al. eds. (St. Joseph, Michigan, 1971) pp. 242-252. Also see footnote 18.

[35]The estimated points were derived by combining maximum yield data for Oklahoma supplied by W. E. McMurphy, Agronomy Department, Oklahoma State University, with the relationships given in J. Janick, Plant Science, An Introduction to World Crops (San Francisco, 1969).

It was further assumed that if growth does not occur due to unfavourable temperature conditions, two consecutive days of temperatures favourable for growth must occur before growth will recommence. See: J. R. Haun, "Determination of Wheat Growth - Environment Relationships", Agronomy Journal, 65(1973), pp. 813-816.

[36]H. Pass, E. L. Smith and L. Edwards, Winter Wheat Variety Tests, 1972, Oklahoma State University, Research Report P-687 (Stillwater, 1973) and L. Rommann, W. E. McMurphy and F. E. LeGrand, "Forage Production From Small Grains, 1972-73", Current Report, Oklahoma State University (Stillwater, 1973), pp. 2002-2002.3.

[37]"Annual Reports Wheatland Conservation Experiment Station, Cherokee, Oklahoma", (unpublished mineos, Oklahoma State University).

[38]See footnote 36.

[39]Personal communication with C. E. Denman, Agronomy Department, Oklahoma State University, October 5, 1973.

[40]Dent and Anderson, p. 27.

[41]The terms in quotation marks coincide with the terms used in the computer output.

[42]For example, assume 170 is the date threshold and .5 is the rainfall threshold. If no rainfall event of greater than .5 inches occurs after day 170 until day 190 when .65 inches falls, seeding cannot begin until day 191.

[43]All measurements of forage are in pounds of dry matter on an oven-dry basis which is 12 to 15 percent moisture. Alfalfa hay is considered to be about 12 percent moisture and therefore the two feeds can be substituted on a one-to-one basis. These moisture level coefficients were verified in a personal communication with C. E. Denman, Agronomy Department, Oklahoma State University, October 5, 1973.

CHAPTER IV

ANALYTICAL METHODS

The overall purpose of the chapter is to present the details of the economic analysis subsystem. This includes a discussion of the farm business organization used as the unit of analysis followed by the specification of the actual analytical procedures. The economic and physical conditions under which planning may take place and under which tha analyses are conducted are given considerable attention. This sets the stage for the presentation of the simulation results and the net returns analyses which are presented in the next chapter.

Representative Farm

In studies which investigate farm resource allocations, potential adjustments and income and growth prospects, a requisite is the establishment of representative resource bases and enterprise organizations.[1] Since farms vary in size, resources available including managerial ability, suitability to particular enterprises and composition of soil types there is no true representative farm. However, defining a representative farm situation facilitates making economic studies applicable to a larger area than one farm, one community or even one county. The resource base chosen must represent some specific type of operation such as irrigated versus dryland or crop-livestock versus all crop and is usually designed to represent an operator with average or above average management skills. This study departs somewhat from the representative farm concept. The objectives of the study are to investigate the decision strategies of a wheat-stocker operator. The representative farm is therefore not designed to be representative of all family farm firms in the area but representative only of wheat and livestock operations in the area.

It is acknowledged that some problems may arise regarding the optimal use of available resources. Excess labor for example may be utilized by the addition of other enterprises. However such activities are relativley independent of the wheat and livestock operations which use wheat forage. Thus the analysis developed for an efficient unit specializing in wheat and wheat related livestock operations also applies to the wheat acreage of more diversified farms in the area.

The representative farm selected is designed to be an efficient combination of resources for the production of wheat and stocker cattle. Specifically, it is designed to be large enough to be efficient for the type of machinery and equipment utilized by producers in the area. This accounts for the lumpiness of some inputs while allowing for the completion of necessary functions in a timely nature largely with family-operator labor. It is assumed the farm is operated by a manager having average or above average managerial ability.

The size of farm operations in North-Central Oklahoma can be specified in half or quarter section increments (320 or 160 acres respectively). The size selected for this study is 960 acres or 1.5 sections.[2] It is assumed that 30 acres is taken up by home, buildings, roads and turnrows and that the remaining 930 acres is productive cropland. No allowance is made for idle or fallow land. Details of the machinery and equipment complement and a summary of the machinery and equipment costs for the representative farm is given in Appendix B.

Analytical Procedures

Model Strategy Alternatives

For the wheat producer who wishes to consider the alternative of adding a stocker enterprise there are two critical decision periods during the production year. The first is the fall when the method of livestock procurement and the stocking rate or number of animals per acre must be determined. The second is the spring when a decision must be made regarding producing wheat and/or grazing out. It is assumed this decision must be made by March 1.

In the fall there are a number of procurement methods that might be utilized. Cattle may be contracted in the summer for delivery at a specified date or animals may be purchased on the open market on a specified date. Both of these methods assume no consideration is given to moisture or growing conditions existing at the time the purchase decision is made. A third alternative is to delay the purchase until a sufficient amount of forage is available. This may mean an amount sufficient to begin grazing or sufficient growth such that the anticipated forage available by the time cattle are delivered will be sufficient to begin grazing.

The spring or March decision may also involve a combination of factors which include the March to May stocking rate. For example, after deciding on the stocking rate, enough animals may be purchased to utilize the total acreage for graze out, or all winter grazed animals may be sold and wheat produced on all acreage, or animals winter grazed may be retained and wheat produced on acreage not required for grazing, or some combination of retaining winter grazed animals and purchasing more cattle but also producing wheat on a portion of the total acreage.

A very large number of combinations of purchasing procedure, fall stocking rate, and spring stocking rate exist. The values of the controllable variables selected for analysis from the range of possibilities in this study are discussed below.

1. Purchasing Procedure

(i) Buy for delivery on a specified date which was assumed to be November 1. This could either be purchasing on the open market or contracting ahead.

(ii) Buy only when forage growth has exceeded a specified amount. It was assumed the cattle would be delivered and placed on grazing fourteen days after purchased.

2. Fall Stocking Rate

An average stocking rate for the fall-winter period for the study area is considered to be about 2.5 acres per head or 0.4 head per acre.[3] This means that for 930 acres of grazing land, about 375 head could be grazed. Two other stocking rates were selected, one each 125 head above and below the accepted mean. Thus the three selected stocking rates or number of animals purchased in the fall are 250, 375 and 500 head.

3. Spring Stocking Rate

The mean stocking rate for the spring period for the area is about one head per acre. It was assumed that if graze out alternatives were selected in the fall, that the stocking rate would be one head per acre.

4. March Alternatives

As noted above there are an infinite number of grain-graze out combinations that could be specified. These were reduced to the following three:

(i) Sell winter grazed cattle in March; produce wheat only.

(ii) Retain winter grazed animals and purchase enough animals to graze all 930 acres; produce no wheat grain.

(iii) Retain winter grazed animals but purchase no more animals; produce wheat on grazing acreage not required for grazing.

These decision alternatives are presented in a network flow diagram in Figure 8.

5. Revised March Alternatives

The discussion of the policy variables above assumes that decisions are made only once during the year. But the decision can be revised at the beginning of the spring growing period. As noted above the accepted stocking rate for the graze out period is one head per acre. Two other stocking rates were selected; namely, .75 head per acre and 1.5 head per acre. For the analyses of revised March decisions it was assumed that the medium fall stocking rate had been used and that cattle had been purchased for delivery on November 1. A zero stocking rate or produce wheat was also considered a possibility to give four alternatives. Figure 9 presents a modified

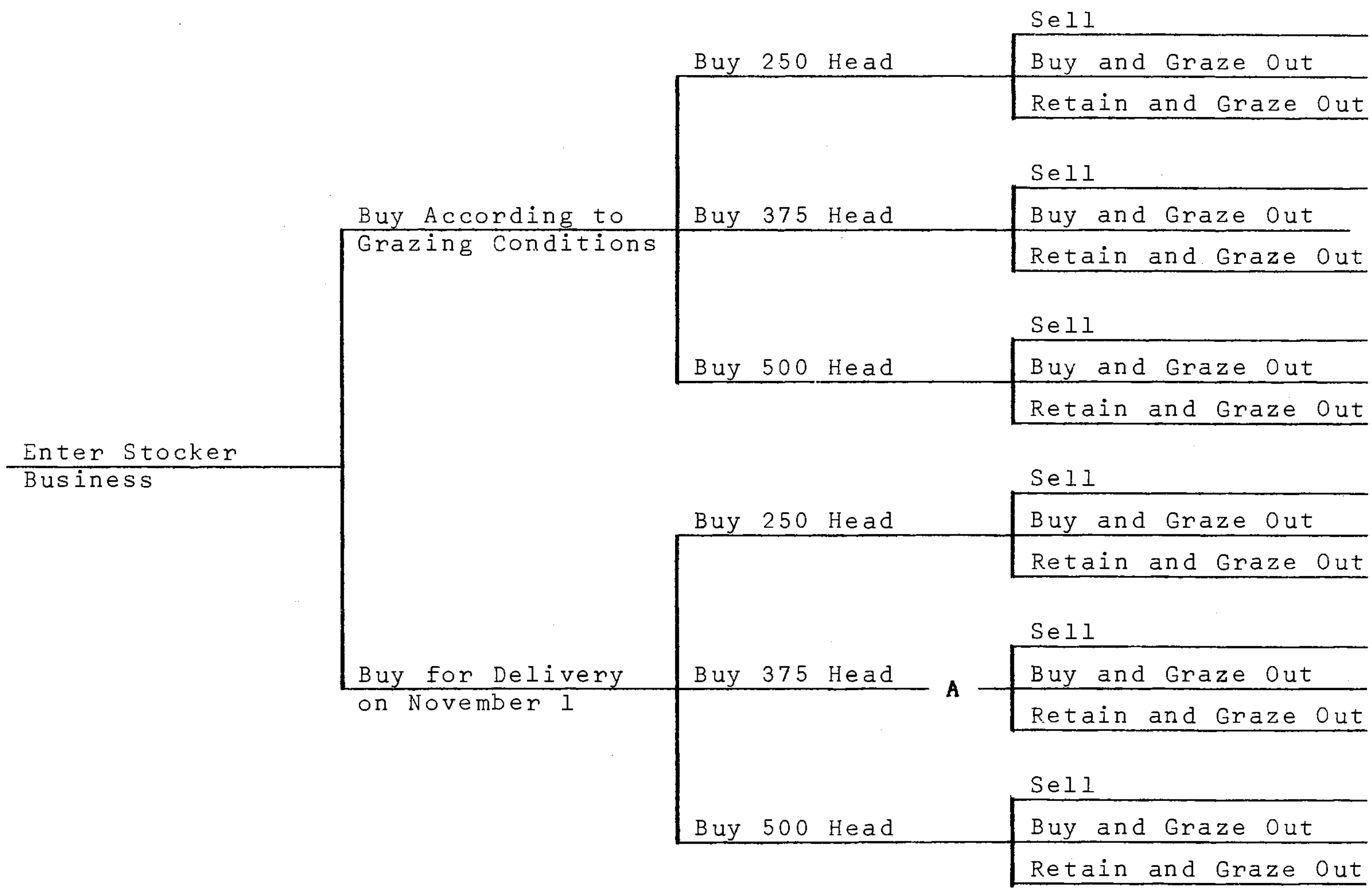

Figure 8. Network of Decision Alternatives

version of Figure 8 for the revised March decisions. Note that the retain same number and graze out alternative in Figure 8 is dropped and otherwise branch A in Figure 9 replaces A in Figure 8.

The Computation of Strategy Returns

The net returns measure discussed in the analyses has the following definition:

Net Returns = Total Receipts - (Operating Inputs including the Cost of Animals + Machinery and Equipment Fuel, Lubrication and Repair Costs + Annual Operating Capital Costs)

Not included in the costs portion of the above definition are the capital and ownership costs for land, buildings, machinery and equipment, the labor costs and charges for management. The net returns may then be defined as the returns to land, labor, investment capital, overhead, risk and management.

For fall purchased animals, it is assumed that a two percent death loss occurs and that this deduction is made from the inventory of animals three weeks after they are purchased. If stockers are carried over for the graze out period, no further death loss is taken. For animals purchased in March, a two percent death loss is taken from the number purchased, after the third week of grazing.

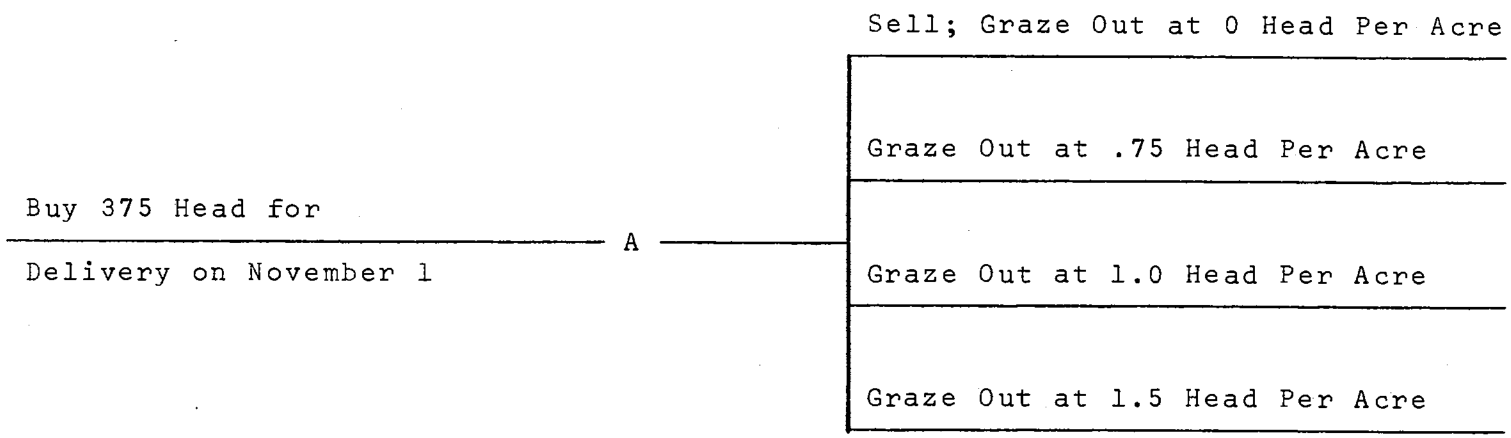

Figure 9. Network of Revised March Decisions

It is assumed that fall purchased cattle are purchased at a uniform weight of 400 pounds and the stockers gain 1.35 pounds per day for the fall-winter period. Cattle purchased in March are assumed to have a uniform weight of 550 pounds when purchased. It was also assumed that all stockers grazed out, whether fall or spring purchased have a rate of gain of 1.8 pounds per day for the graze out period.

Costs and returns estimates were developed for the wheat and stocker enterprises based on budgets developed for the area. A summary of the budgets is presented in Appendix B. The definition of net returns given above is specified mathematically in equation (4-1).

$$\begin{aligned} NR_i = {} & (P_w \cdot A \cdot Y_w) + (P_{lsmy} \cdot W_{lsmy} \cdot N_{lsmy}) \\ & + (P_{lsmr} \cdot W_{lsmr} \cdot N_{lsmr}) - ((P_{lf} \cdot W_{lf} \cdot N_{lf}) \\ & + (P_{lbmr} \cdot W_{lbmr} \cdot N_{lbmr}) + 22{,}933.80 \\ & + N_{lf}(19.45 + C_1) + N_{co}(2.65 + C_2) \\ & + N_{lbmr}(10.32 + C_3) + (1.67A) + (H_i \cdot P_h)) \end{aligned} \tag{4-1}$$

where:

NR_i = the net returns for the i^{th} stocking rate,

P_{lsmy} = price of livestock sold in May in dollars per cwt.,

W_{lsmy} = weight of cattle sold in May in cwts.,

N_{lsmy} = number of livestock sold in May,

P_{lsmr} = price of livestock sold in March in dollars per cwt.,

W_{lsmr} = weight of livestock sold in March in cwts.,

N_{lsmr} = number of livestock sold in March,

P_w = price of wheat in dollars per bushel,

A = acreage of wheat harvested,

Y_w = yield of wheat in bushels per acre,

P_{lf} = price of calves purchased in fall in dollars per cwt.,

W_{lf} = weight of calves purchased in fall in cwts.,

N_{lf} = number of calves purchased in fall,

P_{lbmr} = price of cattle bought in March in dollars per cwt.,

W_{lbmr} = weight of cattle bought in March in cwts.,

N_{lbmr} = number of cattle bought in March,

N_{co} = number of head carried over from winter grazing,

H_i = hay required for supplemental feeding in tons for the i^{th} stocking rate,

P_h = price of hay in dollars per ton,

22,933.80 = 930 * 24.66 where $24.66 is the cost per acre for crop production,

19.45 = variable stocker costs per head for the fall-winter period,

2.65 = variable stocker costs per head for the graze out period for stockers carried over,

10.32 = variable stocker costs per head for the graze out period for stockers purchased in March,

1.67 = variable costs per acre for grain harvesting, and

C_1, C_2 and C_3 = interest on animals purchased.

The Computation of Variance of Returns

The decision maker is interested in predictors for the uncontrollable variables in equation (4-1). These include the prices and the yields of wheat and forage with the latter being reflected through the hay consumption. The expected net returns using expected prices and yields is given by equation (4-2).

$$\begin{aligned}\overline{NR}_i = (\overline{P}_w \cdot A \cdot \overline{Y}_w) + (\overline{P}_{lsmy} \cdot W_{lsmy} \cdot N_{lsmy}) \\ + (\overline{P}_{lsmr} \cdot W_{lsmr} \cdot N_{lsmr}) - ((P_{lf} \cdot W_{lf} \cdot N_{lf}) \\ + (\overline{P}_{lbmr} \cdot W_{lbmr} \cdot N_{lbmr}) + 22{,}933.80 \\ + N_{lf}(19.45 + C_1) + N_{co}(2.67 + C_2) \\ + N_{lbmr}(10.32 + C_3) + (1.67A) + (\overline{H}_i \cdot P_h)) \qquad (4\text{-}2)\end{aligned}$$

where the bar (—) over a term indicates an expected or average value. Note that for decisions made in either the fall or on March 1, the purchase price of fall purchased cattle is known and therefore there is no bar over P_{1f}.

The variance of the net returns is given by the identity in equation (4-3).

$$\text{Var}\ (NR_i) = E(NR_i - N\overline{R}_i)^2 \tag{4-3}$$

where E signifies the expected value.

Substituting (4-1) and (4-2) into (4-3), expanding the square and combining terms results in the expression for variance of net returns shown in equation (4-4).

$$\begin{aligned}
\sigma^2_{Ri} = {} & a^2(\sigma_1^2\sigma_2^2 + \overline{P}_w^2\sigma_2^2 + \overline{Y}_w^2\sigma_1^2) + b^2\sigma_3^2 + c^2\sigma_4^2 + d^2\sigma_4^2 + e^2\sigma_5^2 \\
& + 2ab(\overline{Y}_w(P_{13}\sigma_1\sigma_3 + \overline{P}_w\overline{P}_{1my}) - \overline{Y}_w\overline{P}_w\overline{P}_{1my}) \\
& + 2ac(\overline{Y}_w(P_{14}\sigma_1\sigma_4 + \overline{P}_w\overline{P}_{1mr}) - \overline{Y}_w\overline{P}_w\overline{P}_{1mr}) \\
& - 2ad(\overline{Y}_w(P_{14}\sigma_1\sigma_4 + \overline{P}_w\overline{P}_{1mr}) - \overline{Y}_w\overline{P}_w\overline{P}_{1mr}) \\
& - 2ae(\overline{P}_w(P_{25}\sigma_2\sigma_5 + \overline{Y}_w\overline{H}_i) - \overline{P}_w\overline{Y}_w\overline{H}_i) \\
& + 2bc(P_{34}\sigma_3\sigma_4) - 2bd(P_{34}\sigma_3\sigma_4)
\end{aligned} \tag{4-4}$$

where:

$a = A$,

$b = W_{1smy} \cdot N_{1smy}$,

$c = W_{1smr} \cdot N_{1smr}$,

$d = W_{1bmr} \cdot N_{1bmr}$,

$e = P_h$,

σ_1 = standard erroe of P_w,

σ_2 = standard error of Y_w,

σ_3 = standard error of P_{1my},

σ_4 = standard error of P_{1mr},

σ_5 = standard error of H_i,

P_{13} = correlation coefficient of P_w and P_{1my},

P_{14} = correlation coefficient of P_w and P_{1mr},

P_{25} = correlation coefficient of Y_w and H_i, and

P_{34} = correlation coefficient of P_{1my} and P_{1mr}.

For situations where decisions are made in March equation (4-4) can be further reduced. If cattle are purchased in March, none are sold and all the acreage is grazed out. The variance is given by equation (4-5)

$$\sigma_{Rw}^2 = b^2\sigma_3^2 + c^2\sigma_5^2 \qquad (4\text{-}5)$$

If all cattle sold in March and all acreage is used to produce grain, the variance is given by equation (4-6).

$$\sigma_{Rw}^2 = a^2(\sigma_1^2\sigma_2^2 + \overline{P}_w^2\sigma_2^2 + \overline{Y}_w^2\sigma_1^2) \qquad (4\text{-}6)$$

The derivation of the relationships given in equations (4-4), (4-5) and (4-6) is given in Appendix C.

Price Relationships Used In The Analysis

Livestock Prices

It is assumed that all livestock in the analysis are choice steers and the prices for the Oklahoma City market are appropriate.

In the analyses where prices are considered certain, the March price of stockers is used as the base price. That is, the models are constructed such that the March price of choice stocker cattle must be specified and the other livestock prices can be computed based on this one specified price.

Using a data series from 1956 to 1972 the relationship in equation (4-7) was estimated.

$$P_{1n} = (P_{1mr} / 1.237) + 2.9517 \qquad (4\text{-}7)$$

where:

P_{1n} = the price of choice stockers, 500-800 pounds,[4] November 1, year t, and

P_{1mr} = the price of choice stockers, 500-800 pounds, March, year t+1.

In comparing the November prices of choice stockers and choice steer calves, 350 to 550 pounds[5] for the Oklahoma City market for the years 1962 to 1972, the relationship given in equation (4-8) was found.

$$P_{1f} = 1.15 \; P_{1n} \qquad (4\text{-}8)$$

where:

P_{1f} = the price of choice calves 350 to 550 pounds, November 1.

The November-March price relationship then becomes:

$$P_{1f} = 1.15((P_{1mr} / 1.237) + 2.9517) \qquad (4\text{-}9)$$

The cattle purchased in the fall are classified as calves and the cattle sold in March as stockers. Therefore a seasonal index of stocker prices cannot be used to get the equivalent price. Equation (4-9) was estimated to describe the price relationship.

The relationship between the price for choice stockers in March and May is based on the monthly seasonal indexes for choice 550 to 750 pound stocker and feeder steers. The indexes are 100.6 and 101.4 respectively or the relationship can be expressed as given in equation (4-10).

$$P_{1my} = 1.008\ P_{1mr} \qquad (4\text{-}10)$$

where:

P_{1my} = the price of choice stockers, 550 to 750 pounds, in May.

<u>Wheat and Hay Prices</u>

The price specified for wheat is assumed to be the price received delivered to the local elevator at the end of the month of June.

The alfalfa hay price is assumed to be the delivered price per ton for good quality hay. There is no provision made to allow the hay price to have seasonal variation. The simulation essentially purchases hay instanteously when it is required and regardless of the month the purchase price is constant.

Historical Price Series

For situations where prices are variable rather than fixed, a twenty year period of historical prices is used. The period selected is from the 1951-1952 crop year to the 1970-1971 crop year. This period is deemed the most desirable period of twenty consecutive years because it avoids the war years at the beginning of the period and avoids the period of escalating wheat and cattle prices that occurred after mid 1971. It can be noted that prices may have been effected in the early part of the period by the Korean conflict and in the latter part by a trend of increased feedlot capacity and slaughter cattle output in Oklahoma.

Alternative Planning Environments

Economic Conditions

The simulation of production and utilization of the wheat crops and the accompanying computation of returns can be handled in a number of ways as suggested by the strategy alternatives discussed in the prevoius section. Three general procedures are discussed as follows:

1. Fixed strategies with certain and uncertain prices.
2. Flexible strategies, no data analysis.
3. Flexible strategies, data analysis.

1. Fixed Strategies With Certain And Uncertain Prices

This is a rather naive type of analysis with strategies being specified at the beginning of the production year and allowing no adjustments in those strategies at the March decision point. The strategies considered for this analysis are the nine strategies given in Figure 8 for buying stockers according to grazing conditions.

These strategies are first simulated for fixed or certain pricing situations. That is, no year to year variation in prices is considered.

Two March livestock prices are used; namely, \$35.00 and \$40.00 per cwt. For each livestock price, four wheat prices are used; \$1.25, \$1.50, \$2.50 and \$3.50 per bushel. For all these pricing combinations, the price of alfalfa hay is assumed to be \$35.00 per ton. Some of livestock-wheat combinations are also analyzed assuming the price of alfalfa hay to be \$50.00 per ton. The purpose of this analysis to two-fold. First, it is a type of model validation. Using random weather occurrences, the physical outputs can be compared with the coefficients considered acceptable for the area and used in enterprise budgets. Second, using fixed prices, a general comparison can be made between strategies for various price levels and price ratios that a decision maker might expect for the next production year. At the beginning of a crop year little is known regarding the weather occurrences but the prevailing price levels can be observed even though assuming fixed prices is naive in that no variability is allowed.

Fixed strategies are also simulated using the twenty year series of prices in place of the fixed prices. Thus, the distribution of incomes represents the variation in income that might be expected from following a given strategy year after year as weather events and prices vary.

2. Flexible Strategies, No Data Analysis

Even though historical averages lead a producer to favor certain strategies, it is unlikely that grazing decisions are made completely inflexible if moisture, growth and price conditions indicate an adjustment is warranted. In the problem being studied, the adjustment period is in late February or early

March. At this time specific soil moisture and growth conditions can be specified and the operator must decide on the stocking rate for the spring period. Of course one of the latter is a zero stocking rate where all acreage is used to produce wheat and none is grazed out.

For this type of analysis, decisions can be based on existing conditions and expectations for the immediate future rather than on decisions made in the fall. It is assumed that the medium stocking rate existed during the fall-winter period and the net returns computations assume no hay consumption during the month.

Flexible strategies are analyzed using the uncertain historical price series and by using projections of the trends shown by the historical series. The solutions can be thought of a "no data" situations as expectations are not based on phenomena observable at the time the decision is made.

3. Flexible Strategies, Data Analysis

Information can be updated to that available in February when possible adjustments are made in strategies. Prediction models are estimated for the uncontrollable variables and the strategies are then analyzed using three wheat price and three livestock price forecasts.

Physical Conditions In Fall Decision Period

For the purposes of this research, the winter wheat production year is assumed to begin on August 1 and end on June 30. In order to simulate soil moisture conditions, some starting soil moisture level must be defined. The soil moisture level can be reset to a specified level at the beginning of each year or the soil moisture balance can run continuously for a twenty year period. Four soil moisture balance situations are defined as follows:

1. Continuous simulation of soil moisture for twenty years.
2. Reset the soil moisture level at the beginning of each production year at the permanent wilting point.
3. Reset the soil moisture level each year at the field capacity.
4. Reset the soil moisture level midway between the wilting point and the field capacity.

Forage production simulations were run for each soil moisture situation. It was found that the starting situation only had an effect on final grain yield, forage yield and hay requirements in one year out of twenty and in that year the difference was small. Therefore, an analysis of the effect of soil moisture level on August 1 of each production year was not conducted.

Physical Conditions In Spring Decision Period

Soil moisture and forage growth conditions can be observed in February when the March decision is being contemplated. These conditions can be directly observed by the operator while information on the other variables such as rainfall amounts in available from data collection agencies and is usually published on a regular basis, often in daily, weekly or monthly general circulation publications.

In the model developed in this study levels of soil moisture and forage growth are readily delineated at any point during the production year. From the twenty years of daily soil moisture balances simulated on a continuous basis, the March 1 soil moisture levels for the two profiles were summed for each year and arranged in ascending order of magnitude. The range was from 7.86 inches to 11.40 inches. Note that the possible range is from 6.95 inches to 11.63 inches. The twenty readings were divided into three groupings as follows:

1. 7.86 inches to 8.96 inches — 7 observations.
2. 9.38 inches to 9.82 inches — 6 observations.
3. 10.00 inches to 11.40 inches — 7 observations.

Within each of these three groups a specific soil moisture level was selected to represent low, medium and high moisture levels. The points were 8.25 inches, 9.50 inches and 10.75 inches. Note that the mean of the middle group readings was 9.50 ± 1.25 inches. It was assumed that the specified levels were proportionally divided between zones 1 and 2 according to the field capacities of each zone.[6]

A similar approach was used to specify forage growth levels on March 1. Out of the twenty years, there were three years where the accumulated forage by March 1 was insufficient to begin grazing. Using the medium stocking rate, i.e., purchase 375 head in the fall, the resulting forage levels for the remaining seventeen years are presented in Table X in ascending magnitude of total forage. The forage levels were divided into two groups according to the total accumulated forage as follows:

Low	858-1444 pounds	8 observations.
High	1699-2967 pounds	9 observations.

To derive a specific forage level for March 1, both the total forage and forage on the ground amounts were averaged. The computed means for the low situation were 1168 pounds of total forage and 690 pounds of forage on the ground. For the high situation the comparable figures were 2208 pounds and 1309 pounds respectively.

Summary

The representative farm for this study was discussed in the first section of this chapter followed by the specification of the analytical procedures and the method of computing the net returns. Different planning

TABLE X

PREDICTED FORAGE LEVELS, MARCH 1 RESULTING FROM SIMULATION OF PRODUCTION MODEL FOR TWENTY YEAR PERIOD IN POUNDS OF DRY MATTER PER ACRE[a,b]

Total Accumulated Forage With No Grazing	Forage On Ground With Grazing
858	822
976	600
1024	664
1176	636
1252	739
1281	656
1331	635
1444	786
1699	1033
1850	961
1905	1086
2069	1304
2090	1224
2211	1515
2477	1756
2608	1763
2967	2100

[a]The decision action for this simulation was purchase 375 stockers on November 1.

[b]The predicted production levels are arranged in ascending order of magnitude by the total accumulated forage with no grazing.

environments were delineated according to the price and strategy situations and according to the soil moisture and growth conditions at the beginning of the production year and at the beginning of the spring growth period. The general analytical procedures are presented in flowchart form in Figure 10.

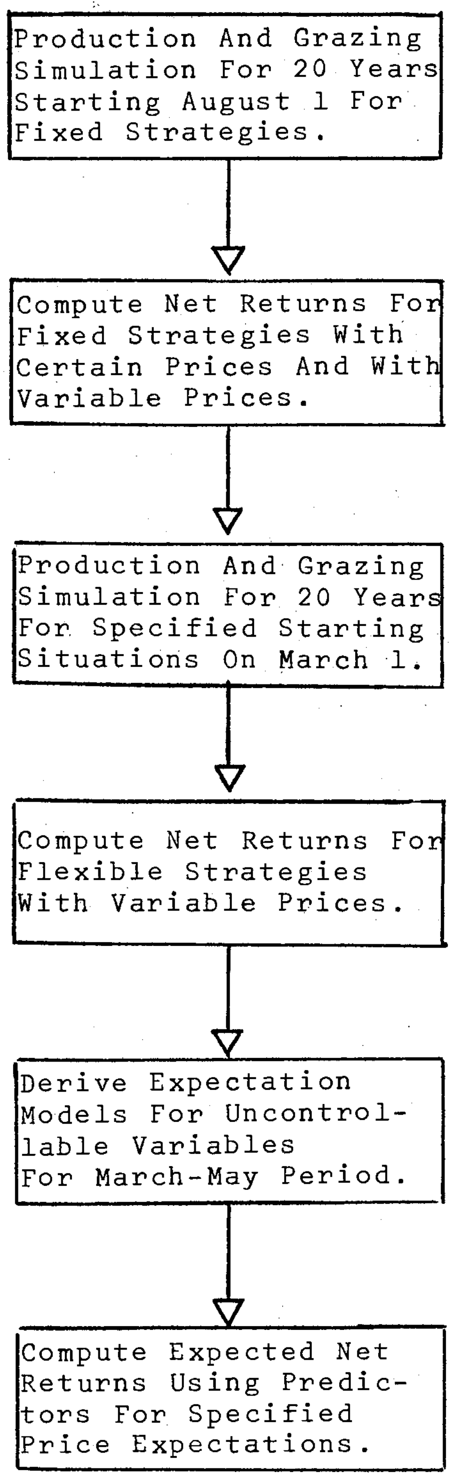

Figure 10. Flowchart of Analytical Procedures

FOOTNOTES

[1]Examples include W. L. Bateman, "An Economic Analysis and Comparison of Part-Time and Full-Time Beef Farm Operations in Eastern Oklahoma", (unpublished Ph.D. dissertation, Oklahoma State University, 1973); J. R. Martin and J. S. Plaxico, Polyperiod Analysis of Growth and Capitol Accumulation of Farms in the Rolling Plains of Oklahoma and Texas, Economic Research Service, Technical Bulletin 1381 (Washington, 1967); P. L. Strickland, O. L. Walker and W. A. Holbrook, Income Potential From Beef Cattle Farming, Eastern Prairies of Oklahoma, Oklahoma State University, Bulletin No. B-655 (Stillwater, 1968) and L. J. Connor and O. L. Walker, Potential Long Run Adjustments for Oklahoma Panhandle Farms, Oklahoma State University, Technical Bulletin T-114 (Stillwater, 1965).

[2]Personal communication with R. L. Sharkey Jr., Area Farm Management Agent, North Central Oklahoma on August 22, 1973.

[3]R. L. Sharkey Jr., Crop and Livestock Budgets, North Central Oklahoma, Oklahoma State University, Extension Bulletin (Stillwater, 1973).

[4]The weight classification as of 1972 is 600-700 pounds.

[5]The weight classification as of 1972 is 400-500 pounds.

[6]The starting soil moisture levels were as follows:

Situation	Total Inches	Upper	Lower
Low	8.25	1.69	6.56
Medium	9.50	1.94	7.56
High	10.75	2.20	8.55

CHAPTER V

ANALYSIS

The analysis conducted using the models of the biological and economic subsystems are discussed in this chapter. The analyses presented follow two general trends. First, the situations analysized become more detailed and less general. The first situations are very general in the sense that a decision is made only once during the production year. The latter situations allow decisions to change during the year. Second, the initial models assume the decision maker has no information beyond a knowledge of long run averages. The latter situations utilize more current information in the decision making process so that the operator can revise his expectations and allow him to establish his posterior distribution of the states of nature. Thus as the assumption regarding prices and strategy flexibility change it is also necessary to recalculate the net returns distribution.

If decisions are not allowed to change during the year they are referred to as "fixed" strategies. For the situations where strategies are re-evaluated at the beginning of the spring period the term "variable" or "flexible" strategies is used.

Fixed Strategy Analyses

Decision Alternatives

In the fall, the decision maker has two decisions to make with regard to grazing during the fall-winter period. These are the purchasing strategy and the number of animals to purchase. The operator may also look ahead to the decisions that must be made for the spring or graze out period.

For the purposes of this analysis the combination of the three decisions, that is, the purchase method, the fall-winter stocking rate, and the spring decision for the graze out period, all made in the summer-fall period, is referred to as a straight through strategy or simply as a strategy. In the analysis, three stocking rates and three spring decisions were considered to make nine basic strategies. These are specified as strategies 1 through 9. A supplementary strategy, 4A is the same as strategy 4 in stocking rate and graze out action but differs in purchase strategies. Strategies 1 through 9 all assume that stockers are purchased for delivery on November 1 regardless of growing conditions. Strategy 4A assumes cattle are purchased according to growing conditions.

In all strategies, the difference between the number purchased and the number sold represents the death loss. It is assumed in this analysis that the stocking rate for the graze out period is one head per acre. Thus for

TABLE XI

SPECIFICATION OF DECISIONS BY STRATEGY NUMBER

Strategy Number	Strategy Codes	Fall Purchase Strategy[a]	No. Hd. Pur'd Fall	No. Hd. Sold March	No. Hd. Pur'd March	No. Hd. Sold May
1	BN S1 SL	2	250	245	0	0
2	BN S1 GO	2	250	0	685	916
3	BN S1 RE	2	250	0	0	245
4	BN S2 SL	2	375	367	0	0
5	BN S2 GO	2	375	0	563	918
6	BN S2 RE	2	375	0	0	367
7	BN S3 SL	2	500	490	0	0
8	BN S3 GO	2	500	0	440	921
9	BN S3 RE	2	500	0	0	490
4A	BG S2 SL	1	375	367	0	0

[a]By purchase strategy 1, cattle are purchased when forage accumulation has reached a specified amount. Cattle are delivered fourteen days later. By purchase strategy 2, cattle are purchased in the fall for delivery on November 1.

strategies 2, 5 and 8 the number of cattle available on March 1 plus the number purchased in March sum to 930.

Note that these strategies are specified by decision maker action only. No delineation was made for climatological conditions at or prior to the beginning of the fall grazing period. It was noted in the previous chapter that different soil moisture levels were specified for August 1, a date on which the producer starts to consider seeding date and other more sophisticated purchasing strategies such as contracting ahead or purchasing a futures contract. It was found that specifying different soil moisture levels at this time had no effect on the growing conditions at the beginning of the fall grazing period.

Simulation Of Production

Twenty years of daily weather phenomena were simulated and then followed by the computation of the soil moisture balance for each day of the twenty years. In the third step these data series were used to simulate wheat growth and production. The results of this simulation are presented in Table XII. The earliest seeding date was day 175 or August 22 in year 12 and the latest was day 234 or October 20 in year 10. The mean date was day 186 or September 2. In the twenty years, there was sufficient forage available to begin grazing on November 1 in 11 years. It can be noted that the grazing date is given as zero for

TABLE XII

SEEDING DATES, DAYS ON WHICH GRAZING COULD BEGIN AND GRAIN YIELDS, TWENTY YEARS SIMULATED WEATHER DATA[a,b]

Year of Simulation	Seeding Date	Date Begin Grazing	Wheat Yield Bu. Per Acre
1	179	246	58.7
2	183	257	34.2
3	181	246	17.3
4	179	246	27.4
5	176	246	53.0
6	185	253	24.7
7	180	249	32.2
8	203	0	16.6
9	177	246	25.7
10	234	0	17.6
11	183	246	36.4
12	175	246	24.3
13	194	268	27.4
14	178	246	26.8
15	191	0	25.5
16	189	261	28.4
17	189	261	28.4
18	176	246	30.5
19	181	246	28.3
20	184	246	50.6
Mean	185.8		30.2
Std. Dev.	13.3		11.8

[a]The assumptions for the simulation of production are: eight days after seeding there are 120 pounds of dry matter in the field and growth begins; a rainfall event of at least .4 inches is required after the earliest possible seeding date before seeding can begin; at least 800 pounds of dry matter must be produced before grazing can begin, and at least 600 pounds of forage must be maintained in the field at all times after grazing begins.

[b]The dates are the days of the climatological year and the equivalent calendar dates are given in Table XXXVIII.

three years. This indicates that sufficient forage had not accumulated by March 1 to allow grazing to begin. In these cases, a criterion built into the simulator assumes any livestock purchased in the fall are sold on March 1, regardless of the previously specified March decision. Of the remaining six years (grazing began on November 1 in eleven years and no grazing in three years), the beginning of grazing was delayed until after November 16 on only two occasions, once until November 23 and once until February 18.

For the medium or accepted stocking rate, the average hay requirement was 90.4 tons per year for the fall-winter period. This is equal to .246 tons or 492 pounds of hay per animal per year. If the three no grazing years are excluded, the average hay requirement was .109 tons or 319 pounds per animal per year. If cattle are not purchased until pasture conditions are known, strategy 4A, the predicted hay requirement was .111 tons or 222 pounds per animal per year. The hay requirement used in published budgets for the study area is about 320 pounds per animal per year.[1]

It can also be noted from Table XIII that for the medium stocking rate, supplemental hay was required in only half of the years for the fall-winter period.

The average yield of wheat per acre was predicted to be 30.2 bushels. Published budgets for the study area use a predicted yield of 32 and 27 bushels per acre for classes

TABLE XIII

HAY CONSUMPTION BY STRATEGY

Strategy Codes	Average Amount Tons	Standard Deviation Tons	Annual Max. Required Tons[a]	No.of Yrs. No Hay Required
BN S1 SL	49.5	82.0	223.5	11
BN S1 GO	140.4	189.7	635.8	8
BN S1 RE	74.1	93.0	250.0	8
BN S2 SL	90.4	123.2	334.8	10
BN S2 GO	237.9	212 2	738.0	6
BN S2 RE	149.9	137.8	376.7	6
BN S3 SL	141.5	166.4	447.0	8
BN S3 GO	340.6	231.8	838.3	3
BN S3 RE	248.1	177.4	524.8	3
BG S2 SL	40.8	63.6	249.6	6

[a]This was the maximum annual amount of hay required in the twenty replications.

I and II and classes III and IV land respectively. The simulated yields ranged from 16.6 bushels per acre to 58.7 bushels per acre.[2]

Decision Models For The Straight Through Strategies

The first decision analysis is rather naive in that an operator is unlikely to make completely inflexible plans in Spetember-October when the plans can be easily altered during the production year as climatic and price conditions dictate. However, it can be viewed as a long run planning tool and like any long run planning exercise, it carries limiting assumptions. It assumes that the decision maker has knowledge of the distribution of the weather phenomena and hence the growth and yield distribution for a twenty year period. It also assumes that the fixed price ratios will be constant.

The first analysis was conducted with certain prices. The analysis of the same strategies with uncertain prices will be presented later in this section. The results of the certain price analysis are presented in Tables XIV through XVII.

In reference to Table XIV, in general the expected returns were greatest for the strategy of selling all winter grazed cattle in the spring, i.e., in March.[3] At the lowest wheat price and the low stocking rate, the expected income for retaining was slightly higher than for

TABLE XIV

MEAN AND STANDARD DEVIATION OF NET RETURNS BY STRATEGY AND SELLING PRICE OF WHEAT: MARCH CATTLE PRICE $35.00 PER CWT.; HAY PRICE $35.00 PER TON

Strategy Codes	Wheat Price Per Bushel: $1.25		$1.50		$2.50		$3.50	
	Net Returns Parameters: Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
	Dollars							
BN S1 SL	15036	15259	22045	17960	50081	28826	78116	39728
BN S1 GO	11001	9060	11696	8128	14473	7889	17250	12443
BN S1 RE	15282	13446	20627	15157	42008	22320	63390	29717
BN S2 SL	16612	16342	23621	19621	51656	29817	79691	40688
BN S2 GO	11499	10006	12193	9060	14971	8376	17748	12435
BN S2 RE	16189	13813	20706	14992	38774	20235	56841	25927
BN S3 SL	18031	17540	25040	20180	53075	30901	81110	41732
BN S3 GO	12014	10847	12708	9890	15486	8869	18263	12486
BN S3 RE	16511	14123	20193	14797	34920	18196	49648	22314
BG S2 SL	16473	16242	23482	18910	51518	29700	79553	40567

TABLE XV

MEAN AND STANDARD DEVIATION OF NET RETURNS BY STRATEGY AND SELLING PRICE OF WHEAT: MARCH CATTLE PRICE $35.00 PER CWT.; HAY PRICE $50.00 PER TON

Strategy Codes	Wheat Price Per Bushel $1.25		$1.50		$2.50		$3.50	
	Net Returns Parameters							
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
	Dollars							
BN S1 SL	14294	16051	21302	18725	49338	29529	77373	40402
BN S2 SL	15255	17688	22264	20315	50299	31005	78335	41821
BN S3 SL	15909	19500	22918	22074	50953	32630	78988	43374
BG S2 SL	15861	16670	22870	19315	50906	30054	78941	40895

TABLE XVI

MEAN AND STANDARD DEVIATION OF NET RETURNS BY STRATEGY AND SELLING PRICE OF WHEAT: MARCH CATTLE PRICE $40.00 PER CWT.; HAY PRICE $35.00 PER TON

Strategy Codes	Wheat Price Per Bushel $1.25		$1.50		$2.50		$3.50	
	Net Returns Parameters							
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
	Dollars							
BN S1 SL	17119	15259	24128	17960	52163	28826	80198	39728
BN S1 GO	18232	10662	18924	9494	21702	7498	24479	10895
BN S1 RE	18749	13804	24094	15486	45476	22578	66857	29936
BN S2 SL	19722	16342	26731	19015	54766	29817	82801	40688
BN S2 GO	19774	11598	20468	10436	23246	8173	26023	11030
BN S2 RE	21372	14389	25889	15521	43957	20621	62025	26224
BN S3 SL	22196	17540	29205	20180	57240	30901	85275	41732
BN S3 GO	21364	12433	22059	11276	24836	8814	27614	11163
BN S3 RE	23446	14919	27127	15527	41855	18690	56582	22633
BG S2 SL	19136	16792	26145	19444	54180	30199	82216	41048

TABLE XVII

MEAN AND STANDARD DEVIATION OF NET RETURNS BY STRATEGY AND SELLING PRICE OF WHEAT: MARCH CATTLE PRICE $40.00 PER CWT.; HAY PRICE $50.00 PER TON

Strategy Codes	Wheat Price Per Bushel $1.25		$1.50		$2.50		$3.50	
	Net Returns Parameters Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
	Dollars							
BN S1 SL	16376	16051	23385	18725	51420	29529	79456	40402
BN S2 SL	18365	17688	25374	20315	53409	31005	81445	41821
BN S3 SL	20074	19500	27083	22074	55118	32630	83154	43374
BG S2 SL	18524	17208	25533	19840	53568	30547	81603	41372

selling, but in all other situations the opposite was true. Also, in all situations, the graze out strategy was inferior in terms of the expected income. The graze out strategy was definitely superior in all situations with respect to minimum variance of income. This was true for all stocking rates and all wheat prices.

The high stocking rate increased expected returns by about $3000. per year over the low stocking rate but the standard deviation of returns also increased. It should also be remembered that there is a considerable increase in the hay consumption for the high stocking rate over the low stocking rate. For example, for the sell strategy, the hay requirement doubled from the low to the high stocking rate.

If strategy BG S2 SL is followed rather than strategy BN S2 SL, the expected income is slightly reduced as the pounds of beef gained is reduced and as might be expected, the variance of the expected income is also slightly lower.

The expected hay price was increased from $35.00 to $50.00 per ton. This has the effect of reducing the difference in expected incomes between stocking rates for a specified price situation. For example, comparing Table XIV and XV, for the $1.50 wheat price the difference in the expected returns between strategies BN S1 SL and BN S2 SL was reduced from about $1600 to less than $1000. The $50.00 hay price (Table XV) makes the purchase according to conditions strategy more favourable in comparison with the November 1 purchase strategies. This can be observed by comparing the expected returns of strategies BG S2 SL and BN S2 SL.

Tables XVI and XVII are similar to Tables XIV and XV respectively, except the March cattle price has been increased from $35.00 to $40.00 per cwt. With the low wheat price ($1.25) and the low stocking rate the graze out strategy, BN S1 RE, becomes more favourable than the sell strategy, BN S1 SL, in terms of expected income. For the medium stocking rate and the low wheat price, the expected returns were about equal for the two strategies, BN S2 RE and BN S2 SL. However, the retain strategy, RE, was superior to both at all stocking rates for the low wheat price. With the wheat price increased to $1.50 per bushel, the sell strategy again becomes superior in expected income.

It should be noted that the expected incomes for the graze out strategies are not constant for all wheat prices. In a previous discussion it was noted that three years out of twenty, no grazing was produced and all cattle were sold in March due to the poor growth conditions. Thus for the graze out strategies, GO, graze out actually occurred in only seventeen of the twenty years and wheat was produced in three years. Thus as wheat price increases, the mean income for GO strategies increases as well, rather than remaining constant across wheat prices.

Increasing the hay price to $50.00 per ton (Table

XVII) had a similar effect to the previous analysis for $35.00 cattle price.

Testing The Form Of The Income Distribution With Fixed Prices

The twenty years of generated returns for selected strategy and price combinations were used to test the form of the returns distribution. The Kolmorgov-Smirnov one-sample test[4] was used to test the hypothesis that the distribution of net returns did not differ significantly from a normal distribution.

The strategy combinations tested are presented in Table XVIII

TABLE XVIII

STRATEGY-PRICE COMBINATIONS TESTED FOR FORM OF RETURNS DISTRIBUTION

Test Number	Strategy Codes	Wheat Price	March Price Of Stockers
1	BN S2 SL	$1.50	$35.00
2	BN S2 SL	3.50	35.00
3	BN S2 GO	1.50	35.00
4	BN S3 SL	1.50	35.00
5	BN S3 SL	3.50	35.00

These combinations were selected as being more extreme in strategy action and in the dispersion of income than some of the other strategy-price combinations.

In all cases it was found that the hypothesis could not be rejected at the 20 percent significance level. Specifically, the observed value of D was less than the tabulated critical values for twenty observations at all significance levels tabulated, i.e., at the .01, .05, .10, .15 and .20 significance levels. A summary of the procedure and the calculations are given in Appendix D.

The return parameters presented earlier along with the assumptions of a normal distribution may then be used to develop distribution of returns tables.

Distribution Of Returns, Fixed Prices

The distribution of returns for the medium stocking rate strategies were computed and are shown in Table XIX for two price situations. The numbers are the net returns at points on the probability distribution for the strategy and price situations indicated. The expected returns for strategy BN S2 SL and the low price situation is $23,621. For this combination the probability of receiving returns less than-$7659 is .05. The distribution for low and high stocking rates could be computed in a similar fashion.

Using a Bayes criterion, strategy BN S2 SL would be selected as it exhibits the greatest expected returns for both price situations. However, if the subjective

TABLE XIX

NET RETURNS TABLE FOR MEDIUM STOCKING RATE STRATEGIES WITH HAY PRICE $35.00 PER TON

Probability Of Obtaining Smaller Returns	Strategy Codes: BN S2 SL		BN S2 GO		BN S2 RE	
	Specified Prices					
	P_{lmr} = 35. P_w = 1.50	P_{lmr} = 40. P_w = 2.50	P_{lmr} = 35. P_w = 1.50	P_{lmr} = 40. P_w = 2.50	P_{lmr} = 35. P_w = 1.50	P_{lmr} = 40. P_w = 2.50
.05	- 7659	5717	- 2711	9801	- 3956	10031
.10	- 749	16553	582	12771	1492	17529
.20	7641	29666	4566	16366	8086	26598
.40	18804	47213	9898	21176	16909	38734
.50	23621	54766	12193	23246	20706	43957
.60	28438	62319	14488	25316	24503	49180
.80	39628	79866	19820	30126	33326	61316
.90	47991	92979	23804	33721	39920	70385
.95	54901	103815	27097	36691	45368	77884

estimate of prices was the low price combination, the producer might adopt a Bayes situation subject to a minimum absolute income such as -$5000 at an acceptable probability level such as .05. Thus the producer would then select the strategy with the maximum expected returns subject to the condition that the income at the lower five percent probability level not be less than -$5000. In this case strategy BN S2 RE would be selected.

Distribution Of Returns,
Variable Prices

Without the use of either a price predictor or a subjective judgement of expected prices, a distribution of prices similar to that which occurred in recent years must be assumed. This was achieved by applying the price series discussed in the previous chapter to the simulation of production and grazing for the nine strategies. The expected returns for each of the strategies are presented in the bottom portion of Table XX along with the standard deviation of returns which was computed directly from the twenty replications.

The form of the distribution was checked by testing the twenty simulated returns against the hypothesis that they follow a normal distribution. Strategies BN S1 SL, BN S2 GO and BN S3 RE were tested using the K-S goodness of fit test. In all cases, the hypothesis could not be rejected.

TABLE XX

NET RETURNS BY STRATEGY FOR FIXED STRATEGIES AND UNCERTAIN PRICES

Prob. Of Obtain'g Smaller Returns	Strategy Codes								
	BN S1 SL	BN S1 GO	BN S1 RE	BN S2 SL	BN S2 GO	BN S2 RE	BN S3 SL	BN S3 GO	BN S3 RE
.05	-12340	-21967	- 9069	-12535	-23893	- 9797	-13214	-25927	-12341
.10	- 4037	-16925	2626	- 4025	-18397	- 3727	- 4418	-19947	- 6344
.20	6012	-10823	5171	6275	-11747	3618	6226	-12711	912
.40	19458	- 2658	15604	20057	- 2847	13447	20472	- 3028	10623
.50	25245	857	20095	25989	983	17678	26603	1140	14892
.60	31032	4372	24585	31914	4813	21909	32734	5308	18981
.80	44478	12537	35019	45703	13713	31738	46980	14991	28692
.90	54537	18639	42816	56003	20363	39083	57624	22227	35948
.95	62830	23681	49259	64513	25859	45153	66420	28207	41945
Ex.R.[a]	25245	857	20095	25989	983	17678	26603	1140	14802
S.D. of R.[a]	22848	13875	17729	23419	15122	16702	24205	16454	16500
Ave. Amt. Hay Req'd in Tons	49.5	140.4	74.1	90.4	237.9	149.9	141.5	340.6	248.1

[a]These expected returns and standard deviations of returns were calculated directly from the twenty years of simulation.

The net returns distribution for each of the nine strategies was computed and is presented in the top portion of Table XX.

If a strategy was selected according to the Bayes criterion, with the assumption that utility is a linear function of money income, strategy BN S3 SL would be selected. Use of a modified Bayes criterion can have significantly different results. Consider for example, a Bayes criterion subject to the five percent probability of not less than -$10,000. In this situation strategy BN S1 RE would be selected. Strategy BN S1 RE would also be chosen if the criterion specified that the ten percent probability income must be positive.

Another approach would be a criterion modified by the expected hay requirements. A producer may not wish to produce hay and may feel he has limited opportunity to purchase hay in his area. For example, the criterion may become the Bayes criterion subject to expected hay requirements being less than 100 tons per year. In this situation strategy BN S2 SL would be selected.

Flexible Strategies, No Data Analyses

The analyses discussed up to this point have assumed that decisions were made in the fall for the whole production year. On March 1, when the operator has an opportunity to change his strategy, soil moisture and growth conditions can be observed.

From the simulation of weather phenomena and wheat growth, three March 1 soil moisture levels and two accumulated forage conditions were specified. In addition three rather than one stocking rates were delineated for the graze out alternative. A zero stocking rate is also possible implying no cattle are grazed and only wheat is produced. The combination of three soil moisture levels, two forage levels and four stocking rates result in 24 different graze out period situations. These situations are presented in Table XXI.

It is important to note the specific use of some terminology. The term "graze out period" refers to the portion of the production year after March 1 and does not necessarily imply that wheat is grazed out as opposed to producing grain. In the previous portion of this chapter, the word "strategy" was used to denote a combination of fall stocking rate and graze out period action. The word "situation" is used to denote a combination of the graze out period, stocking rate and the soil moisture and forage conditions on March 1. If the word "strategy" is used it refers to the previously discussed strategies. The analyses are conducted under the assumption that the actions taken on March 1 are relatively independent of the decision made prior to March, in the sense that strategies can be freely altered and no penalities are involved for doing so.

The simulated wheat yields for each year are presented

TABLE XXI

SPECIFICATION OF SITUATIONS, SPRING PERIOD

Situation Codes	Soil Moisture Level Mar. 1[a]	Accum. Forage Level Mar. 1[b]	St. Rate Mar.-May Hd. Per Ac.
SML FL S1	Low	Low	.75
SML FL S2	Low	Low	1.00
SML FL S3	Low	Low	1.50
SML FH S1	Low	High	.75
SML FH S2	Low	High	1.00
SML FH S3	Low	High	1.50
SMM FL S1	Medium	Low	.75
SMM FL S2	Medium	Low	1.00
SMM FL S3	Medium	Low	1.50
SMM FH S1	Medium	High	.75
SMM FH S2	Medium	High	1.00
SMM FH S3	Medium	High	1.50
SMH FL S1	High	Low	.75
SMH FL S2	High	Low	1.00
SMH FL S3	High	Low	1.50
SMH FH S1	High	High	.75
SMH FH S2	High	High	1.00
SMH FH S3	High	High	1.50

TABLE XXI (Continued)

Situation Codes	Soil Moisture Level Mar. 1[a]	Accum. Forage Level Mar. 1[b]	St. Rate Mar.-May Hd. Per Ac.
SML FL SO	Low	Low	0.00
SML FH SO	Low	High	0.00
SMM FL SO	Medium	Low	0.00
SMM FH SO	Medium	High	0.00
SMH FL SO	High	Low	0.00
SMH FH SO	High	High	0.00

[a]The soil moisture levels are defined as the total number of inches of water in the profile as follows:

Low = 8.25 inches
Medium = 9.50 inches
High = 10.75 inches

[b]The accumulated forage levels are defined as the pounds of dry matter as follows:

Low = 1170 pounds
High = 2260 pounds

in Table XXII for each of the six starting moisture-growth conditions on March 1. It can be noted the starting growth conditions in the production model have a significant effect on the final yield. For example, with low forage conditions, the average yield per acre for the medium soil moisture level is only 1.09 bushels higher than for the low moisture level. On the other hand, for the medium soil moisture level, the average yield for high forage level was 6.88 bushels per acre greater than for the low forage level.

Expected Returns, Graze Out Actions

The planning environment in the first section assumed that strategies were fixed once they were specified for the production year. This assumption is now relaxed to allow another decision in the spring to alter the original strategy. Expected returns therefore must be recalculated.

Again two types of no data analyses are possible. First, the production results can be analyzed with uncertain prices and second, trend prices could be used. These trend prices are based on historical trends rather than on the mean of an historical period.

Many producers assume that prices will continue their upward trend and are therefore unwilling to use a distribution of prices based entirely on an historical period or on a mean of the historical prices as their prediction of prices for the future.

TABLE XXII

SIMULATED WHEAT YIELDS BY YEAR OF SIMULATION AND BY SOIL MOISTURE AND FORAGE CONDITIONS MARCH 1, IN BUSHELS PER ACRE

Year Of Sim.	Soil Moisture Conditions: Low		Medium		High	
	Forage Conditions					
	Low	High	Low	High	Low	High
1	18.68	25.03	20.25	27.06	21.56	29.04
2	21.79	29.25	23.01	31.08	24.14	32.30
3	17.31	22.78	17.67	23.46	18.64	25.35
4	18.15	23.61	18.57	24.43	19.23	25.70
5	17.92	23.58	18.78	25.25	19.70	26.97
6	18.65	24.51	19.50	26.14	20.95	28.20
7	18.11	23.84	19.57	26.66	21.20	29.24
8	18.13	23.85	18.59	24.73	19.80	27.03
9	17.77	23.34	19.19	26.09	19.90	27.46
10	20.83	26.63	22.24	29.27	22.96	30.04
11	18.29	24.66	19.74	26.98	20.59	27.89
12	18.40	24.17	19.44	25.89	20.22	27.40
13	19.46	26.00	21.13	29.23	22.18	31.12
14	18.27	23.98	19.20	25.78	19.95	27.23
15	19.95	26.40	21.31	28.92	22.88	30.53
16	21.96	28.68	22.83	30.23	23.54	31.43
17	18.65	24.55	19.58	25.76	20.67	27.87
18	18.72	25.02	19.50	26.53	21.98	30.70
19	18.25	24.21	18.70	25.08	19.14	25.93
20	21.76	29.35	23.96	31.77	24.47	32.36
Mean	19.05	25.19	20.14	27.02	21.18	28.69
Range	17.31-21.96	22.78-29.35	17.67-23.96	23.46-31.77	18.64-24.47	25.35-32.36

They could also be considered as the certain price a producer who makes the contract ahead would face. The expected returns for the simulation of the eighteen graze out actions are shown on the left side of Table XXIII and the standard deviations of returns is given in the far right column.

A number of these simulations were tested for the form of the net returns distribution again using the K-S test for goodness of fit. The hypothesis that the returns can be represented by a normal distribution could not be rejected at all significance levels.

There are a number of means of computing a projected price for the next cycle or two of livestock prices. These include a detailed econometric model projection, a trend line analysis of the last one or two cycles and the subjective estimate of an individual producer. Subject estimates, of course, will differ for each producer and therefore are difficult to quantify and cumbersome to utilize in a general analysis. For this analysis, the trend line alternative was chosen. The yearly average Oklahoma City price for choice steers, 600-700 pounds for the period 1953 to 1972 was chosen as the dependent variable. Least squares regression was used to estimate a function with time as the independent variable. The estimated equation is given by equation (5-1).

TABLE XXIII

PARAMETERS OF THE RETURNS DISTRIBUTIONS FOR GRAZE OUT SITUATIONS FOR VARIABLE AND FIXED MAY LIVESTOCK PRICES

Situation Codes	Expected Returns			Std. Dev. Of Returns
	Variable Prices	Projected Prices $37.15	$41.05	
SML FL S1	- 5679	12026	15689	10742
SML FL S2	- 3856	16214	23380	13514
SML FL S3	- 815	27272	36781	19318
SML FH S1	1054	16880	22872	10739
SML FH S2	3917	23397	30563	13231
SML FH S3	7448	34455	43964	18919
SMM FL S1	- 4440	10406	16398	10643
SMM FL S2	- 2460	16923	24089	13431
SMM FL S3	789	27841	37350	19332
SMM FH S1	1180	17103	23095	10684
SMM FH S2	5330	23966	31132	13277
SMM FH S3	9571	35024	44533	18788
SMH FL S1	- 3223	11116	17107	11027
SMH FL S2	- 1228	17635	24801	13766
SMH FL S3	2400	28693	38202	19393
SMH FH S1	1233	17103	23095	10715
SMH FH S2	6055	24821	31987	13330
SMH FH S3	11478	35879	45388	19111

$$P = 17.6685 + .7791t \qquad (5\text{-}1)$$
$$(11.68) \quad (6.17)$$
$$[.126]$$

where:

P = the projected yearly average price for choice steers 600-700 pounds, in dollars per cwt., and

t = the number of years after 1953.

Using this trend line the estimated price for 1978 is $37.15 per cwt. and for 1983 is $41.05 per cwt.[5]

The eighteen graze out situations were simulated using these projected prices and the resulting expected returns are presented in Table XXIII. Using the assumption of normality and the net returns parameters presented in Table XXIII, the net returns distributions were computed for the eighteen situations. These are presented in Tables XXIV through XXVII. The standard deviation of returns used to establish the distributions is that computed directly from the twenty simulations using the variable or uncertain prices compared to the twenty year historical price series. It is assumed that even with a projected price, the price series over a ten or twenty year period will have a cycle similar to that which has occurred in the past. It might be expected that since the price level is higher for the projected prices the deviation of income might also be higher. However, it was felt this would not produce a significant bias in the

TABLE XXIV

NET RETURNS FOR HIGH FORAGE LEVELS WHEN PROJECTED MARCH CATTLE PRICE IS $37.15 PER CWT.

Probability Of Obtaining Smaller Returns	Situation Codes								
	SML FH S1	SML FH S2	SML FH S3	SMM FH S1	SMM FH S2	SMM FH S3	SMH FH S1	SMH FH S2	SMH FH S3
.05	- 882	1632	3333	- 472	2125	4118	- 523	2893	4441
.10	3117	6440	10208	3410	6950	10945	3371	7737	11386
.20	7840	12259	18529	8109	12789	19208	8083	13600	19791
.40	14160	20046	29663	14397	20603	30265	14389	21444	31038
.50	16880	23397	34455	17103	23966	35024	17103	24821	35879
.60	19600	26748	39247	19809	27329	39783	19817	28197	40720
.80	25920	34535	50381	26097	35143	50840	26123	36042	51967
.90	30643	40354	58701	30796	40981	59103	30835	41905	60372
.95	34642	45162	65577	34678	45807	65930	34729	46749	67317
Exp. Hay Req't	8.1	90.4	325.5	0.0	69.7	304.8	0.0	38.6	273.7

TABLE XXV

NET RETURNS FOR LOW FORAGE LEVELS WHEN PROJECTED MARCH CATTLE PRICE IS $37.15 PER CWT.

Prob. Of Obt'ng Smaller Returns	Situation Codes SML FL S1	SML FL S2	SML FL S3	SMM FL S1	SMM FL S2	SMM FL S3	SMH FL S1	SMH FL S2	SMH FL S3
.05	- 5644	- 6017	- 4506	- 7102	- 5171	- 3960	- 7023	- 5010	- 3208
.10	- 1741	- 1106	- 2514	- 3234	- 290	3065	- 3016	- 8	3839
.20	2983	4838	11010	1447	5617	11567	1833	6047	12368
.40	9305	12791	22379	7710	13521	22944	8323	14148	23781
.50	12026	16214	27272	10406	16923	27841	11116	17635	28693
.60	14747	19627	32165	13102	20325	32738	13909	21122	33605
.80	21068	27590	43533	19365	28229	44115	20399	20223	45018
.90	25793	33534	52030	24046	34136	52617	25248	35278	53547
.95	29696	38444	59050	27914	39017	59642	29255	40280	60594
Exp. Hay Req't	269.4	351.7	586.8	243.6	325.9	566.1	217.8	300.0	535.1

TABLE XXVI

NET RETURNS FOR LOW FORAGE LEVELS WHEN PROJECTED MARCH CATTLE PRICE IS $41.05 PER CWT.

Probability Of Obtaining Smaller Returns	Situation Codes								
	SML FL S1	SML FL S2	SML FL S3	SMM FL S1	SMM FL S2	SMM FL S3	SMH FL S1	SMH FL S2	SMH FL S3
.05	- 1982	1149	5003	- 1110	1995	5549	- 1032	2156	6301
.10	1922	6060	12023	2758	6876	12574	2975	7158	13348
.20	6646	12004	20519	7439	12783	21076	7824	13213	21877
.40	12968	19957	31888	13702	20687	32453	14313	21314	33290
.50	15689	23380	36781	16298	24089	37350	17107	24801	38202
.60	18410	26803	41674	19094	27491	42247	19900	28288	43114
.80	24732	34756	53043	25357	35395	53624	26390	36389	54527
.90	29456	40700	61539	30038	41302	62126	31239	42444	63056
.95	33360	45611	68559	33906	46183	69151	35246	47446	70103
Exp. Hay Req't	269.4	351.7	586.8	243.6	325.9	566.1	217.8	300.0	535.1

TABLE XXVII

NET RETURNS FOR HIGH FORAGE LEVELS WHEN PROJECTED MARCH CATTLE PRICE IS $41.05 PER CWT.

Probability Of Obtaining Smaller Returns	Situation Codes SML FH S1	SML FH S2	SML FH S3	SMM FH S1	SMM FH S2	SMM FH S3	SMH FH S1	SMH FH S2	SMH FH S3
.05	5206	8798	12842	5520	9291	13627	5469	10059	13950
.10	9109	13606	19717	9402	14116	20454	9363	14903	20895
.20	13832	19425	28038	14101	19955	28717	14075	20766	29300
.40	20152	27212	39172	20389	27769	39774	20381	28611	40547
.50	22872	30563	43964	23095	31132	44533	23095	31987	45388
.60	25592	33914	48756	25801	34495	49292	25809	35363	50229
.80	31912	41701	59890	32089	42309	60349	32115	43208	61476
.90	36635	47520	68211	36788	48148	68612	36827	49071	69881
.95	40538	52328	100770	40670	52973	75439	40721	53915	76826
Exp. Hay Req't	8.1	90.4	325.5	0.0	69.7	304.8	0.0	38.6	273.7

results and this factor could be ignored.

It can be noted from these tables that regardless of the soil moisture or forage conditions on March 1, the heaviest stocking rate produces the highest expected returns. Assuming a linear utility function again, the Bayes criterion suggests the 1.5 head per acre stocking rate would be selected, if the primary decision was to graze out rather than produce grain. A couple of limitations might modify this selection. These would be the number of animals that could be purchased and the expected amount of hay required. If, for example the producer observed on March 1 that soil moisture was good but growing conditions up to that time had been relatively poor and he wished to limit hay requirements to 200-300 tons, he would select either the low or the medium stocking rate. A similar type of analysis can be made with the net returns distributions for the predicted price of $41.05.

<u>Expected Returns, Produce Wheat Actions</u>

The results of the simulation of the produce wheat only actions with variable prices are given on the left side of Table XXVIII with the standard deviation of returns again in the right column.

Two projected wheat prices were used. The first, $1.66 is a simple average of the annual prices for the past twenty years. The second is this mean plus $.50 per bushel or $2.16.[6]

TABLE XXVIII

PARAMETERS OF THE RETURNS DISTRIBUTIONS FOR PRODUCE WHEAT ONLY SITUATIONS FOR PROJECTED AND UNCERTAIN PRICES

Situation Codes	Expected Returns: Uncertain Prices	Projected Prices: P_{lmr} = 37.15, P_w = 1.66	P_{lmr} = 37.15, P_w = 2.16	P_{lmr} = 41.05, P_w = 1.66	P_{lmr} = 41.05, P_w = 2.16	Std. Dev. Of Returns
SML FL SO	10654	15484	24343	17910	26769	5767
SML FH SO	20088	24931	36636	27357	39062	7026
SMM FL SO	12325	17160	26524	19586	28950	5976
SMM FH SO	22931	27780	40342	30205	42768	7431
SMH FL SO	13933	18776	28627	21202	31053	6281
SMH FH SO	25470	30362	43702	32787	46128	7579

The expected returns for these projected wheat prices in conjunction with the previously projected livestock prices are presented in Table XXVIII. The standard deviation was again computed directly using variable wheat prices for the twenty replications. Again, it was assumed that the deviation of returns would be consistent with the historical period and that the higher projected prices would not significantly change the deviation of returns.

Using the parameters presented in Table XXVIII, the net returns distributions presented in Table XXIX were computed.

A comparison can now be made between graze out actions and produce wheat actions. Note that SML FH SO, SMM FH SO and SMH FH SO represent the high forage conditions on March 1. Comparing SML FH SO with situations SML FH S1, SML FH S2 and SML FH S3 in Table XXIV, SML FH SO has a slightly higher expected income than SML FH S1 the medium stocking rate but if the criterion was to select the strategy with highest expected returns subject to highest returns at the five percent probability level, the produce wheat action would definitely be the superior. If the producer is willing to go to the higher stocking rate, it is superior in expected income to the produce wheat strategy. The same type of situation exists for the medium and high soil moisture levels. That is, in terms of maximizing expected income, produce wheat is slightly superior to the medium stocking rate but inferior to the heavy stocking rate.

Consider now the low forage situations, i.e., SML FL SO, SMM FL SO and SMH FL SO with Table XXV. At the low soil moisture level, the expected returns of the medium graze out rate are higher than the expected returns for producing wheat. For the medium soil moisture situations SMM FL SO and SMM FL S1, SMM FL S2 and SMM FL S3 the

TABLE XXIX

NET RETURNS TABLE FOR PRODUCE WHEAT SITUATIONS FOR PREDICTED MARCH CATTLE PRICE OF $37.15 PER CWT. AND PROJECTED WHEAT PRICE OF $1.66 PER BUSHEL

Probability Of Obtaining Smaller Returns	Situation Codes SML FL SO	SML FH SO	SMM FL SO	SMM FH SO	SMH FL SO	SMH FH SO
.05	5997	13373	7329	15556	8444	17895
.10	8093	15926	9501	18256	10726	20649
.20	10629	19017	12129	21525	13489	23982
.40	14023	23151	15646	25898	17185	28442
.50	15484	24931	17160	27780	18776	30362
.60	17745	26711	18674	29662	20357	32282
.80	21139	30845	22191	34035	24053	36742
.90	23675	33936	24819	37304	26816	40075
.95	25771	36489	26991	40004	29098	42829

expected returns for medium stocking rate are equal to the produce wheat decision. And at the high soil moisture level the expected returns of producing wheat exceed those of the medium stocking rate for graze out.

It should also be noted however that for the graze out actions, the returns at the five percent probability level are all negative while those for producing wheat are all positive. Thus if a producer is a risk averter, the produce wheat action will always be selected.

Flexible Strategies, Data Analyses

All the previous analyses were "no data" solutions as no predictors were used. In order to establish posterior distributions, predictors must be established for the random variables at the end of the production year based on observable determinants at or prior to the time the March decision is made. The random variables include the yield of wheat, the price of wheat, the price of cattle and the yield of grazing which is measured in proxy fashion by the amount of hay required to supplement the deficiet grazing. The posterior distributions should of course be based on observable events immediately prior to the decision period allowing the decision maker to utilize the most recent and most available data.

Prediction Models

The prediction model for the price of wheat given in equation (5-2) is based solely on the price of wheat in February. A number of other exogenous variables were considered including, the stocks of grain on January 1, the exports from July to January and the acreage planted the previous fall. None of these variables proved satisfactory in estimating a predictor for the July price of wheat. In many instances when these variables were used in various combinations with the February price in using least squares regression to estimate a relationship, the regression coefficients were not significantly different from zero.

Another approach would be to use a seasonal index. However the regression equation relationship was utilized as it was superior in its ease of computation of the functional relationship and the standard error of the estimate.

A similar situation exists for the predictor for May livestock prices presented in equation (5-3). Other more detailed models can be devised with variables which are very significant in explaining the variability of prices.[7] For ease of utilization in the "data" analysis presented in the next section however, the simple type of model has advantages. Specifically, to analyze particular situations, a prediction or estimate has to be made for any variable which is completely exogenous to the system. For example, if some measure of the number of cattle marketed was used in a predictor as an independent variable, to analyze specific situations, various levels of the variable would have to be specified which of course would add greatly to the complexity of the analysis.

The wheat yield and hay consumption predictors presented in equations (5-4) through (5-8) are based entirely on variables which are endogenous to the system.

A predictor equation for hay requirements is estimated rather than a predictor for grazing yield. The reason for this is twofold. First, the amount of hay directly affects the net returns as it is assumed that all hay requirements are purchased and second it is assumed that excess grazing cannot be sold and therefore the yield of grazing does not directly effect the net returns equation.

$$\hat{P}_w = .29898 + .7516P_{wf} \qquad (5\text{-}2)$$

$$(1.254) \quad (5.811)$$

$$[.129]$$

$$R^2 = .65$$

$$S = .18491$$

where:

$\hat{P}_w$ = the predicted price of wheat, Oklahoma, in July, in dollars per bushel,

P_{wf} = the average price of wheat, Oklahoma, in February, in dollars per bushel,

S = the standard error of estimate,

( ) = T value, and

[ ] = standard error of coefficient.

$$\hat{P}_{1my} = 1.95312 + .92658P_{1mr} \qquad (5\text{-}3)$$

(11.064)

[.084]

$$R^2 = .67$$

$$S = 1.75032$$

where:

$\hat{P}_{1my}$ = the predicted price of choice steers, Oklahoma, 600-700 pounds, in May, in dollars per cwt., and

P_{1mr} = the price of choice steers, Oklahoma, 600-700 pounds, in March, in dollars per cwt.

$$\hat{Y}_w = 12.97350 + .006113F \qquad (5\text{-}4)$$

(15.577) (18.373)

[.0039]

$$R^2 = .67$$

$$S = 2.34266$$

where:

$\hat{Y}_w$ = the predicted yield of wheat in bushels per acre, and

F = the accumulated forage on March 1 in pounds of dry matter per acre.

$$\hat{H} = 627.9213 - 20.6992SM - .2513F + 188.0907SR^2 \quad (5\text{-}5)$$

(15.389) (-5.486) (-28.173) (27.724)

[3.773] [.0089] [6.784]

$$R^2 = .82$$

$$S = 92.04$$

where:

$\hat{H}$ = the predicted hay requirement for March-May period for any stocking rate in tons for 930 acres grazed,

SM = the soil moisture of the 48 inch profile on March 1 in inches of water,

F = the accumulated forage on March 1 in pounds of dry matter per acre, and

SR = the stocking rate March to May in head per acre.

Note that the above equation can be used to predict the hay requirements for any stocking rate. It is also possible to estimate a function for each stocking rate. Estimated relationships are presented in equations (5-6) through (5-8).

$$\hat{H}_1 = 586.17839SR_1 - .19321F \quad (5\text{-}6)$$

(25.073) (-19.829)

[23.379] [.009]

$$R^2 = .87$$

$$S = 58.173$$

$$\hat{H}_2 = 634.70266SR_2 - .25957F \qquad (5\text{-}7)$$

$$(25.679) \qquad (-18.889)$$

$$[24.717] \qquad [.014]$$

$$R^2 = .89$$

$$S = 82.001$$

$$\hat{H}_3 = 616.99213SR_3 - .29160F \qquad (5\text{-}8)$$

$$(24.206) \qquad (-13.725)$$

$$[25.489] \qquad [.021]$$

$$R^2 = .93$$

$$S = 126.849$$

where:

$\hat{H}_i$ = the predicted hay requirement for March-May period stocking rate i in tons for 930 acres grazed,

SR_1 = stocking rate of .75 head per acre,

SR_2 = stocking rate of 1.0 head per acre,

SR_3 = stocking rate of 1.5 head per acre, and

F = the accumulated forage on March 1 in pounds of dry matter per acre.

The advantages of the three equations rather than the one include:

1. Statistically a better fit was achieved with the individual equations.

2. The standard error of the estimate for the one equation overestimates the standard error for the low stocking rate and underestimates it for high stocking rates.

The advantages of equation (5-5) include:

1. Computations can be simplified with only one rather than three equations.
2. It is a continuous type equation and the hay requirement for any stocking rate can be estimated. The individual equations were discrete and are applicable only for the specific stocking rate they were estimated for.

It should be noted that when equations (5-6), (5-7) and (5-8) were estimated with the SM term included, the coefficient for that term was not significant. Therefore, using the individual equations,the predicted hay requirements will be the same for different soil moisture levels with the other variables held constant. The predicted hay requirements for the eighteen situations are presented in Table XXX. It can be noted that for the medium soil moisture situations (Situations 7 to 12) the three equations more accurately predict the mean of the simulation runs. At the low and high soil moisture levels, the single equation appears to be superior.

The means and variances for all the random variables are presented in Table XXXI. The equation for the variance of net returns for graze out and for producing wheat were

TABLE XXX

HAY REQUIREMENTS FOR GRAZE OUT SITUATIONS, MARCH TO MAY PERIOD

Situation Codes	Mean Of Simulation Runs	Predicted Using Single Eqn.	Predicted Using Three Eqns.
		Tons	
SML FL S1	258.2	269.4	213.6
SML FL S2	379.0	351.7	331.0
SML FL S3	639.7	586.8	584.3
SML FH S1	7.0	8.1	3.0
SML FH S2	93.4	90.4	48.1
SML FH S3	340.2	325.5	266.5
SMM FL S1	212.4	243.6	213.6
SMM FL S2	328.7	325.9	331.0
SMM FL S3	584.4	566.1	584.3
SMM FH S1	1.9	0.0	3.0
SMM FH S2	39.7	69.7	48.1
SMM FH S3	265.1	304.8	66.5
SMH FL S1	167.1	217.8	213.6
SMH FL S2	284.6	300.0	331.0
SMH FL S3	526.0	535.1	584.3
SMH FH S1	0.0	0.0	3.0
SMH FH S2	11.1	69.3	48.1
SMH FH S3	194.6	273.7	266.5

TABLE XXXI

DATA AND NO DATA VARIANCE ESTIMATES
FOR THE RANDOM VARIABLES

V'ble	Units	Mean	No Data Variance	Data Parameters	
				Variance	St. Error of Est.
P_{1my}	$/cwt.	25.84	22.64	3.0636	1.7503
P_w	$/Bu.	1.66	.0932	.0342	.1849
Y_w	Bu./Ac.	23.46	16.63	5.4880	2.3427
H	Tons	241.06	45588.42	8472.0224	92.0436
H_1	Tons	108.27	14537.30	3384.11	58.17
H_2	Tons	189.53	26849.13	6724.17	82.00
H_3	Tons	425.39	41423.54	16089.88	126.84

given in equations (4-5) and (4-6) respectively. They are repeated here.

$$\sigma^2_{Ri} = b^2\sigma^2_{pl} + e^2\sigma^2_{hi}$$

$$\sigma^2_{Rw} = a^2(\sigma^2_{pw}\sigma^2_{yw} + \overline{P}^2_w\sigma^2_{yw} + \overline{Y}^2_w\sigma^2_{pw})$$

where:

a = acreage of wheat,

b = $W_{1smy} \cdot N_{1smy}$,

e = price of hay,

σ_{pw} = standard error of P_w,

σ_{yw} = standard error of Y_w,

σ_{pl} = standard error of P_{1my}, and

σ_{hi} = standard error of H_i.

For the graze out situations, the above parameters have the following values:

$$W_{1smy} = 6.85$$

$$N_{1smy} = 690,\ 918,\ 1374$$

Therefore b_1 = 4276.5

b_2 = 6288.3

b_3 = 9411.9

e = 35. and 50.

The variance and the standard deviations for the graze out situations are presented in Table XXXII. Note that in

TABLE XXXII

VARIANCE AND STANDARD DEVIATION OF NET RETURNS, DATA SITUATION FOR GRAZE OUT STRATEGIES WITH CERTAIN HAY PRICES

Stocking Rate Code	Parameter	Using Single Hay Predictors		Using Three Hay Predictors	
		Hay Prices			
		P_H = \$35.00	P_H = \$50.00	P_H = \$35.00	P_H = \$50.00
1	Variance	42381766.00	53184791.00	36150191.00	40464791.00
	Std. Dev.	6510.13	7272.79	6012.50	6361.19
2	Variance	79576729.00	90379754.00	77436654.00	86009754.00
	Std. Dev.	8920.58	9506.87	8799.81	9274.14
3	Variance	165398733.00	176201758.00	174730783.00	195244258.00
	Std. Dev.	12860.74	13274.10	13218.58	13972.98

the equation for the variance of net returns for graze out strategies, the predicted price of cattle does not appear but the variance of the price does. The price of hay does however appear as no predictor equation for it was estimated.

For the produce wheat situations, the parameters of the variance equation have the following values:

$$a = 930$$

$$\overline{Y}_w = 30.2$$

$$\sigma^2_{pw} = .0342$$

$$\sigma^2_{yw} = 5.488$$

The three predicted wheat prices were \$1.50, \$2.50 and \$3.50 per bushel. The standard deviations of returns using these three prices were \$402.86, \$402.875 and \$402.89 respectively. In the derivation of the distributions of net returns only one parameter is used, \$403, which is designated as σ^2_{Rw}.

Net Returns Distributions

We now have a different and the final economic environment. Flexible strategies are still being considered but rather than facing a no data situation, the producer is able to confront a data situation with a greatly reduced variability of income. By using various predictions of prices with the use of the predictor equation new expected returns are calculated utilizing the hay requirements predicted by the single equation from which the distribution of returns are calculated. The parameters for the distributions are presented in Table XXXIII. Note that two hay prices, \$35.00 per ton and \$50.00 per ton, and three prices for choice stockers at Oklahoma City were used. The livestock prices are comparable to March prices of \$35.00, \$37.50 and \$40.00 per cwt. The prices used are seasonably adjusted from these March prices to get the prices of \$35.28, \$37.80 and \$40.32.

Using the parameters in Table XXXIII, the net returns distributions for the low livestock forecast price given in Table XXXIV were computed. The distributions for the other price forecasts can be computed in a similar manner.

Situations SMM FL S1, SMM FL S2 and SMM FL S3 are for low starting forage conditions and low, medium and high stocking rates respectively. Situations SMM FH S1, SMM FH S2 and SMM FH S3 have high stocking forage conditions.

If a linear utility function is assumed and a single Bayes criterion is used with no limitations, situation SMM FH S3 or the high stocking would be selected for the high forage-low hay price situation. A similar selection is made for the high forage-high hay price situation. If

TABLE XXXIII

ESTIMATED PARAMETERS FOR THE DISTRIBUTION OF RETURNS FOR GRAZE OUT DECISIONS AND MEDIUM SOIL MOISTURE SITUATIONS FOR DATA PROBLEM

Situation Codes	P_H = \$35.00				P_H = \$50.00			
	Expected Returns By Price Forecast			Std. Dev. Of Returns	Expected Returns By Price Forecast			Std. Dev. Of Returns
	P_{1my} = \$35.28	P_{1my} = \$37.80	P_{1my} = \$40.32		P_{1my} = \$35.28	P_{1my} = \$37.80	P_{1my} = \$40.32	
SMM FL S1	5274	9115	12955	6510	1620	5461	9301	7273
SMM FL S2	10525	15119	19712	8921	5637	10230	14824	9507
SMM FL S3	18348	24443	30539	12861	9856	15952	22047	13274
SMM FH S1	13800	17641	21481	6510	13800	17641	21481	7273
SMM FH S2	19492	24086	28679	8921	18447	23040	27634	9507
SMM FH S3	27493	33589	39684	12861	22921	29021	35112	13274

TABLE XXXIV

NET RETURNS FOR GRAZE OUT DECISIONS AND MEDIUM SOIL MOISTURE SITUATIONS FOR FIXED HAY PRICES AND FORECAST LIVESTOCK PRICES

Probability Of Obtaining Smaller Returns	Specified Prices P_{1my} = \$35.28 P_H = \$35.00					
	Situation Codes					
	SMM FL S1	SMM FL S2	SMM FL S3	SMM FH S1	SMM FH S2	SMM FH S3
.05	- 5435	- 4150	- 2808	3091	4817	6337
.10	- 3069	- 908	1808	5457	8059	11010
.20	- 206	3015	7522	8320	11982	16667
.40	3625	8265	15090	12151	17232	24235
.50	5274	10525	18348	13800	19492	27493
.60	6923	12785	21606	15449	21752	30751
.80	10754	18035	29174	19280	27022	38319
.90	13617	21958	34889	22143	30925	43976
.95	15668	25028	39030	24250	34074	48175

TABLE XXXIV (Continued)

Probability Of Obtaining Smaller Returns	Specified Prices P_{1my} = \$35.28 P_H = \$50.00					
	Situation Codes					
	SMM FL S1	SMM FL S2	SMM FL S3	SMM FH S1	SMM FH S2	SMM FH S3
.05	-10344	-10002	-11980	1836	2808	1085
.10	- 7701	- 6547	- 7156	4479	8939	5909
.20	- 4502	- 1466	- 1318	7678	10444	11747
.40	- 222	3229	6494	11958	16039	19559
.50	1620	5637	9856	13800	18447	22921
.60	3462	8045	13218	15642	20855	26283
.80	7742	12740	21030	19922	26450	34095
.90	10941	17821	26868	23121	27995	39933
.95	13584	21276	31692	25764	34086	44757

a high hay price is forecast, and a limitation is placed on the criterion such as maximize expected return subject to the maximum return at the five or ten percent level, the medium rather than the high stocking rate would be selected (situation SMM FH S2 rather than SMM FH S3).

The parameters for the data net returns distributions for produce wheat decisions March 1 are presented in Table XXXV for medium soil moisture conditions. Situation SMM FL S0 refers to low starting forage and SMM FH S0 to high starting forage conditions. Comparing the expected returns for a predicted May livestock price of $35.28 and low hay price in Tables XXXII and XXXV a single Bayes criterion would select the graze out at high stocking rate strategy over wheat for a predicted wheat price of $1.50. However if predicted wheat price was $2.00, the produce wheat strategy would be superior. Similar conditions exist for the high forage situations.

The parameters in Table XXXV were used to compute the distributions of returns for wheat decisions presented in Table XXXVI.

It can be noted that the produce wheat strategies have a narrow range of returns. If a producer wished to adopt a risky criterion such as maximize expected returns at the 80 or 90 percent probability point, he would select the graze out strategy over the produce wheat strategy.

TABLE XXXV

ESTIMATED PARAMETERS FOR THE DISTRIBUTION OF RETURNS FOR PRODUCE WHEAT DECISION AND MEDIUM SOIL MOISTURE CONDITIONS FOR DATA PROBLEM

Price Forecasts	Situation Codes SMM FL SO	Situation Codes SMM FH SO
	Expected Returns	
$P_{1my} = 35.28$		
$P_w = 1.50$	12815	22105
$P_w = 2.00$	22175	34563
$P_w = 2.50$	31.536	47020
$P_{1my} = 37.80$		
$P_w = 1.50$	14370	23660
$P_w = 2.00$	23730	36118
$P_w = 2.50$	33091	48575
$P_{1my} = 40.32$		
$P_w = 1.50$	15925	25215
$P_w = 2.00$	25285	37673
$P_w = 2.50$	34646	50130
	Standard Deviation Of Returns[a]	
	403	403

[a]The standard deviations for different wheat price predictions was less than $1.00.

TABLE XXXVI

NET RETURNS FOR PRODUCE WHEAT ONLY DECISION AND MEDIUM SOIL MOISTURE SITUATIONS

Probability Of Obtaining Smaller Returns	Price Forecasts P_{1my} = \$35.28					
	P_w = \$1.50		P_w = \$2.00		P_w = \$2.50	
	Situation Codes					
	SMM FL SO	SMM FH SO	SMM FL SO	SMM FH SO	SMM FL SO	SMM FH SO
.05	12152	21442	21512	33900	30873	46357
.10	12299	21589	21659	34047	31020	46504
.20	12476	21766	21836	34224	31197	46681
.40	12713	22003	22073	34461	31434	46918
.50	12815	22105	22175	34563	31536	47020
.60	12917	22207	22277	34665	31638	47122
.80	13154	22444	22514	34902	31875	47359
.90	13331	22621	22691	35079	32052	47536
.95	13478	22768	22838	35226	32199	47683

Summary

The first analysis was conducted for the naive assumptions of fixed or certain prices and fixed strategies. Under the assumption that utility is a linear function of expected money income, so that maximizing expected returns maximizes expected utility, the strategy of having a high stocking rate and selling cattle off in March and producing wheat was generally the optimal strategy. If the low stocking rate was selected, however and the price ratio of wheat to cattle was 1.25 to 35. or .0357:1, retaining the same number of animals is slightly superior to selling. If the price ratio was reduced further to .03125:1, the retain strategy is superior at all stocking rates, the higher stocking rate again having the greatest expected returns. With a price ratio of 1.50 to 40. or .0375:1, the sell strategy is superior to the return strategy at all stocking rates.

It should be noted that if a criterion is followed whereby the minimum variance strategy is selected, the graze out at the low stocking rate strategy would be selected at all price ratios studied. With uncertain prices, a minimize variance would select the same strategy as with certain prices. If the criterion is to maximize expected returns regardless of the variance, the heavy stocking rate-sell in spring strategy is optimal.

If a criterion is chosen which maximizes expected returns subject to the maximum absolute income, i.e., maximum income or minimum loss at the five percent probability level, the retain at low stocking rate strategy would be selected.

Another alternative is to select the strategy which maximizes income subject to the constraint that expected hay requirements not exceed some specified level. If this is set at 100 tons for example, the sell in spring-medium stocking rate strategy would be followed.

The second analysis was conducted by allowing strategies to be altered in the spring, assuming the medium stocking rate had been followed during the winter. For the no data solution, considering graze out strategies only, a criterion which maximizes expected returns would select the heavy stocking rate for all soil moisture and forage level combinations. If the criterion is to minimize variance on the other hand, the low stocking rate would always be selected.

If it is assumed that the producer has 100 acres of alfalfa available which has an expected yield of three tons per acre, a total yield of 300 tons is available.

If the criterion then becomes one that maximizes returns subject to hay requirement not exceeding 300 tons, the high stocking rate could only be used when soil moisture and forage levels on March 1 are both high. If soil moisture is medium or low, the low stocking rate would be chosen.

The last analysis was a data solution for decisions revised in March. Within the grazing strategy, the heavy stocking rates again exhibited the greatest expected returns. Comparing graze out strategies with produce wheat strategies for low beginning forage levels, the produce wheat was superior only when the price reached $2.00 per bushel with the price of cattle at $35.28 per cwt. A similar situation resulted with high forage levels, at the low and medium stocking rates, where wheat was superior at $1.50 per bushel but at the higher stocking rate wheat had to increase to $2.00 per bushel to be superior.

FOOTNOTES

[1]R. L. Sharkey, Jr., Crop and Livestock Budgets, North Central Oklahoma, Oklahoma State University, Extension Bulletin (Stillwater, 1973).

[2]There were reported actual yields for the 1972-73 crop year to be in the 50-60 bushels per acre range. Personal communication with B. B. Tucker, Agronomy Department, Oklahoma State University, August 29, 1973.

[3]Hereafter the strategy of selling all livestock in March is referred to as the sell strategy, retaining the same number is referred to as the retain strategy and purchasing cattle in March to graze out all acreage is referred to as the graze out strategy.

[4]B. Ostle, Statistics in Research, 2nd ed. (Ames, 1963), p. 471.

[5]Unpublished projections by ERS, U. S. Department of Agriculture estimate the price for "all cattle and calves" for 1978 at $36.50 per cwt. and for 1985 at $40.00 per cwt.

[6]The unpublished projection by ERS, U. S. Department of Agriculture is $1.60 per bushel for 1978.

[7]A number of good models are presented in J. H. Davis, "A Quantitative Procedure To Aid Stocker Operators in Selecting Among Alternative Production-Marketing Strategies", (unpublished M. S. thesis, Oklahoma State University, 1973).

CHAPTER VI

SYNOPSIS

Summary

Winter cereals were traditionally grown in Oklahoma exclusively for their grain production. With a changing price ratio between livestock and wheat, the use of the forage portion of the wheat plant became a common practice. Since the early 1950's livestock prices have shown a steady upward trend while the wheat prices during the same period (up to the 1972-73 crop year) had a downward trend. This situation coupled with the discovery that grazing does not adversely affect the potential yield of grain, provided the growth point is not removed, encouraged use of the forage portion. In nutritional value, wheat forage is very similar to other crops which allows significant gains to be made with little supplemental feeding required.

The wheat producer who has the opportunity to add a stocker enterprise to his operation faces two decision periods during the production year. The first occurs prior to the grazing period. At this time, the operator must decide if the added returns of utilizing this supplementary product will exceed the added costs. If this decision is affirmative, the operator must then decide on the method of procuring stockers and what stocking rate will be followed for the winter period. The spring decision period occurs when the growing point emerges above the ground level. At this stage of growth the operator must decide between grazing out his acreage or producing wheat or possibly a combination of the two. If a total or partial graze out strategy is followed, the stocking rate for the spring period must be determined.

Many of the variables affecting these decisions are uncontrollable by the decision maker. These factors include the amount and occurence of rainfall, temperature and the prices of wheat and livestock. Outcomes cannot be predicted with certainity but rather only a probability of the various possible outcomes can be predicted.

The specific objectives of this study then were:

1. To construct a simulation model of grain and forage production.
2. To determine the expected net returns and the distribution of net returns for various stocking rates and price ratios.
3. To determine the expected net returns and the distribution of net returns using prediction models for the uncontrollable variables.

To achieve these objectives, the system of wheat production and utilization was divided into two subsystems. The first subsystem involves the random occurrence of weather phenomena, the growth of the wheat plant, the production of forage and grain and the conversion of forage into beef. The second subsystem includes the specification of decision alternatives and the computation of expected returns.

It was determined that simulation of this system was the most feasible technique of analysis, as this method allows inclusion of probabilities of random events and allows sequential time to be part of the model. Another essential requirement of the analysis was that experimentation with the controllable or policy variables be feasible. The infeasibility of conducting this research in the field necessitated the use of a technique which allows experiments to be conducted on a computer and simulation is such a technique.

To perform this experimentation, mathematical models were constructed for the relationships between (i) climatological phenomena, (ii) climatological phenomena and soil factors, (iii) soil factors, climatological phenomena and plant growth and (iv) plant growth and supplemental feeding requirements.

The criteria for the selection of decision alternatives was based on the Bayes formulation. The basic Bayes criterion selects strategies according to the maximum expected income which assumes a linear utility function for the operator. The use of nonlinear utility functions was allowed by the utilization of conditional criteria.

The Bayes formula also allows posterior probabilities to be established by applying additional information to the prior distribution of events.

Models were developed to simulate maximum and minimum temperature, rainfall and evapotranspiration on a daily basis throughout the year. These models were then utilized to compute the soil moisture balance, also on a daily basis.

The production of forage was divided into two periods, the fall and winter period and the spring period and a different production function was used for each period. For the fall-winter period a natural exponential function was used and for the spring period a Spillman-type function was used. The potential growth of daily forage was corrected for soil moisture and temperature conditions, to produce the net forage production for that day. During the grazing period, a forage balance was computed weekly. It was assumed that any forage deficiency would be replaced with alfalfa hay and the specified rate of gain would be maintained. The total accumulated forage that would have been in the field with no grazing at the end of the season was converted to the equivalent grain yield.

A 960 acre farm in North Central Oklahoma was used for the representative farm. It was assumed that 930 acres of the farm was available for crop production. It was also assumed that all necessary labor in addition to that provided by the operator and his family would be available for hire.

The analysis was conducted under three different planning environments. The first assumed fixed strategies throughout the year; the second assumed strategies could be altered in March but for a "no data" situation; the third also assumed flexible strategies but for a "no data" situation. The strategies incorporated a combination of four sets of decisions. These were the method of purchasing cattle in the fall, the fall-winter stocking rate, the spring useage of wheat and the spring stocking rate if a graze out or partial graze out alternative is selected. A summary of the results follows:

1. Fixed Strategies

Three fall-winter stocking rates were considered with three alternative courses of action on March 1 which were sell winter grazed cattle, retain the same number but reduce the acreage to the stocking rate of one head per acre and produce grain on the remainder of the acreage, and graze out all acreage purchasing enough cattle to graze at the one head per acre rate. In general the sell in March strategy had the greatest expected returns of the three March strategies for all wheat prices considered and the graze out strategy had the lowest variance of returns for both certain and uncertain price situations. If the price ratio wheat per bushel to cattle per cwt. was .03125:1 the retain strategy was superior in expected returns but if the rate was .0375:1, the sell in spring and produce wheat strategy had the greatest expected returns at all stocking rates. However due to the variability in yields, the sell in March-produce wheat strategy also had the greatest variability of returns and the graze out the least. In terms of price variability, the uncertain wheat price (historical series) had less variability than the stocker cattle prices.

2. Variable Strategies - No Data

In addition to the zero stocking rate, (produce wheat) and the one head per acre, two other stocking rates were utilized. They were .75 head and 1.5 head per acre. It was assumed that there were six observable states of nature on March 1; namely, three soil moisture levels and two forage growth levels. Expected returns were computed both for uncertain prices and for projected prices which were based on historical trends in the price series.

In this analysis, the expected returns using uncertain prices were again greater for produce wheat than graze out. But contrary to the first analysis, the produce wheat strategies also displayed the least variability of income. With projected prices, the graze out strategies had higher expected net returns at the higher grazing levels than the produce wheat strategies.

If hay consumption was limited to 300 tons per year, the high stocking rate could only be used when soil moisture and forage levels on March 1 are both high. If soil moisture is medium or low, the low stocking rate would be chosen.

It was also found that the different soil moisture levels had little effect on yield while the March 1 forage yield had a marked effect on predicting final yield.

3. Flexible Strategies - Data Analysis

To establish posterior distributions, predictors were developed for the uncontrollable variables which include, the price of stockers, the price of wheat, the yield of wheat and the amount of hay required. Using the computed variance of net returns for the data situation, payoff tables were constructed for various price predictors. It was found that with a price prediction of $35.28 per cwt. for May stockers and $1.50 per bushel for July wheat, graze out has the greatest expected returns at the low forage level for the normal stocking rate, but with the high forage level, the produce wheat has the greatest expected returns. With wheat at $2.00 per bushel, the produce wheat strategy is superior at both the low and the high forage situations, even with a predicted stocker price of $40.32 per cwt.

TABLE XXXVII

SUMMARY OF SUPERIOR STOCKING RATES[a] FOR DATA ANALYSIS OF FLEXIBLE STRATEGY SITUATIONS BY WHEAT PRICE, FORAGE SITUATION AND INCOME MEASUREMENT[b]

Forage Level On Mar. 1	Wheat Price Per Bushel: $1.50		$2.00		$2.50	
	Income Measurements					
	Mean	5% Prob. Level	Mean	5% Prob. Level	Mean	5% Prob. Level
Low	1.5	0.0	0.0	0.0	0.0	0.0
High	0.0	0.0	0.0	0.0	0.0	0.0

[a]In head per acre for graze out period.

[b]P_{lmy} = \$35.28, P_H = \$35.00.

These results are summarized in Table XXXVII. Two measurements of income are presented to assess the superiority of strategies. The first is the expected income and the second is the income at the five percent level as presented in income distribution tables in Chapter V. As a measurement of risk, the strategy with the highest income at the five percent probability level is preferred. For example, for the low wheat price and the low forage level, the high stocking rate has the greatest expected income but the zero stocking rate or the produce wheat strategy has the highest returns at the five percent probability level. As noted above, increasing the May livestock price from $35.28 to $40.32 per cwt. did not change the results presented in Table XXXVII.

Conclusions

The major analytical conclusions fall into two categories. First, reconsideration of decisions in March can have a significant effect on the strategy that will be followed for the duration of the production year depending upon the price and growth conditions. Considering only the one decision period, i.e., all decisions made in the fall, the graze out strategy did not compare very favourably with the sell in March and produce wheat strategy. However, when the decision was reconsidered in March, the graze out strategy compared very favourably in terms of the expected net returns with the produce wheat strategy particularilly at the low forage levels. The analysis also indicated strong support for increasing the stocking rate above the normal or accepted rate of 1.0 head per acre for the graze out period. However, the heavier stocking rate required much more supplemental feeding. If a producer does not have the hay available or is not equipped to feed a large number of animals, the heavier stocking rate would probably be considered an infeasible alternative. Second, the use of prediction models greatly reduces the variability of the expected income. For example, the standard deviation of net returns for graze out strategies was reduced about 30 percent while the standard deviation of returns for produce wheat alternatives was reduced by over 90 percent.

Presentation of Results to Laymen

An important implication from this study is the consideration of the most feasible and efficient means of transmitting the information that was generated. Presentation of research results to an operator poses a much different problem than explaining results in a research report. For a general audience, the results must be concise, yet easily understood so that the major implicatications can be quickly grasped.

In a situation where a non optimizing routine is used and where the selection of strategies depends on personal preferences, it is really not feasible to reduce the number of situations from which an operator might choose. Even with a limited number of controllable variables, the possible combinations becomes large if each controllable variable has more than two possible discrete settings. For example, consider the case of the wheat-stocker operator who has three possible fall-winter stocking rates and four possible spring stocking rates. Then immediately there are twelve possible strategies. Superimposed upon this is the specification of the states of nature during the production year. Continuing with the above example, if the states of nature on March 1 are delineated into four different states, there are now 48 possible outcome situations--a large number of alternatives to be evaluated even for the trained analyst.

One means of presenting the material is to simplify the payoff tables presented in this study to include the expected income, the ten percent probability income and the expected hay requirement. An operator may then reveal his preferences by freely choosing the alternative he desires for the various states of nature. The problem of shuffling through a large number of tables still exists. A large number of tables were presented in this study but it can be noted that many possible combinations were excluded from the formal analysis. If all were presented, it can be envisioned that an operator would quickly become confused and impatient.

One alternative to the payoff table method of presentation is a type of lexiographic analysis for each state of nature. The customary approach with lexiographic analysis is based on the assumption that an individual has a hierarchy of wants and the basic wants cannot be satisfied until the higher wants have been satisfied. It also assumes there is a satisficing level for each of these wants.

A variation of this approach is possible for the analysis of the wheat-stocker operation. Rather than considering satisficing levels for two goals such as the profit level and the amount of physical output (such as pounds of beef), consider profit level and the hay used for the production year. Instead of reaching a satisficing level of hay utilized, a maximum amount that a producer wishes to use can be established. In Figure 11, X* and Y* denote the satisficing level of normal goals such as output and profit. Let hay required be represented by the variable X and net returns by Y. The maximum hay to be utilized is denoted by X*. This could be conditioned on how much hay the producer wishes to handle or the amount he considers he could normally purchase in the immediate area. An alternative which has an expected outcome of a_1 in Figure 11 would then not be selected and a_2 would be preferrable even though the expected income is less. Of course a_3 would be preferred to a_2 and a_4 would be preferred to a_3. However a_5 would be the most preferrable as it has achieved the satisficing level of net returns but has not exceeded the hay maximum established.

The objective of this approach would be to plot the strategy points and allow the individual operator to impose his own satisficing levels. It should be noted however that this approach considers only the two dimensions--expected income and hay requirements and avoids the distribution of income.

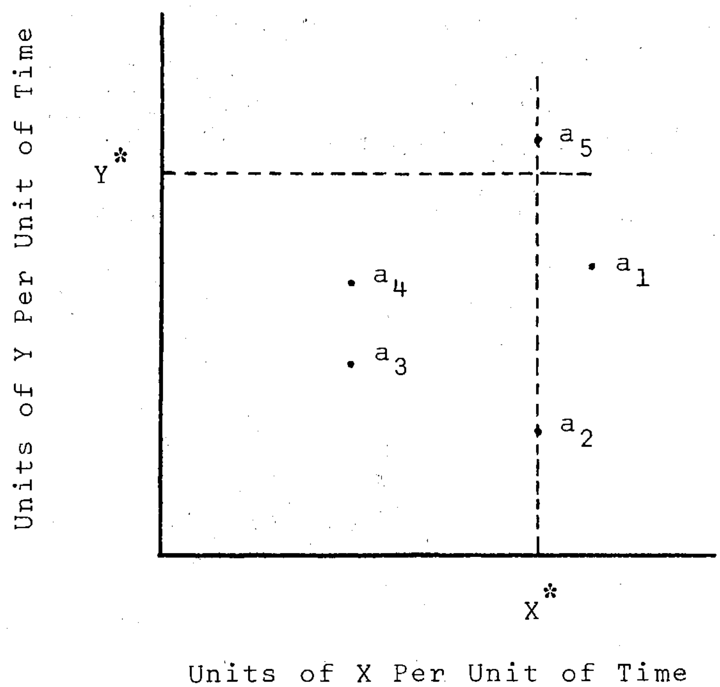

Figure 11. Combinations of Two Output Goals

Another alternative is the efficiency frontier approach. The efficiency frontier as shown in Figure 12 is the relationship between expected net returns (E(NR)) and the variance of net returns (or the standard deviation of net returns). The curves shown in Figure 12 are derived from the parameters presented in Tables XXIII and XXVIII for the high soil moisture high forage levels for projected prices of $37.15 for choice steers and $1.66 for wheat. The curve AB then represents the efficiency frontier for graze out strategies. The point C represents the produce wheat situation for the same state of nature. The actual efficiency frontier that the producer faces in then CDB and the risk averter whose indifference curve is concave upward and slopes upward to the right would select point C under these circumstances. That is an indifference curve which went through point C would have a higher utility than one which went through point B. It is possible that an indifference curve could be relatively flat and pass through both points C and B. A person with such an indifference curve would be less of a risk averter and in fact would be more willing to accept risk. The line EF represents the ten percent probability returns for the graze out decisions and point G for the produce wheat strategy. The important point demonstrated is that much of the information presented in table form can be presented in a form displayed by Figure 12. This reduces the tedium of reading through many tables but it requires somewhat more expertise in interpreting the

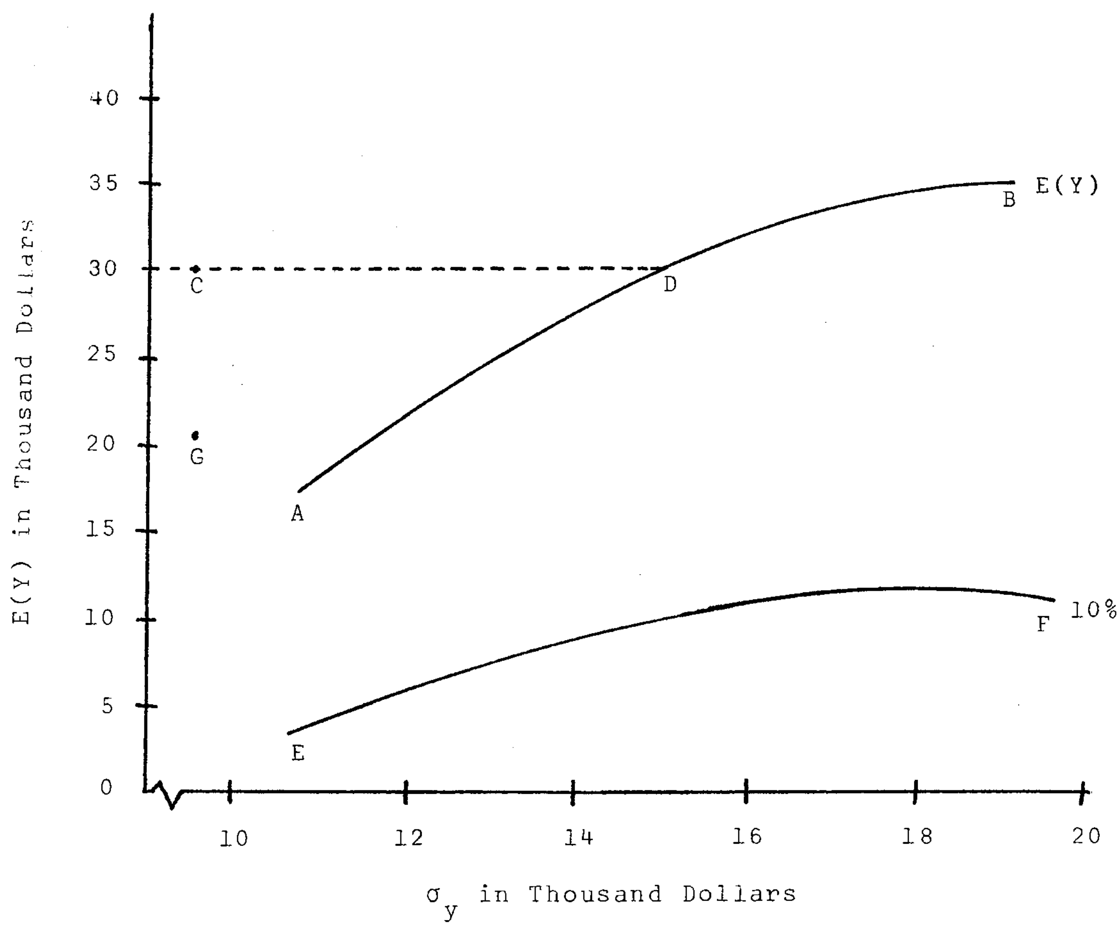

Figure 12. Efficiency Frontier for Wheat Strategies

implications of the analysis. Figure 12 for example demonstrates that, historically, wheat strategy has shown much less variability of income than a graze out strategy, due largely to the smaller variability in wheat prices than in livestock prices.

It is emphasized that the objective of research is to determine as much about the problem as is feasible, given the time and data constraints. The researcher, however does have the responsibility to make the results meaningful to the audience who face the researched problem. The intention of the above discussion is to suggest means of achieving this extension of research results.

Limitations

A number of limitations pertaining to the physical production model must be mentioned. It is felt the simulation of rainfall, temperature and pan evaporation, the basic climatological models, are adequate. There is some question about the relationship between pan evaporation and evapotranspiration. The water withdrawal from the soil profile is primarily a function of the evapotranspiration rate. The water holding capacity of the soil profile is another complicating factor. The amount of growth by a plant is determined in part by the percentage of available water in the profile which in turn is directly dependent on the evapotranspiration. The simulation of soil moisture balance resulted in significant changes in the percentage of soil moisture available over short periods of time. For additions of soil water, instantaneous recharge was assumed which meant the profile could be at wilting point one day and field capacity the next. For modeling purposes this may be a necessary assumption. The difference between permanent wilting point and field capacity was a relatively small interval in terms of available water. Accordingly the profile could be depleted from field capacity to permanent wilting point in only a few days. The result of this characteristic of the soil water balance is that the occurrence of rainfall events may have been more influential on plant growth in some instances than is true in the field.

Climatically, Oklahoma has the feature of having a significant difference in conditions from one side of the state to the other. The differences are not abrupt but nonetheless they are marked. This adds to the problem of validating a climatic-soil moisture model. As the amount of rainfall increases, for example, the accuracy of the model becomes more crucial in terms of accounting for the disappearance of rainfall through runoff and recharge of the soil profile. As the amount of rainfall increases then from west to east across the state, the variability in soil moisture and hence in growing conditions also increases necessitating more attention to detail in the formulation of a soil moisture balance model.

The relationship most crucial to the model is the production function for forage growth. There is little experimental documentation of the relationship used necessitating experimentation or a procedure of successive approximations to determine the values for the R-factors. These factors account for a number of variables not included in the model but which nonetheless are determinants of yield. These include geographical location, crop, variety and seeding date. The R-factors are also essentially residuals for the undefined interactions between the variables that are included in the model. For example, the τ, σ and R-factors are all parameters with the property of being between zero and one. The assumption that growth is a function of the product of these three parameters immediately places a severe restriction on the potential yield. This is not to imply that the particular mathematical form used for the production functions is not relevant. It was deemed the preferable form, given the knowledge and information available. But it does imply that the multiplicative type of function may produce a significant margin of error. More investigation is required to determine if, in fact, the multiplicative form is the most appropriate.

There is another problem with the growth production functions. An average daily temperature was specified below which growth would not occur for that particular day. Reoccurrence of "growing" temperatures, however, bring forth instantaneous growth. If, for example, a number of consecutive non-growing days were followed by a number of growing days, and if soil moisture was not limiting, growth would occur on the first day reoccurrence of the growing days. In this way there is no truly dormant winter period as the tau factor was allowed to handle this. Similarly, no build up of heat units or growing degree days was required to bring the plant out of dormancy and begin the rapid spring growth stage.

The model was developed with primary consideration to the production and utilization of forage for grazing and secondary consideration to the yield of wheat for grain. This was for a very good reason. The forage or grazing production of winter cereals has always been regarded purely as a supplementary crop and hence by definition the need for economic or physical analysis was limited. As a consequence, the accumulated fund of research results concerned with isolating growing characteristics of the plant throughout the year was almost void. Attention then was focused on the production of forage rather than grain.

The model to estimate wheat grain production is a very aggregate type of model. In relating grain yield solely to the total accumulated forage figure many contributing factors were overlooked. A more comprehensive model would consider growing conditions of specified stages of plant growth which would in turn require these stages to be identified as functions of the random climatic events. For example, a model might consider the temperature and soil moisture conditions at the shooting or boot stages, as well as such growth increases as accumulated growth up to the beginning of the spring growth period. This of course, would involve intensive investigation to determine the motive of these relationships. An alternative for this study would have been to go back to the beginning of the crop year, assume a maximum potential yield and then reduce the potential yield according to the daily stress on the plant throughout the year.

The complexity of the conversion portion of the model was reduced by assuming many coefficients were constant. For example, the annual death loss, the daily rate of gain, the quality of forage and the quality of animals purchased were all taken as fixed. The quality of forage was allowed to slightly vary from the winter to spring period. In the winter, 9.55 pounds of forage was required per pound of gain and in the spring period, only 8.35 pounds of forage was required per pound of gain. However, no year to year variation in these coefficients was allowed. A more detailed model could consider grades of cattle other than choice and could relate the rate of gain and death loss to the climatic conditions.

Recommendations for Further Study

It should be readily apparent from the previous section what some of the specific research needs are. In general, the physical and agronomic phases need much more validation, specifically validation under field conditions. A better understanding of many of the relationships developed in this study would have applications beyond identifying optimal grazing strategies for winter cereals. They could for example be useful in fertility, irrigation and pollution abatement research. The general recommendation is that multi-disciplinary or bioeconomic research be actively pursued. This research has demonstrated the advantages of the systems approach to defining problems and determining solutions for these problems. The scientific method has long provided a framework by which professionals in segregated disciplines have conducted their research. The results of such research, however are often not commumicated to other disciplines. A parallel can be drawn between the relationship of professionals in various disciplines and the relationships of the extension agent and farm manager discussed in the first chapter. Similar types of breakdowns in communication occur. It appears the systems approach is being adopted by operators in the real world. A case in point is the development of large feedlot enterprises in western Oklahoma. They have achieved their present size by thinking of the procurement of animals and other inputs, the conversion of nutrients into beef and the sale of slaughter cattle as a total system. It beehooves agricultural scientists to cross their discipline lines and adopt a similar posture.

There appears to be another potential gain from adopting a systems approach. The development of a long term, multidisciplinary approach to research would demonstrate to adminstrators and public officials the role of individual projects in addressing the major agricultural problems. It would also give adminstrators a deeper understanding of how research funds are distributed and spent and thereby make adminstrators more willing to increase allocations.

In terms of specific recommendations, research to define precisely some of the parameters for which assumptions were made would be very useful. This includes the minimum amount of forage that must be maintained in the field, the amount of forage necessary to allow grazing to begin and identification of the critical growth stages as measured by climatological variables such as temperature. A good example is the assumption of March 1 being the beginning of the spring growth period. It appears the variation in climate during the winter period would produce a wide variation in the calendar date on which the growth point emerged above the ground level. This of course, has ramifications for stocking actions and the amount of potential growth during the spring period.

One of the problems of many research projects is making the results generally applicable. The simulation of the production subsystem indicates the model is sensitive to some of the parameters used in determining the soil moisture balance. This implies that the application of the model to other climatic areas would require careful scrutiny of these parameters. It would be useful to modify the model to increase the ease with which it could be utilized in other areas and at the same time increase its predictability for other areas.

The method of empirical analysis and presentation of results for this study was different from the results available from the usual optimizing routines such as linear programming. The technique does not optimize, since not all points on the production possibilities frontier are considered and decision maker preferences are not quantified. If this last deficiency could be overcome the technique would prove to be very beneficial. In any case, it seems desirable to pursue means of making the type of analysis more useful in the hands of extension agents so that decision makers could reveal their preferences and thereby circumvent the problem of establishing utility functions.

Another useful area of investigation would be the utilization of a production-utilization model like that developed in this study in the evaluation of more formalized marketing strategies. Specifically these would be marketing strategies designed to reduce or transfer price risks such as formal contracting and hedging. In addition, the results might be different if the system was expanded to include the feedlot enterprise. It seems apparent that some of the economic advantages of using wheat as a graze out crop can be captured by transferring cattle to a feedlot enterprise rather than selling at the end of the graze out period.

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APPENDIX A

DAYS OF THE CLIMATOLOGICAL YEAR

TABLE XXXVIII

THE DAY NUMBERS OF CLIMATOLOGICAL YEAR BY WEEKS

Week	Day	Date	Week	Day	Date	Week	Day	Date
1	1	Mar. 1	9	63	May 2	18	123	Jul. 1
	4	4	10	64	3		126	4
	7	7		67	6	19	127	5
2	8	8		70	9		130	8
	11	11	11	71	10		133	11
	14	14		74	13	20	134	12
3	15	15		77	16		137	15
	18	18	12	78	17		140	18
	21	21		81	20	21	141	19
4	22	22		84	23		144	22
	25	25	13	85	24		147	25
	28	28		88	27	22	148	26
5	29	29		91	30		151	29
	32	Apr. 1	14	92	31		154	Aug. 1
	35	4		95	Jun. 3	23	155	2
6	36	5		98	6		158	5
	39	8	15	99	7		161	8
	42	11		102	10	24	162	9
7	43	12		105	13		165	12
	46	15	16	106	14		168	15
	49	18		109	17	25	169	16
8	50	19		112	20		172	19
	53	22	17	113	21		175	22
	56	25		116	24	26	176	23
9	57	26		119	27		179	26
	60	29	18	120	28		182	29

TABLE XXXVIII (Continued)

Week	Day	Date	Week	Day	Date	Week	Day	Date
27	183	Aug.30	35	245	Oct.31	44	305	Dec.30
	186	Sep. 2	36	246	Nov. 1		308	Jan. 2
	189	5		249	4	45	309	3
28	190	6		252	7		312	6
	193	9	37	253	8		315	9
	196	12		256	11	46	316	10
29	197	13		259	14		319	13
	200	16	38	260	15		322	16
	203	19		263	18	47	323	17
30	204	20		266	21		326	20
	207	23	39	267	22		329	23
	210	26		270	25	48	330	24
31	211	27		273	28		333	27
	214	30	40	274	29		336	30
	217	Oct. 3		277	Dec. 2	49	337	31
32	218	4		280	5		340	Feb. 3
	221	7	41	281	6		343	6
	224	10		284	9	50	344	7
33	225	11		287	12		347	10
	228	14	42	288	13		350	13
	231	17		291	16	51	351	14
34	232	18		294	19		354	17
	235	21	43	295	20		357	20
	238	24		298	23	52	358	21
35	239	25		301	26		361	24
	242	28	44	302	27		364	27
							365	28

APPENDIX B

ENTERPRISE BUDGETS

The Machinery Complement

The machinery complement of the representative farm is given in Table XXXIX. It was designed to correlate with a representative machinery complement for a 960 acre operation and also with the complement deemed adequate to permit timely completion of essential tasks. The complement was constructed with the assistance of Roy L. Sharkey, Jr., Area Farm Management Agent, North Central Oklahoma and Darrel D. Kletke, Associate Professor, Department of Agricultural Economics.

A summary of the annual costs of the machinery and equipment complement is given in Table XL.

Enterprise Budgets

A summary of the enterprise budgets is presented in Tables XLI and XLII. Note that in these summary tables the costs of stockers or the interest on the purchase of the animals is not included.

TABLE XXXIX

MACHINERY AND EQUIPMENT COMPLEMENT FOR REPRESENTATIVE FARM

Item	Size
Machinery	
Tractor	95 Horsepower
Tractor	75 Horsepower
Combine	18 Foot
Truck	2 Ton
Pickup	1/2 Ton
Drills (2)	16 X 10 inch Rows
Tandem Disk	14 Foot
Chisel	13 Foot
Mulboard Plow	5 Furrow
Springtooth	24 Foot
Spike Harrow	20 Foot
Equipment	
Stocker Trailer	18 Foot
Fence, 4-Wire	5 Miles
Fence, Electric	5 Miles
Water Tank	1134 Gallon
Tank Heater	1
Portable Corral	100 Head
Portable Loading Chute	1
Working Chute	1
Barn	2000 Square Feet

TABLE XL

SUMMARY OF ANNUAL MACHINERY AND EQUIPMENT COSTS

Type of Cost	Machinery	Equipment
	Dollars	
Ownership[a]	4748	613
Interest[b]	3341	345
Operating[c]	4503	125

[a]The ownership costs include depreciation, insurance and taxes.

[b]An annual rate of 10 percent was charged on investment capital.

[c]The operating costs include repairs, fuel and lubrication. The operating costs are based on the computed hours of annual use for the representative farm.

TABLE XLI

SUMMARY OF ANNUAL VARIABLE CROP PRODUCTION COSTS PER ACRE

Operating Inputs	$20.25
Interest on Operating Inputs	1.50
Machinery, Cultivation and Crop Care	2.81
Total	24.66
Machinery, Harvesting	1.67
Total	26.23

TABLE XLII

SUMMARY OF ANNUAL STOCKER COSTS PER HEAD EXCLUDING THE PURCHASE COST OF THE STOCKER

November - March	
Operating Inputs	$19.17
Interest on Operating Inputs	.28
Total	19.45
March - May, Stockers Carried Over	
Operating Inputs	2.50
Interest on Operating Inputs	.15
Total	2.65
March - May, Stockers Bought in March	
Operating Inputs	10.25
Interest on Operating Inputs	.07
Total	10.32

APPENDIX C

PROCEDURES FOR ESTIMATING THE VARIANCE

OF NET RETURNS

The net returns for the operation studied in this research is defined by equation (C-1).

$$NR_i = (P_w \cdot A \cdot Y_w) + (P_{lsmy} \cdot W_{lsmy} \cdot N_{lsmy})$$
$$+ (P_{lsmr} \cdot W_{lsmr} \cdot N_{lsmr}) - ((P_{lf} \cdot W_{lf} \cdot N_{lf})$$
$$+ (P_{lbmr} \cdot W_{lbmr} \cdot N_{lbmr}) + 22{,}933.80$$
$$+ N_{lf}(19.45 + C_1) + N_{co}(2.67 + C_2)$$
$$+ N_{lbmr}(10.32 + C_3) + (1.67A) + (H_i \cdot P_h)) \qquad \text{(C-1)}$$

The variance of net returns (σ^2_{Ri}) is given by definition (C-2).

$$\sigma^2_{Ri} = E(NR_i - \overline{NR}_i)^2 \qquad \text{(C-2)}$$

where the bar (-) denotes expected value.

If expected values are computed for prices, the yield of wheat and the hay requirement, expected net returns is given by equation (C-3).

$$\overline{NR}_i = (\overline{P}_w \cdot A \cdot \overline{Y}_w) + \overline{P}_{lsmy} \cdot W_{lsmy} \cdot N_{lsmy})$$
$$+ (\overline{P}_{lsmr} \cdot W_{lsmr} \cdot N_{lsmr}) - ((P_{lf} \cdot W_{lf} \cdot N_{lf})$$
$$+ (\overline{P}_{lbmr} \cdot W_{lbmr} \cdot N_{lbmr}) + 22{,}933.80$$

$$+ N_{1f}(19.45 + C_1) + N_{co}(2.67 + C_2)$$

$$+ N_{1bmr}(10.32 + C_3) + (1.67A) + (\overline{H}_i \cdot P_h)) \qquad \text{(C-3)}$$

The terms without a bar are constants.

The subtraction of (C-3) from (C-1) is given by equation (C-4).

$$(NR_i - \overline{NR}_i) = aP_wY_w - a\overline{P}_w\overline{Y}_w + bP_{1smy} - b\overline{P}_{1smy} + cP_{1smr}$$

$$- c\overline{P}_{1smr} - ((P_{1f} \cdot W_{1f} \cdot N_{1f} - P_{1f} \cdot W_{1f} \cdot N_{1f})$$

$$+ (dP_{1bmr} - d\overline{P}_{1bmr}) + (22{,}933.80 - 22{,}933.80)$$

$$+ (N_{1f}(19.45 + C_1) - N_{1f}(19.45 - C_1))$$

$$+ (N_{co}(2.67 + C_2) - N_{co}(2.67 + C_2))$$

$$+ (N_{1bmr}(10.32 + C_3)) + (1.67A - 1.67A)$$

$$+ (eH_i - e\overline{H}_i))$$

$$= a(P_w \cdot Y_w - \overline{P}_w \cdot \overline{Y}_w) + b(P_{1smy} - \overline{P}_{1smy})$$

$$+ c(P_{1smr} - \overline{P}_{1smr}) - (d(P_{1bmr} - \overline{P}_{1bmr})$$

$$+ e(H_i - \overline{H}_i)) \qquad \text{(C-4)}$$

The variance of net returns can then be computed by squaring equation (C-4) and taking the expected value. This is given in equation (C-5).

$$\sigma^2_{Ri} = E(a^2(P_w \cdot Y_w - \overline{P}_w \cdot \overline{Y}_w)^2 + b^2(P_{lmy} - \overline{P}_{lmy})^2$$

$$+ c^2(P_{lmr} - \overline{P}_{lmr})^2 + d^2(P_{lmr} - \overline{P}_{lmr})^2 + e^2(H_i - \overline{H}_i)^2$$

$$+ 2ab(P_w \cdot Y_w - \overline{P}_w \cdot \overline{Y}_w)(P_{lmy} - \overline{P}_{lmy})$$

$$+ 2ac(P_w \cdot Y_w - \overline{P}_w \cdot \overline{Y}_w)(P_{lmr} - \overline{P}_{lmr})$$

$$- 2ad(P_w \cdot Y_w - \overline{P}_w \cdot \overline{Y}_w)(P_{lmr} - \overline{P}_{lmr})$$

$$- 2ae(P_w \cdot Y_w - \overline{P}_w \cdot \overline{Y}_w)(H_i - \overline{H}_i)$$

$$+ 2bc(P_{lmy} - \overline{P}_{lmy})(P_{lmr} - \overline{P}_{lmr})$$

$$- 2bd(P_{lmy} - \overline{P}_{lmy})(P_{lmr} - \overline{P}_{lmr})$$

$$- 2be(P_{lmy} - \overline{P}_{lmy})(H_i - \overline{H}_i)$$

$$- 2ce(P_{lmr} - \overline{P}_{lmr})(H_i - \overline{H}_i)$$

$$+ 2de(P_{lmr} - \overline{P}_{lmr})(H_i - \overline{H}_i)) \qquad \text{(C-5)}$$

Note that it was assumed that $P_{lbmr} = P_{lsmr}$ and only symbol P_{lmr} is used in equation (C-5). In addition, since cattle are both bought and sold in March in the same year, either the coefficient c or coefficient d will be zero. Therefore, the term $2cd(P_{lmr} - \overline{P}_{lmr})(P_{lmr} - \overline{P}_{lmr})$ is not included in equation (C-5).

In order to make the appropriate substitutions for expected values in equation (C-5) it is necessary to derive some further relationships.

1. Let X and Y be two positively correlated random variables.

The definition of covariance is given by equation (C-6).

$$E((X - \overline{X})(Y - \overline{Y})) = \sigma_{xy} \qquad \text{(C-6)}$$

$$\begin{aligned} E((X - \overline{X})(Y - \overline{Y})) &= E(XY - X\overline{Y} - \overline{X}Y + \overline{XY}) \\ &= E(XY) - E(X)\overline{Y} - \overline{X}E(Y) + \overline{XY} \\ &= E(XY) - \overline{XY} - \overline{XY} + \overline{XY} \\ &= E(XY) - \overline{XY} \end{aligned}$$

Therefore:

$$E(XY) = \sigma_{xy} + \overline{XY} \qquad \text{(C-7)}$$

The definition of the correlation coefficient of X and Y is given by equation (C-8).

$$\rho_{xy} = \frac{E((X - \overline{X})(Y - \overline{Y}))}{\sigma_x \sigma_y} \qquad \text{(C-8)}$$

Substituting equation (C-6) into equation (C-8) results in the definition of the covariance of X and Y given by equation (C-9).

$$\rho_{xy} = \frac{\sigma_{xy}}{\sigma_x \sigma_y}$$

Therefore:

$$\sigma_{xy} = \rho_{xy}\sigma_x\sigma_y \qquad \text{(C-9)}$$

Then substituting equation (C-9) into equation (C-7) results in equation (C-10).

$$E(XY) = \rho_{xy}\sigma_x\sigma_y + \overline{XY} \qquad \text{(C-10)}$$

2. Let X, Y and Z be three random variables.

Assume: (i) X and Y are independent.

(ii) Z and Y are independent.

(iii) X and Z are positively correlated.

Then:

$$E((XY - \overline{XY})(Z - \overline{Z}) = E(YXZ - XY\overline{Z} - \overline{XY}Z + \overline{XYZ})$$

$$= E(Y)E(XZ) - E(X)E(Y)\overline{Z}$$

$$- \overline{XY}E(Z) + \overline{XYZ}$$

$$= \overline{Y}(\sigma_{xz} + \overline{XZ}) - \overline{XYZ} - \overline{XYZ} + \overline{XYZ}$$

$$= \overline{Y}(\sigma_{xz} + \overline{XZ}) - \overline{XYZ} \qquad \text{(C-11)}$$

Substituting equation (C-9) into equation (C-11) results in equation (C-12).

$$E((XY - \overline{XY})(Z - \overline{Z}) = \overline{Y}(\rho_{xz}\sigma_x\sigma_z + \overline{XZ}) - \overline{XYZ} \quad \text{(C-12)}$$

3. Let X and Y be two independent random variables.

$$E((XY - \overline{XY})^2) = E((XY)^2 - 2XY\overline{XY} + (\overline{XY})^2)$$

$$= E(XY)^2 - 2E(XY)XY + \overline{X}^2\overline{Y}^2$$

$$= E(X^2)E(Y^2) - 2E(X)E(Y)\overline{XY} + \overline{X}^2\overline{Y}^2$$

$$= (\sigma_x^2 + \overline{X}^2)(\sigma_y^2 + \overline{Y}^2) - 2\overline{XYXY} + \overline{X}^2\overline{Y}^2$$

$$= \sigma_x^2\sigma_y^2 + \sigma_x^2\overline{Y}^2 + \sigma_y^2\overline{X}^2 + \overline{X}^2\overline{Y}^2 - 2\overline{X}^2\overline{Y}^2$$

$$+ \overline{X}^2\overline{Y}^2$$

$$= \sigma_x^2\sigma_y^2 + \sigma_x^2\overline{Y}^2 + \sigma_y^2\overline{X}^2 \quad \text{(C-13)}$$

The following assumptions are made about the variables in equation (C-5).

1. P_w and Y_w are independent for an individual producer.
2. P_{1my} and Y_w and P_{1mr} and Y_w are independent.
3. H_i and P_w, H_i and P_{1my} and H_i and P_{1mr} are independent.
4. P_{1my} and P_{1mr} are positively correlated.
5. P_{1my} and P_w and P_{1mr} and P_w are positively

correlated.

6. Y_w and H_i are positively correlated.

7. $P_{1smr} = P_{1bmr} = P_{1mr}$.

For situations where decisions are made in March, the expected net returns is given in equations (C-14) and (C-15) and the variance in equation (C-16).

$$NR - \overline{NR} = (A \cdot P_w \cdot Y_w - A \cdot \overline{P}_w \cdot \overline{Y}_w) + b(P_{1my} - \overline{P}_{1my}) - e(H - \overline{H}) \quad \text{(C-14)}$$

$$E(NR_i - \overline{NR}_i)^2 = E(a^2(P_wY_w - \overline{P}_w\overline{Y}_w)^2 + b^2(P_{1my} - \overline{P}_{1my})^2 + e^2(H - \overline{H})^2 + 2ab(P_wY_w - \overline{P}_w\overline{Y}_w)(P_{1my} - \overline{P}_{1my}) - 2ae(P_wY_w - \overline{P}_w\overline{Y}_w)(H_i - \overline{H}_i) - 2be(P_{1my} - \overline{P}_{1my})(H_i - \overline{H}_i) \quad \text{(C-15)}$$

$$\sigma^2_{Ri} = a^2(\sigma^2_1\sigma^2_2 + P^2_w\sigma^2_2 + Y^2_w\sigma^2_1) + b^2\sigma^2_3 + e^2\sigma^2_5 + 2ab(\overline{Y}_w(\rho_{13}\sigma_1\sigma_3 + \overline{P}_w\overline{P}_{1my}) - \overline{Y}_w\overline{P}_w\overline{P}_{1my}) - 2ae(\overline{P}_w(\rho_{25}\sigma_2\sigma_5 + \overline{Y}_w\overline{H}_i) - \overline{P}_w\overline{Y}_w\overline{H}_i) \quad \text{(C-16)}$$

where:

$$2beE((P_{1my} - \overline{P}_{1my})(H_i - \overline{H}_i)) = 0$$

APPENDIX D

TESTING THE FORM OF THE NET RETURNS DISTRIBUTION

Summary Of The Procedure For Using The Kolmogorov-Smirnov Test

The hypothesis is that the returns for the twenty years simulated are normally distributed.

Reference: Bernard Ostle, Statistics in Research, 2nd., Ames: Iowa State University Press, 1963, pp471-472 and 560.

The procedure is as follows:

1. Arrange the twenty net returns in ascending order of magnitude.
2. Compute the mean and standard deviation of the net returns.
3. Compute Z values for each return figure x. where:

$$Z = \frac{x - \mu}{\sigma}$$

4. Find the value for G(Z), the expected relative cumulative frequency for the standard normal distribution.
5. Compute $S_n(Z)$, the actual relative cumulative frequency.
6. Compute the absolute difference between G(Z) and $S_n(Z)$.
7. Find D, the maximum absolute difference and compare with tabulated critical values for

sample size of twenty. These critical values are given below according to the level of significance.

Level of Significance for D				
.20	.15	.10	.05	.01
.231	.246	.264	.294	.356

The calculations for fixed strategies for two price situations are given in Table XLIII as an example of the Kolmogorov-Smirnov test. It can be seen that both the maximum absolute differences, .2052 and .1859, are less than the critical value at the .20 significance level, .231.

TABLE XLIII

APPLICATION OF THE KOLMOGOROV-SMIRNOV TEST TO THE SIMULATED RETURNS FOR FIXED STRATEGIES AND CERTAIN PRICES

Strategy BN S2 SL

P_w = \$1.50 P_{1mr} = \$35.00

Simulated Returns (Dollars)	Z	G(Z)[a]	$S_n(Z)$[b]	$\lvert G(Z) - S_n(Z)\rvert$[c]
- 3799	-1.4420	.0749	.05	.0249
- 2474	-1.3723	.0853	.10	.0147
2004	-1.1368	.1292	.15	.0208
6233	- .9144	.1814	.20	.0196
8644	- .7876	.2148	.25	.0352
16252	- .3875	.3483	.30	.0483
17597	- .3168	.3745	.35	.0245
18632	- .2623	.3973	.40	.0027
18752	- .2560	.4013	.45	.0487
20613	- .1581	.4364	.50	.0636
22050	- .0826	.4681	.55	.0819
22956	- .0349	.4860	.60	.1140
24184	.0296	.5120	.65	.1380
27309	.1939	.5753	.70	.1247
28022	.2314	.5909	.75	.1590
29237	.2953	.6141	.80	(.1859)
35539	.6267	.7356	.85	.1144
55334	1.6677	.9525	.90	.0525
58738	1.8468	.9678	.95	.0178
66592	2.5020	.9938	1.00	.0062

TABLE XLIII (Continued)

Strategy BN S3 SL

P_w = \$3.50 P_{lmr} = \$35.00

Simulated Returns (Dollars)	Z	G(Z)[a]	$S_n(Z)$[b]	$\lvert G(Z) - S_n(Z)\rvert$[c]
26392	-1.3111	.0951	.05	.0451
29484	-1.2370	.1075	.10	.0075
35101	-1.1024	.1357	.15	.0144
38434	-1.0226	.1539	.20	.0462
55426	- .6154	.2676	.25	.0176
62076	- .4561	.3228	.30	.0228
67034	- .3372	.3669	.35	.0169
67955	- .3152	.3745	.40	.0256
71165	- .2383	.4052	.45	.0449
71656	- .2265	.4091	.50	.0910
75009	- .1461	.4404	.55	.1097
77125	- .0954	.4602	.60	.1399
79566	- .0369	.4841	.65	.1660
86712	.1342	.5517	.70	.1493
89071	.1907	.5754	.75	.1747
91282	.2437	.5948	.80	(.2052)
106485	.6080	.7291	.85	.1210
152673	1.7148	.9564	.90	.0564
160616	1.9051	.9719	.95	.0219
178941	2.3442	.9904	1.00	.0097

[a]Expected Relative Cumulative Frequency

[b]Relative Cumulative Frequency

[c]( ) = D = Max. $\lvert G(Z) - S_n(Z)\rvert$

APPENDIX E

COMPUTER OUTPUT

In Table XLIV, a sample output for the production, utilization and balance of forage (Subroutine FORAGE) is presented. Two features of this table should be noted. First, there are three main sections in the table. The first section displays the input data required to make a simulation run under the heading "PARAMETERS FOR THIS ANALYSIS". The daily forage production and balance is shown in the second section under the heading "FORAGE GROWTH AND BALANCE IN LBS PER ACRE". The critical dates for each of the twenty years in this particular simulation run are given in the third section. The second feature to be noted regards the second section of the output. Although twenty years were simulated for each run or strategy, the results of only three years are presented here. The years of simulation are organized according to the climatological year which begins on March 1. Thus day 1 of year 1 is March 1 but the production year 1 begins on day 193 of the climatological year 1 and ends on day 92 of climatological year 2.

The columns under the heading "TOT FORAGE" are the daily and accumulated production with no grazing or forage removal. The columns under the heading "FORAGE BAL" are the daily and accumulated forage with grazing. If grazing has not been allowed the "ACCUM FORAGE BAL" will be equal to the "ACCUM TOT FORAGE". The last set of columns entitled "SPRING FTN" is the daily and total accumulated aggregate forage for the spring period only.

TABLE XLIV

SAMPLE OUTPUT OF FORAGE PRODUCTION AND UTILIZATION SIMULATOR

PARAMETERS FOR THIS ANALYSIS

SEEDING DATE THRESHOLD-DAY	168
-RAINFALL	0.40
CATTLE PURCHASE STRATEGY	2*
CATTLE PUR-FORG GROWTH THRESHOLD	600.
FORAGE GROWTH FACTOR-FALL	0.120
-SPRING	0.930
INITIAL GROWTH LEVEL-FALL	120.
MINIMUM FORAGE TO START GRAZING	800.
MINIMUM FORAGE TO BE MAINTAINED	600.
MAXIMUM FORAGE GROWTH-SPRING	1500.
MARCH STRATEGY	1**
STOCKING RATE,MAR-MAY,HD PER AC	1.00
SOIL TYPE	1

* 2=BUY CATTLE IN MID OCTOBER. DELIVERY NOV. 1.

** 1=SELL ALL CATTLE ON PASTURE. PRODUCE WHEAT ONLY.

TABLE XLIV (Continued)

DAY(DAY 1=MAR 1)	YEAR 1						YEAR 2						YEAR 3					
	FORAGE GROWTH AND BALANCE IN LBS PER ACRE																	
	TOT FORAGE		FORAGE BAL		SPRING FTN		TOT FORAGE		FORAGE BAL		SPRING FTN		TOT FORAGE		FORAGE BAL		SPRING FTN	
	DLY	ACCUM	DLY	ACCUM	DLY	ACCUM	DLY	ACCUM	DLY	ACCUM	DLY	ACCUM	DLY	ACCUM	DLY	ACCUM	DLY	ACCUM
1	0.	0.	0.	0.	0.	0.	0.	2967.	0.	2100.	0.	0.	0.	976.	0.	600.	0.	0.
2	0.	0.	0.	0.	0.	0.	0.	2967.	0.	2100.	0.	0.	0.	976.	0.	600.	0.	0.
3	0.	0.	0.	0.	0.	0.	0.	2967.	0.	2100.	0.	0.	0.	976.	0.	600.	0.	0.
4	0.	0.	0.	0.	0.	0.	0.	2967.	0.	2100.	0.	0.	0.	976.	0.	600.	0.	0.
5	0.	0.	0.	0.	0.	0.	118.	3085.	83.	2184.	0.	0.	0.	976.	0.	600.	0.	0.
6	0.	0.	0.	0.	0.	0.	127.	3212.	90.	2273.	0.	0.	50.	1026.	31.	631.	0.	0.
7	0.	0.	0.	0.	0.	0.	169.	3381.	120.	2393.	0.	0.	0.	1026.	0.	631.	0.	0.
8	0.	0.	0.	0.	0.	0.	163.	3544.	116.	2509.	0.	0.	0.	1026.	0.	631.	0.	0.
9	0.	0.	0.	0.	0.	0.	0.	3544.	0.	2509.	0.	0.	54.	1080.	33.	664.	0.	0.
10	0.	0.	0.	0.	0.	0.	0.	3544.	0.	2509.	0.	0.	51.	1131.	32.	696.	0.	0.
11	0.	0.	0.	0.	0.	0.	0.	3544.	0.	2509.	0.	0.	0.	1131.	0.	696.	0.	0.
12	0.	0.	0.	0.	0.	0.	150.	3695.	106.	2615.	0.	0.	0.	1131.	0.	696.	0.	0.
13	0.	0.	0.	0.	0.	0.	140.	3835.	99.	2714.	0.	0.	0.	1131.	0.	696.	0.	0.
14	0.	0.	0.	0.	0.	0.	0.	3835.	0.	2714.	0.	0.	0.	1131.	0.	696.	0.	0.
15	0.	0.	0.	0.	0.	0.	0.	3835.	0.	2714.	0.	0.	0.	1131.	0.	696.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.	3835.	0.	2714.	0.	0.	0.	1131.	0.	696.	0.	0.
17	0.	0.	0.	0.	0.	0.	0.	3835.	0.	2714.	0.	0.	0.	1131.	0.	696.	0.	0.
18	0.	0.	0.	0.	0.	0.	0.	3835.	0.	2714.	0.	0.	0.	1131.	0.	696.	0.	0.
19	0.	0.	0.	0.	0.	0.	209.	4044.	148.	2862.	0.	0.	54.	1185.	33.	729.	0.	0.
20	0.	0.	0.	0.	0.	0.	0.	4044.	0.	2862.	0.	0.	55.	1240.	34.	763.	0.	0.
21	0.	0.	0.	0.	0.	0.	0.	4044.	0.	2862.	0.	0.	40.	1280.	24.	787.	0.	0.
22	0.	0.	0.	0.	0.	0.	223.	4267.	158.	3020.	0.	0.	0.	1280.	0.	787.	0.	0.
23	0.	0.	0.	0.	0.	0.	192.	4459.	136.	3156.	0.	0.	0.	1280.	0.	787.	0.	0.
24	0.	0.	0.	0.	0.	0.	244.	4702.	173.	3328.	0.	0.	52.	1332.	32.	819.	0.	0.
25	0.	0.	0.	0.	0.	0.	331.	5034.	234.	3563.	0.	0.	60.	1392.	37.	856.	0.	0.
26	0.	0.	0.	0.	0.	0.	338.	5371.	239.	3801.	0.	0.	61.	1453.	37.	893.	0.	0.
27	0.	0.	0.	0.	0.	0.	0.	5371.	0.	3801.	0.	0.	146.	1598.	90.	983.	0.	0.
28	0.	0.	0.	0.	0.	0.	0.	5371.	0.	3801.	0.	0.	110.	1708.	68.	1051.	0.	0.
29	0.	0.	0.	0.	0.	0.	0.	5371.	0.	3801.	0.	0.	149.	1858.	92.	1143.	0.	0.
30	0.	0.	0.	0.	0.	0.	0.	5371.	0.	3801.	0.	0.	95.	1953.	58.	1201.	0.	0.
31	0.	0.	0.	0.	0.	0.	0.	5371.	0.	3801.	0.	0.	87.	2040.	54.	1255.	0.	0.
32	0.	0.	0.	0.	0.	0.	197.	5568.	140.	3941.	0.	0.	0.	2040.	0.	1255.	0.	0.
33	0.	0.	0.	0.	0.	0.	344.	5912.	243.	4184.	0.	0.	0.	2040.	0.	1255.	0.	0.
34	0.	0.	0.	0.	0.	0.	428.	6341.	303.	4488.	0.	0.	101.	2141.	62.	1317.	0.	0.
35	0.	0.	0.	0.	0.	0.	325.	6666.	230.	4718.	0.	0.	162.	2303.	100.	1417.	0.	0.
36	0.	0.	0.	0.	0.	0.	0.	6666.	0.	4718.	0.	0.	102.	2406.	63.	1479.	0.	0.
37	0.	0.	0.	0.	0.	0.	0.	6666.	0.	4718.	0.	0.	85.	2490.	52.	1531.	0.	0.
38	0.	0.	0.	0.	0.	0.	0.	6666.	0.	4718.	0.	0.	0.	2490.	0.	1531.	0.	0.
39	0.	0.	0.	0.	0.	0.	339.	7004.	240.	4957.	0.	0.	0.	2490.	0.	1531.	0.	0.
40	0.	0.	0.	0.	0.	0.	393.	7398.	279.	5236.	0.	0.	0.	2490.	0.	1531.	0.	0.
41	0.	0.	0.	0.	0.	0.	0.	7398.	0.	5236.	0.	0.	123.	2613.	76.	1607.	0.	0.
42	0.	0.	0.	0.	0.	0.	0.	7398.	0.	5236.	0.	0.	252.	2866.	155.	1763.	0.	0.
43	0.	0.	0.	0.	0.	0.	496.	7893.	351.	5587.	0.	0.	328.	3194.	202.	1964.	0.	0.
44	0.	0.	0.	0.	0.	0.	613.	8506.	434.	6020.	0.	0.	303.	3497.	186.	2151.	0.	0.
45	0.	0.	0.	0.	0.	0.	500.	9006.	354.	6374.	0.	0.	250.	3747.	154.	2304.	0.	0.
46	0.	0.	0.	0.	0.	0.	0.	9052.	46.	6420.	46.	46.	0.	3822.	75.	2379.	75.	75.
47	0.	0.	0.	0.	0.	0.	0.	9117.	65.	6485.	65.	111.	0.	3847.	25.	2404.	25.	100.
48	0.	0.	0.	0.	0.	0.	0.	9191.	74.	6559.	74.	185.	0.	3884.	37.	2441.	37.	137.
49	0.	0.	0.	0.	0.	0.	0.	9222.	30.	6590.	30.	216.	0.	3884.	0.	2441.	0.	137.
50	0.	0.	0.	0.	0.	0.	0.	9247.	26.	6615.	26.	241.	0.	3884.	0.	2441.	0.	137.
51	0.	0.	0.	0.	0.	0.	0.	9304.	57.	6672.	57.	298.	0.	3942.	58.	2499.	58.	195.
52	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4000.	58.	2557.	58.	253.
53	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4058.	58.	2615.	58.	311.
54	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4102.	44.	2659.	44.	355.
55	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4152.	51.	2710.	51.	405.
56	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4199.	47.	2757.	47.	453.

TABLE XLIV (Continued)

57	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4227.	27.	2784.	27.	480.
58	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4242.	15.	2800.	15.	495.
59	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4260.	18.	2818.	18.	514.
60	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4275.	15.	2833.	15.	529.
61	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4304.	29.	2862.	29.	557.
62	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4319.	15.	2876.	15.	572.
63	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4341.	22.	2898.	22.	594.
64	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4367.	26.	2924.	26.	620.
65	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4367.	0.	2924.	0.	620.
66	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4367.	0.	2924.	0.	620.
67	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4367.	0.	2924.	0.	620.
68	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4367.	0.	2924.	0.	620.
69	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4376.	11.	2935.	11.	631.
70	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4393.	15.	2950.	15.	646.
71	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4405.	12.	2962.	12.	658.
72	0.	0.	0.	0.	0.	0.	0.	9304.	0.	6672.	0.	298.	0.	4419.	14.	2976.	14.	672.
73	0.	0.	0.	0.	0.	0.	0.	9318.	14.	6686.	14.	312.	0.	4429.	10.	2987.	10.	682.
74	0.	0.	0.	0.	0.	0.	0.	9325.	6.	6693.	6.	319.	0.	4439.	10.	2997.	10.	692.
75	0.	0.	0.	0.	0.	0.	0.	9333.	9.	6701.	9.	327.	0.	4449.	10.	3006.	10.	702.
76	0.	0.	0.	0.	0.	0.	0.	9339.	5.	6707.	5.	333.	0.	4454.	6.	3012.	6.	708.
77	0.	0.	0.	0.	0.	0.	0.	9346.	7.	6714.	7.	340.	0.	4460.	6.	3017.	6.	713.
78	0.	0.	0.	0.	0.	0.	0.	9356.	10.	6724.	10.	350.	0.	4469.	9.	3026.	9.	722.
79	0.	0.	0.	0.	0.	0.	0.	9362.	6.	6730.	6.	356.	0.	4476.	7.	3033.	7.	729.
80	0.	0.	0.	0.	0.	0.	0.	9371.	9.	6739.	9.	365.	0.	4484.	8.	3042.	8.	737.
81	0.	0.	0.	0.	0.	0.	0.	9377.	6.	6745.	6.	371.	0.	4491.	7.	3048.	7.	744.
82	0.	0.	0.	0.	0.	0.	0.	9383.	6.	6751.	6.	377.	0.	4497.	6.	3054.	6.	750.
83	0.	0.	0.	0.	0.	0.	0.	9389.	6.	6758.	6.	384.	0.	4501.	4.	3058.	4.	754.
84	0.	0.	0.	0.	0.	0.	0.	9396.	6.	6764.	6.	390.	0.	4507.	6.	3064.	6.	760.
85	0.	0.	0.	0.	0.	0.	0.	9401.	5.	6769.	5.	395.	0.	4511.	4.	3068.	4.	764.
86	0.	0.	0.	0.	0.	0.	0.	9405.	5.	6773.	5.	399.	0.	4516.	6.	3074.	6.	770.
87	0.	0.	0.	0.	0.	0.	0.	9409.	4.	6777.	4.	403.	0.	4522.	5.	3079.	5.	775.
88	0.	0.	0.	0.	0.	0.	0.	9411.	3.	6779.	3.	406.	0.	4527.	5.	3084.	5.	780.
89	0.	0.	0.	0.	0.	0.	0.	9416.	4.	6784.	4.	410.	0.	4528.	1.	3085.	1.	781.
90	0.	0.	0.	0.	0.	0.	0.	9420.	4.	6788.	4.	414.	0.	4529.	1.	3087.	1.	783.
91	0.	0.	0.	0.	0.	0.	0.	9420.	0.	6788.	0.	414.	0.	4529.	0.	3087.	0.	783.
92	0.	0.	0.	0.	0.	0.	0.	9420.	0.	6788.	0.	414.	0.	4529.	0.	3087.	0.	783.
93	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
94	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
95	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
96	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
97	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
98	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
99	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
100	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
101	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
102	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
103	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
104	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
105	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
106	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
107	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
108	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
109	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
110	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
111	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
112	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
113	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
114	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
115	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
116	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
117	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
118	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
119	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
120	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
121	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
122	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

TABLE XLIV (Continued)

123	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
124	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
125	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
126	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
127	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
128	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
129	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
130	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
131	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
132	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
133	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
134	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
135	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
136	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
137	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
138	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
139	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
140	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
141	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
142	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
143	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
144	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
145	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
146	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
147	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
148	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
149	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
150	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
151	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
152	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
153	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
154	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
155	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
156	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
157	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
158	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
159	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
160	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
161	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
162	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
163	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
164	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
165	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
166	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
167	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
168	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
169	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
170	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
171	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
172	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
173	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
174	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
175	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
176	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
177	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
178	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
179	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
180	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
181	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
182	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
183	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
184	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
185	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
186	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
187	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
188	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

TABLE XLIV (Continued)

189	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
190	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
191	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
192	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
193	0.	120.	0.	120.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
194	6.	126.	6.	126.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
195	8.	133.	8.	133.	0.	0.	0.	0.	0.	0.	0.	0.	0.	120.	0.	120.	0.	0.
196	6.	140.	6.	140.	0.	0.	0.	0.	0.	0.	0.	0.	7.	127.	7.	127.	0.	0.
197	5.	145.	5.	145.	0.	0.	0.	120.	0.	120.	0.	0.	7.	134.	7.	134.	0.	0.
198	9.	154.	9.	154.	0.	0.	1.	121.	1.	121.	0.	0.	2.	136.	2.	136.	0.	0.
199	9.	163.	9.	163.	0.	0.	6.	127.	6.	127.	0.	0.	4.	140.	4.	140.	0.	0.
200	9.	172.	9.	172.	0.	0.	7.	134.	7.	134.	0.	0.	8.	148.	8.	148.	0.	0.
201	9.	181.	9.	181.	0.	0.	7.	140.	7.	140.	0.	0.	3.	152.	3.	152.	0.	0.
202	10.	191.	10.	191.	0.	0.	4.	144.	4.	144.	0.	0.	5.	157.	5.	157.	0.	0.
203	10.	200.	10.	200.	0.	0.	4.	148.	4.	148.	0.	0.	5.	162.	5.	162.	0.	0.
204	6.	206.	6.	206.	0.	0.	9.	157.	9.	157.	0.	0.	8.	169.	8.	169.	0.	0.
205	6.	212.	6.	212.	0.	0.	8.	165.	8.	165.	0.	0.	10.	179.	10.	179.	0.	0.
206	13.	225.	13.	225.	0.	0.	9.	174.	9.	174.	0.	0.	9.	189.	9.	189.	0.	0.
207	11.	236.	11.	236.	0.	0.	7.	181.	7.	181.	0.	0.	5.	194.	5.	194.	0.	0.
208	9.	245.	9.	245.	0.	0.	3.	184.	3.	184.	0.	0.	12.	206.	12.	206.	0.	0.
209	11.	256.	11.	256.	0.	0.	8.	192.	8.	192.	0.	0.	11.	217.	11.	217.	0.	0.
210	12.	268.	12.	268.	0.	0.	10.	202.	10.	202.	0.	0.	7.	224.	7.	224.	0.	0.
211	14.	281.	14.	281.	0.	0.	9.	211.	9.	211.	0.	0.	11.	235.	11.	235.	0.	0.
212	11.	293.	11.	293.	0.	0.	6.	217.	6.	217.	0.	0.	9.	244.	9.	244.	0.	0.
213	17.	310.	17.	310.	0.	0.	12.	229.	12.	229.	0.	0.	8.	252.	8.	252.	0.	0.
214	19.	328.	19.	328.	0.	0.	12.	241.	12.	241.	0.	0.	7.	259.	7.	259.	0.	0.
215	20.	348.	20.	348.	0.	0.	10.	251.	10.	251.	0.	0.	11.	271.	11.	271.	0.	0.
216	21.	369.	21.	369.	0.	0.	7.	258.	7.	258.	0.	0.	16.	287.	16.	287.	0.	0.
217	18.	386.	18.	386.	0.	0.	11.	269.	11.	269.	0.	0.	7.	294.	7.	294.	0.	0.
218	14.	400.	14.	400.	0.	0.	8.	277.	8.	277.	0.	0.	15.	310.	15.	310.	0.	0.
219	12.	412.	12.	412.	0.	0.	10.	287.	10.	287.	0.	0.	19.	328.	19.	328.	0.	0.
220	24.	436.	24.	436.	0.	0.	6.	293.	6.	293.	0.	0.	10.	338.	10.	338.	0.	0.
221	26.	461.	26.	461.	0.	0.	11.	304.	11.	304.	0.	0.	11.	348.	11.	348.	0.	0.
222	25.	487.	25.	487.	0.	0.	18.	322.	18.	322.	0.	0.	18.	367.	18.	367.	0.	0.
223	14.	500.	14.	500.	0.	0.	9.	331.	9.	331.	0.	0.	22.	389.	22.	389.	0.	0.
224	16.	516.	16.	516.	0.	0.	17.	348.	17.	348.	0.	0.	13.	402.	13.	402.	0.	0.
225	15.	532.	15.	532.	0.	0.	10.	358.	10.	358.	0.	0.	19.	421.	19.	421.	0.	0.
226	14.	545.	14.	545.	0.	0.	9.	367.	9.	357.	0.	0.	13.	435.	13.	435.	0.	0.
227	26.	571.	26.	571.	0.	0.	11.	378.	11.	378.	0.	0.	20.	455.	20.	455.	0.	0.
228	31.	602.	31.	602.	0.	0.	10.	388.	10.	388.	0.	0.	12.	466.	12.	466.	0.	0.
229	14.	616.	14.	616.	0.	0.	10.	398.	10.	398.	0.	0.	19.	485.	19.	485.	0.	0.
230	25.	641.	25.	641.	0.	0.	9.	407.	9.	407.	0.	0.	23.	508.	23.	508.	0.	0.
231	27.	668.	27.	668.	0.	0.	11.	418.	11.	418.	0.	0.	26.	534.	26.	534.	0.	0.
232	28.	696.	28.	696.	0.	0.	24.	442.	24.	442.	0.	0.	28.	562.	28.	562.	0.	0.
233	28.	724.	28.	724.	0.	0.	12.	453.	12.	453.	0.	0.	33.	595.	33.	595.	0.	0.
234	14.	738.	14.	738.	0.	0.	10.	463.	10.	453.	0.	0.	28.	623.	28.	623.	0.	0.
235	36.	775.	36.	775.	0.	0.	24.	487.	24.	487.	0.	0.	12.	635.	12.	635.	0.	0.
236	20.	795.	20.	795.	0.	0.	13.	500.	13.	500.	0.	0.	36.	671.	36.	671.	0.	0.
237	21.	816.	21.	816.	0.	0.	28.	528.	28.	528.	0.	0.	18.	688.	18.	688.	0.	0.
238	35.	851.	35.	851.	0.	0.	14.	543.	14.	543.	0.	0.	18.	706.	18.	706.	0.	0.
239	30.	880.	30.	860.	0.	0.	19.	562.	19.	562.	0.	0.	17.	723.	17.	723.	0.	0.
240	31.	911.	31.	911.	0.	0.	21.	583.	21.	583.	0.	0.	34.	757.	34.	757.	0.	0.
241	45.	956.	45.	956.	0.	0.	29.	612.	29.	612.	0.	0.	42.	799.	42.	799.	0.	0.
242	50.	1006.	50.	1006.	0.	0.	19.	631.	19.	631.	0.	0.	35.	834.	35.	834.	0.	0.
243	33.	1039.	33.	1039.	0.	0.	24.	655.	24.	655.	0.	0.	19.	853.	19.	853.	0.	0.
244	25.	1065.	25.	1065.	0.	0.	0.	655.	0.	655.	0.	0.	15.	868.	15.	868.	0.	0.
245	30.	1095.	30.	1095.	0.	0.	0.	655.	0.	655.	0.	0.	19.	887.	19.	887.	0.	0.
246	29.	1123.	29.	1123.	0.	0.	14.	670.	14.	670.	0.	0.	0.	887.	0.	887.	0.	0.
247	32.	1155.	32.	1155.	0.	0.	10.	680.	10.	680.	0.	0.	0.	887.	0.	887.	0.	0.
248	69.	1225.	69.	1225.	0.	0.	10.	690.	10.	690.	0.	0.	0.	887.	0.	887.	0.	0.
249	34.	1259.	34.	1259.	0.	0.	11.	701.	11.	701.	0.	0.	0.	887.	0.	887.	0.	0.
250	53.	1311.	53.	1311.	0.	0.	12.	714.	12.	714.	0.	0.	0.	887.	0.	887.	0.	0.
251	45.	1356.	45.	1356.	0.	0.	11.	725.	11.	725.	0.	0.	0.	887.	0.	887.	0.	0.
252	27.	1383.	27.	1347.	0.	0.	9.	734.	9.	734.	0.	0.	0.	887.	0.	851.	0.	0.
253	39.	1423.	38.	1385.	0.	0.	24.	758.	24.	758.	0.	0.	0.	887.	0.	851.	0.	0.
254	42.	1464.	40.	1426.	0.	0.	19.	777.	19.	777.	0.	0.	0.	887.	0.	851.	0.	0.

TABLE XLIV (Continued)

255	64.	1529.	63.	1489.	0.	0.	10.	787.	10.	787.	0.	0.	0.	887.	0.	851.	0.	0.
256	58.	1587.	57.	1545.	0.	0.	18.	805.	18.	805.	0.	0.	0.	887.	0.	851.	0.	0.
257	32.	1619.	31.	1576.	0.	0.	11.	817.	11.	817.	0.	0.	0.	887.	0.	851.	0.	0.
258	42.	1661.	41.	1617.	0.	0.	15.	832.	15.	832.	0.	0.	0.	887.	0.	851.	0.	0.
259	0.	1661.	0.	1581.	0.	0.	18.	850.	18.	850.	0.	0.	0.	887.	0.	814.	0.	0.
260	0.	1661.	0.	1581.	0.	0.	17.	867.	17.	867.	0.	0.	0.	887.	0.	814.	0.	0.
261	0.	1661.	0.	1581.	0.	0.	11.	878.	11.	878.	0.	0.	0.	887.	0.	814.	0.	0.
262	0.	1661.	0.	1581.	0.	0.	18.	896.	18.	896.	0.	0.	0.	887.	0.	814.	0.	0.
263	22.	1683.	21.	1602.	0.	0.	0.	896.	0.	860.	0.	0.	0.	887.	0.	814.	0.	0.
264	39.	1723.	37.	1639.	0.	0.	0.	896.	0.	860.	0.	0.	0.	887.	0.	814.	0.	0.
265	24.	1747.	23.	1662.	0.	0.	0.	896.	0.	860.	0.	0.	0.	887.	0.	814.	0.	0.
266	30.	1776.	28.	1654.	0.	0.	0.	896.	0.	860.	0.	0.	0.	887.	0.	778.	0.	0.
267	22.	1799.	21.	1675.	0.	0.	16.	912.	16.	875.	0.	0.	0.	887.	0.	778.	0.	0.
268	26.	1825.	24.	1699.	0.	0.	10.	922.	9.	885.	0.	0.	0.	887.	0.	778.	0.	0.
269	30.	1855.	28.	1728.	0.	0.	11.	933.	11.	896.	0.	0.	0.	887.	0.	778.	0.	0.
270	43.	1898.	40.	1768.	0.	0.	10.	943.	9.	868.	0.	0.	0.	887.	0.	778.	0.	0.
271	26.	1924.	24.	1792.	0.	0.	0.	943.	0.	868.	0.	0.	0.	887.	0.	778.	0.	0.
272	0.	1924.	0.	1792.	0.	0.	0.	943.	0.	868.	0.	0.	0.	887.	0.	778.	0.	0.
273	0.	1924.	0.	1756.	0.	0.	0.	943.	0.	868.	0.	0.	0.	887.	0.	742.	0.	0.
274	33.	1957.	30.	1785.	0.	0.	0.	943.	0.	868.	0.	0.	0.	887.	0.	742.	0.	0.
275	27.	1984.	24.	1811.	0.	0.	0.	943.	0.	868.	0.	0.	0.	887.	0.	742.	0.	0.
276	0.	1984.	0.	1811.	0.	0.	0.	943.	0.	868.	0.	0.	13.	900.	11.	753.	0.	0.
277	0.	1984.	0.	1811.	0.	0.	0.	943.	0.	833.	0.	0.	12.	912.	10.	763.	0.	0.
278	0.	1984.	0.	1811.	0.	0.	10.	953.	9.	841.	0.	0.	0.	912.	0.	763.	0.	0.
279	0.	1984.	0.	1811.	0.	0.	10.	963.	9.	850.	0.	0.	0.	912.	0.	763.	0.	0.
280	0.	1984.	0.	1775.	0.	0.	0.	963.	0.	850.	0.	0.	0.	912.	0.	726.	0.	0.
281	0.	1984.	0.	1775.	0.	0.	0.	963.	0.	850.	0.	0.	0.	912.	0.	726.	0.	0.
282	29.	2013.	26.	1801.	0.	0.	0.	963.	0.	850.	0.	0.	22.	935.	18.	746.	0.	0.
283	33.	2046.	30.	1831.	0.	0.	0.	963.	0.	850.	0.	0.	11.	946.	9.	754.	0.	0.
284	0.	2046.	0.	1831.	0.	0.	0.	963.	0.	815.	0.	0.	9.	955.	7.	762.	0.	0.
285	0.	2046.	0.	1831.	0.	0.	0.	963.	0.	815.	0.	0.	11.	965.	8.	770.	0.	0.
286	0.	2046.	0.	1831.	0.	0.	0.	963.	0.	815.	0.	0.	13.	978.	10.	780.	0.	0.
287	0.	2046.	0.	1795.	0.	0.	0.	963.	0.	815.	0.	0.	0.	978.	0.	745.	0.	0.
288	37.	2084.	33.	1828.	0.	0.	0.	963.	0.	815.	0.	0.	0.	978.	0.	745.	0.	0.
289	21.	2105.	18.	1846.	0.	0.	0.	963.	0.	815.	0.	0.	0.	978.	0.	745.	0.	0.
290	0.	2105.	0.	1846.	0.	0.	0.	963.	0.	815.	0.	0.	0.	978.	0.	745.	0.	0.
291	0.	2105.	0.	1846.	0.	0.	0.	963.	0.	779.	0.	0.	0.	978.	0.	745.	0.	0.
292	0.	2105.	0.	1846.	0.	0.	0.	963.	0.	779.	0.	0.	0.	978.	0.	745.	0.	0.
293	0.	2105.	0.	1846.	0.	0.	0.	963.	0.	779.	0.	0.	0.	978.	0.	745.	0.	0.
294	0.	2105.	0.	1811.	0.	0.	0.	963.	0.	779.	0.	0.	0.	978.	0.	709.	0.	0.
295	0.	2105.	0.	1811.	0.	0.	0.	963.	0.	779.	0.	0.	10.	988.	7.	716.	0.	0.
296	0.	2105.	0.	1811.	0.	0.	0.	963.	0.	779.	0.	0.	10.	997.	7.	723.	0.	0.
297	0.	2105.	0.	1811.	0.	0.	0.	963.	0.	779.	0.	0.	0.	997.	0.	723.	0.	0.
298	0.	2105.	0.	1811.	0.	0.	0.	963.	0.	744.	0.	0.	0.	997.	0.	723.	0.	0.
299	0.	2105.	0.	1811.	0.	0.	0.	963.	0.	744.	0.	0.	0.	997.	0.	723.	0.	0.
300	31.	2136.	27.	1838.	0.	0.	0.	963.	0.	744.	0.	0.	0.	997.	0.	723.	0.	0.
301	0.	2136.	0.	1802.	0.	0.	0.	963.	0.	744.	0.	0.	0.	997.	0.	687.	0.	0.
302	0.	2136.	0.	1802.	0.	0.	0.	963.	0.	744.	0.	0.	0.	997.	0.	687.	0.	0.
303	0.	2136.	0.	1802.	0.	0.	0.	963.	0.	744.	0.	0.	0.	997.	0.	687.	0.	0.
304	0.	2136.	0.	1802.	0.	0.	0.	963.	0.	744.	0.	0.	0.	997.	0.	687.	0.	0.
305	0.	2136.	0.	1802.	0.	0.	0.	963.	0.	708.	0.	0.	0.	997.	0.	687.	0.	0.
306	0.	2136.	0.	1802.	0.	0.	0.	963.	0.	708.	0.	0.	0.	997.	0.	687.	0.	0.
307	0.	2136.	0.	1802.	0.	0.	0.	963.	0.	708.	0.	0.	0.	997.	0.	687.	0.	0.
308	0.	2136.	0.	1766.	0.	0.	0.	963.	0.	708.	0.	0.	0.	997.	0.	652.	0.	0.
309	0.	2136.	0.	1766.	0.	0.	0.	963.	0.	708.	0.	0.	0.	997.	0.	652.	0.	0.
310	0.	2136.	0.	1766.	0.	0.	0.	963.	0.	708.	0.	0.	0.	997.	0.	652.	0.	0.
311	0.	2136.	0.	1766.	0.	0.	0.	963.	0.	708.	0.	0.	15.	1013.	10.	662.	0.	0.
312	0.	2136.	0.	1766.	0.	0.	0.	963.	0.	672.	0.	0.	0.	1013.	0.	662.	0.	0.
313	0.	2136.	0.	1766.	0.	0.	0.	963.	0.	672.	0.	0.	0.	1013.	0.	662.	0.	0.
314	0.	2136.	0.	1766.	0.	0.	0.	963.	0.	672.	0.	0.	0.	1013.	0.	662.	0.	0.
315	0.	2136.	0.	1731.	0.	0.	0.	963.	0.	672.	0.	0.	0.	1013.	0.	626.	0.	0.
316	0.	2136.	0.	1731.	0.	0.	0.	963.	0.	672.	0.	0.	0.	1013.	0.	626.	0.	0.
317	0.	2136.	0.	1731.	0.	0.	0.	963.	0.	672.	0.	0.	0.	1013.	0.	626.	0.	0.
318	0.	2136.	0.	1731.	0.	0.	0.	963.	0.	672.	0.	0.	0.	1013.	0.	626.	0.	0.
319	0.	2136.	0.	1731.	0.	0.	0.	963.	0.	637.	0.	0.	0.	1013.	0.	626.	0.	0.
320	0.	2136.	0.	1731.	0.	0.	0.	963.	0.	637.	0.	0.	0.	1013.	0.	626.	0.	0.

TABLE XLIV (Continued)

321	0.	2136.	0.	1731.	0.	0.	0.	963.	0.	637.	0.	0.	0.	1013.	0.	626.	0.	0.
322	31.	2167.	25.	1720.	0.	0.	0.	963.	0.	637.	0.	0.	0.	1013.	0.	600.	0.	0.
323	0.	2167.	0.	1720.	0.	0.	0.	963.	0.	637.	0.	0.	0.	1013.	0.	600.	0.	0.
324	0.	2167.	0.	1720.	0.	0.	0.	963.	0.	637.	0.	0.	0.	1013.	0.	600.	0.	0.
325	0.	2167.	0.	1720.	0.	0.	0.	963.	0.	637.	0.	0.	0.	1013.	0.	600.	0.	0.
326	23.	2189.	18.	1738.	0.	0.	0.	963.	0.	601.	0.	0.	0.	1013.	0.	600.	0.	0.
327	26.	2215.	20.	1758.	0.	0.	0.	963.	0.	601.	0.	0.	0.	1013.	0.	600.	0.	0.
328	23.	2238.	19.	1777.	0.	0.	0.	963.	0.	601.	0.	0.	0.	1013.	0.	600.	0.	0.
329	27.	2265.	21.	1762.	0.	0.	0.	963.	0.	601.	0.	0.	0.	1013.	0.	600.	0.	0.
330	35.	2300.	27.	1790.	0.	0.	0.	963.	0.	601.	0.	0.	0.	1013.	0.	600.	0.	0.
331	0.	2300.	0.	1790.	0.	0.	0.	963.	0.	601.	0.	0.	0.	1013.	0.	600.	0.	0.
332	0.	2300.	0.	1790.	0.	0.	0.	963.	0.	601.	0.	0.	0.	1013.	0.	600.	0.	0.
333	0.	2300.	0.	1790.	0.	0.	0.	963.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
334	0.	2300.	0.	1790.	0.	0.	0.	963.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
335	0.	2300.	0.	1790.	0.	0.	0.	963.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
336	0.	2300.	0.	1754.	0.	0.	0.	963.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
337	0.	2300.	0.	1754.	0.	0.	0.	963.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
338	0.	2300.	0.	1754.	0.	0.	12.	976.	8.	608.	0.	0.	0.	1013.	0.	600.	0.	0.
339	0.	2300.	0.	1754.	0.	0.	0.	976.	0.	608.	0.	0.	0.	1013.	0.	600.	0.	0.
340	0.	2300.	0.	1754.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
341	32.	2331.	24.	1778.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
342	45.	2376.	34.	1812.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
343	0.	2376.	0.	1777.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
344	0.	2376.	0.	1777.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
345	0.	2376.	0.	1777.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
346	0.	2376.	0.	1777.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
347	0.	2376.	0.	1777.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
348	0.	2376.	0.	1777.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
349	0.	2376.	0.	1777.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
350	0.	2376.	0.	1741.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
351	0.	2376.	0.	1741.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
352	0.	2376.	0.	1741.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
353	95.	2472.	70.	1811.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
354	107.	2579.	78.	1890.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1013.	0.	600.	0.	0.
355	175.	2754.	128.	2018.	0.	0.	0.	976.	0.	600.	0.	0.	38.	1051.	22.	622.	0.	0.
356	0.	2754.	0.	2018.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1051.	0.	622.	0.	0.
357	0.	2754.	0.	1982.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1051.	0.	600.	0.	0.
358	0.	2754.	0.	1982.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1051.	0.	600.	0.	0.
359	0.	2754.	0.	1982.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1051.	0.	600.	0.	0.
360	107.	2861.	77.	2059.	0.	0.	0.	976.	0.	600.	0.	0.	42.	1093.	24.	624.	0.	0.
361	106.	2967.	77.	2136.	0.	0.	0.	976.	0.	600.	0.	0.	40.	1133.	23.	647.	0.	0.
362	0.	2967.	0.	2136.	0.	0.	0.	976.	0.	600.	0.	0.	43.	1176.	25.	672.	0.	0.
363	0.	2967.	0.	2136.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1176.	0.	672.	0.	0.
364	0.	2967.	0.	2100.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1176.	0.	636.	0.	0.
365	0.	2967.	0.	2100.	0.	0.	0.	976.	0.	600.	0.	0.	0.	1176.	0.	636.	0.	0.

TABLE XLIV (Continued)

CRITICAL DATES

YEAR	SEEDING	START GROWTH		START GRAZE
1	179	193	0	246
2	183	197	0	257
3	181	195	0	246
4	179	193	0	246
5	176	190	0	246
6	185	199	0	253
7	180	194	0	249
8	203	217	0	0
9	177	191	0	246
10	234	248	0	0
11	183	197	0	246
12	175	189	0	246
13	194	208	0	268
14	178	192	0	246
15	191	205	0	0
16	189	203	0	261
17	189	203	0	355
18	176	190	0	246
19	181	195	0	246
20	184	198	0	246

VITA

Henry Douglas Jose

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Doctor of Philosophy

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Biographical:

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