OPTIMAL SUPPLEMENTAL FORAGE STOCKS FOR STOCHASTIC WHEAT GRAZING SYSTEMS

By

TOMMY JOE HONEYCUTT

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Thesis Approved:

James N. Trapp

Thesis Adviser

Odell L. Walker

Daniel J. Bernardo

Norman N. Durham

Dean of the Graduate College

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CHAPTER I

THE RESEARCH PROBLEM

The grazing of winter wheat in Oklahoma for the dual production of grain and beef is a common practice. This production practice utilizes wheat forage produced during the early phases of wheat growth to provide farmers with an additional source of revenue with little or no negative effect upon wheat grain production. The economic contribution of this production practice to the Oklahoma agricultural economy is significant. In 1988, over 2.83 million hectares (7 million acres) of winter wheat were planted in Oklahoma (Oklahoma Ag. Statistics, 1988). Previous studies have estimated that 30 to 70 percent of Oklahoma wheat acreage is grazed with the majority of the state's wheat producing areas having grazing rates in excess of 50 percent (Harwell, 1974). However, the added economic returns derived from the grazing of winter wheat are accompanied by several enterprise specific management problems associated with this form of agricultural production.

Wheat forage production in Oklahoma is subject to a significant degree of volatility. Thus, supplemental feeding of stockers during periods of low forage availability is an important component of the management scheme for winter wheat grazing. Previous research by Rodriguez et al. (1988) shows the wheat pasture grazing season to be one of the most volatile weather periods of the entire year for Oklahoma in terms of the variation in rainfall, temperature, and solar radiation. In addition, the seasonality of supplemental forage prices, and the fact that these prices are often highly correlated with current wheat forage growth conditions, create additional incentives for producers to store supplemental forage stocks prior to the beginning of the grazing season. The storage of a sufficient level of supplemental forage stocks prior to the grazing season should allow managers to avoid the risk of having to purchase high priced supplemental feed during periods of low wheat forage availability. The decision regarding the optimal level of supplemental forage stocks to hold prior to the winter wheat grazing season is complicated by many factors other than variations in the price of supplemental forage. These include the deterioration of hay while it is stored, waste during feeding, and the matching of stocking rates with supplemental feed stocks. This thesis will address the determination of optimal forage stock levels subject to these complications.

Problem Statement

Stored hay stocks are the most prevalent form of supplemental forage used by the typical Oklahoma wheat grazing operation. However, the use of stored hay stocks to provide supplemental feed to wheat stockers presents a management problem.

The optimal hay storage decision is dependent upon a variety of factors. The expected amount of wheat forage production and, consequently, the amount of supplement that the producer expects to feed to stockers during the upcoming grazing season is probably the key factor to be considered. Producer expectations regarding supplemental forage needs during the grazing season are complicated greatly by the uncertain nature of wheat forage production during the grazing season. Also, large round bales are a common means of storing hay in anticipation of low wheat forage production. These bales are often stored outside and unprotected from the various negative impacts of the surrounding environment. As a result, this method of hay storage often results in a significant reduction in both the quantity and quality of supplemental forage available for use due to weathering and other biological factors. The exposure of round bales of hay to climatic factors, especially precipitation, and the resulting storage losses further complicate the decision making process.

The storage of inadequate supplemental forage stocks will result in either stocker weight loss, termination of the grazing season during periods of low wheat forage availability, or the purchase of additional hay stocks during the grazing season at high prices. On the other hand, the overstocking of hay supplies will result in unnecessarily high production costs due mainly to the high level of storage losses associated with the exposure of large round bales to precipitation during periods of high wheat forage production which make the supplemental feeding of stockers unnecessary.

The optimal supplemental forage stock decision is further complicated by losses encountered during the hay feeding process. Waste is inherent in the feeding process when supplemental forage is provided in the form of large round bales. The utilization of large round bales of hay by producers may provide convenience and reduced labor requirements for the feeding process, but it is accompanied by a high level of waste when compared to some of the alternative feeding methods. The accumulation of these feeding waste losses over time can become a major management consideration, especially in larger wheat grazing operations.

The effective farm manager must consider all of these factors before deciding upon annual hay storage levels for the wheat grazing season that insure the highest levels of economic returns to the wheat grazing operation.

Objectives

The primary objective of this study is to determine the optimal level of supplemental forage stocks with which to start the winter wheat pasture grazing season given alternative stocking rates, uncertain weather conditions, and seasonal rises in hay prices associated with normal, as well as adverse, weather conditions. Achievement of this primary objective gives rise to the need to understand the impacts of weather upon a number of key dynamic wheat and animal growth relationships, supplemental feed nutrient values, and market conditions. Thus a number of supporting objectives will also be defined.

The first supporting objective of this research is to identify the dominant sources of uncertainty which exist within wheat grazing systems. This section of the analysis will be mainly concerned with weather related uncertainties which can be traced to the variation in precipitation levels and the resulting effects upon wheat forage production.

Another important supporting objective of this research effort is to determine the effects that the waste encountered with the feeding of large round bales of hay has upon the level of supplemental forage required during the grazing season and upon net returns to the producer from the operation of dual beef and wheat grain production systems. The impacts of differing levels of efficiency in the feeding of supplemental forage will be the basis for this analysis.

A third supporting objective of this analysis is to evaluate the effect that changing hay prices have upon the optimal or target supplemental forage stock level. This section of the research is intended to examine the effects that higher hay prices have upon the level of net returns to the producer and the variability associated with those returns under management strategies which vary with respect to targeted hay storage levels and stocking density.

The fulfillment of the primary and supporting objectives of this study will provide useful information to aid in making many of the complex decisions faced by the managers of dual beef and wheat production systems in Oklahoma. The results of this study will help to provide a better understanding of the major factors which affect producer decisions regarding the optimal level of supplemental forage stocks to maintain prior to the wheat grazing season.

A supplementary objective of this study is to highlight some of the major characteristics of the Wheat Grazing Systems Model. This model will be used to accomplish the purposes of this study. It is hoped that the use and documentation made of the model in this study will provide insight into possible future economic analysis which this model can facilitate.

Procedure

The Wheat Grazing Systems Model (WGS Model) developed by Rodriguez et al. was chosen to analyze the questions examined by this study. The WGS Model combines a wheat growth model, a stocker growth model, and a weather simulator to assimilate the dynamic biological and technical properties of a winter wheat grazing operation under weather uncertainty. The adaptation of the WGS Model to allow for the management of supplemental forage inventories and the analysis of waste from the storage and feeding of large round bales of hay was an important component of this study. A monthly hay price series was also incorporated into WGS to allow for simulation of the purchase of supplemental forage after the beginning of the wheat grazing season. This price series was adjusted to correlate periods of low wheat forage production (i.e., periods of unfavorable growing conditions) with periods which exhibit higher than normal hay prices.

The WGS Model will be implemented using an input parameter file consisting of data which is representative of a typical winter wheat grazing operation in west central Oklahoma. The majority of the data for input parameters was obtained from a survey of Oklahoma wheat producers (Walker et al. , 1988). Input data include, but are not limited to, values involving stocking density, grazing season length, stocker purchase weight, sowing date, planting depth, seeding rate, wheat variety, soil characteristics, and nutrient content of the supplemental forage.

Output data will be obtained from WGS for key precipitation, soil moisture, and wheat forage production variables over fifty year production periods for the typical western Oklahoma wheat grazing operation. These data will be compiled and analyzed for average values and variability over the simulation period to determine the sources of uncertainty for wheat grazing operations in western Oklahoma.

The focal point of the analysis will consist of comparing various management schemes on the basis of the average and standard deviation of net returns to the producer. These management schemes will consist of different combinations of the targeted quantity of supplemental forage stocks to maintain prior to the grazing season and stocking density levels. These management strategies will also be evaluated for their sensitivity to supplemental forage prices and waste from the feeding and storage of supplemental feed.

Chapter Outline

The remaining chapters will attempt to provide more detail as to how the various objectives of this research effort were accomplished. A brief review of the major components of the Wheat Grazing Systems Model will be provided in Chapter II. This review will outline the key characteristics of the wheat growth sub-model, stocker growth sub-model, and stochastic weather simulator which interface to produce the WGS Model. Emphasis will be placed on summarizing the integration of these three sub-models.

Chapter III will be comprised of a review of past research and economic analysis which used the WGS Model as the major analysis tool. A summary of three previous research papers will be included. These previous studies utilized WGS to provide estimates of forage supply volatility, to analyze grazing management decisions, and to examine the effects of wheat price upon optimal stocking density decisions. An effort will also be made to present similarities and differences between these previous applications of WGS and this study.

A detailed description of the modifications made within the WGS Model will be presented in Chapter IV. Modifications concerning the feeding and storage of supplemental forage stocks and the development of an economic subroutine to allow for the evaluation of forage stock management alternatives will be detailed. The calculation of values related to the technical, biological, and economic characteristics of wheat grazing systems will be discussed. Examples of annual budget and hay inventory output from the WGS Model will also be presented.

Chapter V will document the procedures used to accomplish the objectives of this research effort and the results which were obtained from these analyses. Key input parameter values for the WGS model will be discussed and examples of basic biological and economic output from WGS will be presented. Results of the analysis of various decision rules concerning the target quantity of supplemental forage stocks as stocking density and hay price vary will be a major component of this chapter.

The final chapter will consist of a summary of the research results and an evaluation of the fulfillment of the research objectives. The remainder of the last chapter will attempt to analyze the strengths and weaknesses of the current version of WGS and provide suggestions for potential future applications of the Wheat Grazing Systems Model as a tool for economic analysis.

CHAPTER II

A REVIEW OF THE WHEAT GRAZING SYSTEMS MODEL AND ITS SUPPORTING LITERATURE

The Wheat Grazing Systems Model (WGS Model) was developed through combining a wheat growth model, a stocker growth model, and a weather simulator. These three basic components were integrated to stochastically simulate the dual production of wheat and beef. The CERES-Wheat model developed by J.T. Ritchie (Ritchie and Otter, 1985) was used to simulate wheat growth and phasic development. Stocker growth was modeled primarily through the use of National Research Council equations (1984 and 1987) describing nutrient requirements and stocker growth. The weather simulator used was compiled by Rodriguez et al. from historical weather data for El Reno, Oklahoma, following the guidelines prescribed by Larsen and Pense (1981 and 1982). The remainder of this chapter will be devoted to summarizing the main components of the three major sub-models utilized in the WGS Model and providing a description of how these sub-models interface with each other in producing the output for WGS.

Wheat Growth

Wheat growth and development were simulated using the CERES-Wheat model developed by J.T. Ritchie (Ritchie and Otter, 1985). The Ritchie model operates on the basis of simulating above ground dry matter growth per square meter of area. Some of the main factors addressed by the CERES-Wheat model include:

1) phasic development or duration of growth phases as related to plant genetics, weather, and other environmental factors,
2) apical development as related to morphogenesis of vegetative and reproductive structures,
3) extension growth of leaves and stems, and senescence of leaves,
4) biomass accumulation and partitioning,
5) the impact of soil water deficit on growth and development,
6) the impact of nitrogen deficit on growth and development.

(Ritchie and Otter, 1985)

To analyze all of these issues, the CERES-Wheat model requires climatic, soil, plant genetics, and management decision inputs.

Daily weather inputs required are solar radiation, maximum air temperature, minimum air temperature, and precipitation. Weather inputs for this study were generated by the stochastic daily weather simulator developed for El Reno, Oklahoma. Details of the weather simulator will be discussed later.

Soil inputs include drainage and runoff coefficients, radiation reflection coefficients, soil water-holding capacity, and rooting preference coefficients at several depth increments. Soil inputs utilized for the purposes of this research were typical soil characteristics for western Oklahoma. Saturated soil water content and initial soil water content at the beginning of the simulation are also required. Sensitivity analysis done by Larsen et al. determined that CERES-Wheat was extremely sensitive to the initial soil water balance level. The problems associated with acquiring initial soil water values were partially ameliorated by simulating the stochastic weather model and CERES-Wheat model for ninety days prior to the planting date. This procedure generated a realistic array of stochastic initial soil water balances and made the model much less sensitive to the initial soil water levels (Larsen, 1981). In the current version of the WGS Model, the weather simulator and soil water balance routine are started on Julian day 172 (June 21), approximately ninety days before planting date, to assure a realistic set of initial soil water balance conditions.

In simple terms, soil water balance is determined for the CERES-Wheat model through the following equation.

(2.1) $S = P + I - EP - ES - R - D$

where:

S = quantity of soil water
P = precipitation
I = irrigation
EP = evaporation from plants
ES = evaporation from the soil
R = runoff
D = drainage from the soil profile

(Ritchie, 1984)

The calculation of soil water balance within the CERES model allows the yield reductions due to soil water deficits to be accounted for in the final season yield totals. The model also uses root development to assist in determining the amount of water available to the wheat plant in the root zone.

Required wheat plant genetic parameters are those related to photo period sensitivity, duration of grain filling, conversion of mass to kernel numbers, grain filling rates, vernalization requirements, stem size, tillering habit, and cold hardiness. The TAM W 101 variety of wheat was chosen for the purposes of this study. The genetic parameter inputs utilized were those appropriate for this variety.

Management information required by the model includes latitude of the site, plant density, planting depth and date of planting. In the current version of the WGS Model, the plant density is assumed to be 259 plants per square meter (24.07 plants/square foot), planting depth is 3 centimeters (1.17 inches), and the annual sowing date is Julian day 262 (September 19). The model is capable of accepting irrigation data. However, in this study, all wheat production is assumed to be rain-fed only.

CERES-Wheat uses the photosynthesis process to accumulate above ground biomass. The model simulates leaf area index and tiller numbers daily on a per square meter basis. Tiller numbers per square meter are a function of the daily heat units, a genetic parameter, and the number of plants per square meter which is a function of the seeding rate. Other growth data produced by the CERES Model include leaf weight, intercepted photosynthetically active radiation, maximum floret number, kernel numbers per plant, and grain weight. At the end of the growing season, grain yield is calculated as the product of plant population, kernels per plant, and weight per kernel (Ritchie and Otter, 1985).

Further details of the CERES-Wheat model will not be discussed here, but will be deferred until after the animal growth model is presented. The CERES model as modified to reflect the impact of grazing can then be presented.

Animal Growth

The animal/stocker growth portion of the WGS Model was developed by Rodriguez et al. through the incorporation of equations describing stocker growth, maintenance, voluntary intake, and weight loss. When combined, these equations permit the environmental and management conditions which affect stocker growth, maintenance, and voluntary intake to be simulated. A major contribution of the Rodriguez et al. research was to successfully interface the CERES-Wheat model with the stocker growth model.

The primary variable in the stocker growth model is net energy available for animal weight gain. It is calculated only after numerous environmental, managerial, and nutritional factors affecting its value are taken into consideration. The actual rate of wheat forage intake, and thus the amount of energy available for growth, has been shown to be affected by forage quality, forage quantity, temperature, and the rate of stocker adaptation to a new environment.

The amount of forage that stockers will voluntarily consume is an important factor to consider when modeling stocker growth. The National Research Council uses the following equation to calculate voluntary intake:

(2.2) $VI = LWT^{.75} (.1493\ ME_m - .046\ ME_m^2 - .0196)$

where:

VI = voluntary intake
LWT = animal weight
ME_m = metabolic energy for maintenance of the feed
ME_m^2 = ME_m quantity squared

This equation predicts increasing voluntary intake for increasing forage quality up to 1.6228 Meal/kg NE_m (Rodriguez et al., 1989).

The quantity of forage available to the stocker may also be a limiting factor affecting voluntary intake. This factor becomes especially important when considering the highly variable forage quantities that winter wheat pasture produces.

> Experimental data (Ford, 1984) suggests that 750 g DM/kg LWT is the level of forage availability for which wheat voluntary intake (VI) starts to decline as forage availability (FA) decreases. The following relationship developed by Loewer et al., (1987) was used to estimate intake dependent on forage quantity:
>
> (2.3) $PVI = (2\ FA/B) - (FA^2) / (B^2), 0<FA\leq B; PVI=1, FA>B$
>
> where potential voluntary intake (PVI) is a fraction of VI or 1, FA is the forage availability (g DM/kg LWT) and B is the threshold value where forage intake starts to decline as FA decreases (g DM/kg LWT). When $FA \geq B$ then PVI in this equation equals 1 (Fig.1). (Rodriguez et al., 1989)

Extremes in environmental temperature can have an impact upon voluntary intake (National Research Council, 1987). Voluntary intake is not affected by temperature in the thermoneutral region (between 15 and 25 C): thus, the multiplier for temperature effect on voluntary intake (TVI) within the thermoneutral range is defined as 1.0. At low environmental temperatures, voluntary intake is increased because of increases in the amount of energy intake required by stockers subjected to these temperature extremes. Between 15 and -5 C, each degree below 15 C causes a .25% increase in voluntary intake, while between -5 to -15 C voluntary intake is increased .5% per degree below -5 C. For any given temperature between -15 and 15 C the corresponding value of TVI is calculated ($1.0\leq TVI\leq 1.1$) and used as a multiplier of VI. Effects of temperatures above the thermoneutral region were not included in the WGS Model because of the low probabilities associated with the

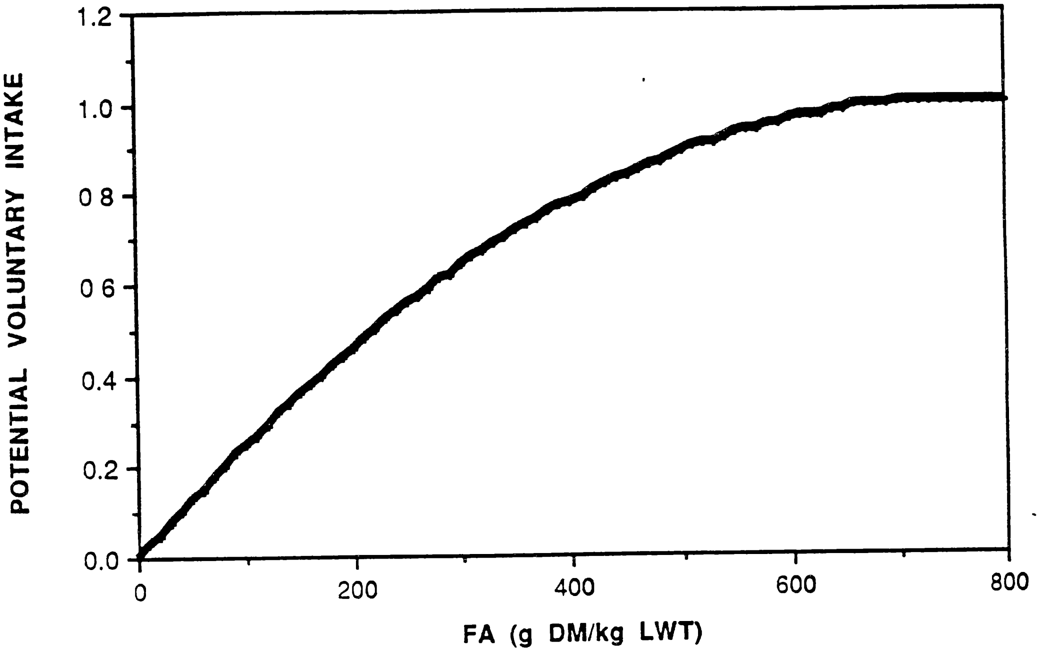

Figure 1. Potential Voluntary Intake Function

occurrence of daily temperature maximums in this range during the typical winter wheat grazing season (Rodriguez et al., 1989).

Another factor affecting voluntary intake levels is the adaptation period faced by stockers when they are introduced to the wheat pasture environment. Past research has indicated that the low weight gains during the first two weeks of grazing may result from a reduction in intake while stockers are adjusting to a new environment (McMurphy, 1977; Brorsen, 1979). An arc tangent function (AVI) was used to adjust voluntary intake in the conditioning period during the first two weeks on wheat pasture.

(2.4) $AVI=.8+.49*3.1416*\arctan(3.1416*.2*(x-7)),\ 1\leq x\leq 13;\ AVI=1.0,\ x>13$

where x is time (in days) since animals were put in the pasture, 7 is the time location of the inflection point, .8 is the "AVI" location (y) of the inflection point, .49 is the step size (distance from the maximum point to the minimum point) and .2 is the slope at the inflection point. The arc tangent function is presented graphically in Fig. 2. During the first few days after placing the animals on wheat pasture, AVI is reduced to about 60% (about maintenance level). Over the remaining days, AVI increases to 100%. This function is based on empirical observations; future experimentation could permit more accurate parameter estimation of the arc tangent function to represent the animal response at the beginning of wheat grazing (Rodriguez et al., 1989) .

After calculation of the multipliers related to environmental, managerial, and nutritional factors, the net energy available for gain may now be calculated as:

(2.5) $NE_{ag}=(VI*PVI*TVI*AVI - (NE_{rm}/NE_m))*NE_g$

where NE_m and NE_g are the net energy for maintenance and gain for the feedstuff (Mcal/kg) (Rodriguez et al., 1989).

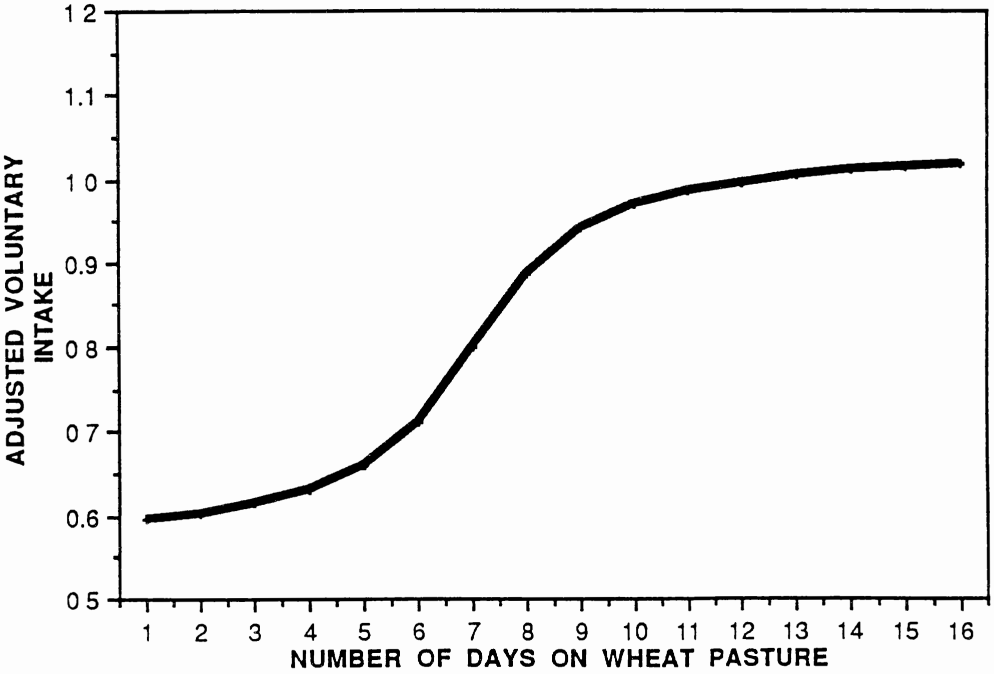

Figure 2. Adjusted Voluntary Intake Function

The calculation of the net energy required for maintenance of the stocker's current body weight is achieved through the following equation:

(2.6) $NE_{rm} = (.077 + ADD)\ LWT^{.75}$

where NE_{rm} is the net energy required for maintenance (Mcal /day), ADD is the increased maintenance requirement fraction due to temperatures below 20 C (i.e., one percent increased maintenance requirement per degree below 20 C), and LWT is again representative of stocker live weight (Rodriguez et al., 1989).

Net energy for maintenance and for weight gain in the feedstuff are polynomial functions of metabolizable energy:

(2.7) $NE_{m} = 1.37\ ME - .138\ ME^{2} + .0105\ ME^{3} - 1.12$

(2.8) $NE_{g} = 1.42\ ME - .174\ ME^{2} + .0122\ ME^{3} - 1.65$

Metabolizable energy (ME) in the feedstuff is in Mcal/kg. ME was obtained by multiplying digestible energy in the feedstuff (in Mcal/kg) by 0.82 (Rittenhouse et al., 1971; Mader et al., 1983; Rodriguez et al., 1989).

Live daily gain for stockers during the wheat grazing season is determined through equations recommended by the National Research Council (1984). Live daily gain (LDG) is calculated as follows:

(2.9) $LDG = 13.91\ NE_{ag}^{.9116}\ LWT^{-.6837}$

where NE_{ag} is the net energy available for weight gain (Mcal/day) from both wheat and the supplement provided for animal consumption and LWT is the live weight of the stocker in kilograms.

Provisions are also made in the animal growth sub-model for the possibility of stocker weight loss in circumstances when the animal's maintenance requirements for net energy are not met. Rodriguez et. al. utilized the following equation to account for stocker weight loss during the grazing season:

(2.10) $LDG = -(NE_{rm} - VI * NE_m) / 5.0$

This equation allows for a determination of the amount of body tissue that is catabolized to meet the stocker's daily net energy maintenance requirements when forage and supplement intake do not meet nutrition requirements. This particular form of the equation assumes a tissue loss rate of 5 Mcal/kg (Bath et al., 1965). This equation will result in a negative rate of daily gain whenever net energy requirements exceed the animal's net energy intake (Rodriguez et al., 1990a).

Weather Simulation

The weather simulation portion of the WGS Model was accomplished through the use of a stochastic daily weather simulation model for El Reno, Oklahoma. The model was developed and implemented by Rodriguez et al. (1988) following guidelines from Larsen and Pense for agronomic models (1982). Historical data concerning precipitation, temperature, and solar radiation from the El Reno area were used to estimate the appropriate parameters for the equations to be included in the weather simulator.

Two data sets were used to implement the weather model. The first data set, obtained from the Oklahoma Climatological survey (McDonald et al., 1983), consisted of daily precipitation, daily minimum temperature, and daily maximum temperature from 1966 to 1985 at El Reno, OK. These weather variables were used to estimate: a) monthly sets of two parameter gamma distributions conditioned to previous day precipitation; and b) monthly bi-variate normal distributions for maximum and minimum temperatures conditioned to current day precipitation. The second data set consisted of daily solar radiation and precipitation from 1978 to 1986 at the Forage and Livestock Research

Laboratory near El Reno, OK. This data was used to estimate gamma and beta distributions of solar radiation conditioned to dry and wet days, respectively (Rodriguez et al., 1988).

A first order Markov chain (Bond, 1979; Larsen and Pense, 1982) was used to determine the probability of a wet or dry day depending upon the state of the previous day (wet or dry). A day with precipitation totalling .24 millimeters (0.01 inches) of precipitation or more was considered to be a wet day while any day with precipitation totalling less than this amount was considered a dry day. This distinction was necessary to avoid rainfall events which occur between 0 and the lower limit of climatological data (an hundredth of an inch) in the data set. Two gamma distributions with two parameters were estimated for every month to assign rainfall intensities on wet days. The precipitation sequence is determined completely by the probability of a wet day given the presence of either a wet or dry previous day (Rodriguez et al., 1988).

Daily maximum and minimum temperatures from the data set were used to estimate the parameters of a temperature determination equation which is based upon the placement of a sine wave in correlation with the proper Julian day.

For dry days, B and G parameters of the gamma functions were estimated for transformed solar radiation differences by month (Larsen and Pense, 1982). For wet days, solar radiation differences on the interval [0,1] were estimated using the transformation suggested by Larsen and Pense (1982). These differences were used to estimate monthly p and q parameters for the standard beta distribution. Beta random variates were simulated by using a relationship which generates a random variate using two gamma random variates (Mihram, 1972; Rodriguez et al., 1988).

An analysis of the output for this weather simulator conducted by Rodriguez et al. (1988) provided the following conclusions.

> Variability in daily precipitation, measured with the coefficient of variability, is around 100% with no seasonal pattern throughout the year. In contrast, the variability of maximum and minimum daily temperatures is higher in the winter (100% or more) than in the summer (35% or less). Similar to the variability in temperatures, coefficients of variability of solar radiation are larger in winter (up to 87%) than summer (up to 36%). These results suggest that, in general, weather in El Reno is more variable in winter than summer.

The high variability associated with winter weather in western Oklahoma appears to be a major contributing factor in the variability associated with winter wheat forage production.

For more information on model performance and validation refer to "A Stochastic Daily Weather Simulation Model for El Reno, Oklahoma" (Technical Bulletin T-165, Agriculture Experiment Station, Division of Agriculture, Oklahoma State University, September, 1988).

Sub-Model Integration

Each of the three sub-models within the Wheat Grazing Systems Model interacts with the other two sub-models on a daily basis during the simulation of each production period. The stochastic weather simulator produces daily climatic data for the entire calendar year for each grazing season. This data is then transferred to both CERES-Wheat and the animal growth sub-models as required climatic input for their operation. The weather simulation routine begins on Julian day 172 (June 21) and operates through the wheat planting period, stocker grazing season, wheat grain harvest, and finally ends simulation for the production year on Julian day 185 (July 4) of the following year. The information passed from the weather simulator to the other sub-models includes: daily minimum and maximum temperature, daily precipitation, and daily solar radiation.

Interaction between the plant and stocker growth sub-models is a key element of the model and requires a series of equations to attempt to accurately depict both the effects that grazing has upon wheat growth and development and the effects that wheat forage production has upon stocker growth. After the appropriate daily animal intake level has been estimated, the corresponding level of forage consumption in grams per plant per day is calculated by the following equation:

(2.11) $FCONS = VI*PVI*TVI*AVI*SD*K/PLANTS$

where SD is stocking density, K is a constant to transform units from kilograms to grams and PLANTS is the number of wheat plants per square meter. The dry matter amount of wheat forage available for grazing is the sum of leaf weight and stem weight in grams per square meter. The forage consumption of leaf weight and stem weight is assumed to be proportional to their contributions to total dry matter available (Rodriguez et al., 1990a).

The plant leaf area in the WGS model is updated on a daily basis by the equation:

(2.12) $PLA_t = PLA_{t-1} + [-PLAS + (GROLF - FCONS*P1)/SLW_t]$

where PLA_t and PLA_{t-1} are plant leaf area in day t and t-1, respectively (both in cm^2/plant); PLAS is the rate of leaf area senescence (cm^2/plant/day); GROLF is the rate of leaf growth (grams/plant/day); P1 is the proportion of leaf biomass with respect to above ground biomass; and SLW_t is the specific leaf weight in day t (grams/cm^2) which changes as a function of plant phenology (Ritchie and Otter, 1985; Rodriguez et al., 1990a).

The leaf area index (leaf area relative to ground area) is calculated as follows:

(2.13) $LAI = PLA*PLANTS*0.0001$

(Rodriguez et al., 1989)

The changes in plant leaf area (PLA_t) which occur as a result of wheat forage consumption by stockers (FCONS) determine subsequent changes in leaf area index (LAI). Reductions in LAI may affect plant growth in four primary ways: (1) a reduction in the potential carbon fixation in grams per plant per day; (2) an increase in soil evaporation; (3) a decrease in transpiration for LAI below 3; and (4) changes in the rate of leaf area senescence (PLAS) (Rodriguez et al., 1990a).

In addition to the above mentioned effects of grazing on the forage production and leaf senescence, grazing also affects grain growth. The ratio of cumulative forage intake throughout the grazing season to forage dry matter before the jointing stage of the wheat plants (REDUCE) is used to retard the rate of grain filling according to the following relationship:

(2.14) $GROGRN = RGFILL*GPP*(1/K)*(1-0.5*REDUCE)$

where GROGRN is the rate of growth of the wheat grain (grams/day/plant), RGFILL is the rate of grain fill (mg/day/grain), GPP is the number of grains per plant (a variety specific genetic constant which is determined through model input) and 1/K is a constant to transform milligrams to grams. The weight term in the right parentheses assigns a maximum of 50 percent reduction in GROGRN due to grazing if REDUCE is 1. This value was estimated by minimizing deviations about observed grain yields from grazing trial data (Christiansen et al., 1989). Based on the original structure of CERES-Wheat (Ritchie and Otter, 1985), low levels of stem and leaf weight affect grain yield. The weight term in equation 2.14 was used to accentuate the negative effects of grazing upon grain yield (Rodriguez et al., 1990a).

More detailed information concerning the plant-animal interface portion of the WGS Model and model performance may be found in "A Wheat Grazing Systems Model for the U.S. Southern Plains: Model Description and Performance", Agricultural Systems, 33: 41-59 (Rodriguez et al., 1990a).

Future research by agricultural scientists in the wheat grazing systems area could provide valuable new insights into the complex interaction which takes place between animal and plant during the grazing season. These new research results could potentially allow for a more accurate depiction of the plant-animal interface.

CHAPTER III

PREVIOUS APPLICATIONS OF THE WHEAT GRAZING SYSTEMS MODEL

The Wheat Grazing Systems Model (WGS Model) has been utilized in several previous analyses to address a variety of pertinent economic questions. One of the first applications of the model was to calculate stocker supplementation costs for wheat grazing operations and use these values as a measure of forage supply volatility under alternative stocking densities. Later applications included the analysis of the impact of selected grazing management parameters and a study of the effects of wheat price on the optimal stocking rates for wheat pasture. The remainder of this chapter will attempt to summarize these previous applications of the WGS Model and to distinguish between past research efforts and the analysis encompassed by this study.

Forage Supply Volatility

Rodriguez et al. (1989) utilized the WGS Model to produce an estimator of the forage supply volatility associated with the dual production of wheat and beef. This particular application of the WGS Model was an effort to identify the expected supplementation costs associated with various stocking density levels. These supplementation costs were used as estimators of the volatility of wheat forage production under different management schemes.

This particular study is referenced heavily in Chapter II to provide explanations of equations used to calculate stocker growth, stocker maintenance, forage intake, and weight loss. Also, the methods involved in providing the analysis for this past application of the model are drawn upon to provide the basic approach to the current application of the WGS Model regarding target hay storage levels.

The forage supply volatility study used the WGS Model to determine the amount of stocker supplementation necessary to offset shortfalls in wheat forage production due to unfavorable climatic growing conditions. Specifically, supplementation schedules were generated which detailed the amount and timing of hay feedings required to maintain a targeted level of animal growth when wheat pasture forage production fell below levels sufficient to fulfill nutrient requirements for the targeted growth.

The WGS Model was iterated fifty times under three different stocking density levels to obtain corresponding schedules of supplemental feeding. The cost of providing the simulated amounts of supplement during periods of low wheat forage production was then calculated. The input parameters required by the WGS Model for these simulations were taken from a survey of Oklahoma wheat producers (Walker et al., 1988). The survey indicated that the average stocking density for an Oklahoma wheat grazing operation was 1.2 head per hectare (0.49 hd/ac). Two additional stocking densities analyzed were 2.4 hd/ha (0.97 hd/ac) and 3.6 hd/ha (1.46 hd/ac). Supplementation schedules for all three stocking densities were produced and analyzed.

The supplementation schedules obtained from the WGS Model indicated that supplementation rates increased geometrically with higher stocker densities. When considering fifty year averages, the highest stocking density

(3.6 hd/ha - 1.46 hd/ac) required roughly thirteen times more supplement than the lowest stocking density (1.2 hd/ha - 0.97 hd/ac) (Rodriguez et al., 1989).

This forage supply volatility study produced some interesting results with regard to the frequency of occurrence of supplementation throughout the grazing season. As the grazing season progresses, there is an increasing trend in the frequency of supplementation under the two highest stocking density levels although the trend is not as pronounced under the 2.4 hd/ha (0.97 hd/ac) stocking density. Under the average stocking density of 1.2 hd/ha (0.49 hd/ac), the first two-thirds of the grazing season is characterized by a constant frequency of supplementation which tends to decrease over the last third of the grazing season. Rodriguez et al. (1989) determined that the differences in supplementation frequencies are related to the higher probabilities of low forage availability levels which occur under the higher stocking density levels.

This application of the WGS Model also attempted to identify the quantities of stored hay supplement which would meet stocker nutrient requirements in all possible wheat forage deficit situations. Hay storage levels which would provide protection against 90% of the wheat forage deficit situations were also computed and found to be considerably lower than the storage quantities required for 100% protection (Rodriguez et al., 1989).

Overall, Rodriguez et al. (1989) determined that average supplement costs increased geometrically as stocking density increased. They also found that the year-to-year volatility of supplemental feed costs increased geometrically with stocking density.

An important result of this study was that a new method of analyzing supplementation decisions faced by wheat pasture beef producers was documented and presented for possible future research use. In fact, the methods utilized in the forage supply volatility study were used as the basis for the current study dealing with optimal levels of supplemental forage stocks to hold prior to the wheat grazing season. Stochastic simulation of fifty wheat grazing seasons under varying stocking densities to generate annual supplemental feeding schedules was a major basis of the research for the current study.

Grazing Management Decisions

Rodriguez et al. (1990b) also combined the WGS Model with stochastic dominance analysis to investigate the risk due to weather uncertainty faced by wheat-stocker producers. Different management schemes were simulated with the WGS Model. The output of these simulations was then analyzed using stochastic dominance to discriminate among the managerial decision strategies simulated. The management decisions determined to be preferred by stochastic dominance analysis were then compared to management schemes which are currently being used by Oklahoma wheat farmers. The study also examined the technological relationship between wheat grain production and beef production and the major economic trade-offs which result.

The base farm situation considered was specified to represent a "typical" western Oklahoma wheat operation. All biological and managerial input parameters for the WGS model were set to reflect the base farm. The two major management variables studied were the beginning and ending dates for the grazing season and stocking density. Stocking density levels ranging from 0.0 hd/ha to 3.0 hd/ha (1.2 hd/ac) by increments of 0.30 hd/ha (0.12 hd/ac) were examined. Three possible dates for both the beginning and ending of the wheat grazing season were considered. November 1, November 8, and November 15 were the possible beginning dates included in the study while

March 1, March 8, and March 15 were the dates considered for termination of the grazing season. A total of 91 combinations of stocking density, beginning date, and ending date management schemes were examined. Each management strategy was evaluated on the basis of average net producer returns from a fifty year production period and the variance associated with that level of net returns (Rodriguez et al., 1990b).

Net returns to the producer were simulated using the concept of residual returns to owned resources which were calculated on an annual basis using the following equation:

$$(3.1)\quad NR = (Pb_{lwt,t} * Yb) + (Pw * Yg) - (Cb + Cg)$$

where NR represents net producer returns (\$/ha); $Pb_{lwt,t}$ represents stocker price received (Pb) which varies as a function of animal live weight (lwt) due to the inverse relationship between live weight and price and as a function of time (t) due to the seasonality patterns which exist in stocker prices; Yb is total beef production per hectare which is obtained by multiplying stocking density times stocker weight gain per head during the grazing season; Pw is the wheat price received (\$/kg); Yg is the final grain yield (kg/ha); Cb is the variable production cost associated with beef production (\$/ha); and Cg is the variable production cost associated with the wheat enterprise (\$/ha) (Rodriguez et al., 1990b).

Seasonality of stocker price patterns was simulated using a harmonic time series price model developed by Franzmann and Walker (1972). Variations in prices received for stockers at the end of the grazing season due to differences in ending animal weights were accounted for through the utilization of a series of weight/price relationship equations estimated from data originating from the Oklahoma City Cattle Market (USDA-AES). Wheat price was considered to be constant over the entire production period at a value of \$0.10 per kg (\$2.72/bu) which was the average wheat price for Oklahoma from

1983-87. Since this study was focused mainly upon production risks associated with weather uncertainty, price risk was not examined (Rodriguez et al., 1990b).

Wheat production costs were estimated from published enterprise cost estimates for dry land production in Oklahoma (Oklahoma Cooperative Extension Service). Variable costs for wheat production were calculated as a function of total annual grain yield as follows:

$$(3.2) \quad Cg = 115.72 + (0.0081 * Yg) + 0.0044 * (Yg - 544)$$

where Cg is wheat production cost ($/ha) and Yg is annual grain yield (kg/ha). The constant (115.72) depends on management decisions such as tillage, fertilizer application, and planting density. The remainder of the equation accounts for those production costs that vary with the quantity of grain yield (Rodriguez et al.,1990b).

Stocker production costs included costs associated with conditioning animals prior to the grazing season, transportation and marketing, veterinary and medical, labor, and interest charges on operating capital. Stocker costs were calculated as:

$$\begin{aligned}(3.3) \quad Cb = SD * \{&(LWTO * Pb_{lwt,t}) + (0.04564 * TWG) + \\ &(0.097 * KHY) + [(LWTO * Pb_{lwt,t}) * \\ &(LGH/365) * 0.12] + 32.1\}\end{aligned}$$

where $Pb_{lwt,t}$ is the price of steer calves as previously defined ($/kg); TWG is the total weight gain during the grazing season (kg); KHY is the quantity of supplemental hay fed (kg); and LGH is the length of the grazing season (days), including a 14 day conditioning period. An annual interest rate of 12 percent was used to calculate the charges for operating capital (Rodriguez et al., 1990b).

After calculating the mean and variance of net producer returns for each of the 91 management strategies, Rodriguez et al. (1990b) used stochastic dominance criteria to distinguish producer preference among specific management schemes. First degree stochastic dominance, second degree stochastic dominance, and stochastic dominance with respect to a function were all applied in the study. Producers were assumed to be utility maximizers and their utility level was assumed to be a function of net returns where utility was defined as a single-valued index of producer satisfaction related to both the expected net returns and the probability of alternative net return levels (Rodriguez et al., 1990b).

The application of the first degree stochastic dominance criterion resulted in the elimination of 80 of the 91 alternative management decision possibilities from inclusion in the efficiency set. Second degree stochastic dominance was used to further discriminate among management alternatives where a producer's risk preference met the following assumptions: 1) more net returns are preferred to less; 2) the producer's utility increases at a decreasing rate as net returns increase; and 3) the farmer is a risk averse utility maximizer. This resulted in reducing the efficiency set to four management combinations which had grazing seasons which started on November 1 and continued until March 15 with varying stocking densities ranging from 0.6 to 1.5 hd/ha (0.24 to 0.61 hd/ac). Second degree stochastic dominance was unable to distinguish producer preference among these four management alternatives (Rodriguez et al., 1990b).

To further discriminate between management alternatives, Rodriguez et al. (1990b) applied stochastic dominance with respect to a function as a criterion to establish producer preference. This criterion was applied for different intervals of risk preference based upon the Pratt-Arrow absolute risk aversion coefficients (King and Robison, 1984; Cochran et al., 1985). The intervals used were considered to be indicative of risk loving, risk neutral, slightly risk averse, and strongly risk averse producer preferences.

If the producer was assumed to be a risk lover, four management schemes were identified as risk efficient. These schemes had grazing seasons from November 1 to March 15 and stocking density levels ranging from 1.5 to 2.4 steers/ha (0.61 to 0.97 steers/ac). Generally these strategies resulted in high net returns, but also exhibited relatively high levels of income variability. Under the assumption of risk neutrality, four management alternatives with grazing season of November 1 to March 15 and stocking densities from 0.6 to 1.2 and 2.7 hd/ha (0.24 to 0.49 and 1.09 hd/ac) were included in the risk efficient set. The risk efficient set for slightly risk averse producers included the grazing season from November 1 to March 15 with a stocking density of 0.6 or 0.9 hd/ha (0.24 or 0.36 hd/ac). The strongly risk averse criterion resulted in the grazing season of November 1 to March 15 with a stocking density of 0.9 hd/ha (0.36 hd/ac) dominating all other management decision combinations (Rodriguez et al., 1990b).

This study failed to designate a managerial strategy which was dominant for all risk preferences which indicates that optimal grazing management decisions depend upon the views that producers have about risk in the production process. However, all of the risk efficient sets of management alternatives consisted of strategies with a grazing season from November 1 to March 15 implying that regardless of a producer's risk preference this will be the preferred grazing season. The authors concluded that risk averse producers preferred lower stocking densities because they were not willing to accept the increased probabilities of wheat forage shortages that accompanied the higher stocking density levels. They also concluded that the management strategy of not grazing available wheat pasture and producing only grain was not a member of the risk efficient set under any of the risk attitudes.

Rodriguez et al. (1990b) also utilized this study to present an analysis regarding the economically optimum combination of beef and wheat. Average net returns to the producer for both the grain and beef enterprises were examined for the grazing season from November 1 to March 15. Expected net returns from grain production were found to decline as stocking density increased, but the increasing returns from beef production more than offset this trend up to 1.5 hd/ha (0.61 hd/ac), where the maximum net returns from the combined enterprises occurred. The net returns from beef and wheat combined were found to be relatively flat from 0.6 hd/ha to 2.4 hd/ha (0.24 to 0.97 hd/ac). This observation helped to reinforce the concept that preference differences among alternative stocking densities were due primarily to the variability of net returns rather than the expected values. The researchers also concluded that the stocking density level was strongly related to the variability of net returns for both the beef and wheat enterprises (Rodriguez et al., 1990b).

The data obtained from this study also indicated that the economically optimum combination of beef and grain enterprises (i.e. stocking density) depends upon specific weather conditions, managerial conditions, and market prices faced by the producer during the grazing season (Rodriguez et al., 1990b).

The study concludes by comparing the average/typical management scheme implemented by western Oklahoma producers against the optimal management strategies indicated by the various stochastic dominance criteria. The average/typical management scheme in western Oklahoma consists of a grazing season which extends from November 8 to March 8 in combination with a stocking density of 1.2 hd/ha (0.49 hd/ac). This scheme was found to yield an average net return which was lower than the expected average net return from any of the management alternatives included in the risk efficient sets. Producers may prefer the shorter 120-day grazing season rather than the longer 134-day grazing season identified by stochastic dominance criteria because of perceptions they hold about the risks involved with the longer grazing season. For example, beginning the grazing season one week earlier in the fall could be perceived as a risky decision about wheat forage availability early in the grazing season. Additionally, producers may perceive that terminating the grazing season one week later could reduce grain yield significantly. Both of these perceptions could result in a conservative stance by producers as to the ideal length of the wheat grazing season (Rodriguez et al., 1990b).

Wheat Price Effects

Rodriguez and Trapp (1990) utilized the WGS Model to accomplish the purposes of yet another study. The major focus of this study involved the examination of wheat price effects on the optimal stocking density decisions faced by dual beef and wheat producers under stochastic livestock prices and climatic conditions.

The price of wheat was treated as an exogenous variable in this analysis. This assumption was based upon the fact that due to current government commodity programs farmers often know the price they will receive for their wheat grain before planting the crop. In the absence of government programs, wheat price can still often be accurately predicted based upon national inventory trends, futures markets, and expected supply and demand conditions (Rodriguez and Trapp, 1990).

A conceptual model describing the dynamic inter-relationships between net returns to the producer from both the wheat grain and beef production enterprises was formulated and presented. This model was based upon the interaction between grain and beef production and the technological relationships involved in these interactions. Net returns to the producer from the wheat grazing system were calculated as:

$$(3.4) \quad NR = (Pb) * (Yb) + Pg * (Yg) - (Cb) - (Cg)$$

where Pb is steer selling price ($/cwt), Yb represents beef production per acre (lb), Pg is the price of wheat ($/bu) which is assumed to be viewed as a constant by the producer during the production period, Yg is expected grain yield (bu/ac), Cb is defined as the cost of beef production ($/ac), and Cg is the cost associated with grain production ($/ac). Each of these functions is in turn a function of the complex physical and economic interrelationships which exist between beef and grain production as described by the WGS Model (Rodriguez and Trapp, 1990).

The expected net revenue function was partially differentiated with respect to stocking density to obtain a set of first order conditions which needed to be met if a stocking density level was to be found which maximized expected total net returns from the wheat pasture system. Optimization conditions of expected marginal revenue equated with expected marginal cost were presented and shown to result in changes in the optimal stocking density whenever the price of grain (Pg) changed. A higher wheat price indicated a decrease in stocking density and a lower wheat price necessitated an accompanying increase in stocking density if an optimum solution was to be maintained (Rodriguez and Trapp, 1990).

The WGS Model was utilized in this study in a manner similar to the application discussed in the previous section concerning the economic analysis of grazing management decisions. Stochastic simulation results were obtained which used many of the same revenue and cost equations seen in previous research efforts involving the WGS Model. One characteristic of the model which was changed for this study involved the incorporation of stochastic purchase and selling stocker prices. The following equation was used to determine the steer price at the end of the wheat grazing season:

$$(3.5) \quad Pb = \exp [1.754 + 0.58339 * \ln (PO) + ep]$$

where Pb is the expected price ($/cwt) of a 295 kg (650 lb) steer at the end of the grazing season; PO is the price ($/cwt) of a 204 kg (450 lb) steer purchased at the beginning of the grazing season. PO was modelled as a normal random deviate with mean of $1.55/kg ($70.40/cwt) and a standard deviation of $0.25/kg ($11.20/cwt); and ep is a normal deviate with mean zero and standard deviation of $0.16/kg ($7.10/cwt). The relationships exhibited by this price equation were estimated using 50 weekly observations between 1977 and 1987 from the Oklahoma City Livestock Market. Since the ending stocker weight for a particular grazing season was not necessarily 295 kg (650 lb), the price obtained from equation 3.5 was used as a base for additional calculations to estimate the price of stockers in other weight classes from which a stocker selling price for the ending weight of that production period was interpolated (Rodriguez and Trapp, 1990).

Another characteristic which differentiated this study from other WGS studies was the fact that the termination date for the grazing season was not input as a fixed parameter, but instead it was allowed to vary from season to season as a producer decision based upon the beginning of the critical jointing stage of phasic development for wheat plants. The jointing stage begins when the first node of the wheat plant's stem becomes visible (Rodriguez and Trapp, 1990).

Eleven alternative stocking densities were utilized in this study to estimate the demand schedule for stockers which would maximize net revenues. These stocking densities ranged from 0.0 to 3.00 hd/ha (1.20 hd/ac) at intervals of 0.30 hd/ha (0.12 hd/acre). Eleven wheat price levels were also considered which ranged from \$0.055/kg (\$1.50/bu) to \$0.147/kg (\$4.00/bu) at intervals of \$0.009/kg (\$0.25/bu). Each possible combination of wheat price and stocking density was then simulated for fifty wheat grazing seasons. Eleven distributions of total net producer returns for each of the eleven wheat prices were examined for one interval of the Pratt-Arrow absolute risk aversion coefficient with a generalized stochastic dominance program (Cochran and Raskin, 1988). The interval chosen corresponded to a slightly risk averse producer (Rodriguez and Trapp, 1990).

The determination of the optimal stocking density used maximum expected (fifty year average) net returns as a criteria for each of the wheat price levels. This determination was made through the trade off between animal growth and grain yield, production costs, selling prices, and the effect of the stocking density on the selling price of beef. Average net returns were calculated through WGS simulations of fifty years of winter wheat production for a typical wheat grazing operation in western Oklahoma. For a wheat price input of \$0.055/kg (\$1.50/bu), expected net returns [E(NR)] were \$33.84/ha (\$13.70/ac) when no grazing took place (SD = 0). As stocking density was increased, E(NR) increased up to \$128.69/ha (\$52.10/ac) at a stocking density of 2.07 hd/ha (0.84 hd/ac) and then decreased to \$94.85/ha (\$38.40/ac) at the highest stocking density of 3.00 hd/ha (1.20 hd/ac). When the wheat price was changed to \$0.147/kg (\$4.00/bu), E(NR) were \$351.23/ha (\$142.20/ac) with no grazing. E(NR) reached a maximum at \$401.13/ha (\$162.40/ac) at a stocking density of 1.48hd/ha (0.60 hd/ac) and then declined with higher stocking rates to $328.51/ha ($133/ac) at 3.00 hd/ha (1.20 hd/ac) (Rodriguez and Trapp, 1990).

Since the maximum level of E(NR) did not necessarily correspond to the lowest risk (or variation) in expected net revenue over the fifty year period, stochastic dominance with respect to a function (King and Robison, 1984) was used as the criterion to determine producer preferences among the alternative stocking density levels given each of the wheat price levels. The preferences were determined for a slightly risk averse producer. These decision makers prefer low variability for given expected net returns. For wheat prices of $0.055/kg ($1.50/bu) and $0.064/kg ($1.75/bu), a stocking density of 0.60 hd/ha (0.24 hd/ac) was found to maximize utility. The higher prices of wheat resulted in a preferred stocking density of 0.90 hd/ha (0.36 hd/ac). The expected net returns of these preferred management alternatives ranged from $390.51/ha ($158.10/ac) at a wheat price of $0.147/kg ($4.00/bu) to $76.82/ha ($31.10/ac) at $0.055/kg ($1.50/bu). As wheat price fell from $0.147/kg ($4.00/bu) to $0.055/kg ($1.50/bu), the coefficient of variation in E(NR) rose from 33.5 to 59.5 percent, maximum net returns decreased from $637.01/ha ($257.90/ac) to $178.83/ha ($72.40/ac), and minimum net returns decreased from $115.35/ha ($46.70/ac) to -$7.90/ha (-$3.20/ac) (Rodriguez and Trapp, 1990).

This study found that Oklahoma wheat producers choose stocking densities between those of slightly risk averse and risk neutral decision makers. This conclusion was based upon survey results which indicated that on average these producers stock wheat pastures at the rate of 1.2 hd/ha (0.5 hd/ac) (Vogel et al., 1987; Walker et al., 1988).

Rodriguez and Trapp (1990) also examined the underlying causes of variability in net returns. They concluded that increases in the variability of beef net returns with respect to stocking density were due to variability in beef production, variability in production costs, variability associated with stocker purchase price, and the variability associated with stocker selling price. Similar variability in grain production and production costs were found to affect the variability in net returns to the grain enterprise. The minimum variability in the combined net returns of beef and wheat was found to occur at 0.90 hd/ha (0.36 hd/ac). The researchers concluded that increasing the stocking density up to 0.90 hd/ha (0.36 hd/ac) decreased the variability in expected total net returns when compared to the option of producing grain only. This minimum variance stocking density was well below the profit maximizing stocking density which was determined to be 1.8 hd/ha (0.72 hd/ac).

The results of this study were also used to determine a demand schedule for stockers based upon the varying levels of wheat price. The demand schedule which was determined from the WGS simulation results yielded an estimated cross price elasticity of demand for stockers of -0.346 indicating that profit maximizing decision makers would/should decrease stocking density 0.35 percent for every one percent increase in the price of wheat. For example, if the price of wheat rose from $0.110/kg ($3.00/bu) to $0.129/kg ($3.50/bu), the demand for stockers would change from 1.55/ha (0.628/ac) to 1.47/ha (0.595 hd/ac). Rodriguez and Trapp (1990) generalized from this relationship that a wheat price increase from $0.110/kg ($3.00/bu) to $0.129/kg ($3.50/bu) would reduce the demand for stocker cattle in six western Oklahoma counties (Beckman, Caddo, Custer, Grady, Kiowa, and Washita) with 566,800 hectares (1.4 million acres) of wheat by 46,200 head.

The authors of this study emphasized the fact that caution must be used in generalizing these results because of the dependency of these results on the rate of product transformation which exists between beef and grain production in wheat pasture systems. They noted that this relationship was determined by parameters within the WGS Model pertaining to the technical relationships between animal growth and grain yield and ,thus, depended upon the appropriate parameterization of these concepts within WGS. Data with which to specify these parameters is very limited. With this in mind, the researchers compared two demand schedules resulting from different assumed technical trade offs between animal growth and grain yield and found that the incorporation into the WGS Model of a large negative impact of grazing upon grain yield resulted in a much more inelastic demand curve for stockers with respect to wheat price changes (Rodriguez and Trapp, 1990).

The authors suggested that the concept of using the WGS Model to determine demand schedules for stockers with respect to wheat price could be a useful tool in future management and policy analysis to determine the effects of wheat price upon stocking density decisions given variable livestock prices, random weather events, and the restrictions imposed upon producers by various government programs and policies. They also suggested that expanding the geographic parameterization of the model could allow for the inclusion of a substantial amount of additional wheat producing acreage into these analyses (Rodriguez and Trapp, 1990).

Overall, this particular research effort helped to clarify some of the complex and dynamic processes involved with the optimal stocking decisions for wheat grazing systems. A variety of wheat price and technical relationship effects were considered.

Relationships to Current Study

The manner in which the WGS Model was utilized in these three previous studies is very similar to the method employed in the current study.

However, the current version of the WGS Model has been adapted to allow for the assimilation of additional physical and economic characteristics of wheat grazing operations. Of the three research applications of the model, more similarities exist with the study involving the application of supplementation costs as an estimator of forage supply volatility (Rodriguez et al., 1989). The other two studies (Rodriguez et al., 1990b ; Rodriguez and Trapp, 1990) also exhibit some similarities such as the use of average net returns to the producer as a criteria for determining the optimal stocking density, but many fundamental differences exist.

The forage supply volatility project serves as a foundation for the current research project involving the determination of optimal target hay storage levels. Both projects involve the use of supplementation schedules to examine economic questions concerning the typical western Oklahoma wheat and beef production system. Both also attempt to examine the effects of stocking density upon supplemental feeding levels and related management alternatives. However, the forage supply volatility study used the simplifying assumption that supplemental feed, when needed, was available at the seasonal average price. The current study attempts to provide further detail and insight into the biological, climatic, and financial considerations involved in the storage of supplemental forage to insure against possible shortfalls in wheat forage production. Differences include, but are not limited to, such items as the deterioration over time of hay stored as large round bales, wastage encountered in the hay feeding process, hay price effects upon optimal supplement storage levels, changes in production costs associated with changing levels of supplemental feeding, and determination of optimal perennial hay storage levels using average expected net revenue as the decision criteria.

CHAPTER IV

THE ADAPTATION OF THE WHEAT GRAZING SYSTEMS MODEL

Adaptation of the Wheat Grazing Systems Model (WGS Model) to allow for the assimilation of the managerial and physical aspects of the storage and utilization of large round bales of hay was a major component of this study. Large round bales are the most common form of hay storage in Oklahoma. This particular form of hay storage presents some unique biological and economic considerations for producers who utilize large round bales of hay as supplemental feed during periods of low wheat forage production which are often encountered with wheat grazing systems in Oklahoma.

The first major alteration was contained within the stocker growth portion of the WGS Model. An inventory system for hay storage levels was incorporated within the stocker growth model to allow for the analysis of management decisions related to hay stocks. Equations concerning hay deterioration due to climatic factors were also included in the hay storage sub-model. The climatic variables necessary for operation of the hay storage sub-model were input from the weather simulation portion of the WGS Model. Also included in the hay sub-model were factors to consider the effects of hay waste during the feeding process.

Other changes to the WGS Model were contained within the cost accounting subroutine. This subroutine calculates revenue, cost, and other economic information related to both the grain and beef enterprises. The subroutine was augmented to consider costs related to storing and feeding hay. The remainder of this chapter will provide further details concerning the adaptation of the WGS Model to accomplish the objectives related to this research effort.

Hay Storage

The increased use of large round bales of hay in the last several years and the variety of methods utilized by producers for their storage has prompted researchers to focus studies upon the relationships between climatic factors, storage methods, and the resulting quantity and quality losses due to the deterioration of supplement stored in this form. Studies of this type have generally tended to focus on climatic effects, usually precipitation, upon such qualitative and quantitative parameters as total mass, dry matter content, moisture content, crude protein content, dry matter digestibility, acid detergent fiber, neutral detergent fiber, and in-vitro dry matter disappearance associated with large round bales. Comparisons have been made of various storage methods available to producers including direct ground contact with no cover, direct ground contact with black polyethylene cover, storage on wooden pallets with no cover, storage on wooden pallets with black polyethylene cover, bales stacked in rows, bales stacked singly, unsheltered bales placed on a polyethylene ground cover, storage with a polyethylene circumferential wrap, or storage inside a barn (Huhnke, 1988 and 1989a). The consequences of long term versus short term storage have also been examined (Rider, 1979).

As a result of these studies and extension service efforts to convey these results to the farm population, producer awareness concerning deterioration losses associated with large round bales has increased. A majority of agricultural engineers and extension service personnel now recommend that producers follow certain prescribed guidelines to minimize supplement losses when storing large round bales outside and unprotected. These guidelines (Huhnke, 1989b) include storing bales in a well-drained area that is not shaded and is open to breezes to enhance the drying process. They also recommend stacking bales end-to-end in north-south rows with at least one foot of space between rows. Storing large round bales in this manner should result in the minimum deterioration loss levels attainable without the utilization of other physical storage facilitating means. For the purposes of this study, it is assumed that the wheat grazing operation for which production is simulated follows these guidelines for the storage of large round bales. Study thus far has indicated that given the rainfall and temperature range in the major wheat producing areas of Oklahoma further physical protection of stored hay is not economical.

The replication of the losses due to environmentally related deterioration for the present version of the WGS Model was limited to losses in dry matter. Dry matter loss was the deterioration loss component for which the largest and most consistent source of data was available. This allowed for estimation of deterioration losses to be obtained through manipulation of the hay inventory system portion of the animal growth sub-model.

The hay inventory system installed in the WGS Model consisted of four separate accounts of hay dry matter differentiated on the basis of hay stock quality (i.e., age and deterioration). The first account consisted of hay purchased during the current production period with the remaining accounts containing hay stocks which were purchased in production periods one, two, or three years previous. Thus, the fourth account contains all hay which was purchased at least three or more production periods earlier. Hay stock quantities were transferred between accounts at the end of each grazing season. Hay was assumed to be utilized for supplemental feeding on the basis of earliest purchase date. For example, hay stocks contained in the fourth account, if any, would be fed before hay stocks in any of the remaining accounts.

Equations and related parameters included in the WGS Model to estimate dry matter loss in large round bales due to climatic factors focused upon the impact of precipitation on dry matter. The algorithms designed to calculate dry matter deterioration were based on information obtained in a personal interview with Ray Huhnke (Associate Professor, Department of Agricultural Engineering, Oklahoma State University). Dry matter losses encountered during the grazing season were calculated on the basis of the assumption that these losses are directly related to rainfall levels. A dry matter decrease of 0.5% of the original mass was assumed for each additional 25.4 millimeters (one inch) of rainfall received where the original mass was defined as the amount of hay dry matter in storage at the beginning of the grazing season. A lag time of two weeks was assumed after the rainfall event before the corresponding dry matter deterioration became apparent. Dry matter loss during the grazing season was calculated in the WGS Model on a daily basis as follows:

$$(4.1)\quad LOSS = 0.005 * OHAY * (RNF14/25.4)$$

where LOSS represents the total daily dry matter deterioration (kg/ha) due to rainfall, OHAY is the beginning of season original dry matter mass (kg/ha), and the last term represents the two week lagged rainfall event (inches) adjusted for metric unit conversion (mm). An interesting observation is that hay deterioration tends to be the worst in years when it is generally not needed (i.e., high rainfall years are generally associated with favorable wheat forage production years).

Likewise in dry years when hay is needed, it generally does not deteriorate as much.

If the producer was faced with the situation of high wheat forage production which resulted in an excess of stored hay at the end of the grazing season, an estimate of potential dry matter loss was made for the average climatic conditions faced by typical western Oklahoma wheat grazing operations during the non-grazing season time period. Dry matter decrease for these carry-over hay stocks, which are generally stored from March through October, was assumed to be 20% of the quantity of hay dry matter remaining at the end of the grazing season.

An important assumption related to the calculation of all deterioration levels was the limit placed upon the total amount of deterioration that is likely to take place when large round bales are stored for extended periods or under high rainfall conditions. Past research experiments dealing with round bale hay storage have indicated that total dry matter deterioration losses under long term hay storage are limited to approximately 50% of original (purchase) dry matter mass due to the insulating effects of the weathered outer layers of the round bale. This limiting assumption resulted in hay stocks which experienced no further decomposition due to precipitation or storage time after being held through at least three grazing seasons, being exposed to at least 2540 millimeters (100 inches) of rainfall, or a combination of time and rainfall resulting in a dry matter decrease equalling 50% of original dry matter mass. This characteristic of the model made the inclusion of more than four hay stock accounts unnecessary.

Management of Hay Stocks

The WGS Model was also adapted to allow for analysis of management decisions regarding the optimal hay storage level at the beginning of the grazing season. A variable was included to represent the level of hay stocks which the producer wanted to have on hand at the beginning of the wheat pasture grazing season. The value entered for this variable was treated as a constant by the WGS Model during the simulation of any fifty year production period. It was used to calculate the quantity of hay the producer needed to purchase before the start of the wheat grazing season to raise total hay stocks to the desired or "target" storage level. Thus, the quantity to be purchased was calculated as:

$$(4.2) \quad PHAY = TARGET - EHAY$$

where PHAY represents the quantity to be purchased (kg/ha), TARGET is the target hay storage level (kg/ha), and EHAY is the quantity of hay stocks held over from the previous grazing season (kg/ha).

The target hay storage levels, which were input as management decision variables, in actual practice often do not provide a quantity of hay stocks which is sufficient to cover all possible wheat forage shortfalls. If inadequate hay storage is provided at the beginning of the season, the producer is faced with several management choices. The producer may choose to continue to keep stockers on the wheat pasture with no further supplementation in anticipation of later wheat forage growth while risking stocker weight loss. Another option is to sell the stockers early and accept a lower seasonal weight gain at the current market price. Such a forced sale runs the risk of being undertaken when the market is depressed due to other producers facing the same problem, thus creating large supplies of stocker cattle in the local market. Yet another option consists of purchasing enough additional hay to retain stockers on the wheat pasture for the entire grazing season. This last alternative was considered most likely under typical production conditions and, as a result, was incorporated within the WGS Model to allow for in-season hay stock adjustments by the producer.

The management option which involves additional hay purchases during periods of prolonged wheat forage shortfalls or in cases where the producer decides to hold a low or zero level of hay storage prior to the grazing season has both advantages and disadvantages. The producer may benefit by retaining ownership of the stockers which may result in additional stocker weight gains once wheat forage growth resumes or increases. Retaining ownership of the stockers for the entire grazing season may also permit the producer to receive higher prices for his cattle at the end of the wheat grazing season than he would have received by selling the stockers during the time period when low wheat forage production was experienced. One potential disadvantage of this management option may be the incurrence of high production costs due to high hay prices during periods of unfavorable growing conditions because of a relative scarcity and unavailability of hay supplies.

For the purposes of simulation, once a producer fed all existing hay from available stocks he was allowed to purchase enough additional hay on a truck load integer basis to meet stocker maintenance and growth requirements for the remainder of the wheat grazing season. A hay pricing scheme was also incorporated within the WGS Model to allow the cost associated with the purchase of additional supplemental feed to be calculated. Details concerning the hay price series will be presented in the next section of this chapter dealing with the economic aspects of the current version of the WGS Model.

Revenue and Cost

An economic subroutine was developed for the Wheat Grazing Systems Model to allow for the compilation of net returns to the producer from the grain and beef enterprises. This subroutine was constructed to provide an accounting system for specific returns received and costs incurred by producers. The four major economic segments involved in the calculation of net returns to the producer for a wheat and beef dual production system are: 1) returns from grain production; 2) costs incurred in grain production; 3) returns from the production of beef; and 4) costs incurred in the production of beef. The remainder of this chapter will focus upon the details of the methods which were utilized for the calculation of these four key economic measures within the WGS Model.

Returns from Grain Production

Since the WGS Model produces output for grain and beef production on a per hectare basis, all calculations concerning revenues and costs were computed on a per hectare basis. Gross returns to the producer from grain production were based upon the harvested grain yield output from the wheat growth portion of the WGS Model. Grain yield in turn was a function of the climatic conditions during the growing season and the physical and biological relationships between wheat grain and beef production. A stochastic price for wheat was not utilized to accomplish the purposes of this study. Rather, the price of wheat was assumed to be constant under all production conditions at $0.10/kg ($2.72/bushel) which was the average price for Oklahoma over the period from 1983 - 1987. Annual returns to the producer from grain production were then calculated as the product of grain yield on a kilogram per hectare basis and the price of wheat in dollars per kilogram.

The cost incurred from the production of wheat was calculated through equations previously utilized in other studies involving the WGS Model (Rodriguez et al., 1990b). Annual cost from the production of wheat ($/ha) was calculated as follows:

$$(4.3) \quad CW = 115.72 + 0.0081 * GY + 0.0044 * (GY - 544)$$

where CW represents the total cost of wheat production ($/ha) and 115.72 is a constant which depends upon land preparation techniques implemented, fertilization levels, and planting density. The last two terms in the equation represent hauling and harvesting costs that vary with the level of grain yield.

Beef Production Costs and Revenues

The computation of annual gross returns ($/ha) to the producer from the production of beef were based upon the product of ending stocker weight, which was output from the animal growth portion of the WGS Model, and stocking density, which was a management input parameter required for the WGS Model. Final stocker weight was a function of the amount of wheat forage production during the grazing season and the quality of the supplemental feed provided during periods of low wheat forage availability.

The price received for stockers at the end of the grazing season varied as an inverse function of final stocker weight. This price was based on data from the Oklahoma City Livestock Market for March feeder cattle. Thirteen year average prices expressed in 1988 dollars for weight classes ranging from 450 to 900 pounds (204.12 to 408.20 kilograms) were converted to metric equivalents and used to assign prices for specific ending stocker weights. A series of equations was developed for inclusion in the economic subroutine to compute a stocker price ($/kg) based upon final stocker weight. This series of equations is presented in Table I. The equations in Table I calculate stocker selling price where PSS is the stocker price received ($/kg) and LWT is the final stocker weight (kg/hd). Once the appropriate stocker price ($/kg) was determined, returns for each animal ($/hd) could be calculated. The product of revenue per head ($/hd) and the stocking density (hd/ha) resulted in the return from beef production on a per hectare basis($/ha).

The cost associated with the beef enterprise portion of a wheat grazing system is a function of stocking density, the length of the grazing season, prices of various services and inputs, and the amount of supplemental feed provided for stockers. Beef production cost calculations for the economic subroutine of WGS were based upon published cost estimates for a typical dryland wheat grazing operation of 100 or more head of stockers in western Oklahoma with a grazing season of 135 days (Oklahoma Cooperative Extension Service).

The largest cost incurred in the beef enterprise is the purchase of stockers before the beginning of the wheat grazing season. This cost was calculated as the product of beginning stocker weight (kg/hd) and beginning stocker price ($/kg). The beginning stocker price was assumed to be a constant for the purposes of this research. The price was input as $2.053/kg ($93.12/cwt) which was the thirteen year average price expressed in 1988 dollars for 204 kg (450 lb) October stockers at the Oklahoma City Livestock Market. The beginning stocker weight was treated as a management input parameter and was also held constant throughout this study at 204.0 kg (450 lb) which was the average beginning weight for wheat pasture stockers according to a recent survey of Oklahoma wheat producers (Walker et al., 1988).

TABLE I

STOCKER SELLING PRICE EQUATIONS

Stocker Weight kg (lbs)	Corresponding Price Equation
204.12 - 249.48 (450 - 550)	PSS = 2.190 + ((-0.0031526) * (LWT - 204.12))
249.48 - 294.84 (550 - 650)	PSS = 2.047 + ((-0.0027116) * (LWT - 249.48))
294.84 - 340.20 (650 - 750)	PSS = 1.924 + ((-0.0013007) * (LWT - 294.84))
340.20 - 408.20 (750 - 900)	PSS = 1.865 + ((-0.0013668) * (LWT - 340.20))

Stocker selling costs included such items as commission, yardage, inspection, brucellosis testing, and beef promotion check-off. Marketing costs for this study were calculated as follows:

(4.5) $CMKT = 0.03784 * LWT$

where CMKT represents stocker marketing costs ($/hd) and LWT is ending stocker weight (kg/hd).

Transportation costs directly involved with the transferring of stockers to and from the wheat pasture were also specified to vary as a function of stocker weight. Transportation costs were calculated as:

(4.6) $CHAUL = 0.0077 * (LWT + LWTO)$

where CHAUL represents stocker transportation costs ($/hd), LWT is ending stocker weight (kg/hd), and LWTO is beginning stocker weight (kg/hd).

Producers were assumed to borrow the amount of operating capital necessary to finance the original stocker purchase at the beginning of the grazing season for the entire length of the season. A fourteen day lead time for stocker purchase before the grazing season was assumed to allow producers time to process stockers and acclimate them to their new environment. Considering these assumptions, operating capital costs were calculated with the following equation:

(4.7) $COPCAP = (CPUR) * ((GDAYS + 14) * I/365)$

where COPCAP represents operating capital costs for the beef enterprise ($/hd), CPUR is the stocker purchase cost ($/hd), GDAYS is the length of the grazing season (days), and I is the annual interest rate which for this study was input as 12 percent.

All labor costs for the beef enterprise were assumed to be variable costs which exhibited economies of size over certain ranges of enterprise scope and/or input use. For computation purposes, labor costs were divided into two separate categories. These categories were machinery and equipment labor and livestock labor.

Machinery and equipment labor costs for the beef enterprise encompassed labor which involved the utilization of machinery and equipment to provide supplemental feed to stockers during periods of low wheat forage production. An average quantity of supplemental feed (175.45 kg/hd - 386 lb/hd) was used to allocate labor costs associated with the beef enterprise. This value was obtained from published extension service information concerning the budgeting of variable and fixed costs encountered by Oklahoma wheat producers (Oklahoma Cooperative Extension Service). Machinery and equipment labor costs were computed through the series of cost equations presented in Table II. These equations were applied on the basis of the quantity of supplement fed during the grazing season.They calculate labor costs associated with supplemental feeding where MELABOR represents machinery and equipment labor costs ($/hd), HAYFED is the total amount of supplemental feed provided during the grazing season (kg/ha), and SD is the stocking density (hd/ha).

Machinery and equipment labor costs were calculated under the assumption that economies of volume existed in the hay feeding process. An increase/decrease in the quantity of hay fed relative to the average, up to a 50 percent change, resulted in a decrease/increase in per unit labor costs. Labor costs per unit were changed at the rate of 0.4 percent for every one percent change in hay feed. A change away from the base quantity of hay fed of more than 50 percent did not result in any additional change in labor costs per unit of hay fed.

TABLE II

MACHINERY AND EQUIPMENT LABOR COST EQUATIONS

Total Hay Fed (kg/ha)	Corresponding Cost Equation
less than 87.73	MELABOR = 0.041311 * (HAYFED/SD)
87.73 - 263.17	MELABOR = (0.041311 - (0.0000785 * ((HAYFED/SD) - 87.72)))*(HAYFED/SD)
greater than 263.17	MELABOR = 0.02754 * (HAYFED/SD)

Livestock labor costs for this study were considered to be those costs involving the routine inspection and general supervision of the stockers while they were utilizing the wheat pasture. An average stocking density of 1.2 hd/ha (0.49 hd/ac) was used to allocate these labor costs on a per hectare basis. The equations presented in Table III were used to calculate total livestock labor costs as stocking density varied. These equations calculated livestock labor costs where LSLABOR represents livestock labor costs ($/hd) and SD is stocking density (hd/ha). These figures were based on published data concerning wheat grazing costs (Oklahoma Cooperative Extension Service).

Economies of volume were also assumed to exist in the calculation of livestock labor costs on a per stocker basis. An increase/decrease in stocking density relative to the average, up to a 50 percent change, resulted in a decrease/increase in labor costs on a per head basis. Labor costs per head were changed at the rate of 0.4 percent for every one percent change in stocking density. Any movement of more than 50 percent above or below the average stocking density of 1.2 hd/ha (0.49 hd/ac) did not have any additional effect upon per head labor costs.

The next major cost component involved the purchase cost of supplemental feed for use in periods of unfavorable wheat growth conditions. This cost component was examined in two major subdivisions: hay that was purchased and stored before the beginning of the grazing season, and hay which was purchased during the grazing season to meet forage shortfalls. The amount of hay cost allocated to the beef enterprise in any grazing season was a function of the amount of supplemental hay actually fed to stockers during that grazing season and the amount of dry matter storage loss. Dry matter storage loss due to environmentally related deterioration encountered during the grazing season and as a result of storing any excess hay stocks through the

TABLE III

LIVESTOCK LABOR COST EQUATIONS

Stocking Density (hd/ha)	Corresponding Cost Equation
less than 0.6	LSLABOR = 7.72
0.6 - 1.8	LSLABOR = 7.72 - (2.1467 * (SD - 0.6))
greater than 1.8	LSLABOR = 5.15

summer months for possible use during the next grazing season were considered. The amount of hay fed to stockers during the grazing season was a function of the amount of supplement required to meet stocker nutrient requirements for maintenance and targeted growth given wheat forage availability and the amount of supplement that was wasted due to inefficiencies in the feeding process. As discussed earlier, hay deterioration was assumed to be a function of precipitation levels.

The supplemental feed for this study was assumed to be Sudan grass hay with nutrient levels of: 8 percent crude protein ; 1.18 Mcal/kg of net energy available for maintenance ; and 0.61 Mcal/kg of net energy available for gain. These nutrient levels were treated as input parameters for the WGS Model. If simulation data is desired for production which uses another type of supplemental feed, the changing of the input parameters for these three nutrient values would be sufficient to achieve the desired results.

The occurence of either low wheat forage availability levels or snow cover could prompt the provision of supplemental feed to stockers during the wheat grazing season. Stocker nutrient needs and potential intake of supplement were calculated (kg/ha) on a daily basis. This value was used as a base for determining the amount of hay to be fed to each stocker on days in which there was a shortfall in wheat forage availability. A waste factor was used in combination with this value to obtain the final amount of daily supplement fed. The waste factor utilized for this study reflected an expected 20% loss of supplement dry matter associated with the feeding of large round bales under typical management conditions (Personal communication with animal scientists at Oklahoma State University).

Costs associated with the supplemental feeding and dry matter deterioration loss of stored hay stocks acquired before the beginning of the wheat grazing season were determined on the basis of the ten year average October hay price for Oklahoma. This price was calculated from the USDA price series for the average price received by Oklahoma farmers for all hay and was \$0.0683/kg (\$61.96/ton) (Trapp, 1988).

The calculation of the costs associated with the utilization of hay stocks acquired after the beginning of the grazing season was more complex. A monthly hay price series for the months October through March was incorporated within the model. This price series was used in the calculation of the cost associated with additional hay purchases during the grazing season based on the month of purchase. This price series was based on the ten year average monthly index for the Oklahoma all hay price data (Trapp, 1988). The monthly average price index (October - March) was adjusted upward by one standard deviation to account for the fact that during times of low wheat forage production local hay prices were likely to be somewhat above the mean due to an increased need for supplemental hay by all wheat pasture producers. The price was also adjusted upward to reflect the transportation and search costs involved in finding and moving the hay to the location of wheat pasture for use. This resulted in the price series which is presented in Table IV. A review of the price series indicates that compared to the \$0.0683/kg (\$61.96/ton) price for initial purchases of hay to store, the purchase price of additional hay during the grazing season ranged from 22 to 33 percent higher depending on the month of purchase.

This price series assumed that hay prices were higher during periods of low wheat forage availability. However, prices were not correlated directly to wheat pasture in the sense that hay price was not related to the severity of the wheat forage shortfall. In order to consider the possibility of a direct correlation between wheat pasture conditions and hay prices, sensitivity tests correlating

TABLE IV

MONTHLY HAY PRICE SERIES

Month	Price ($/ton)	 ($/kg)
October	75.56	0.0833
November	78.88	0.0870
December	81.45	0.0898
January	82.46	0.0909
February	81.90	0.0903
March	79.20	0.0873

hay prices with wheat pasture output data from the WGS Model will be conducted later in this study. A new hay price series operating on the assumption of perfect correlation between hay price and wheat pasture conditions will be developed and used later in this study to gauge the impacts of hay price upon supplemental forage stock decisions.

The month of hay purchase was determined within the WGS Model as the first date during the grazing season on which low wheat forage availability (or snow cover) and lack of stored hay stocks combined to necessitate the purchase of hay to meet stocker nutrient requirements. Once the need for the purchase of additional hay stocks was established, the producer was required to purchase hay stocks which were sufficient to provide stockers with supplement for the remainder of the grazing season. It was assumed that the producer could accurately forecast his hay needs for the remainder of the grazing period and made all of his purchases at one point in time. The producer was required to make additional hay purchases on a truck load integer basis which usually resulted in purchases slightly above the amount of supplement required to finish the grazing season. These excess stocks were then held in storage for utilization in subsequent years.

The amount of dry matter loss from hay stocks purchased during the grazing season was also accumulated for each grazing season. The cost of this quantity of hay deterioration was also allocated based upon the adjusted price index series. After a total cost figure, including both hay fed to stockers and deterioration losses, was obtained for both stored and purchased hay, the total annual hay costs to the beef enterprise for the grazing season were calculated as the sum of these two sub-totals.

The total operating cost to the producer for the beef enterprise was calculated within the WGS Model as a composite of all the previously discussed variable costs and a fixed cost component which included veterinary, medical, and feed costs incurred during the fourteen day processing period before the beginning of the grazing season and other fixed stocker costs such as salt and minerals provided during the grazing season. Total stocker costs (\$/ha) were calculated as follows:

$$(4.8)\quad CS = SD * (CPUR+CMKT+CHAUL+CTOTSUP+MELABOR+ LSLABOR + CFIX + COPCAP)$$

where CS represents total stocker costs (\$/ha), SD is stocking density (hd/ha), CPUR represents stocker purchase cost (\$/hd), CMKT is stocker marketing cost (\$/hd), CHAUL is stocker transportation cost (\$/hd), CTOTSUP includes total supplement costs (\$/hd), MELABOR and LSLABOR are the labor costs (\$/hd) associated with machinery and equipment operation and livestock care, CFIX is the fixed cost component (\$/hd), and COPCAP represents the operating capital cost (\$/hd) associated with financing the original stocker purchase.

Net Returns to Wheat and Stockers

The calculation of net returns to the producer for both the beef and grain enterprises was accomplished by taking the difference between revenue obtained through the sale of the two products and their associated production costs. A total net revenue for the wheat grazing system was then obtained by summing the net revenues from the beef and wheat enterprises.

The current version of the WGS Model prints an annual budget detailing several of the revenue and cost values for the total production system as well as on an enterprise specific basis. A schedule detailing the purchase, storage, and utilization of hay stocks in the hay inventory system is also available on an annual basis. Examples of WGS budget and hay inventory output are presented in Tables V and VI, respectively.

TABLE V

AN EXAMPLE OF ANNUAL BUDGET OUTPUT FROM THE WGS MODEL

Year = 50 Stocking Density (hd/ha) = 1.2
Target Hay Storage Level (kg/ha) = 700

Net Revenue ($/ha) :
Total = 330.64 Wheat = 236.50 Beef = 94.14

Wheat Enterprise:

Grain yield (kg/ha) =3984.37
Price received ($/kg) = 0.10
Gross revenue ($/ha) = 399.61
Total cost ($/ha) = 163.13

Beef Enterprise:

Final stocker weight (kg/hd) = 296.80
Stocker weight gain (kg/hd) = 92.80
Price received ($/kg) = 1.92
Gross revenue ($/ha) = 684.34
Total cost ($/ha) = 590.20
Stocker purchase weight (kg/hd) = 204.00
Price paid ($/kg) = 2.05
Stocker purchase cost ($/hd) = 419.93
Marketing cost ($/hd) = 11.23
Transportation cost ($/hd) = 3.86
Livestock labor ($/hd) = 6.43
Machinery & equipment labor ($/hd) = 0.78
Operating capital cost ($/hd) = 18.62
Hay cost ($/hd) = 1.70

TABLE VI

AN EXAMPLE OF HAY INVENTORY OUTPUT FROM THE WGS MODEL

```
Year                        = 50     Target hay storage (kg/ha)       = 700
Stocking density (hd/ha)    = 1.2    End of grazing season (Julian)   =  67

Annual Totals (kg/ha):
Total hay used              =  30.32
Total hay fed               =  18.93
                  account #1            =  0.00
                          #2            =  0.00
                          #3            =  0.00
                          #4            =  18.93
Total hay deterioration     =  11.39
                  account #1            =  3.57
                          #2            =  6.43
                          #3            =  0.00
                          #4            =  0.00
Hay lost to feeding waste   =  3.79

Inventory  (kg/ha):
Hay remaining in storage after grazing season        =  669.68
                                          account  #1              =  12.88
                                                   #2              =  23.22
                                                   #3              =  25.59
                                                   #4              =  607.99
Hay purchased prior to grazing season                =  16.45

In-Season Hay Purchases (kg/ha):
Hay Purchased during grazing season  =  0.00
                   hay fed           =  0.00
                   hay deterioration =  0.00
Date of Purchase (Julian)            =   0

Account Definitions:
#1 = hay purchased in current year
#2 = hay purchased one year ago
#3 = hay purchased two years ago
#4 = hay purchased three or more years ago
```

CHAPTER V

PROCEDURES AND RESULTS

The modified version of the Wheat Grazing Systems Model (WGS Model) described in the preceding chapter was used to analyze the effects of stochastic weather conditions, dry matter deterioration in stored hay stocks, feeding waste, and hay prices upon the optimal level of supplemental hay stocks to be held under alternative stocking densities for Oklahoma wheat grazing systems. Simulation output from the WGS Model for key biological and climatological factors of production will be presented in the first part of this chapter to identify the sources of production uncertainty which are encountered in the management of winter wheat grazing operations in western Oklahoma. The remainder of the chapter will focus upon the presentation of results from the analysis of the key questions addressed by this study.

Biological and Other Basic Output

Oklahoma producers who utilize wheat grazing systems face many problems which can be traced to the variability in production outcomes. Much of this variability is associated with the uncertain weather patterns which exist during the typical winter wheat grazing season in Oklahoma. This uncertainty is addressed in the WGS Model through the incorporation of a stochastic daily weather simulator. In an effort to illustrate the stochasticness of weather and its impact upon wheat forage production, grain yield, and net revenue from grain production, several key WGS output variables were examined for a grain production only system over a fifty year production period. The subsequent impacts of stochastic forage production and weather upon beef production will be examined in later sections.

Daily Rainfall

The first output variable to be examined was cumulative daily rainfall. The model started simulation for each year of the production period on Julian day 172 (June 21). This date was chosen to accommodate the initiation of the soil water balance routine included in CERES-Wheat. (See Chapter II.) Cumulative rainfall data (measured in millimeters) output from WGS was obtained on a daily basis over a simulated fifty year production period for western Oklahoma. The annual period which was examined started on Julian day 172 (June 21), continued through the wheat production period and ended on Julian day 171 (June 20) of the following year. The fifty year average cumulative rainfall during the production year was 782.97 mm/year (30.83 in/year) with a standard deviation of 157.65 mm (6.21 in). The fifty year daily cumulative rainfall averages along with the depiction of the range from one standard deviation above the mean to one standard deviation below the mean are presented in graphical form in Figure 3.

Extractable Soil Water

The next output variable examined was potentially extractable soil water which is a measure of the soil moisture available for plant use within the soil profile. Potentially extractable soil water (also referred to as plant extractable soil water) in the soil profile is calculated within the WGS Model as total soil water in the profile minus total water at the lower limit of extractable soil water

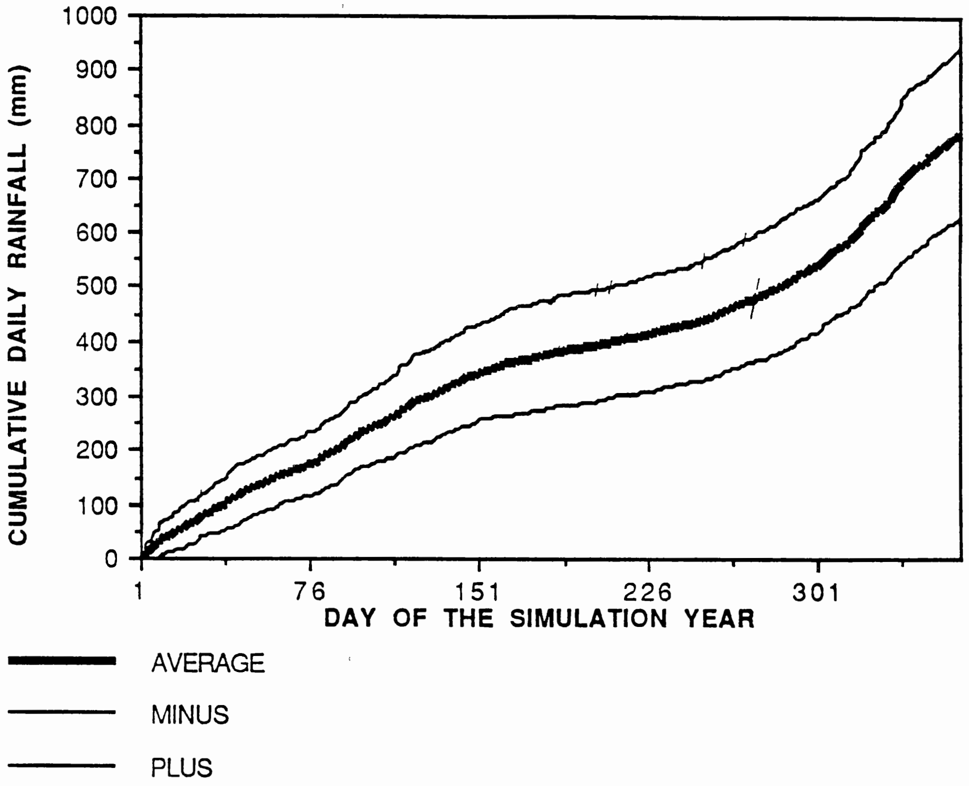

Figure 3. Cumulative Daily Rainfall

(Ritchie and Otter, 1985). As was the case with cumulative rainfall, the calculation of potentially extractable soil water began on Julian day 172 (June 21) and continued through Julian day 171 (June 20) of the following year (i.e., the ending value for potentially extractable soil water from the previous year had no effect on the calculations for the following year).

The data point characterized by the highest fifty year average for potentially extractable soil water was Julian day 334 (November 30) with a value of 19.78 cm (7.71 in) and a standard deviation of 4.65 cm (1.81 in). The highest daily standard deviation was experienced on Julian day 148 (May 28) with a value of 6.37 cm (2.48 in). Fifty year daily averages for potentially extractable soil water are presented in graphical form in Figure 4 with the range of one standard deviation above and below the mean also depicted.

Wheat Plant Dry Matter Growth

Cumulative daily dry matter growth during the growing season was also examined. The input parameter for the sowing date was Julian day 262 (September 19). With this in mind, the earliest date on which above ground biomass, which was the basis for the measurement of cumulative above ground dry matter for the wheat plants, was simulated occurred on Julian day 266 (September 23) with an average dry matter accumulation of 0.02 kg/ha (0.018 lb/ac) and a standard deviation of 0.13 kg/ha (0.12 lb/ac).

The calculation of fifty year averages for dry matter production during the wheat growing season was complicated by the occurrence of variable harvest dates. The harvesting date for wheat grain is variable in the WGS Model and is a function of the phasic development or maturity of the wheat plant which is in

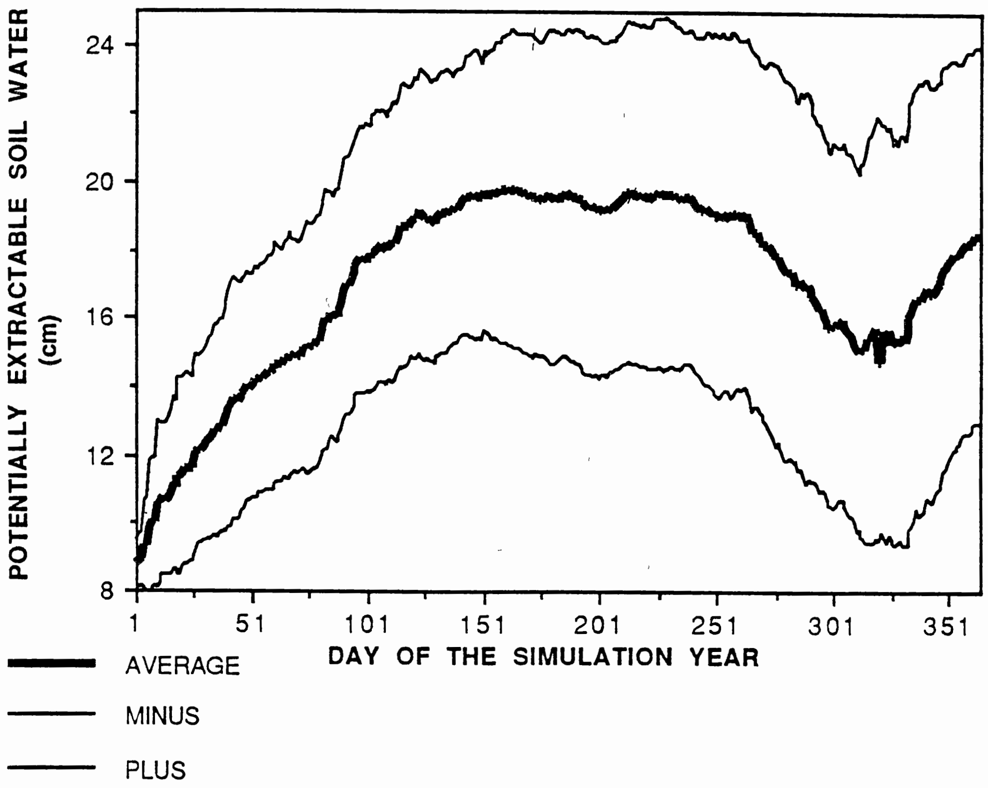

Figure 4. Potentially Extractable Soil Water

turn a function of many biological and climatological factors affecting wheat growth and development. The latest harvesting date occurrence during the fifty year production period was Julian day 154 (June 3) with a final cumulative dry matter value of 2864.50 kg/ha (2556.71 lb/ac). The earliest harvest date recorded was Julian day 132 (May 12) which occurred in two production years with an average ending dry matter for the two years of 8903.23 kg/ha (7946.58 lb/ac). The calculation of average daily dry matter values after this date treated the data from production years in which harvest had already occurred as nonexistent data points (i.e., they were not treated as data points of zero dry matter when calculating the mean). In contrast, the calculation of the average daily cumulative dry matter for the early days of the growing season, which in some years experienced no above ground dry matter production, included the absence of dry matter as a value of zero. The latest date for the first appearance of above ground dry matter was Julian day 329 (November 25) with a dry matter production of 0.96 kg/ha (0.86 lb/ac). A graph representing the fifty year average cumulative daily dry matter production along with the range of one standard deviation above and below the mean is depicted in Figure 5.

Grain Yield and Net Returns

The last two basic output variables to be examined in a wheat grain production only setting were grain yield and net returns to the producer. Grain yield in the absence of grazing over the fifty year simulation period ranged from 899.57 kg/ha (13.38 bu/ac) to a high yield of 4903.96 kg/ha (72.95 bu/ac) with a mean yield of 3322.96 kg/ha (49.43 bu/ac) and a standard deviation of 1019.34 kg/ha (15.16 bu/ac). The high and low net revenues over the fifty year

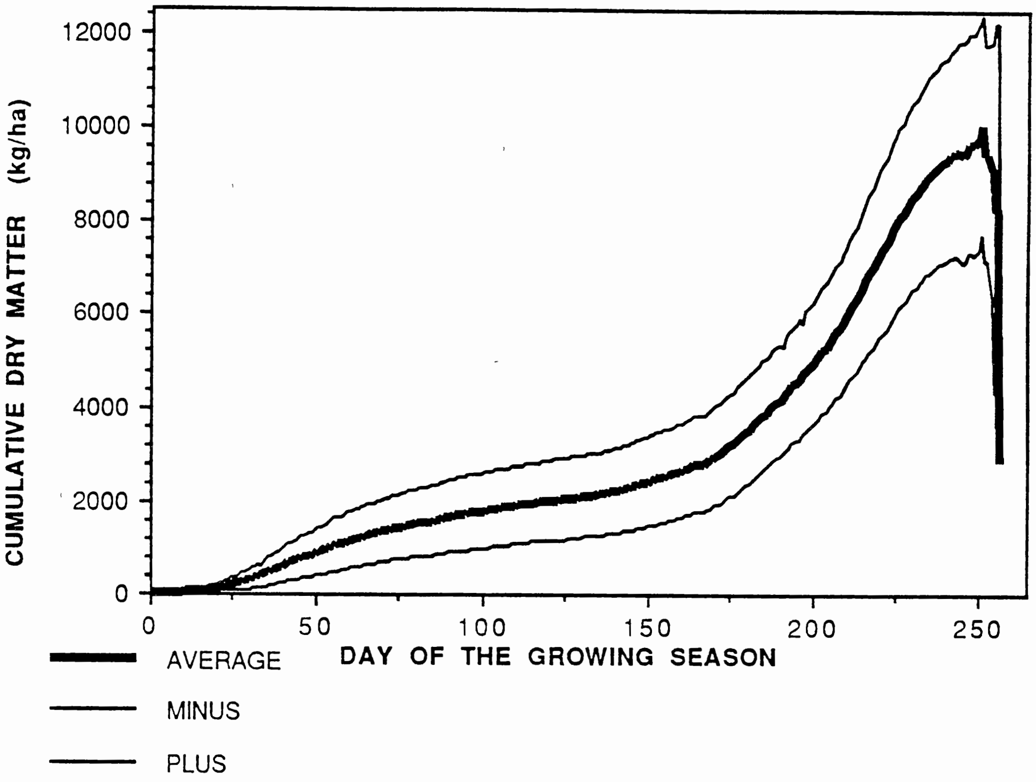

Figure 5. Cumulative Daily Dry Matter

production period corresponded to their counterparts in grain yield with a range of - $34.35/ha (- $13.91/ac) to $317.22/ha ($128.43/ac). Only two negative net revenue years were experienced. The average net revenue from grain production was $178.41/ha ($72.23/ac) with a standard deviation of $89.49 /ha ($36.23/ac). The results for grain yield and net revenue for the production of wheat grain only over the fifty year period are presented in tabular form in Table VII.

Beef Production and Net Returns

An additional set of basic WGS output was generated to analyze the stochasticness of beef production and returns. This data set was obtained under the assumption of a "typical" stocking density and grazing season length (i.e. grazing from November 8 to March 8 with a stocking density of 1.2 hd/ha (0.49hd/ac)) (Walker et al., 1988). Supplemental feed consisting of sudan grass hay was fed as needed.

Over the fifty year simulation period, beef production, measured as the difference between ending stocking weight and beginning stocker weight, ranged from a low of 41.00 kg/hd (90.39 lb/hd) to a high of 94.40 kg/hd (208.11 lb/hd). Average simulated beef production was 88.79 kg/hd (195.75 lb/hd) with a standard deviation of 11.45 kg/hd (25.24 lb/hd). The high net revenue figure for the beef enterprise was $98.48 /ha ($39.87/ac), while the low value was $40.65/ha (-$16.46 /ac). Average net revenue from beef production was $81.43/ha ($32.97 /ac) with a standard deviation of $29.17/ha ($11.81/ac). Data for beef production and associated returns is presented in Table VIII.

The relationship between ending stocker weight and the amount of supplemental forage fed during the grazing season was also analyzed. A

TABLE VII

ANNUAL GRAIN YIELD AND NET RETURNS IN THE ABSENCE OF GRAZING

Year	Yield (kg/ha)	Net Revenue ($/ha)	Year	Yield (kg/ha)	Net Revenue ($/ha)
1	1145.71	-12.74	26	2531.68	108.94
2	3074.82	156.63	27	2405.86	97.90
3	3626.61	205.07	28	4434.17	275.97
4	2252.88	84.47	29	3602.77	202.98
5	3989.13	236.90	30	4283.38	262.73
6	3575.64	200.60	31	4172.31	252.98
7	3471.80	191.48	32	1879.21	51.66
8	4609.08	291.33	33	1468.35	15.59
9	1352.91	5.45	34	2228.19	82.30
10	3071.04	156.30	35	4699.38	299.26
11	3654.75	207.54	36	2468.60	103.40
12	3515.80	195.34	37	1657.39	32.18
13	2556.50	111.12	38	2880.85	139.60
14	4903.96	317.22	39	2024.26	64.39
15	3230.99	170.34	40	3255.28	172.47
16	2853.02	137.15	41	3539.52	197.43
17	3479.53	192.16	42	4023.82	239.95
18	4466.39	278.80	43	3894.35	228.58
19	3865.30	226.03	44	4103.47	246.94
20	3168.43	164.85	45	4042.93	241.62
21	4564.31	287.40	46	3974.13	235.58
22	899.57	-34.35	47	3335.91	179.55
23	3520.08	195.72	48	4377.51	271.00
[illegible]	4574.06	288.25	49	3034.21	153.06
25	4190.83	254.61	50	4217.30	256.93

Grain Yield:			Net Revenue:		
	Mean	3322.96		Mean	178.41
	Std. Dev.	1019.34		Std. Dev.	89.49

TABLE VIII

ANNUAL BEEF PRODUCTION AND NET RETURNS FOR A TYPICAL WHEAT GRAZING OPERATION

Year	Beef Production (kg/hd)	Net Revenue ($/ha)	Year	Beef Production (kg/hd)	Net Revenue ($/ha)
1	52.10	-32.23	26	64.15	-5.65
2	105.01	62.34	27	111.47	86.86
3	108.[illegible]	78.65	28	108.24	79.19
4	110.02	85.93	29	109.80	87.68
5	111.71	92.29	30	112.35	92.66
6	109.48	88.68	31	109.71	88.33
7	107.15	84.36	32	110.77	91.40
8	110.77	92.46	33	108.02	86.99
9	110.65	92.52	34	112.23	95.10
10	107.40	84.52	35	112.39	96.58
11	90.61	53.74	36	110.87	93.57
12	110.03	88.64	37	109.57	89.94
13	110.56	90.91	38	104.79	83.92
14	110.52	91.66	39	112.97	98.48
15	106.57	81.12	40	106.50	83.87
16	102.98	79.57	41	109.52	89.40
17	110.69	93.08	42	108.64	87.60
18	110.86	92.71	43	112.87	92.13
19	107.83	85.31	44	111.58	96.69
20	111.48	94.93	45	110.23	92.16
21	112.87	98.37	46	109.99	91.43
22	48[illegible]	-40.65	47	109.98	91.29
23	110.35	80.04	48	111.15	93.86
24	111.39	85.85	49	112.30	97.80
25	110.06	85.04	50	110.99	94.14

Beef Production:			Net Returns:	
	Mean	106.19	Mean	81.43
	Std. Dev.	13.74	Std. Dev.	29.17

graph depicting this relationship is presented in Figure 6. This figure indicates that as the amount of supplemental hay fed during the grazing season increases ending stocker weight decreases. This reflects the fact that wheat forage is of higher nutritional quality than the Sudan grass hay which was used as the source of supplemental forage. Thus, in years of low wheat forage production (i.e., high levels of supplementation), stockers are unable to attain the desired level of ending weight. Irregularities found in Figure 6 reflect the fact that the amount of animal growth is affected by factors other than the amount of supplemental forage fed during the grazing season. Differences in the timing of supplemental feedings and subsequent wheat forage production were a major cause of these irregularities. Another factor affecting animal growth is temperature range during the grazing season which affects feed intake.

Net Returns from Beef and Wheat

Data pertaining to net returns from the beef enterprise, grain enterprise, and the entire wheat grazing operation for a fifty year simulation under a "typical" western Oklahoma management strategy is presented in Table IX.
Total net revenue for the combined beef and grain enterprises ranged from a low of -\$87.80/ha (\$35.55/ac) to a high of \$371.15/ha (\$150.26/ac). Average total net revenue was \$232.40/ha (\$94.09/ac) with a standard deviation of \$104.36/ha (\$42.25/ac). Net revenue from the grain enterprise was \$150.97/ha (\$61.12/ac) with a standard deviation of \$86.01/ha (\$34.82/ac). Net revenue figures for the beef enterprise were identical to those presented in the previous section on beef production with an average of \$81.43 /ha (\$32.97/ac) and a standard deviation of \$29.17/ha (\$11.81/ac).

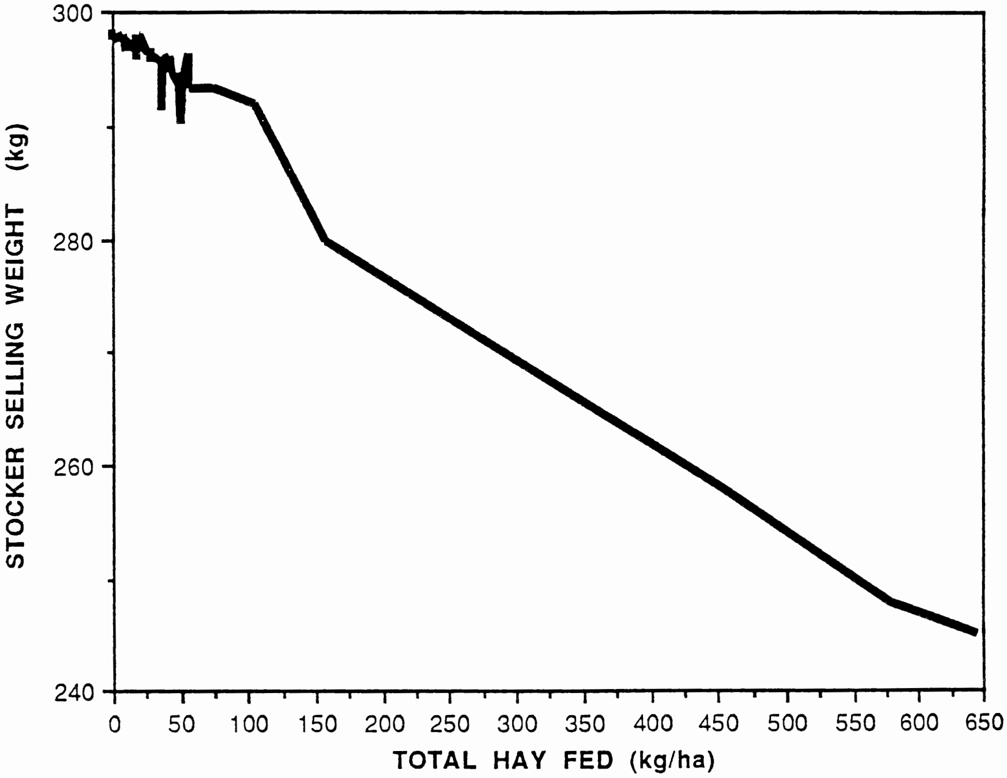

Figure 6. Stocker Selling Weight

TABLE IX

ANNUAL NET RETURNS BY ENTERPRISE FOR A TYPICAL WHEAT GRAZING OPERATION

Year	Wheat ($/ha)	Beef ($/ha)	Total ($/ha)	Year	Wheat ($/ha)	Beef ($/ha)	Total ($/ha)
1	-14.28	-32.23	-46.51	26	3.82	-5.65	-1.82
2	138.46	62.34	200.80	27	82.36	86.86	169.21
3	185.51	78.65	264.15	38	250.33	79.19	329.51
4	72.08	85.96	158.04	29	186.93	87.68	274.61
5	207.25	92.29	299.54	30	213.02	92.66	305.68
6	166.12	88.68	254.80	31	233.15	88.33	321.47
7	132.75	84.36	217.11	32	42.06	91.40	133.47
8	253.91	92.46	346.37	33	11.42	86.99	98.41
9	5.05	92.52	97.57	34	64.25	95.10	159.35
10	135.93	84.52	220.44	35	266.64	96.58	363.22
11	92.45	53.74	146.19	36	67.18	93.57	160.75
12	191.89	88.64	280.53	37	-5.93	89.94	84.01
13	172.62	90.91	263.53	38	103.08	83.92	187.00
14	279.49	91.66	371.15	39	46.44	98.48	144.93
15	145.04	81.12	226.16	40	150.70	83.87	234.57
16	98.16	79.57	177.74	41	145.87	89.40	235.28
17	171.15	93.08	264.23	42	211.95	87.60	299.55
18	246.59	92.71	339.30	43	191.32	98.13	289.45
19	201.25	85.31	286.56	44	220.60	96.69	317.29
20	121.08	94.93	216.01	45	216.42	92.16	308.59
21	257.90	98.37	356.28	46	193.93	91.43	285.35
22	-47.15	-40.65	-87.80	47	153.77	91.29	245.07
23	189.89	[illegible]4	269.93	48	247.28	93.86	314.14
24	257.29	[illegible]35	343.14	49	135.30	97.80	233.10
25	219.75	85.04	304.79	50	236.48	94.14	330.62

Wheat Enterprise:		Beef Enterprise:	
Mean	150.97	Mean	81.43
Std. Dev.	86.01	Std. Dev.	29.17

Combined Enterprises:	
Mean	232.40
Std. Dev.	104.36

Using the coefficient of variation value to compare the variability in net returns for a wheat production only management scheme to the variability in net returns with the addition of a grazing component to the wheat production system yielded results similar to those found in previous studies (Rodriguez and Trapp, 1990; Rodriguez et al., 1990b). The coefficient of variation for total net returns for a system that did not utilize wheat forage for grazing purposes was 50.2 percent (Table VII). However, the coefficient of variation for total net returns for a system that included grazing at a stocking density typical of western Oklahoma operations was only 45 percent (Table IX). This indicates that the inclusion of a beef production enterprise in the wheat production system not only increases the level of net returns ($178.41/ha to $232.40/ha) but also lowers the variability of net returns in a relative sense. It is important to note that while stochastic beef prices were included in one of the previous studies (Rodriguez and Trapp, 1990) the issue of price risk in the beef market was not addressed in the current study.

Summary

Obviously, these five basic output variables experienced a great deal of variability over the fifty year simulated production period. However, almost all of the uncertainty present in the system can be traced back to the stochastic weather simulation through the biological interaction between wheat production and available moisture. Variability in rainfall, temperature, and solar radiation results in an uncertain wheat dry matter production and grain yield which become apparent to the producer in the form of variable net revenues from the production process.

Supplemental Feeding Waste

The utilization of large round bales of hay as a source of supplemental forage for stockers during periods of low wheat forage production presents some problems for production system managers in the form of forage wastage which occurs in the feeding process. The waste encountered with the feeding of large round bales of hay has been estimated to be higher than 20 percent of the forage dry matter that is made available to the animals (Personal communication with animal scientists at Oklahoma State University).

A 20 percent waste level causes a need for a 25 percent increase in hay purchases (i.e., 80 percent of 125 is 100). In other words, to effectively feed a net quantity of 100 units with 20 percent waste, one must feed 125 units. Furthermore, if feeding waste is compounded by hay deterioration over time, a 20 percent waste factor will necessitate a greater than 25 percent increase in initial forage stocks. Likewise, the feeding of a larger volume of hay will require the use of more labor and equipment. Thus, the calculus of determining the impact of waste upon feeding expense is not without complexity.

The WGS Model was employed in an attempt to quantify and analyze the economic impact that feeding waste has upon the cost of supplemental forage required for wheat grazing systems and the labor cost involved in the feeding process. Simulation data describing the effects of feeding waste upon net returns is summarized in Table X.

Results with Typical Stocking Rates

The WGS Model was utilized to obtain output data for fifty year wheat grazing production periods both with and without a feeding waste factor incorporated into the calculation of the required amount of supplemental forage.

TABLE X

SUPPLEMENTAL FEEDING EFFICIENCY

	Feeding Waste Percentage			
	0.0% Stocking Density		20% Stocking Density	
	1.2 hd/ha	2.4 hd/ha	1.2 hd/ha	2.4 hd/ha
	Supplemental Forage Fed (kg/ha)			
Mean	49.96	188.53	63.52	238.22
Standard Deviation	105.01	314.94	132.39	396.33
	Feeding Labor Cost ($/ha)			
Mean	1.68	5.59	2.12	6.98
Standard Deviation	2.87	8.52	3.60	10.74
	Hay Purchase Cost ($/ha)			
Mean	4.99	9.29	6.11	11.35
Standard Deviation	[illegible].31	8.56	7.69	10.44
	Net Revenue ($/ha)			
Mean	234.32	258.74	232.40	251.18
Standard Deviation	102.71	137.53	104.36	142.87

Output was obtained for a management scheme which included typical western Oklahoma management strategies of a stocking density of 1.2 hd/ha (0.49 hd/ac) and a grazing season which extended from November 8 to March 8. Results were derived under the assumption of perfect utilization of supplemental forage (i.e., no waste in the feeding process) as well as an assumed waste factor of 20 percent of the supplemental hay which was made available to stockers. The inclusion of the waste factor in the computation of required supplemental forage use resulted in an increase in hay fed from a fifty year average of 49.96 kg/ha (44.59 lb/ac) to 63.52 kg/ha (56.69 lb/ac) which was an increase of approximately 27 percent. The average annual purchase cost of supplemental forage stocks was found to increase by 22 percent. An increase was also experienced in the average labor cost associated with feeding the supplemental forage to stockers. This cost component increased by 26 percent. Average net revenue to the producer from the wheat grazing operation was found to decrease by nearly one percent from \$234.32/ha (\$94.87/ac) to \$232.40/ha (\$94.09/ac) with the introduction of the waste factor into the WGS Model.

Results with High Stocking Rates

Another management scheme was also used as input for WGS to analyze the effects of feeding waste. The average stocking density was doubled to 2.4 hd/ha (0.97 hd/ac) to quantify the effects of feeding waste upon wheat grazing operations which implemented management alternatives that placed more emphasis upon beef production. The resulting data indicated that the inclusion of the feeding waste factor of 20 percent increased the amount of annual average supplemental forage fed by approximately 26 percent from

188.53 kg/ha (168.27 lb/ac) to 238.22 kg/ha (212.62 lb/ac). The increases in average hay purchase cost and labor cost were found to be 22 percent and 25 percent, respectively. Average net revenue for the fifty year production period experienced a 3 percent decrease from $258.74/ha ($104.75/ac) to $251.18/ha ($101.69/ac).

Summary

These results indicate that feeding waste can have a definite impact upon the management decisions made by wheat-stocker producers. This impact is expected to be especially evident in systems where high stocking rates are used. These producers can expect a significant increase in supplemental forage requirements, feeding related costs, and a decrease in average net returns due to inefficiencies which exist in the process of feeding supplemental forage in the form of large round bales of hay.

Differences observed in the percentage effects of the waste factor upon the output variables examined were attributable to a variety of factors. The apparent discrepancy across percentage effects of the feeding waste factor between hay fed during the grazing season and purchase cost can be explained by the fact that the purchase cost figure was not calculated solely on the basis of the quantity of hay fed. This calculation was based on the combination of hay fed and the quantity of dry matter deterioration losses encountered during the season. The small discrepancy between the percentage increase in the amount of hay fed and associated labor costs was due to the economies of volume which were assumed to exist in the hay feeding process.

Target Supplemental Forage Stocks

The utilization of large round bales stored outside and unprotected as the source of supplemental forage is another aspect of wheat grazing systems that presents some interesting dilemmas to the managers of these systems. The dry matter deterioration and negative price consequences which wheat grazing system managers may encounter as a result of acquiring and holding a level of supplemental forage stocks which is too high or too low increase the importance of the decision as to what level of forage stocks to hold. A major objective of this study was to evaluate various decision rules concerning the level of supplemental forage stocks to maintain for the typical western Oklahoma wheat grazing operation.

The WGS Model was adapted to allow for the evaluation of hay inventory strategies through the incorporation of equations to determine the dry matter deterioration of hay stocks in the form of large round bales and a system of hay accounts which were organized on the basis of hay quality and age. (See Chapter IV for a description of this adaptation.) This adapted version of WGS was used to simulate fifty year production periods in western Oklahoma under two different stocking densities. These stocking density values were combined with an array of decision rules concerning the total quantity of supplemental forage stocks to be held before the start of each winter wheat grazing season. These decision rules, or target hay stock levels, were compared on the basis of average annual net revenue to the producer from the combined beef and wheat enterprises over fifty production periods. The variability associated with these net revenue outcomes was also examined.

Supplemental Forage Stocks with Typical Stocking Rates

The first set of management combinations to be examined included a stocking density of 1.2 hd/ha (0.49 hd/ac) in combination with eleven different target supplemental forage stock levels ranging from 0.0 kg/ha to 700 kg/ha (624.79 lb/ac). The utilization of a management scheme involving a target hay stock level of 0.0 kg/ha required the producer to buy all supplemental forage which was needed at the higher price series that was used to calculate the cost of hay purchased during the grazing season. (See Chapter IV for a description of this price series.) A target hay stock level of 700.0 kg/ha (624.79 lb/ac) was high enough to provide adequate supplies of supplemental forage to avoid making hay purchases during the grazing season when hay prices were higher. Budget and hay inventory output was obtained from the WGS Model for each of the eleven hay storage levels considered. The average net revenues, in-season hay purchases, and total hay deterioration values for the combined beef and wheat enterprises and their associated standard deviations for the eleven management schemes with a stocking density of 1.2 hd/ha (0.49 hd/ac) are presented in Table XI and also Figure 7.

The average net revenues for these management schemes ranged from \$232.40/ha (\$94.09/ac) for a target storage level of 700.0 kg/ha (624.79 lb/ac) to \$233.04/ha (\$94.35/ac) for a target storage level of 175 kg/ha (156.20 lb/ac). The standard deviations for these revenue values ranged from \$107.76/ha (\$43.62/ac) in the absence of pre-grazing season hay storage to a low of \$104.36/ha (\$42.25/ac) for the highest target storage level examined, 700.0 kg/ha (624.79 lb/ac). The change in average net revenue for the eleven target hay storage levels from the lowest to the highest result was less than 0.3

TABLE XI

NET RETURNS, IN-SEASON HAY PURCHASES, AND HAY DETERIORATION WITH TYPICAL STOCKING RATES

Target Hay Storage (kg/ha)	Annual Net Revenue ($/ha) Mean	Annual Net Revenue ($/ha) Std. Dev.	In-Season Hay Purchases (kg/ha) Mean	In-Season Hay Purchases (kg/ha) Std. Dev.	Total Hay Deterioration (kg/ha) Mean	Total Hay Deterioration (kg/ha) Std. Dev.
0	232.73	107.76	59.32	133.64	6.20	5.08
87	232.97	107.56	31.95	120.45	11.70	4.14
131	232.84	107.31	27.73	110.31	18.63	5.17
3	232.75	170.43	25.79	104.59	20.92	6.28
175	233.04	107.18	23.87	98.84	21.89	7.83
196	232.93	107.07	22.75	594.19	23.65	8.81
218	232.95	106.91	21.55	89.09	24.85	10.09
262	232.93	106.54	18.77	78.50	27.16	12.95
350	232.92	105.95	13.48	57.70	30.53	18.32
525	232.73	107.89	4.34	23.24	37.89	29.87
700	232.40	104.36	0.00	0.00	45.21	40.24

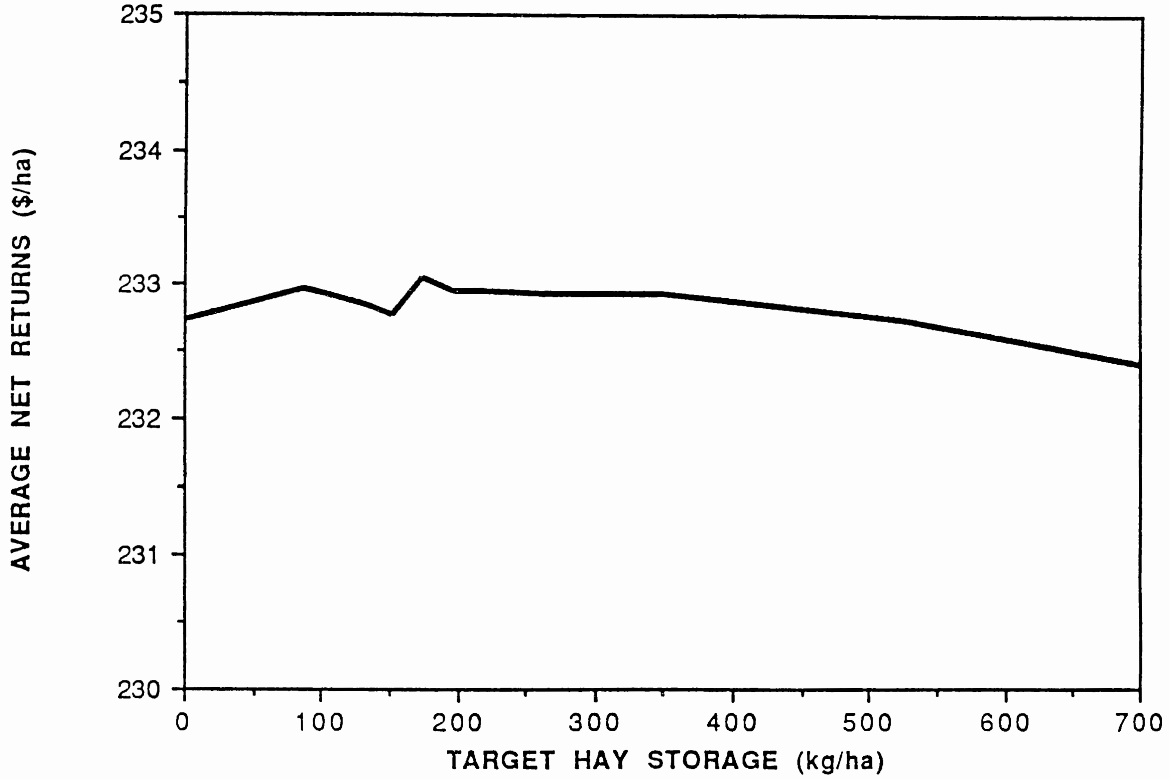

Figure 7. Average Net Returns With Typical Stocking Rates

percent which is not a significant change in outcome for the management changes which were implemented. The variability associated with these net revenue values did decrease over the entire range of data as the target hay storage level was increased. However, the total percentage decrease from highest standard deviation to the lowest was only 3.2 percent. The decreased level of variability associated with the higher target hay storage levels could potentially benefit those producers who place a high priority upon risk aversion during the decision making process.

The differences in net revenue associated with changing management strategies can be attributed completely to changes in net revenue from the beef enterprise. Within the beef production enterprise, changes in average net revenue could be traced solely to changes in costs computed in the supplemental forage sub-component of the WGS Model. Two factors in this sub-component worked to change the costs. First, changing levels of supplemental forage costs could be attributed to the varying quantities of high-priced hay stocks purchased during the grazing season as opposed to hay purchases made prior to the beginning of the season. Secondly, total hay deterioration changes as beginning hay stocks are adjusted. Higher beginning hay stocks require reduced purchases of higher priced hay during the grazing season, but they increase the amount of hay deterioration encountered.

The stability of the profit figures generated over the eleven targeted hay stocks indicates that the market for hay in Oklahoma tends to place the proper value upon hay supplies during the winter months. Any price saving that the producer receives for purchasing supplemental forage before the beginning of the grazing season is neutralized by the dry matter deterioration losses which these stored forage stocks incur as large round bales are exposed to precipitation and other environmental factors. Irregularities present in Figure 7 are indicative of the fact that in some cases an increase in the targeted hay storage level did not result in an increase in the number of years when in-season hay purchases were not required. Thus the producer's net returns were not improved or may even have decreased with a relatively small increase in the targeted level of hay storage.

Supplemental Forage Stocks with High Stocking Rates

Another set of supplemental forage stock levels were analyzed with the stocking density at 2.4 hd/ha (0.97 hd/ac). Eleven supplemental forage strategies were included in this analysis with targeted hay stock levels ranging from 0.0 kg/ha to 1750 kg/ha (1561.96 lb/ac). As with the previous analysis, these target hay storage levels varied from requiring all supplemental forage to be purchased during the season to requiring the purchase of all additional supplemental forage prior to the beginning of the wheat grazing season. However, this analysis did differ in the fact that the three highest hay stock levels implemented resulted in the purchase all supplemental forage requirements prior to the grazing season. Budget and hay inventory output from the WGS Model was obtained for these management strategies over a fifty year production period using a typical western Oklahoma wheat grazing operation as the basis to determine input parameter values. These results are summarized and presented in Table XII and Figure 8.

The fifty year average net revenue for these management alternatives ranged from $231.40/ha ($93.68/ac) for a target hay storage level of 0.0 kg/ha to $251.76/ha ($101.93/ac) for a target level of 1640 kg/ha (1463.78 lb/ac). This increase represents an increase in average net revenue of approximately 9 percent from high to low result. Thus, they indicate that the quantity of

TABLE XII

NET RETURNS, IN-SEASON HAY PURCHASES, AND HAY DETERIORATION WITH HIGH STOCKING RATES

Target Hay Storage (kg/ha)	Net Revenue ($/ha) Mean	Net Revenue ($/ha) Std. Dev.	In-Season Hay Purchases (kg/ha) Mean	In-Season Hay Purchases (kg/ha) Std. Dev.	Total Hay Deterioration (kg/ha) Mean	Total Hay Deterioration (kg/ha) Std. Dev.
0	231.40	194.66	238.87	400.67	9.88	10.41
7	236.08	193.05	194.17	388.14	11.73	8.99
175	239.88	189.46	159.58	362.87	22.24	10.23
437	244.38	178.76	102.25	279.36	59.82	27.21
875	249.67	160.08	39.28	158.44	110.75	60.23
1312	250.92	148.73	12.96	58.27	148.35	79.49
1531	251.66	144.45	2.95	17.39	158.10	88.68
1590	251.72	143.62	1.15	8.20	160.88	91.41
1640	251.76	143.06	0.00	0.00	162.95	93.40
1690	251.18	142.87	0.00	0.00	165.54	94.81
1750	251.29	143.05	0.00	0.00	168.51	96.96

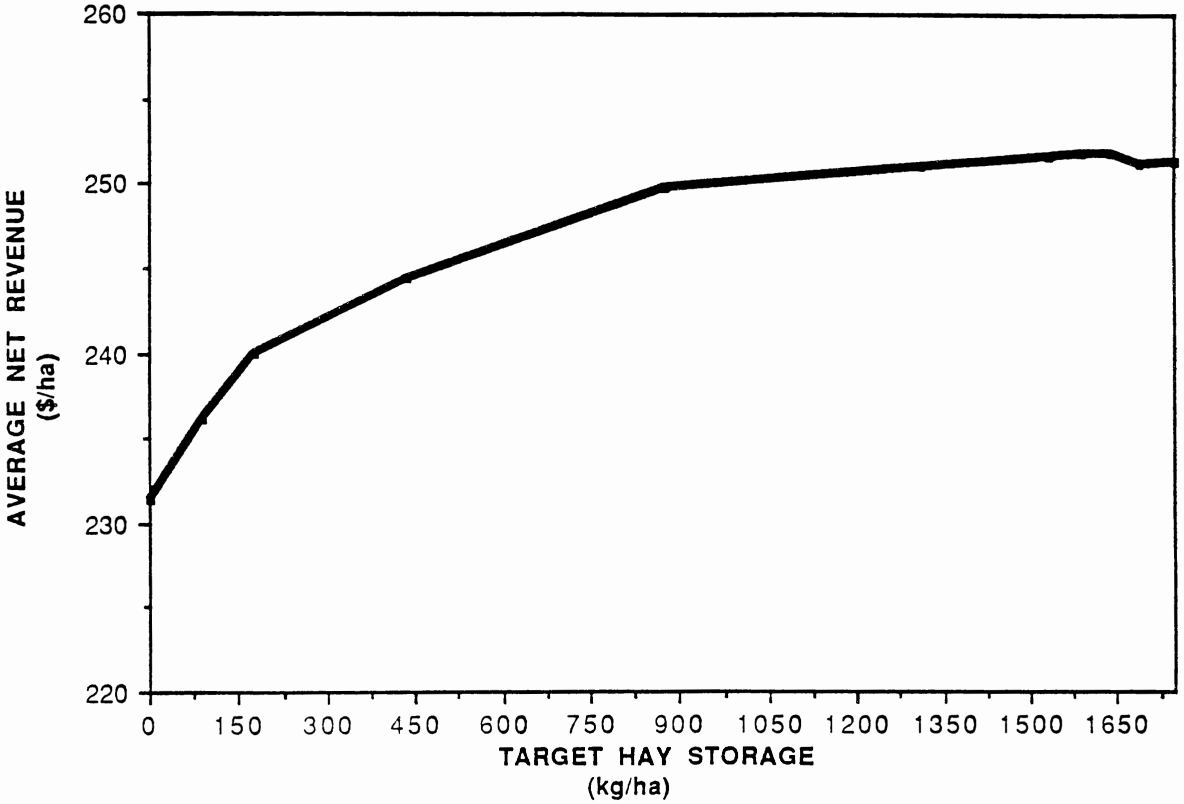

Figure 8. Average Net Returns With High Stocking Rates

supplemental forage stocks which are maintained can be an important decision factor for wheat grazing systems in which relatively more emphasis is placed upon beef production. These results also indicate that with increased stocking density the maintenance of supplemental forage stocks which meet stocker needs during a high percentage of possible production situations will result in higher average producer net revenues than the maintenance of low levels of supplemental forage stocks. In addition, the decrease in average net revenue which occurs with target storage levels higher than 1640 kg/ha (1463.78 lb/ac) indicates that the storage of supplemental forage quantities which are beyond the level which is required during the grazing season will not increase net returns to the producer.

The variability associated with these average net revenue values ranged from $194.66/ha ($78.81/ac) for a target level of 0.0 kg/ha to $142.87/ha ($57.84/ac) for a target of 1690 kg/ha (1508.41 lb/ac) which is a decrease of over 26 percent. This decreased level of revenue variation associated with the maintenance of higher quantities of supplemental forage stocks indicates that for producers who wish to decrease revenue variation the importance of targeted hay storage levels is increased dramatically under scenarios which utilize higher stocking densities. It is interesting to note that increasing the targeted hay storage level beyond the level which met stocker needs during all wheat grazing season outcomes did not decrease the variability associated with average net revenue and, in fact, when the target level was increased from 1690 kg/ha (1508.41 lb/ac) to 1750 kg/ha (1561.96 lb/ac) the standard deviation for the population of annual net revenues increased from $142.87/ha

($57.84/ac) to $143.05/ha ($57.91/ac). This is likely attributable to the increased volatility in the total quantity of hay deterioration associated with larger hay stocks.

These results indicate that the importance of supplemental forage stocks and producer decisions concerning the level of these stocks increases substantially as stocking density levels are increased. The potential for increased average net revenues and decreased variability associated with those revenues as targeted hay storage levels are changed indicates that careful consideration of the questions concerning supplemental forage stocks may yield significant benefits to producers in the form of increased revenues and reduced revenue uncertainty.

Hay Price Sensitivity

The previous section contained economic results which were calculated using the hay price series incorporated into the economic sub-routine of the WGS Model. (See Chapter IV for details.) This price series assumed no direct correlation between wheat pasture conditions and hay price. The WGS price series also contained values which were calculated on the basis of a limited amount of market data. Many areas of possible improvement were evident.

First, this price series was based upon data which covered a time period which was substantially shorter than the time period for which production outcomes were simulated. Second, the assumption of placing a cap on hay prices of one standard deviation above the mean also impacted greatly upon the previous analysis due to the fact that years for which the greatest quantity of supplemental forage purchases was required were also likely to be those years in which hay price was substantially above this one standard deviation limit.

Both of these characteristics seemed to fail to capture the relationship between hay market conditions and periods of low wheat forage production.

Stochastic Hay Pricing Model

With these shortcomings in mind, an attempt was made to develop a stochastic hay pricing model that reflected a correlated relation between local hay prices and wheat pasture conditions. The stochastic model developed was based upon King's methodology for correlating non-normally distributed variables (King, 1979; Trapp, 1989). In the application of King's model made here, perfect correlation between hay price and wheat pasture conditions is assumed. This likely overstates the true correlation. The scope of this study did not permit the true correlation to be ascertained. It is however felt that the stochastic model developed here by assuming perfectly correlated hay prices and wheat pasture conditions is more realistic than the assumption of the preceding section which assumed hay prices to always be one standard deviation above the seasonal price pattern whenever wheat pasture was poor enough to require supplemental forage. Comparison of the results of this hay pricing approach with perfect correlation and those of the previous model with nearly zero price correlation will provide two sensitivity test extremes from which to evaluate the impact of hay price correlation with wheat pasture conditions.

Implementation of King's procedure for correlating non-normally distributed random variables begins with the development of empirical cumulative distribution functions for the two variables in question. These are obtained by arraying a set of random observations for each variable in ascending order. Data used to represent random hay prices were the historical monthly all hay prices received by Oklahoma farmers from 1953 to 1989. This price series was deflated using the Consumer Price Index with October 1988 as the base month. These prices were also then adjusted so that their mean value was the same as the average seasonal hay price assumed in the preceding analysis using non-correlated hay prices. Following these transformations, the hay price data for each month were arrayed in ascending order for each of the months of October through March. According to King's procedure, the lowest price in the array is assigned a cumulative probability of zero and the highest price in the array is assigned a cumulative probability of one. All prices between these two values are assigned an equally likely chance of occurring. Thus, the cumulative distribution value assigned to each price ascends in equal increments with the increment size being equal to a value defined by the inverse of the number of the prices in the array minus one. The resulting distribution is presented in Table XIII. Note that this procedure does not make it impossible for the lowest or highest price to occur. Rather the lowest and highest prices have the same chance of occurring as any other price in the distribution. In principle, this array of values can now be used to assign a price to any randomly drawn cumulative distribution value between and including zero and one. Random cumulative distribution values drawn that fall between the cumulative distribution values assigned to each price are assigned prices by linearly interpolating between the two appropriate prices whose cumulative probabilities bracket the randomly drawn cumulative distribution value.

A similar procedure was followed to form cumulative distributions for wheat pasture conditions. These distributions were based upon supplemental hay purchases made by the WGS Model during the fifty simulations under a given stocking density and assuming a 20 percent feeding waste of hay. An example of this type of distribution is presented in Table XIV. Since the random number generator used in the WGS Model is a "pseudo random number

TABLE XIII

CUMULATIVE PROBABILITY DISTRIBUTION OF HISTORIC HAY PRICES

	Deflated Oklahoma Hay Prices ($/ton) 1953-89 [1\] (Julian Day Range of Each Month)					
	274	305	335	1	32	60
Cumulative	304	334	365	31	59	90
Probability	October	November	December	January	February	March
0.000	45.27	46.45	48.10	40.31	42.43	42.71
0.027	45.27	46.45	48.10	40.31	42.43	42.72
0.054	45.83	46.56	48.36	46.30	46.07	43.72
0.081	45.86	49.08	48.47	48.24	47.85	47.15
0.108	46.53	49.39	49.43	49.87	47.97	47.66
0.135	46.90	54.65	51.49	52.91	52.59	53.11
0.162	50.13	54.99	55.60	57.07	54.25	53.65
0.189	50.62	56.18	58.05	57.18	57.71	54.38
0.216	52.53	57.03	58.81	57.96	57.97	57.91
0.243	53.36	57.21	59.89	58.30	58.25	58.13
0.270	53.65	57.44	59.94	59.39	59.21	58.17
0.297	54.40	57.44	60.38	61.30	59.67	58.52
0.324	54.65	57.55	60.86	61.73	60.06	60.08
0.351	55.44	58.92	61.40	61.74	61.09	60.12
0.378	56.02	60.40	61.42	62.00	61.40	60.80
0.405	57.28	61.40	61.44	63.43	62.52	60.83
0.432	57.79	61.62	62.26	63.55	63.24	61.71
0.459	57.95	61.95	62.72	63.59	63.24	62.08
0.486	57.99	62.55	65.27	63.91	63.40	62.09
0.514	58.24	62.85	65.58	64.88	63.51	62.61
0.541	58.76	64.26	66.77	65.05	64.84	63.37
0.568	60.22	64.98	69.87	67.61	67.01	64.33
0.595	61.02	65.54	70.12	70.12	69.74	65.49
0.622	64.50	66.05	72.05	70.69	70.48	65.65
0.649	65.43	68.68	73.44	72.94	70.80	70.93
0.676	67.44	69.54	75.40	73.75	70.84	71.57
0.703	67.51	72.55	75.71	78.94	78.28	75.20
0.730	68.48	73.64	76.07	81.38	81.15	78.60
0.757	68.67	74.51	79.80	82.54	81.28	80.43
0.784	68.85	75.34	81.48	83.58	81.86	81.71
0.811	72.28	78.71	81.77	84.08	83.11	82.59
0.838	74.47	81.05	83.44	84.57	85.37	82.63
0.865	75.38	81.62	87.43	85.36	89.06	83.23
0.892	83.60	85.00	89.79	90.09	90.60	84.19
0.919	84.33	89.35	91.86	90.27	90.74	90.18
0.946	85.58	90.15	92.89	90.35	92.38	93.67
0.973	87.89	90.55	93.01	97.13	97.41	94.60
1.000	94.51	100.46	101.41	121.77	118.05	108.96

[1\] Prices reported here were adjusted so that their mean value for each month was the same as the average seasonal hay price reported in Chapter IV, Table IV.

TABLE XIV

AN EXAMPLE OF A CUMULATIVE PROBABILITY DISTRIBUTION BASED UPON IN-SEASON HAY PURCHASES

Cumulative Probability	Hay Purchases (kg/ha)	Year	Cumulative Probability	Hay Purchases (kg/ha)	Year
0.00	0.00	43	0.52	61.66	47
0.02	0.00	43	0.54	62.30	31
0.04	0.00	44	0.56	64.61	25
0.06	0.00	39	0.58	78.74	42
0.08	0.00	35	0.60	81.33	28
0.10	0.00	49	0.62	95.57	19
0.12	0.00	21	0.64	99.06	3
0.14	22.10	17	0.66	99.08	10
0.16	22.96	5	0.68	122.35	40
0.18	23.31	14	0.70	132.04	37
0.20	23.63	20	0.72	164.37	15
0.22	24.10	8	0.74	183.93	41
0.24	42.84	34	0.76	201.59	2
0.26	43.13	13	0.78	203.93	6
0.28	43.88	24	0.80	273.45	46
0.30	46.91	27	0.82	374.33	36
0.32	44.40	45	0.84	680.64	29
0.34	44.96	50	0.86	691.17	16
0.36	46.43	90	0.88	749.32	38
0.38	[illegible]	30	0.90	823.01	11
0.40	47.45	18	0.92	830.16	33
0.42	48.83	48	0.94	841.19	7
0.44	60.04	23	0.96	1353.52	26
0.46	60.97	4	0.98	1560.04	1
0.48	61.10	12	1.00	1593.48	22
0.50	61.20	32			

generator", it will generate the exact same sequence of random numbers in each simulation run. Thus, supplemental forage requirements will be the same for each year from run to run as long as stocking density is held constant. Changing the targeted level of hay stocks will change the amount of additional purchases during the grazing season, but not the ranking of supplemental forage needs by year. Thus, the location of each simulated year within the cumulative distribution of supplemental forage requirements can be predetermined.

Assuming that the largest supplemental forage requirement year is associated with the highest hay price year, and vice versa, allows hay prices and wheat pasture conditions to be correlated and a unique hay price ascribed to each year and each month within that year. The procedure used to achieve this correlation is very straightforward. Once the cumulative probability of the wheat pasture condition for a given year is known, it is used to "look-up" a price in the cumulative hay price distribution that is associated with that probability. An example of results from the application of the above procedure is reported in Table XV for the case where a stocking density of 2.4 hd/ha (0.97 hd/ac) is used in combination with a targeted initial hay stock of 437 kg/ha (390.04 lb/ac). The first four columns of the table present data generated by the WGS Model. This data includes simulation year, quantity of in-season hay purchases, net revenue from the wheat grazing operation, and date of in-season hay purchase. The fifth column contains the cumulative probability assigned to each in-season hay purchase quantity. The remaining two columns contain the new hay price and the new net revenue value obtained from the substitution of the correlated hay price into equations used to calculate net returns to the producer.

TABLE XV

AN EXAMPLE OF RESULTS FROM THE STOCHASTIC HAY PRICE MODEL

(Target Hay Storage = 437 kg/ha; Stocking Density = 2.4 hd/ha)

Year	In-Season Hay Purchases (kg/ha)	WGS Net Revenue ($/ha)	Hay Purchase Date (Julian Day)	Cumulative Probability	New Hay Price ($/ton)	New Net Revenue ($/ha)
25	0.00	354.22	0	0.02	0.00	354.22
48	0.00	402.33	0	0.04	0.00	402.33
49	0.00	306.88	0	0.06	0.00	306.88
3	0.00	329.63	0	0.08	0.00	329.63
27	0.00	250.91	0	0.10	0.00	250.91
[illegible]	0.00	355.01	0	0.12	0.00	355.01
28	0.00	387.05	0	0.14	0.00	387.05
8	0.00	387.23	0	0.16	0.00	387.23
47	0.00	288.66	0	0.18	0.00	288.66
29	0.00	258.16	0	0.20	0.00	258.16
10	0.00	276.70	0	0.22	0.00	276.70
30	0.00	332.11	0	0.24	0.00	332.11
12	0.00	369.00	0	0.26	0.00	369.00
31	0.00	388.08	0	0.28	0.00	388.08
14	0.00	414.09	0	0.30	0.00	414.09
32	0.00	209.72	0	0.32	0.00	209.72
13	0.00	300.22	0	0.34	0.00	300.22
5	0.00	277.90	0	0.36	0.00	277.90
18	0.00	386.40	0	0.38	0.00	386.40
17	0.00	331.80	0	0.40	0.00	331.80
20	0.00	250.24	0	0.42	0.00	250.24
45	0.00	365.59	0	0.44	0.00	365.59
24	0.00	402.88	0	0.50	0.00	402.88
35	0.00	418.98	0	0.52	0.00	418.98
4	0.00	236.56	0	0.54	0.00	236.56
36	0.00	129.32	0	0.56	0.00	129.32
9	0.00	206.00	0	0.58	0.00	206.00
37	0.00	93.15	0	0.60	0.00	93.15
43	0.00	327.73	0	0.62	0.00	327.73
44	0.00	379.74	0	0.64	0.00	379.74
21	0.00	3.98	0	0.66	0.00	423.98
39	0.00	210.01	0	0.68	0.00	210.01

TABLE XV (Continued)

(Target Hay Storage = 437 kg/ha; Stocking Density = 2.4 hd/ha)

Year	In-Season Hay Purchases (kg/ha)	WGS Net Revenue ($/ha)	Hay Purchase Date (Julian Day)	Cumulative Probability	New Hay Price ($/ton)	New Net Revenue ($/ha)
2	0.00	267.11	0	0.70	0.00	267.11
40	0.00	284.12	0	0.72	0.00	284.12
46	0.00	247.44	0	0.74	0.00	247.44
41	0.00	216.78	0	0.76	0.00	216.78
23	0.00	339.15	0	0.78	0.00	339.15
19	0.00	338.34	0	0.80	0.00	338.34
6	0.00	251.14	0	0.82	0.00	251.14
42	0.00	344.54	0	0.81	0.00	344.54
16	289.51	47.33	10	0.86	85.22	42.45
38	297.51	45.30	20	0.88	88.01	39.38
11	404.96	-13.72	352	0.90	90.41	-23.00
33	429.51	-41.99	32	0.92	90.81	-52.61
7	442.58	64.12	37	0.94	92.02	52.58
26	935.66	-215.87	365	0.96	92.95	-239.92
11	112.00	-287.08	344	0.98	95.20	-318.41
22	1200.71	-345.55	344	1.00	101.41	-387.61

This method was used to calculate new annual net revenue figures for the fifty year production period for each of the 22 management strategies (i.e., eleven alternate targeted hay stock levels under two different stocking rates). These average net revenue figures for each management strategy and their associated variabilities are summarized in Tables XVI & XVII and Figures 9 & 10.

Results with Typical Stocking Rates

Those management strategies which included a stocking density of 1.2 hd/ha (0.49 hd/ac) resulted in average net revenues which ranged from \$231.41/ha (\$93.69/ac) for a target hay storage level of 0.0 kg/ha to \$232.52/ha (\$93.14/ac) with a target storage level of 525 kg/ha (468.59 lb/ac). The change in average net revenues resulting from the new hay price series tended to favor those management strategies which included higher target storage levels for supplemental forage, but the range among net revenues across management strategies remained relatively narrow. The new standard deviation values for the net revenues from these strategies ranged from a low of \$105.57/ha (\$42.74/ac) with a target storage level of 700 kg/ha (624.79 lb/ac) to a high of \$110.98/ha (\$44.93/ac) for a target storage level of 0.0 kg/ha which represents an increase of 5 percent as the target hay storage level varied from highest to lowest. Variability among net revenues was increased with the incorporation of the new hay price series versus the series used in the previous analysis, but not by a significant amount.

TABLE XVI

NET RETURNS WITH TYPICAL STOCKING RATES AND HAY PRICE CORRELATED WITH WHEAT PASTURE CONDITIONS

Target Hay Storage (kg/ha)	Annual Net Revenue Mean ($/ha)	Annual Net Revenue Std. Dev. ($/ha)
0	231.41	110.98
87	231.98	110.39
131	231.96	109.89
153	231.96	109.76
175	232.31	109.37
196	232.23	109.15
218	232.29	108.87
262	232.34	108.27
350	232.32	107.79
525	232.52	105.57
700	232.40	104.36

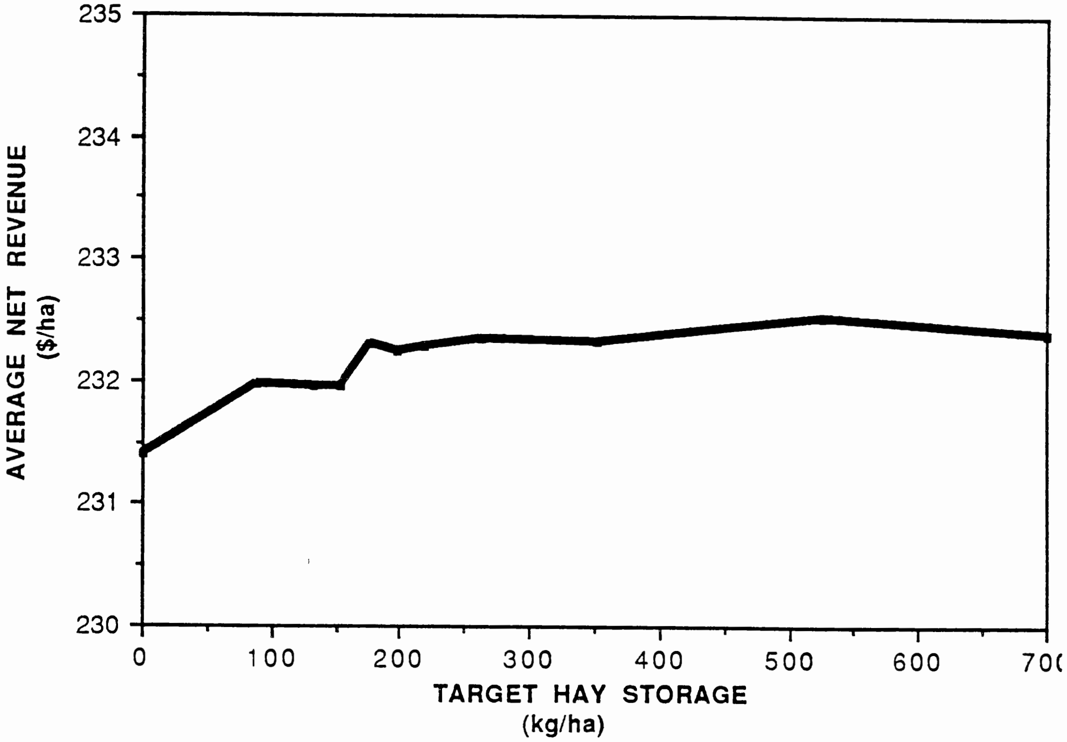

Figure 9. Hay Price Sensitivity Analysis For Typical Stocking Rates

TABLE XVII

NET RETURNS WITH HIGH STOCKING RATES AND HAY PRICE CORRELATED WITH WHEAT PASTURE CONDITIONS

Target Hay Storage (kg/ha)	Annual Net Revenue Mean ($/ha)	Std. Dev.
0	226.50	205.93
87	231.44	203.63
175	235.75	199.26
437	241.59	186.05
875	248.03	165.41
1312	250.33	150.58
1531	251.51	144.92
1590	251.67	143.79
1640	251.76	143.06
1690	251.18	142.87
1750	251.29	143.05

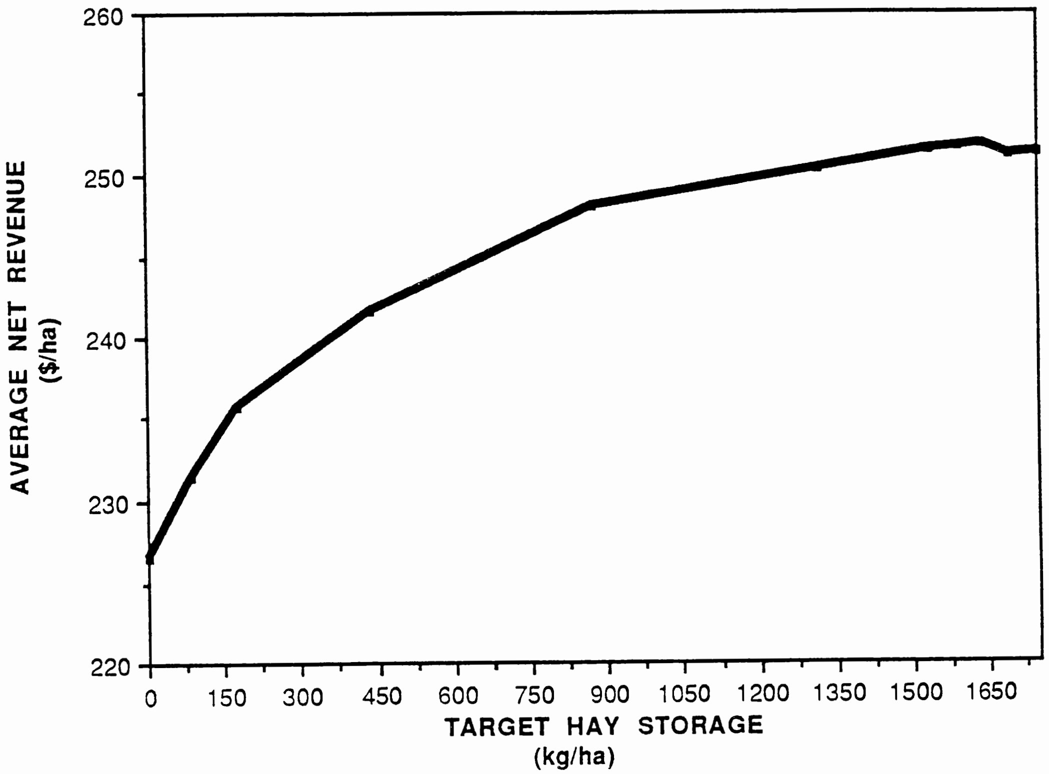

Figure 10. Hay Price Sensitivity Analysis For High Stocking Rates

Results with High Stocking Rates

Management strategies which included a stocking density of 2.4 hd/ha (0.97 hd/ac) produced new average net revenue values ranging from \$226.50/ha (\$91.70/ac) with a target hay storage level of 0.0 kg/ha to \$251.76/ha (\$101.93/ac) for a target hay storage level of 1640 kg/ha (1463.78 lb/ac). As expected, using the new hay price series in the calculation of average net revenue tended to favor those management strategies which employed higher target hay storage levels and also increased the influence which the target hay storage decision has upon net returns to the producer. The range from highest average net revenue to lowest average net revenue under the new hay price series increased to over 11 percent compared to 9 percent previously.

The variability associated with these higher stocking density management schemes was influenced greatly by the incorporation of the new hay price series. Standard deviations for annual net revenue varied from a low of \$142.87/ha (\$57.84/ac) with a target hay storage level of 1690 kg/ha (1508.41 lb/ac) to a high of \$205.93/ha (\$83.37/ac) for a target storage level of 0.0 kg/ha which was an increase of over 44 percent as the target storage level was lowered. Previously, this increase was found to be 26 percent. These figures tend to indicate that the high variability in net revenues experienced with higher stocking density management strategies makes them especially responsive to changes in hay price. The wide range in variability among target supplement storage levels also indicates that producers who seek to lower the variability associated with net revenues will prefer target supplement storage strategies which maintain higher levels of supplemental forage stocks. Under high stocking density management schemes, these high target storage levels not only lower the variability in returns, but also provide increased average net revenues to the producer from the combined grain and beef enterprises.

Conclusions

The comparison of wheat grazing system management strategies based upon stocking density indicates that lower stocking density schemes produce average net revenues which are lower in variability and reduce the importance of producer decisions regarding the level of supplemental forage stocks to maintain. The use of lower stocking densities also seemed to reduce the importance of hay price upon management decisions. However, higher stocking density schemes resulted in increased average net revenues. The increased variability associated with these higher revenues may be reduced to more acceptable levels through the maintenance of adequate levels of supplemental forage stocks. The implementation of higher stocking densities does require the manager to more closely monitor hay prices because of the increased impact of this factor upon producer net revenues.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The application of the Wheat Grazing Systems Model (WGS Model) to the objectives of this study provided some new insights into several of the complex problems faced by managers of dual beef and grain production ems in western Oklahoma. The primary objective of this study was to determine the optimal level of supplemental forage stocks with which to start the winter wheat grazing season given alternative stocking rates, uncertain weather conditions, and seasonal variations in hay prices associated with normal, as well as adverse, weather conditions. The achievement of this objective required an understanding of the impacts of weather upon a number of key dynamic wheat and animal growth relationships. To accomplish an erstanding of these relationships, a number of supporting objectives were also addressed.

The first supporting objective was to identify the dominant sources of uncertainty which exist within wheat grazing systems. The main focus of this objective was weather related uncertainties which could be traced to the variation encountered in annual precipitation and the resulting effects upon wheat forage production.

Another supporting objective of this study was to measure the effects that the forage waste incurred with the feeding of large round bales of hay has upon the quantity of supplemental forage required during the grazing season and upon net returns. A comparison of two levels of efficiency in the feeding process was the basis of this analysis.

The third supporting objective was to evaluate the effect that changing hay prices have upon the optimal or targeted level of supplemental forage stocks. This section of the analysis was intended to examine the effects that higher hay prices have upon the level of net returns to the producer and the variability associated with those returns under alternative stocking densities and targeted hay storage levels. Two hay price series were examined for their effects upon optimal targeted hay storage levels. The first price series ignored any possible correlation between hay price and wheat pasture conditions, while the second price series assumed perfect correlation between these two factors.

The Model and Procedure

A supplementary objective of this study was to highlight some of the major characteristics of the Wheat Grazing Systems Model developed by Rodriguez et al. This model consists of a wheat growth model, a stocker growth model, and a weather simulator. These three sub-models were integrated to assimilate the dynamic biological and technical properties of a wheat grazing operation under weather uncertainty.

The adaptation of the WGS Model to allow for the accomplishment of the aforementioned objectives was an important component of this study. The WGS Model was adapted to allow for the management of supplemental forage stocks based on targeted pre-grazing season hay storage levels. The effects of dry matter deterioration losses which are incurred with the storage and feeding of large round bales of hay were also incorporated into the model to more accurately depict the complex decisions which producers face with regard to the purchase, storage, and use of supplemental forage. Dry matter losses experienced with the storage of large round bales outside and unprotected were assumed to be a function of precipitation.

Since the optimal level of supplemental forage stocks was to be based upon average net returns to the producer, an economic subroutine was developed to determine the revenue and cost associated with both the beef and wheat enterprises. Wheat enterprise revenue was calculated as the product of stochastic grain yields and a constant wheat price. Production cost for the wheat enterprise was treated as a function of yield with both a fixed and variable component. Producer revenue from the beef enterprise was calculated on the basis of stochastic animal growth and a series of stocker price equations which resulted in stocker selling prices inversely related to stocker weight at the end of the grazing season. Costs related to beef production were determined through a series of cost equations relating cost to stocking density, animal weight, quantity of hay fed during the grazing season, and/or length of grazing season. Cost categories addressed included stocker purchase, marketing, transportation, labor, operating capital, supplemental forage, and a fixed cost component which reflected items such as veterinary, medicine, mineral, and other miscellaneous costs which remained constant on a per head basis.

Budget and hay inventory output from the WGS Model was generated for a "typical" western Oklahoma wheat grazing operation over fifty years given alternative targeted hay storage levels under both typical and high stocking density management schemes. The annual budget data was then used to compare targeted hay storage quantities on the basis of average annual net returns to the producer and their associated variabilities.

Summary and Results

A survey of the three sub-models of the WGS Model revealed some of the difficulties which are involved in trying to assimilate the dynamic interactions between weather, soil, wheat growth and phasic development, and animal growth which occur with the grazing of winter wheat. This survey also detailed which factors of the wheat grazing and grain yield process are addressed by the WGS Model.

A quick review of past research efforts which utilized the WGS Model provided an overview of the analysis techniques which have been used in conjunction with the model. This review may have also facilitated the development of concepts concerning the future application of WGS for economic analysis.

Model Adaptation

The presentation of details concerning the adaptation of the WGS Model to allow for the accomplishment of the objectives of this study provided insight into the diverse biological, technical, and economic relationships which must be accounted for in the decision making process. The complexities which confuse producer decisions concerning the optimal level of supplemental forage stocks to maintain prior to the beginning of the wheat grazing season were examined. The key topics discussed included: 1) dry matter deterioration losses and feeding wastage involved in using large round bales of hay as the source of supplemental forage; and 2) the effects of hay price variations in connection with decisions regarding the purchase of supplemental forage stocks before and during the grazing season.

Basic Model Output

Output data from WGS dealing with cumulative daily rainfall, potentially extractable soil water, and daily wheat plant dry matter as simulated over a fifty year production period indicated that variations in rainfall levels produce corresponding uncertainty in the amount of soil moisture available for plant use and the level of wheat forage production which results. The high levels of variability associated with these data indicated that they are a prominent source of the uncertainty which affects producer decisions within the wheat grazing system framework.

Supplemental Feeding Waste

The incorporation of a waste factor within the WGS Model to replicate the feeding waste that is experienced with the use of large round bales indicated that this is a significant source of concern for producers who choose this form of supplemental forage. The amount of supplemental forage required to meet stocker nutrient needs during periods of low wheat forage availability was found to increase by over one-fourth with the inclusion of the waste factor. The decrease in average net revenue to the producer due to feeding wastage was found to be approximately one percent under typical stocking density levels, but the negative impact of feeding loss increased to three percent with higher than normal stocking densities. These changes in net revenue were traced to increased hay purchase costs and increased labor costs associated with the feeding of supplemental forage. These results indicate that a substantial incentive exists for producers to find more efficient methods of feeding large round bales of hay.

Target Supplemental Forage Stocks

Management alternatives which varied with respect to the target level of supplemental forage stocks and stocking density were evaluated. The target level of supplement storage had relatively little effect upon average net revenue to the producer under management schemes which included the typical western Oklahoma stocking density (1.2 hd/ha - 0.49 hd/ac). The highest average net revenues for these schemes were associated with target storage levels which were substantially less than the 700 kg/ha (624.79 lb/ac) level which met stocker nutrient requirements under all possible production outcomes (e.g., 175 kg/ha - 156.20 lb/ac). However, these lower target supplement storage levels also produced net revenues which exhibited higher variability. The lowest variability in producer returns for the typical stocking density was experienced with the target storage level which covered supplemental feeding needs in all situations.

The application of the same analysis to management schemes which included a higher stocking density level (2.4 hd/ha - 0.97 hd/ac) produced very different results. Average net revenues from these strategies varied much more significantly. In contrast to results for the lower stocking density, the target storage quantity (1640 kg/ha - 1463.78 lb/ac) which covered all possible forage shortfalls produced the highest values for average net revenue to the producer. The variability of returns for the higher stocking densities was considerably higher than for the typical stocking density, but this variability was reduced significantly with the implementation of management schemes involving high storage levels of supplemental forage stocks.

Hay Price Sensitivity

An analysis which tested the sensitivity of each of the management alternatives under consideration to changes in hay price indicated that the price of hay has a definite effect upon the optimal level of supplemental forage stocks to maintain. A stochastic hay pricing model was developed which operated on the assumption that hay price was perfectly correlated to wheat pasture conditions. Thus, years in which a high level of supplementation was required to maintain targeted stocker growth rates were also years in which hay price was high. The correlation of hay price to wheat pasture condition was found to increase the variability of returns from management strategies which used lower storage levels for supplemental forage stocks under both high and low stocking densities. The change in hay pricing also produced results which tended to favor an increase in the target storage level for supplemental forage for both high and low stocking densities. In other words, high target supplemental forage stocks produced higher average net revenues and lower variability in returns than low target supplemental forage stocks under a scenario which correlated high hay prices with periods of low wheat forage availability. In general, management strategies with a higher stocking density exhibited more response to the change in hay pricing methods than those which used lower stocking densities.

Conclusions

Lower stocking density schemes produced average net revenues which were lower in variability and reduced the importance of producer decisions regarding the quantity of supplemental forage stocks to maintain prior to the grazing season. The use of lower stocking densities also reduced the impact that hay price changes have upon management decisions. Higher stocking density strategies resulted in increased average net revenues to the producer and much more variation among net revenues. Decisions concerning supplemental forage stocks also became much more important in terms of their effect upon average net revenues when higher stocking densities were utilized. While the implementation of management strategies involving higher stocking densities does require the producer to more closely monitor hay price variations, hay price effects can be minimized through the maintenance of large quantities of supplemental forage stocks. It was also evident that the higher variation in net returns encountered with high stocking densities could be reduced greatly by holding larger quantities of supplemental forage stocks.

The use of average net revenue as a decision rule for selecting the preferred management strategy would result in the selection of a strategy which includes a high stocking density and a high target storage quantity for supplemental forage stocks. Of course, not every manager would be willing to base their choice of a management strategy solely on the highest level of average net revenues. Many managers would be unwilling to accept the higher variability in net returns that accompanies higher stocker densities. They might also be unwilling to acquire and maintain the level of supplemental forage stocks which would be required to reduce the variability of net returns encountered with higher stocking densities.

Implications and Suggestions for Future Research

The procedure utilized in this study and the results obtained through the accompanying analysis hold many implications for future research into the economics of wheat grazing and other agricultural systems which utilize similar production methods. The application of the WGS Model and summary of its past uses presented in this study also raise many questions regarding its potential use in future research into the economic questions related to wheat grazing systems.

Limitations

The lack of data regarding the relationship between wheat pasture conditions and hay price was a major obstacle encountered in this study. As a result, two extreme examples of the correlation between wheat pasture conditions and hay price were examined (i.e., zero and perfect correlation). Further study to determine the relationship between wheat pasture conditions and hay price is needed to provide for a more thorough examination of management decisions regarding the purchase, storage, and use of supplemental forage in wheat grazing operations. Such a study would need to encompass actual historical local weather data and local hay prices.

The current version of the WGS Model restricts it to applications involving only limited changes in the start and/or beginning of the grazing season. The model is also limited in the range of stocking densities and other management input which may be accurately represented. This limitation of the model restricted the consideration of available management options during periods of low wheat forage production to one alternative, the purchase of quantities of supplemental forage adequate to meet targeted stocker nutritional requirements. The possibility of selling stockers during periods of low wheat forage availability or allowing stockers to lose weight in the absence of wheat forage and/or supplemental feed were not considered. The risk of not being able to purchase hay at even the highest price was also not considered in this study.

Current model limitations are due to a lack of research data from wheat grazing trials. Most previous research efforts concerning wheat grazing have focused mainly upon either wheat yield or animal gain, not a combination of the two factors. Past grazing trials have also for the most part been designed to examine a very narrow range of "typical" management inputs. Thus, a very limited amount of data is available regarding the effects of wheat grazing upon both wheat yield and animal growth.

Improvement and expansion of the potential applications of the WGS Model in the future will require data from grazing trials conducted under a variety of growing conditions and management strategies. Future research by agronomists and animal scientists should yield data which will allow the WGS Model to simulate a wider variety of wheat grazing options with greater precision than is currently possible.

Supplemental Forage Studies

The changes in net revenue to the producer which were found to exist under various management strategies regarding the purchase, storage, and use of supplemental forage stocks hold many implications for future research involving production systems which utilize some form of supplemental forage. The dry matter losses incurred with the storage of large round bales of hay and the supplement waste which occurs with the feeding of these large round bales raise interesting questions for researchers investigating other production systems which utilize supplemental forage to an even greater extent than the "typical" western Oklahoma wheat grazing operation.

Beef cow-calf enterprises are just one example of a production system which makes extensive use of supplemental forage stocks during periods of low forage production or periods when no forage growth occurs due to low temperatures, drought, or other unfavorable growing conditions. The application of techniques similar to the ones employed in this study could provide useful information to researchers and producers regarding the optimal level of supplemental forage stocks, supplement storage methods, and many other management decisions.

The analysis under weather uncertainty of the cost associated with improved hay storage methods versus the potential cost of dry matter deterioration losses from storing large round bales of hay outside and unprotected could provide useful management recommendations regarding hay storage alternatives for wheat grazing operations and other beef production systems. The comparison of the cost of supplement waste encountered in the feeding of large round bales to the cost of improved feeding methods might also provide useful information to the managers of these production systems. Increased efficiency in the supplemental forage feeding process could lead to increased producer returns.

Wheat Grazing Studies

A review of this study and previous applications of the WGS Model indicates the versatility of the model in analyzing economic questions pertaining to the grazing of winter wheat for the purpose of producing both grain and beef. The potential use of the model for the comparison of alternative production and marketing strategies is fairly evident. While management decisions involving changes in stocking density, supplemental forage stocks, and grazing season length have been the focus of previous studies, many other management input variables are potential candidates for future analyses involving the WGS Model. Future applications could examine such management decisions as stocker purchase weight, choice of supplemental forage, choice of wheat variety, seeding rate, and sowing date.

One of the most conspicuous areas for potential applications of the WGS Model is risk analysis. While previous studies have focused upon a few of the sources of risk associated with wheat grazing operations and have attempted to identify risk efficient sets of management alternatives, the potential is apparent for the application of the model to a variety of unaddressed risk analysis topics.

The WGS Model also has many possible applications as a policy analysis tool. The generalization of model results, which are on a per hectare basis, to much larger production areas allows the model to be used to obtain results on a whole farm or regional basis. Policies which affect the level of wheat grazing allowed or which affect the ratio of beef price to wheat price are examples of potential policies which could be evaluated.

Future Model Applications

Future adaptations of the WGS Model could provide for the incorporation of intra-season management flexibility. The implementation of this concept would allow the model to adjust various management input parameters in response to developments which occur during the grazing season. These adjustments could be made according to a set of decision rules which could be based upon the actions of typical or even ideal managers. For example, input parameters such as grazing season length and stocking density could be adjusted during the grazing season as a function of wheat forage production.

This action would allow the manager to avoid the high costs and negative net revenues associated with keeping stockers on wheat pasture during periods of unfavorable growing conditions. This characteristic of the model would also allow producers to take better advantage of high wheat forage production by increasing stocking density and/or grazing season length.

Expansion of the capabilities of the WGS Model could also lead to an increasing implementation of the model for policy analysis as a result of greater versatility. New data from wheat grazing trials should enable the model to analyze the impacts of policies which prohibit or allow for the grazing of wheat planted on set-aside acreage throughout the entire growing season which is not currently possible.

In the future, improved versions of the WGS Model could be used to examine many more characteristics of wheat grazing systems. These new versions should be better equipped to recommend management schemes for specific production regions or even specific farms which will allow producers to obtain a higher level of net returns from combined beef and wheat grain enterprises. A better understanding of the complexity of wheat grazing systems and the variables which affect their economic performance should be facilitated with the incorporation of a wider variety of the technical relationships between beef and grain production into the WGS Model.

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VITA

TOMMY JOE HONEYCUTT

Candidate for the Degree of

Master of Science

Thesis: OPTIMAL SUPPLEMENTAL FORAGE STOCKS FOR STOCHASTIC WHEAT GRAZING SYSTEMS

Major Field: Agricultural Economics

Biographical:

Personal Data: Born in Sallisaw, Oklahoma, November 17, 1964, the son of Mr. and Mrs. Leslie B. Honeycutt.

Education: Graduated from Stigler High School, Stigler, Oklahoma, in May 1982; received Associate Degree in Agriculture from Connors State College in May 1986; received Bachelor of Science Degree in Agricultural Education from Oklahoma State University in May 1988; completed requirements for the Master of Science Degree at Oklahoma State University in July, 1990.

Professional Experience: Graduate Research Assistant, August 1988 to June 1990, and Graduate Teaching Assistant, August 1988 to December 1988, in the Department of Agricultural Economics, Oklahoma State University.