EVALUATION OF SOY HULLS AS THE PRINCIPAL INGREDIENT IN A BEEF CATTLE RECEIVING RATION

A Dissertation
Presented to
The Faculty of the Graduate School
University of Missouri-Columbia

In Partial Fulfillment
of the Requirements for the Degree

Doctor of Philosophy

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by

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DECEMBER 2005

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EVALUATION OF SOY HULLS AS THE PRINCIPAL INGREDIENT IN A BEEF CATTLE RECEIVING RATION

Presented by Kija Bunyecha

A candidate for the degree of Doctor of Philosophy

And hereby certify that in their opinion it is worthy of acceptance.

Kevin C. Moore

Monty S. Kerley

M d Monson

DEDICATED AFFECTIONATELY

to my late mom

Sungulwa Maganya

who cared and loved me so much

ACKNOWLEDGEMENTS

This dissertation is a product of encouragement and sincere support from many people. First, I am indebted to my dissertation advisor, Dr. Kevin Moore, for his encouragement and guidance in helping me complete this study. His patience and inspiration helped me go through stressful moments. In the same spirit, I wish to extend my gratitude to my former academic advisor Dr. Melvin Blasé. He helped me get started on this dissertation.

Second, I would like to thank my committee members, Drs. Monty Kerley, Vern Pierce, Michael Monson and Joseph Parcell for their valuable constructive comments and suggestions. Dr. Monty Kerley played a major role in the execution of the experiment where the data for this study were obtained. I thank also my former committee members, Drs. Donald Van Dyne and Donald Osburn for their support during the early preparation of the study. I also extend my gratitude to Dr. Mark Ellersieck of the Department of Statistics for his comments and suggestions on the statistical analysis of the data.

Third, I thank the Farming System Research Project, Ministry of Agriculture, Tanzania for the financial support. In addition, the Black Studies Program at the University of Missouri-Columbia is appreciated for providing part of the financial support.

Last but not least, my deep gratitude goes to my family: my father, Bunyecha Masunga, brothers and sisters for their love and support. Above all, I would like to express my appreciation to my wife, Leticia, and my children for their endless support, encouragement and understanding.

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EVALUATION OF SOY HULLS AS THE PRINCIPAL INGREDIENT IN A BEEF CATTLE RECEIVING RATION

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ABSTRACT

Cattle evolved consuming forages. Adjusting cattle to grain based diets from predominately forage diets remains one of the production problems facing beef cattle producers. Despite years of experience, when cattle are introduced to grain based diets they have a tendency to experience health problems such as acidosis, founder, and bloat.

Past research has suggested that soy hulls are promising feed ingredients that can overcome the side effects cattle experience when started on feed. Recognizing the potential of this byproduct, the present study uses statistical and economic analysis methods to evaluate soy hulls (SH) as the principal variable ingredient in a beef cattle receiving ration.

Results of the study showed that weight and average daily gain of beef steers fed 0 % SH and 25 % SH were statistically similar throughout the feeding period. Results of economic analysis indicated that animals fed 0 % SH yielded slightly higher net benefits compared to animals fed 25 % SH. The difference in net benefits was attributed in part to higher cost of purchasing the animals for the animals fed 25 % SH. Feed costs for animals fed 0 % SH were slightly higher than those fed 25 % SH. Net befits per pound of gain for animals fed 25 % SH were slightly higher than those fed 0 % SH by the end of the trial period. Thus, adjusting net benefits by pound of gain showed 25 % SH as the

most economic ration compared to 0 % SH. Animals fed 50 % SH or 75 % SH performed poorly compared to those fed 0 % SH or 25 % SH both statistically and economically.

This study has demonstrated that a ration containing 25 % soy hulls is a potential alternative choice in the formulation of beef cattle receiving rations. Although the effects of a receiving ration containing 25 % SH on subsequent cattle performance in the feedlot phase is not known, the implications of this study both in the fed beef sector of the beef cattle industry and soybean crop enterprises includes: First, as soy hulls become part of an array of ingredients, the fed beef sector of the beef cattle industry will have greater flexibility of choosing ingredients for making receiving rations. Prices and availability of byproducts are not certain, therefore, if farmers have a wider choice it will help them adjust feed costs accordingly. Second, as farmers become responsive with the use of soy hulls, demand for soy hulls may increase, opening a market for soy hulls as the principal ingredient of beef cattle receiving rations. High demand for soy hulls could also increase its price which in turn could provide incentive to dehull more soybeans. Consequently, the soy hulls could become a driver of farm-gate soybean prices received by farmers, hence bringing an economic impact to the soybean crop enterprise.

CHAPTER 1

INTRODUCTION

1.1 The problem of starting cattle on feed

A major problem of the fed beef sector of the beef cattle industry is to get cattle started on feed. Beef cattle producers have a tendency to try to get cattle started on a high grain ration as quickly as possible so as to realize a return on their large investments in buying cattle, feed and facilities. Past research has shown that the faster cattle are moved to a high grain ration the better performance will usually be (Price, 1981).

Unless managed very carefully, when given a receiving ration, cattle experience side effects such as acidosis, founder, and bloat. Acidosis is the most important of these nutritional disorders and is caused by a rapid production and absorption of acids from the rumen when beef cattle are adjusted to a grain based diet or consume too much grain. Grain rations contain starch, which is broken down quickly by rumen organisms giving off lactic acid as a byproduct. For beef cattle that have been consuming mainly forage or roughages, there will be a very low population of bacteria that can utilize the lactic acid. Lactic acid can increase very rapidly in cattle abruptly moved to rations high in grain. The pH in the rumen of cattle eating forage or roughages will be about medium, but when abruptly moved to high grain rations it is drastically lowered. The presence of lactic acid, which lowers the pH, affects the animal's metabolism mechanism (Perry, 1980; Price, 1981; Klopfenstein and Owen, 1988).

In ruminants, acidosis is separated into two major forms: acute and chronic. Acute acidosis is recognized easily by cattle feeders. It causes the animal to stagger, fall, go into convulsions, and die if not timely attended. Chronic acidosis occurs more frequently, but is seldom recognized by the cattle feeder. The animal may even not appear sick and most recover on their own without any medical treatments. The major effect of chronic acidosis is reduced feed intake with an accompanying reduction in performance (Owen et al., 1984).

Founder prevalence is attributed with acidosis. As the rate of absorption of ruminal acids or glucose exceeds their rates of metabolism or excretion, these compounds can accumulate in blood and directly increase blood pressure which can damage the blood vessels inside the hoof of the animal. As a result, the animal's feet become tender, making it difficult for them to walk; this is because the hoof becomes engorged with blood, creating severe pain and pressure upon the sole of the foot (Price, 1981).

The other side effect is bloat which is caused by an accumulation of gas in the rumen. Gases are produced in the rumen as byproducts of microbial fermentation. Normally, the majority of fermentation gases are eliminated from the rumen via eructation. Eructation is a complex series of muscular contractions in which gas is forced from the rumen through the cardia and is released through the esophagus. Thus, bloat occurs when ruminal conditions prevent normal muscular contractions from occurring (Clarke and Reid, 1974). There are two types of feedlot bloat: free-gas bloat and frothy bloat. Feedlot cattle are susceptible to rumenitis, usually as a result of acidosis incidence. This may interfere with belching, resulting in free-gas bloat. Frothy bloat may develop as a result of the production of an insoluble slime by certain species of bacteria that proliferate in large numbers in cattle on a high carbohydrate diet.

Moreover, grain feeding has a negative associative effect on forage utilization. When grain and forage are fed to the animal together, the starch of the grain is rapidly digested depressing fiber digestion of the forage. This illustrates the dilemma of feeding grain and forage together. A diet having half grain and half forage mixture has very large negative associative effects (Klopfenstein and Owen, 1988).

1.1.1 An overview of the problem

Cattle are naturally grass eating animals. Thus, grain based diets are an unusual source of food. The rumen has a capacity sufficient to accommodate a large quantity of bulky forage normally consumed during grazing. Digestion of forage occurs over a relatively long period of time and is accomplished by the combined processes of microbial fermentation and rumination. Adjusting cattle to grain based diets from predominately forage disrupts the normal microbial environment of the animal.

A survey of 28,593,575 feedlot cattle on the Great Plains between 1990 and 1993 indicated that mortality from digestive disturbances (i.e., acidosis and bloat) was 0.061 % of all fed cattle. Of these digestive mortalities, 24 % were attributed to bloat (Vogel and Parrott, 1994). Generally, feedlot bloat occurs in cattle fed diets that contain more than 50 % grain; it is observed most often when cattle are being shifted from low grain to high grain diets (Cheng and Hironaka, 1973).

Research investigating the effects of supplementation of alternative feed ingredients on beef steers to alleviate or understand digestive disturbances and negative associative effects of feeding grain and forage has been undertaken considerably (Anderson et al., 1988; Galloway et al., 1993; Garces-Yepez et al., 1997; Grisby et al., 1992; Grisby et al., 1993; Hibberd, et al., 1987; Ludden, et al., 1995). One of the alternative feed ingredients that has been investigated is soy hulls.

Anderson et al. (1988b) reported an increase in rumen pH when whole toasted soy hulls replaced ensiled cornstalks in a steer digestion trial. The results suggest that the ruminal fermentation pattern supported by soy hulls does not result in lactic acid production. The same trial reported increased intake of neutral detergent fiber (NDF) as the level of soy hulls supplementation increased, but decreased with corn additions. The trial result showed that corn (grain) has a negative associative effect on fiber (forage) utilization.

A study to investigate nutrient digestion by steers fed a low-quality bromegrass hay diet with incremental levels of soybean hull substitution was carried out by Grigsby et al. (1992). The results indicated that ruminal pH and ammonia concentrate decreased as levels of soy hulls increased, but not to levels considered detrimental to fiber digestion. Consequently, depressed fiber digestion will not result from feeding rations largely composed of soy hulls. Also, the study showed that ruminal and total digestive tract dry matter (DM), organic matter (OM), and cell wall digestibilities increased as the level of soy hulls increased. Additionally, Galloway et al. (1993) reported that a mixture of corn and soy hulls increased digestible OM intake compared to the mean of individual effects of corn and soy hulls.

The existence of associative effects between feedstuffs within nutritionally balanced diets has been investigated for many years (Forbes et al., 1931; 1933; Blaxter and Wainman, 1964; Vance et al., 1972; Peterson et al., 1973; Byers et al., 1976). Garces-Yepez et al. (1997) reported that supplements containing highly digestible fiber (soy hulls) produced less negative associative effects to the animal than high starch supplements (corn-soybean meal) when fed with bermudagrass hay. Also, soy hulls were found to result in fewer negative associative effects on fiber digestion than when corn was used as the energy supplement (McDonnell, 1982).

1.1.2 Problem statement

Cattle evolved consuming forages. Adjusting cattle to grain based diets from predominately forage diets remains one of the production problems facing beef cattle producers. Despite years of experience, when cattle are introduced to grain based diets they have a tendency to experience health problems such as acidosis, founder, and bloat.

1.2 Objectives

1.2.1 Overall objective

The present study has been initiated with an overall objective of evaluating soy hulls as the principal variable ingredient in a beef cattle receiving ration. Soy hulls are a byproduct of the soybean milling industry. They are moderate in crude protein (12.2 %), energy for maintenance (0.84 Mcal/lb), and energy for growth (0.55 Mcal/lb) (NRC, 2000). Their energy content is derived primarily from the fiber component of the feed (67 % NDF), which is unlignified (2 % lignin) and thus, highly digestible (Hibbert, et al., 1987). Because of the nutritional and chemical characteristics of soy hulls, they may be efficiently utilized in feeding programs for beef cattle. Previous studies have suggested that soy hulls are promising feed supplements for growing cattle and have potential for being used in receiving rations.

1.2.2 Specific objectives

The specific objectives were formulated to realize the overall objective of the study. The process of evaluating soy hulls as a principal ingredient in a beef cattle receiving ration applies both statistical and economic analysis. The first three objectives are addressed with statistical analysis and the last two with economic analysis. The specific objectives are:

1. Examine the effect of different treatments (receiving rations) fed to beef cattle steers on body weight, average daily gain, and feed efficiency.
2. Compare the effect of different treatments (receiving rations) at specific times and averaged over time on body weight, average daily gain, and feed efficiency.
3. Examine the effect of time on body weight, average daily gain, and feed efficiency within a treatment.
4. Estimate beef cattle steers' growth response and derive the optimal level of soy hulls in a ration based on economic conditions (if a production function exhibits a plateau).
5. Formulate a least cost receiving ration based on average daily gain for beef cattle steers and determine the amount of soy hulls in such a ration.

1.3 Hypotheses

Hypotheses are statements of the relationships among the variables that a researcher intends to study (Vogt, 1993). Most often hypotheses are derived from the objectives of the study. The nature of the analysis determines the method of testing the hypotheses. Hypotheses one and two were tested based on statistical analysis (the mixed model analysis) while hypotheses three and four relied on economic analysis (the production function analysis). The fifth hypothesis is formulated based on the fourth objective and is realized by carrying out a linear programming analysis. However, this hypothesis is not tested statistically because linear programming presents a normative nature of analysis. Regardless, the hypotheses in this study are stated as null hypotheses.

Hypothesis 1: Beef cattle steers experience the same body weight, average daily gain, and feed efficiency as they are fed various soy hulls based receiving rations.

Hypothesis 2: Beef cattle steers experience the same body weight, average daily gain, and feed efficiency at specific times and averaged over time as they are fed various soy hulls based receiving rations.

Hypothesis 3: Weight of beef cattle steers will not increase as the rate of soy hulls in the ration increases.

Hypothesis 4: Weight of beef cattle steers will not decrease as the rate of soy hulls in the ration increases.

Hypothesis 5: Soy hulls can be a major ingredient in a minimum-cost receiving ration for beef cattle steers.

For the first hypothesis, the null hypothesis one can be stated as Ho: $U_1=U_2=U_3=U_4$ where U_1, U_2, U_3, and U_4 represent mean of ration or treatment 1, 2, 3, and 4 respectively. This hypothesis is tested for each of the measurement variables: body weight, average daily gain, and feed efficiency. The soy hulls levels are 0 %, 25 %, 50 %, and 75 % for treatment or ration 1, 2, 3, and 4 respectively.

The second hypothesis is stated as Ho: $U_{11}=U_{21}$ where U_{11} and U_{21}, stands for mean of ration or treatment 1 and 2 respectively at time period 1. This hypothesis is carried out for each of the measurements mentioned above at each time point. The other hypothesis that compares treatment means averaged over time is stated as Ho: $U_1=U_2$ where U_1 and U_2 are means for treatment 1 and 2 respectively averaged over time. As reported previously, soy hulls are promising feed ingredients to be included in the formulation of receiving rations for beef cattle. The beef cattle steers are expected to show differences in weight, average daily gain, and feed efficiency when fed receiving rations that vary in the amount of soy hulls.

The third hypothesis is formulated on the basis of the theory of production functions which indicates that as the level of inputs increases the output level also increases. From a nutritional point of view, it has been reported that soy hulls increase the body weight of beef cattle (Klopfenstein and Owen, 1988). Logically, the body weight of beef steers is expected to increase as the level of soy hulls increases. For the fourth hypothesis, the theory of production economics suggests that marginal output levels decrease as higher input levels are applied in many biological phenomena. Based on this theory, the coefficient of the quadratic term of a response function is expected to be negative, denoting diminishing marginal returns (Heady et al., 1961).

The rationale for the fifth hypothesis is that feed costs account for a large part of the total costs incurred by beef feeders. As economic pressure increases on the beef cattle industry, producers will look for ways to reduce feed costs. Depending on the cost of more traditional feed ingredients, alternative feeds often will provide an opportunity to reduce the cost of supplementation while attaining nutritive requirements.

1.4 Organization of the study

The organization of other chapters is presented as follows. Chapter 2 is devoted to the theoretical framework of the study. Theories reported are limited to statistics and economic issues. The mixed model theory is briefly reported under statistics. The theory of production over time and concepts of linear programming are discussed as economic issues.

Chapter 3 reports data and methods of analysis. The chapter covers three areas: description of the experiment, data, and method of analyzing the data. The data used were technical and economic in nature. The methods of analysis applied were statistical and economic analyses.

The analytical results are discussed in chapter 4. Results of the statistical analysis reported and discussed included that of modeling the variance-covariance structures for weight, average daily gain, and feed efficiency. The treatment effects on animal performance are also discussed. Economic analysis results are presented in two areas. First, results for validating the estimated production function and derivation of optimal level of soy hulls. Second, results of the linear programming analysis are presented, including the impact of price changes on the optimal solution. Finally, summary of the study, conclusions, research implications, limitations of the study, and recommendations are presented in chapter 5.

CHAPTER 2

THEORETICAL FRAMEWORK

2.1 Introduction

This chapter presents, in very brief form, the theoretical background of the issues related to the study. The theories or concepts provide a framework for conceptualizing the problems and the methods of analyzing them. The theories presented are statistical and economic theories. In statistics the theory of mixed models is illustrated in section 2.2.1 while in economics the theory of production functions is explained in section 2.3.1 and the concepts of response economic efficiency over time in section 2.3.2. Last, the concepts of linear programming are presented in section 2.3.3.

2.2 Statistics

2.2.1 Mixed model theory

The mixed model theory provides a framework of model formulation. The name mixed model comes from the fact that the model contains both fixed and random effect variables (SAS, 1996; Littell et al., 1996). In compact matrix notation, the mixed model is formulated as

$$Y = X\beta + ZU + e \qquad [2.1]$$

where Y is a vector of observations, β is a vector of fixed effect unknown parameters, X is a design matrix for the fixed effect variables and can be either continuous or dummy variables, U is a vector of unobservable random effect parameters, Z is a known design matrix for the random effect variables and contains either continuous or dummy variables like X, and e is a vector of residual random errors whose elements are no longer required to be independent and homogeneous.

The random effect parameters and the residual random errors are assumed to be independent and normally distributed with means and variances as

$$\mathrm{E}\begin{bmatrix} U \\ e \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\mathrm{V}\begin{bmatrix} U \\ e \end{bmatrix} = \begin{bmatrix} G & 0 \\ 0 & R \end{bmatrix}$$

As a consequence, the observed data vector Y is normally distributed with mean and variance as

$$\mathrm{E(Y) = E\ (X\beta + ZU + e) = X\beta}$$

$$\mathrm{V(Y) = V\ (X\beta + ZU + e) = ZGZ' + R}$$

In summary, the assumptions of the mixed model are: (1) the data are normally distributed (Gaussian), (2) the means of the data are linear in terms of a certain set of parameters, (3) the variances of the data are permitted to exhibit non-constant variability, and (4) the covariances are also permitted to display correlation.

The procedure on how to estimate the fixed effect unknown parameters of β and the ways of selecting the model are presented briefly in this section. More discussion is reported elsewhere (Diggle, 1988; Lindsey, 1993; Wolfinger, 1996; SAS, 1996; Littell, et al., 1996; Searle, 1971; Vonesh, et al., 1997).

Estimation of the mixed model [2.1] may conveniently be viewed as a two-stage process. First, the parameters G, and R, which represent the variance-covariance of Y, are modeled. Second, the unknown parameters of β are estimated by minimizing the residuals of model [2.1] using *maximum likelihood* (ML) or *restricted maximum likelihood* (REML) (SAS, 1996).

The procedure of selecting the best model follows a likelihood-based approach. Several statistical measures for model adequacy are printed under SAS procedures, including the REML log likelihood (REML LogL), Akaike information criterion (AIC), and Schwarz Bayesian criterion (SBC). There are reported under the heading "Model Fitting Information" (SAS, 1996).

2.3 Economic issues

2.3.1 The theory of production economics

The theory of production economics provides a framework for making decisions regarding economic problems. For example, the principles of production economics explain the concepts of use of resources (inputs) to maximize profits or minimize costs. For this study, the concepts of production function and response economic efficiency over time for livestock production processes are briefly presented. Rigorous discussion of the concepts of productions and response economic efficiency over time is found in Faris (1960), Winder and Trant (1961), and Dillon (1968).

A production function describes the technical relationship that transforms inputs or resources into outputs or commodities (Debertin, 1986). Such a relationship is sometimes termed a “response function.” For livestock production processes, a basic formulation of a production function that has time as an explicit explanatory variable is presented as

$$Y = f(X_1, X_2, X_3, \ldots, X_n, t) \qquad [2.2]$$

where Y is the level of output produced, the X’*s* represent a combination of physical inputs, and t is time having an explicit effect on the response function. The theory of production economics assumes that such a function exhibits: (i) a continuous smooth causal relation between the inputs and the output; (ii) diminishing marginal returns with respect to each input so that the additional output from succeeding units of input becomes less and less; and (iii) decreasing returns to scale. Assumption (i) implies that the first derivatives, $\partial Y/\partial X_i$ or $\partial Y/\partial t$, of the response function [2.2] exist. Assumption (ii) implies that the first derivatives, $\partial Y/\partial X_i$ or $\partial Y/\partial t$, decreases as X_i or t increases, which in turn implies that the second derivatives, $\partial^2 Y/\partial X_i^2$ or $\partial^2 Y/\partial t^2$, exist and are negative. Lastly, assumption (iii) implies that equal proportionate increases in all inputs results in a less than proportionate increase in output, i.e., $\sum (X_i/Y)(\partial Y/\partial X_i) < 1$ ($i = 1, 2, 3, \ldots, n$).

Unfortunately, not all production functions exhibit the assumptions mentioned above. In fact, a function may reveal constant marginal returns to each respective variable input. In this case the first derivatives remain constant as the respective variable input increases. The second derivatives exist and are zero. In some situations, the function shows increasing marginal returns to each variable input. The first derivatives of such a function increase as the variable input increases and the second derivatives exist and are positive. Furthermore, it is often assumed that stages of increasing, constant and diminishing marginal returns occur in sequence as each variable input increases. Indeed, it is not surprising to see a function demonstrating either increasing, constant, diminishing marginal returns or all three possibilities displayed in sequence. For livestock production, there seems to be empirical evidence for the existence of functions exhibiting diminishing marginal returns (Dillon, 1968).

2.3.2 Response economic efficiency over time

The general principle for obtaining economic efficiency for a livestock production process that includes time as an explicit variable, is to maximize the time dependent objective function per unit of time, which may be in the form of a profit function per unit of time (Dillon, 1968; Winder and Trant, 1961; Faris, 1960). Assuming constant input and output prices over time, the time dependent profit function per unit of time may be represented as

$$\Pi^* = [P_y f(X_1, X_2, X_3, \ldots, X_n, t) - (\Sigma P_i X_i + F)]/t \qquad [2.3]$$

where Π^* is the time dependent profit function per unit of time, the production function is time dependent, X_i is the i^{th} input, t is time, F is the fixed input, P_y is the unit price of output, and P_i is the unit price of the i^{th} input. The best operating conditions, which set up the economically efficient situation, are obtained by maximizing equation [2.3] subject to the relevant explanatory variables specified in the time dependent production function. These conditions are attained when the necessary and sufficient conditions of profit maximization are met.

The necessary condition of profit maximization requires that the first order condition for each of the variables is set to zero, thus implying that the profit maximizing level of the variable is obtained by equating the marginal value product of the respective variable with its price. Most important, it should be noted that no direct price is attached to the variable time. Of itself, time has no price. However, the first order condition for time as a variable should show that maximum profit per unit of time is achieved when marginal profit per unit of time is equated to the average profit per unit of time. In essence, the profit maximizing criterion for the variable time implies that maximum profit per unit of time is attained at the point where average profit per unit of time is maximum. In reference to the time dependent profit function [2.3], these conditions are set as

$$\begin{aligned}
\partial\Pi^*/\partial x_1 &= P_y(\partial(f(x_1, x_2 \dots x_n, t))/\partial x_1) - \{P_{X1} + (\partial t/\partial x_1)\Pi^*\} = 0 \\
\partial\Pi^*/\partial x_2 &= P_y(\partial(f(x_1, x_2 \dots x_n, t))/\partial x_2) - \{P_{X2} + (\partial t/\partial x_2)\Pi^*\} = 0 \\
&\ \vdots \\
\partial\Pi^*/\partial x_n &= P_y(\partial(f(x_1, x_2 \dots x_n, t))/\partial x_n) - \{P_{Xn} + (\partial t/\partial x_n)\Pi^*\} = 0 \\
\partial\Pi^*/\partial t &= P_y(\partial(f(x_1, x_2 \dots x_n, t))/\partial t) - \{\textstyle\sum Px_i(\partial x_i/\partial t)\} = \Pi^*
\end{aligned} \qquad [2.4]$$

The first equation of [2.4], which is reproduced below as [2.5], can be interpreted as follows:

$$P_y(\partial (f(x_1, x_2 \ldots x_n, t))/\partial x_1) = P_{X1} + (\partial t / \partial x_1)\Pi^* \qquad [2.5]$$

The left hand side of equation [2.5] is the marginal value product of x_1 and the expression on the right hand side is the marginal cost of x_1. This marginal cost is the sum of two parts. The first part is the direct marginal cost of x_1. The second part is the time opportunity cost of a unit of x_1; it consists of the maximum average profit per unit of time (Π^*) multiplied by the time ($\partial t / \partial x_1$) required to utilize a unit of x_1. Interpretation of other equations of [2.4] can be inferred similarly except the last one. The last equation of [2.4], which is also reproduced below as [2.6], shows that if maximum profit per unit of time is to be achieved, the marginal profit per unit of time (the left hand term) must equal the average profit per unit of time (the right hand side).

$$P_y(\partial (f(x_1, x_2 \ldots x_n, t))/\partial t) - \sum Px_i(\partial x_i / \partial t) = \Pi^* \qquad [2.6]$$

Thus, solving the set of equations in [2.4] simultaneously gives the required optimal levels of $X_1, X_2, \ldots X_n$, and t. The sufficient condition of profit maximization requires that the second derivative for each variable exists and is negative. In general, this condition demands the determinant of the Hessian matrix be greater than zero.

2.3.3 Linear programming

A brief account of the theoretical formulation of linear programming is given in this section; it is one of the common tools used in optimization problems and its theory is documented extensively elsewhere (Heady, et al., 1963; Debertin, 1986). Linear programming problems have three major components, an objective, alternative methods or processes for attaining the objective, and resources or restrictions. Commonly, the objective is to optimize income or cost, though this is not always the case; the objective may also be to optimize certain types of industrial output representing a particular mix or requirements. The objective is expressed in physical, monetary, or other terms, depending upon the problem being analyzed.

Alternative methods or processes are required to attain the objective otherwise there will be no problem to optimize if different methods or processes are not available. In addition, a linear programming problem does not exit unless resources are restricted or limited.

Given the major components of linear programming the problem is to choose a set of decision variables so that a linear function of decision variables is optimized and a simultaneous set of linear constraints involving the decision variables is satisfied. Mathematically, the problem of linear programming to be optimized is formulated as follows

$$\begin{aligned} &\text{Optimize} \quad F(X) \\ &\text{Subject to } G(X) \in S_1 \\ &\qquad\qquad\quad X \in S_2 \end{aligned}$$

where, F(X) is a linear function to be optimized, G(X) is a set of restrictions that belong to S_1 and X is a set of non-negative decision variables belonging to S_2.

In formulating feed rations for beef cattle, F(X) is a linear cost function to be minimized; G(X) is a set of linear constraints that belong to S_1 which includes nutrient requirement and other restrictions. The vector X consists of feed ingredients as decision variables that fall into non-negative restriction S_2.

The mathematical relationships of linear programming embody important assumptions that govern its application. These assumptions are well known in linear programming literature and are reiterated as follows: (1) additivity, the decision variables must be additive in the sense that when two or more are used, their total product must be the sum of their individual products. This assumption rules out the possibility that interaction or multiplicative terms appear in the objective function or the constraints, (2) divisibility, this assumption says that all decision variables can take on any non-negative value including fractions and it implies that decision variables are continuous, (3) proportionality, it deals with the contribution per unit of each decision variable to the objective function. This contribution is assumed constant and independent of the variable level. In addition, the use of each resource per unit of each decision variable is assumed constant and independent, (4) single-value expectation, this assumption requires that resource restrictions, input-output coefficients, and prices are known with certainty.

CHAPTER 3

DATA AND METHODS OF ANALYSIS

3.1 Introduction

This chapter presents the data and analytical methods used in the study. It gives a description of what was done, how it was done, and why it was done in the specified manner. Problems encountered in the process of conducting the research and the way in which the problems were addressed is described. The chapter covers three major parts: description of the experiment, data, and methods of analyzing the data. The areas described in the experiment include the design of the experiment and feed rations. The data section details the data employed in the study and the way they were collected. Data collected were technical and economic in nature. Last, the methods of analyzing the data are explained. These include the statistical and economic analyses.

The initiation of the experiment was a result of efforts by individuals from the Departments of Animal Science, Statistics, and Agricultural Economics, representing a multidisciplinary endeavor. The Department of Animal Science investigator, Dr. Monty Kerley, played a major role in the design and execution of the experiment. He and his team also collected the technical data for the experiment. The Statistics Department analyst, Dr. Mark Ellersieck, assisted in the design and gave advice on the statistical analysis of the data. The Department of Agricultural Economics research leader, Dr. Melvin Blasé, recommended the design of the experiment appropriate to generate data for performing economic analysis.

3.2 Description of the experiment

3.2.1 Design of the experiment

A total of 36 beef steers (Angus crossbred) with initial body weights ranging from 677 to 889 pounds were used in the experiment. The steers grazed fescue and birdsfoot trefoil for several months before being brought to the feeding experiment. The experiment was carried out at the beef farm of the University of Missouri, Columbia.

The design of the experiment was a randomized complete block design-split plot in time design (RCBD-SPTD). The steers were blocked by weight, each of which constituted a single replication. Blocking was designed to keep the experimental errors within each block as small as possible. Thus, all diets which went to the same block were closely comparable. In addition, replication or blocking provides unbiased comparison of differences among replicates or blocks. Treatments were assigned at random to experimental units within each block. The split plot in time accounted for dependence of data over time. The experiment consisted of 4 treatments replicated 3 times each having 3 beef steers. This resulted in 12 pens with 3 animals per pen (Appendix 3.1).

The pens represented experimental units or subjects where data were collected. In each subject (pen), measurements of weight and feed intake were taken over time and averaged to obtain weight and feed intake per animal at each time period.

3.2.2 Feed diets

The four treatments used in the experiment were identified by the contents of soy hulls and other feed ingredients, in particular corn. On a dry matter basis, the four treatments contained 0 %, 25 %, 50 %, and 75 % of soy hulls. In the same order, corn levels were 67 %, 45 %, 22 %, and 0 %. The control ration contained 0 % soy hulls and

67 % corn. Other ration ingredients included cottonseed hulls and supplement. The supplement ingredients included soybean meal, limestone, dicalcium phosphate, sodium chloride, trace mineral salt, Rumensin® and Tylan®. The ration compositions are reported in Table 3.1.

Table 3.1 Composition of receiving ration for beef steers in an experiment at the University of Missouri, Columbia, MO., 1998.

Items	0 % SH	25 % SH	50 % SH	75 % SH
Feed composition, %				
Corn	67.400	45.100	21.600	0.000
Cottonseed hulls	14.800	14.800	14.900	15.000
Soy hulls	0.000	24.700	49.700	73.700
Soybean meal	14.641	12.780	11.288	9.679
Limestone	1.609	1.200	0.882	0.000
Dicalcium phosphate	0.322	0.200	0.400	0.400
Sodium chloride	0.201	0.200	0.206	0.200
Trace mineral salt	1.006	1.000	1.006	1.000
Rumensin®	0.015	0.014	0.013	0.015
Tylan®	0.006	0.006	0.005	0.006

The animals were fed 75 % of their estimated voluntary intake on the first day and this increased one pound every day after day one until they reached their estimated voluntary intake. Thereafter, they were given their 100 % estimated voluntary intake. They were given *ad libitum* access to water. The steers were weighed the first 2 days before the start of the trial. A third weighing was done 17 days after the second weighing. The fourth measurement was performed 14 days after the third weighing. The last two weighings were done 32 and 33 days after the fourth measurement. In addition, the animals were monitored for any health problems. This was given special attention the first 30 days of the 63 days of the feeding experiment.

3.3 Data

3.3.1 Statistical data

The raw data used in the statistical analysis were weights and feed intake of beef steers (Appendix 3.2). The raw data was analyzed to obtain weight gains, average daily gains, and feed efficiency. The study investigated the following data sets: weight, average daily gain, and feed efficiency.

Weight data used in the analysis was calculated from the raw data (Appendix 3.2). The weights taken on two consecutive dates, July 20th and 21st, 1998, before the onset of the experiment were averaged and represented the initial weight data measurement. The interim weights were taken on August 7th and 21st, 1998. Final weights were the average of weights taken the last two dates of the experiment, September 22nd and 23rd, 1998. The number of observations on weight totaled 48 resulting from the design of the experiment. At any measurement time period, each treatment had 3 observations because the experiment had 3 replicates or blocks. Overtime the total observations per treatment were 12 because 4 measurement time periods were taken. The total measurements per experimental unit (subject or pen) totaled 4.

Weight gain was obtained from the raw data as follows. Weight gain for time 1 represents weight taken on August 7th minus the average of weights recorded on July 20th and 21st. The difference between weights taken on August 7th and 21st is the weight gain for time 2. Weight gain for time 3 is the difference between average weights recorded on

September 22nd and 23rd and the weight taken on August 21st. A total of 36 observations were recorded as weight gains. Each treatment had 3 observations due to blocking and 3 measurement time periods were recorded for each subject.

Average daily gain (ADG) was calculated as weight gain divided by the number of days the steers were fed the receiving ration. The weight gains were calculated as explained earlier. The number of days the steers were fed in time periods 1, 2 and 3 were 17, 14 and 32 respectively. Therefore, the average daily gain for time period 1 was calculated by dividing the weight gain by 17 days. The average daily gains for times 2 and 3 represented weight gains over 14 and 32 days respectively. For each experimental unit 3 observations were recorded making a total of 36 for all subjects.

Feed intake was measured daily in pounds. At each particular time, feed intake per subject (pen) represented the cumulative amount of 3 animals (Appendix 3.2). Feed efficiency was calculated as pen weight gains divided by pen feed intake. Because weight gains were measured 3 times for each pen and there were 12 pens, a total of 36 observations were recorded.

3.3.2 Economic data

Economic data used in the study were prices of feed ingredients for the period 1994-1998 (Appendix 3.3) and prices of feed ingredients and beef steers for the period 2000-2004 (Appendix 3.4). Because the experiment was carried out in 1998, average prices for 1994-1998 were used as benchmarks and during reporting period (2005) average prices for 2000-2004 were used in sensitivity analysis to reflect current situation. Data on cost of haulage of feed ingredients from their sources to Columbia was also collected. Other data employed in the economic analysis were nutrient composition of ingredients (Appendix 3.5) and animal nutrient requirement (Appendix 3.6).

The raw data of corn prices were recorded in dollars per bushel. In order to change the price from dollars per bushel to dollars per pound, a conversion factor of one bushel to 56 pounds was used. The prices of live weight of steers were recorded in dollars per hundredweight. A conversion factor of one hundredweight to 100 pounds was used to change to dollars per pound. The prices for cottonseed hulls, soy hulls, soybean meal, corn gluten feed, dried distiller's grain, rice bran, and brewer's grain are reported in dollars per ton. A conversion factor of 1 ton to 2000 pounds was used to change prices from dollars per ton to dollars per pound. Prices for limestone, dicalcium phosphate, sodium chloride, trace mineral salt, Rumensin® and Tylan® were recorded in dollars per 50 pound bag.

Haulage costs were quotes from a trucking company, Rehagen Bros. Trucking of Freeburg, Missouri and were obtained by calling in 1998 and 2004. The quotes provided were limited only for 1998 and 2004. In 1998 quotes for cottonseed hulls from Kansas City, Missouri to Columbia was 11.25 $/ton while soy hulls and soybean meal from Mexico, Missouri to Columbia was 4.0 $/ton.

In 2004 haulage costs were 14 $/ton for cottonseed hulls and corn gluten feed from Kansas City to Columbia. Soy hulls and soybean meal were charged 6 $/ton from Mexico, Missouri to Columbia. Rice bran and brewer's grain cost 14.0 $/ton from Saint Louis, Missouri to Columbia and distiller's grain 6 $/ton from Macon, Missouri to Columbia. The haulage quotes exclude loading, unloading and gas charges.

3.4 Methods of analysis

3.4.1 Statistical analysis

3.4.1.1 Statistical methods for analyzing repeated measurement data

The nature of the three data sets (weights, average daily gain and feed efficiency) represents 'repeated measurement data.' Repeated measurement data refers to multiple responses taken in sequence on the same experimental unit. For this study, data were taken in sequence from the same animal (pen averages). These types of data are normally correlated because they contain a common contribution from the same experimental unit. Also, measures on the same experimental unit close in time tend to be more highly correlated than measures far apart in time. Furthermore, the variances of repeated measures often change with time. These potential patterns of correlation and variation may combine to produce a complicated variance-covariance structure of repeated measures (Littell et al., 1998; Diggle, 1988; Lindsey, 1993; Wolfinger, 1996). The term "variance-covariance structure" of repeated measurement data refers to variances at individual times and to correlation between measures at different times on the same experimental unit. Data of this nature need a special type of statistical analysis.

Littell et al. (1998) reviewed statistical methods used for analyzing the kind of data gathered in this study, i.e., repeated measurement data. They range from most basic to most sophisticated methods. These include: (1) separate analyses at each time point, (2) univariate analysis of variance, (3) univariate and multivariate analyses of time contrast variable, and (4) mixed model analysis. Each deserves elaboration. The first method examines treatment effects separately at individual observation times and does not require special methods for repeated measurement data. The analysis, therefore, makes no statistical comparisons among times.

The second method, also referred to as a split plot in time analysis, is the most commonly applied method for analyzing repeated measurement data that makes comparisons between times. It treats the data as if they were from a split-plot design with the experimental units to which the treatments are assigned as whole-plot units and the experimental units at particular times as sub-plot units. In SAS, the method is implemented via the general linear model (GLM) procedure. However, this method is valid only if measurements have equal variances at all times and if pairs of measurements on the same experimental unit are equally correlated, regardless of the time lag between the measurements.

The third method enables one to obtain statistical tests for effects involving time trends. One of the underlying assumptions of the method is that the data are independent (data are not correlated). For correlated data, the procedure is not appropriate because it will calculate incorrect standard errors.

The fourth method uses mixed model methodology for analyzing repeated measurement data. The method assumes that repeated measurement data are correlated; specifically, measures close in time are often more correlated than measures far apart in time. The method accounts for variability of the variance-covariance structure of the data. This consideration is important because it improves the ability to analyze repeated measurement data by providing valid standard errors and efficient statistical tests (Littell et al., 1998; Lindsey, 1993; Wolfinger, 1996). In order to implement this method one needs to subject the data to an exploratory data analysis (EDA) to check for data pattern and spread, model the variance-covariance structure of the data, and select one that best fits the data (Wolfinger, 1996). Because this study follows this methodology, these procedures are elaborated in section 3.4.1.2 for the EDA, 3.4.1.3 for modeling the variance-covariance structure and 3.4.1.4 for the procedure of selecting the variance-covariance structure that best fits the data.

3.4.1.2 Exploratory data analysis

Data analysis began by revealing the pattern and features of the data (Hoaglin et al., 1983; Diggle et al., 1994). This procedure is known as EDA. Also, EDA serves to uncover unexpected departures from familiar models (Hoaglin et al., 1983). Generally, implementation of EDA may lead to choosing an appropriate model and method for analyzing the data. The three data sets (weight, average daily gain, and feed efficiency) were plotted to see if any pattern of spread existed.

3.4.1.3 Modeling the variance-covariance structure of the data

After carrying out EDA, the next step is to model the variance-covariance structure of the data set. The idea is to impose several known variance-covariance structures on the data and see which one best fits. Various variance-covariance structures were fitted to each experimental data set; weight, average daily gain, and feed efficiency. The structures were unstructured (UN), compound symmetric (CS), heterogeneous compound symmetric (CSH), first-order autoregressive (AR(1)), heterogeneous first-order autoregressive (ARH(1)), first-order ante-dependence (ANTE(1)), toeplitz (TOEP), and heterogeneous toeplitz (TOEPH). In addition, general linear model (GLM) variance-covariance structure which assumes constant variances and equal correlation among observation was fitted along with the other structures. The simple variance-covariance structure served as a benchmark. For weight data where 4 measurements were taken on the same experimental unit (subject), the structures of these variance-covariances (4 x 4 matrices) are displayed in Appendix 3.7. Further details can be found in SAS (1996).

In SAS, the MIXED procedure has two statements which manage the specification of the variance-covariance structure, RANDOM and REPEATED. The RANDOM statement specifies the variation between experimental units. There were two sets of SAS statements used to fit the respective structures on each set of data. The first set used RANDOM and REPEATED statements, while the second used only the REPEATED statement. The first set of SAS statements were:

```
proc mixed;
classes BLK TRT TIM;
model (RESPONSE VARIABLE) = TRT | TIM;
random BLK BLK * TRT;
repeated TIM /sub=BLK * TRT type=(variance-covariance structure option);
run;
```

where BLK is block, TRT is treatment, TIM is time. In relation to model [2.1] of chapter 2, the fixed effect variables that constitute X are TRT, TIM and TRT*TIM established by the bar operator in the model statement. The random effect variables contained in Z are specified by the RANDOM statement. These were BLK and BLK*TRT. The variable BLK*TRT is the interaction between block and treatment. In statistics, treatment effects are considered as fixed effects while blocks are regarded as random (Littell, et al., 1996). The random error term e was specified by the REPEATED statement and this was achieved by inserting the known variance-covariance structures via the REPEATED option. The effect TIM in the REAPEATED statement specifies the time structured nature of the data within the measurement units. Thus, the above SAS statements generate statistical model [3.1].

$$Y_{ijk} = \mu + \alpha_i + \tau_k + (\alpha\tau)_{ik} + b_j + w_{ij} + e_{ijk} \qquad [3.1]$$

where Y_{ijk} is a response from an animal receiving treatment i in block j at time k; μ is the overall mean; α_i is a fixed effect of treatment i; τ_k is a fixed effect of time k; $(\alpha\tau)_{ik}$ is fixed interaction effect of treatment i with time k; b_j is random effect of block j; w_{ij} is random effect due to interaction of treatment i with block j; and e_{ijk} is a random error for treatment i in block j at time k. In terms of model [2.1], the vector β contains the fixed effects μ, α_i, τ_k, and $(\alpha\tau)_{ik}$. The random vector U contains the between experimental unit random effects b_j and w_{ij}. The residual error e contains e_{ijk}. The assumptions of model [2.1] also hold to model [3.1]. Specifically, the assumptions of the random effects are:

(1) b_j, w_{ij} and e_{ijk} are independent of one another

(2) $b_j \sim$ iid $N(0, \sigma_b^2)$

(3) $w_{ij} \sim$ iid $N(0, \sigma_w^2)$

(4) $e_{ijk} \sim$ iid $N(0, \Sigma)$, where Σ assumes one of the structures available in the SAS program like UN, AR, etc.

The search for the variance-covariance structure to fit the weight data was implemented using model [3.1]. The values of indexes for the weight data were i = 1, 2, 3, 4; j = 1, 2, 3; and k = 1, 2, 3, 4 making a total of 48 number of observations.

The second set of SAS statements was run in anticipation that the data for ADG and feed efficiency do not contain the block and interaction block *treatment. All these data originated from the weight data and were obtained by finding the differences of the raw data of weight. Mathematically the difference data do not contain the block and block*treatment as is illustrated below by subtracting weight of block 1, treatment 1, at time 1 ([3.2]) from weight of block 1, treatment 1 at time 2 ([3.3]). Model [3.4] do not contain the block and block* treatment interaction and represent how ADG and feed efficiency were originally found.

$$Y_{111} = \alpha_1 + \tau_1 + (\alpha\tau)_{11} + b_1 + w_{11} + e_{111} \qquad [3.2]$$

$$Y_{112} = \alpha_1 + \tau_2 + (\alpha\tau)_{12} + b_1 + w_{11} + e_{112} \qquad [3.3]$$

$$Y_{112} - Y_{111} = \tau_2 - \tau_1 + (\alpha\tau)_{12} - (\alpha\tau)_{11} + e_{112} - e_{111} \qquad [3.4]$$

In fact, when ADG and feed efficiency data were subjected to the first SAS statements, there were convergence problems. In view of these, the second set of SAS statements did not include the random statement. These statements are shown below.

```
proc mixed;
classes BLK TRT TIM;
model (RESPONSE VARIABLE) = TRT | TIM;
repeated TIM /sub=BLK * TRT type=(variance-covariance structure option);
run;
```

As in the first set of SAS statements, the variance-covariance structures fitted were unstructured (UN), compound symmetric (CS), heterogeneous compound symmetric (CSH), first-order ante-dependence (ANTE(1)), first-order autoregressive (AR(1)), heterogeneous first-order autoregressive (ARH(1)), toeplitz (TOEP), and heterogeneous toeplitz (TOEPH). The statistical model for the above SAS statements is

$$Y_{ijk} = \mu + \alpha_i + \tau_k + (\alpha\tau)_{ik} + e_{ijk} \qquad [3.5]$$

The definition of variables and parameters is the same as model [3.1]. The indexes values when ADG and feed efficiency data are applied are i = 1, 2, 3; j = 1, 2, 3; and k = 1, 2, 3. The parameters included in model [3.5] assume similar assumptions as model [3.1].

3.4.1.4 Selection of appropriate variance-covariance structures

After fitting the variance-covariance structures on each of the experimental data sets, the structures to assume in the model for final reference was then selected. The structures can be compared using goodness of fit criteria that are printed in the MIXED procedure (SAS, 1996; Vonesh et al., 1997). These criteria include the restricted maximum likelihood log likelihood (REML logL), Akaike information criterion (AIC), and Schwarz Bayesian criterion (SBC). The AIC and SBC are adjusted versions of REML logL to impose a penalty according to the number of parameters estimated. The penalty imposed by SBC is more severe than the one imposed by AIC. Consequently, SBC tends to indicate simpler structures (fewer parameters), while AIC will favor the more complex (more parameters). The two criteria may not agree as to which covariance structure is best. In any case, models with smaller values are preferred. The AIC criterion was used for this study.

After selecting the best structure, the data were finally evaluated for between subject heterogeneity on the variance-covariance structure (Littell et al., 1998). This procedure attempts to see if each group or treatment exhibits different variability. In order to accomplish this procedure the option GROUP = TRT is added in the REPEATED statement. As an example, the first set of SAS statements were implemented as follows:

```
proc mixed;
classes BLK TRT TIM;
model (RESPONSE VARIABLE) = TRT | TIM;
random BLK BLK * TRT;
repeated TIM /sub=BLK * TRT type=(variance-covariance structure) GROUP = TRT;
run;
```

3.4.1.5 Parameter estimation

After selecting the variance-covariance that best fit the data, the next step is to estimate the parameters. For this study, the parameters estimated were treatment means averaged over time and at particular time points for the variables weight, average daily gain, and feed efficiency. In addition, treatment means and treatment mean differences were estimated. Comparison of treatment means depended on the significance of the interaction terms. Comparisons of treatment means at every time point were carried out whenever the interactions were found significant. Otherwise, average means over time were used to make treatment comparisons for data having insignificant interaction terms. Also, comparisons of time effects within a treatment were performed.

Estimates were performed by including the ‘lsmeans’ statement in each set of SAS statements reported earlier. The ‘lsmeans’ statement computes generalized least-square means of fixed effects (SAS, 1996). The code for ‘lsmeans’ statement is ‘lsmeans TRT | TIM/ PDIFF’. The bar operator allows one to generate the variables treatment (TRT), time (TIM), and treatment*time interaction (TRT*TIM). The option specified after a slash (/) requests that differences of the least-square mean be printed. In addition, an option, DDFM = SATTERTH was added in the model statement. This option controls the computation of degrees of freedom for the test of fixed effects table and the lsmeans estimates (Littell et al., 1998).

3.4.1.6 Inference and test statistics

Two types of statistical inferences were made. First, statistical inferences about the overall effect of treatments (TRT), times (TIM), and treatment*time interaction (TRT*TIM) on weight, average daily gain and feed efficiency were carried out based on F-statistics. These inferences provided the procedure for testing the first null hypothesis of the study (Chapter 1). Second, pairwise inferences about estimates of treatment mean differences and time effects within a treatment were performed based on test statistics. These statistical inferences gave more insight about treatment effects and were used to test the second hypothesis (Chapter 1). The option PDIFF indicated in the ‘lsmeans’ statement, as explained in 3.4.1.5, facilitated the implementation of these tests. As an example, the complete SAS program used to estimate the unknown parameters and carry out the statistical inferences was

```
proc mixed;
classes BLK TRT TIM;
model (RESPONSE VARIABLE) = TRT | TIM / DDFM=SATTERTH;
random BLK BLK * TRT;
repeated TIM /sub=BLK * TRT type=(variance-covariance structure) GROUP =
            TRT  R = 1,2,3,4 RCORR = 1,2,3,4;
lsmeans TRT | TIM / PDFF;
run;
```

The option GROUP = TRT was only included if treatments were known to exhibit between subject heterogeneous variability. In such circumstances, the option R allowed profiling out the variance-covariance and correlation matrices for treatment 1, 2, 3, and 4 separately.

3.4.2 Economic analysis

3.4.2.1 Production function analysis

3.4.2.1.1 Modeling growth response function of beef steers

The growth response function for beef steers defines the fundamental relationship between output and inputs or factors of production. The feed ingredients fed to beef steers during the experiment period represent the inputs or factors of production while weight of beef steers stands for the output. As reported earlier, the feed ingredients used in the experiment were corn, cottonseed hulls, soy hulls, soybean meal, limestone, dicalcium phosphate, sodium chloride, trace mineral salt, Rumensin® and Tylan®.

The feed ingredients were formulated to provide the necessary nutrient requirements for growing beef steers. Energy was mainly supplied by corn and soy hulls. For soy hulls, besides being a source of energy, they were envisaged to play a role of altering the digestive activity in the rumen, resulting in less side effects to animals fed a receiving ration (Chapter 1). In fact, this is the main effect of soy hulls being examined in influencing the growth response of beef steers. Soybean meal provided proteins while trace mineral salt, sodium chloride (salt) and limestone were major sources of minerals. Cottonseed hulls, besides having energy and protein, are also considered as a source of roughage.

Another important input thought to influence growth response of steers is time. It is assumed that the contribution of feed ingredients may vary with the time length of the response process so that time directly influences response. Time is considered as a continuous variable whereas in section 3.4.1.1 it was regarded as a classification variable.

The weight data, as was expressed earlier, originated from the same subject or experimental unit. Thus, its variance-covariance structure resembles ones described for repeated measurement data. Additionally, the structural arrangement of the weight data were in blocks and since block was considered random from the onset of the experiment, its role as a random variable still holds when modeling the response function for weight data (Littell et al., 1996). Furthermore, the effect of the interaction term was also deemed to be a random variable when weight data were analyzed statistically. Thus, the random effects, block (BLK) and interaction (TRT*BLK) are added as factors influencing the growth of the beef steers.

With the above considerations, the generalized growth response function for beef steers is conceptualized as

$$Y = f(SH, TIM , CSH, SBM, LIM, DPH, SCH, TMS, RUM, TYL; b, w, e) \qquad [3.6]$$

where Y is weight of steers, SH is the percentage level of soy hulls fed, TIM is time measured in days, CSH is pounds of cottonseed hulls consumed, SBM is pounds of soybean meal consumed, LIM is pounds of limestone fed, DPH is pounds of dicalcium phosphate consumed, SCH is pounds of sodium chloride fed, TMS is pounds of trace mineral salt, RUM is pounds of Rumensin®applied, TYL is pounds of Tylan®and b, w, and e are random variables.

Three types of inputs or factors of production can be identified in equation [3.6], namely variable, fixed, and random factors. The factors SH and TIM, are classified as variable and observable. The variation of SH across rations ranged from approximately 0 % to 75 % (Table 3.1) while TIM ranged from 0 to 63 days. Corn is not included in the model as a factor affecting the growth of beef steers despite the fact that it varied across the rations (Table 3.1). The reason behind this is that its effect on the growth of beef steer is mirrored by SH. Corn and soy hulls (SH) both played the same role of providing energy to the animals and this permitted the use of only one ingredient as a factor of production. The factors CSH, SBM, LIM, DPH, SCH, TMS, RUM, and TYL are classified as fixed at some predetermined levels. The composition of these factors remained approximately constant across the rations. Lastly, as described earlier, the variables b, w, and e are classified as random variables with the following assumptions:

$b_j \sim$ iid $N(0, \sigma_b^2)$

$w_{ij} \sim$ iid $N(0, \sigma_w^2)$

$e_{ijk} \sim$ iid $N(0, \Sigma)$ where Σ assumes one of the structures available in the SAS program.

b_j, w_{ij} and e_{ijk} are independent of one another

3.4.2.1.2 Functional form of beef steers model

A number of functional forms have been used to describe livestock production processes. The algebraic form of the function and the magnitudes of its coefficients vary with factors being varied and magnitude of other inputs in fixed quantity. The task of the investigator is to select an algebraic form of the function that appears to be consistent with the biological and economic theories. Also, guides on appropriate algebraic forms may come from previous investigations.

Generally, livestock production processes are modeled using simple second-order polynomials (Heady, et al, 1983). A second-order polynomial with interactions was used as a functional form for this study. As reported earlier, the generalized growth response function for beef steers included SH and TIM as varying factors of production. Consequently, the polynomial function was formulated based on these factors. The functional form of beef steers is specified as

$$Y = \beta_0 + \beta_1 SH + \beta_2 TIM + \beta_3 SH*TIM + \beta_4 SH^2 + \beta_5 TIM^2 + b + w + e \qquad [3.7]$$

where the variables are defined as stated previously. Model [3.7] is an additive relationship formed of linear, squared and interaction terms. The model represents both linear and curvilinear relationships.

The structure of the function allows the investigator to examine whether the production process exhibits either one or a combination of increasing, constant and decreasing marginal productivities of factors of production. A production process represented by model [3.7] will have increasing marginal productivity when parameters for the squared terms are positive and statistically significant. Decreasing marginal productivities will be depicted by negative and statistically significant squared terms of the equation. Constant marginal productivities are presented by linear terms of the equation. Therefore, the polynomial function provides more flexibility in examining functional forms describing production processes.

3.4.2.1.3 Estimation procedure

As reported earlier, repeated measurement data are normally correlated because they contain a common contribution from the same experimental unit. Moreover, measures on the same experimental unit close in time tend to be more highly correlated than measures far apart in time. Consequently, repeated measurement data are likely to have complicated variance-covariance structures (Diggle, 1988; Wolfinger, 1996; Searle et al., 1992; Littell et al., 1998). For repeated measurement data, use of the ordinary least square (OLS) procedure to estimate parameters of a production function will yield misleading results (Singer, 1998). Recently, other estimation procedures have been developed to handle the repeated measurement data. One of these procedures is the MIXED procedure of SAS (Littell et al., 1998; Singer, 1998).

The MIXED procedure of SAS was used to estimate the parameters of the specified production function of beef steers in [3.7]. One of the advantages of the MIXED procedure is that it does not require transformation of the data. Data transformation may distort the original relationship, making more difficult the interpretation of the data. The variance-covariance structures of the data are modeled directly, leaving the data in its original features (Wolfinger, 1996). In estimating the parameters of [3.7] the assumptions pertaining to the application of the MIXED procedure as explained in section 3.4.1.3 still hold and are reiterated in this section as (1) the data are normally distributed, (2) the means (expected values) of the data are linear in terms of a certain set of parameters, and (3) the variances and covariances of the data are in terms of a different set of parameters, and they exhibit a structure matching one of those available in the MIXED procedure.

The MIXED procedure, as reported in section 3.4.1.3, is implemented by first modeling the variance-covariance of the data. Second, the unknown parameters of the variables are estimated. In section 3.4.1.3, several variance-covariance structures of the data were modeled. These structures included unstructured (UN), compound symmetric (CS), heterogeneous compound symmetric (CSH), first-order autoregressive (AR(1)), heterogeneous first-order autoregressive (ARH(1)), first-order ante-dependence (ANTE(1)), toeplitz (TOEP), and heterogeneous toeplitz (TOEPH). These structures were also applied in modeling random factors of model [3.7]. The SAS syntaxes used to estimate the parameters of the production function were as follows

```
proc mixed;
classes BLK TRT PER;
model  Y = SH  TIM  SH*TIM  SH^2  TIM^2 / s  htype=1;
random BLK BLK * TRT;
repeated PER /sub=BLK * TRT type=(variance-covariance structure option);
run;
```

The class statement specifies block (BLK), treatment (TRT), and time (PER) as classification variables whose values do not contain quantitative information. Compared to the previous SAS statements used in statistical analysis, the classification variable PER is created to replace TIM which is now continuous. Hence, the class statement retains the structural arrangement of the data. The model statement indicates the dependent and independent variables specified in model [3.7]. All variables in the model statement are continuous. The option **S** allows printing of solutions of parameters of the model while htye=1 provide sequentially formulated hypotheses appropriate for polynomial models (Littell et al., 1996). The random statement shows that block and block*treatment are random in the data set. The repeated statement specifies PER as a class variable to indicate the time structured nature of the data within the experimental unit. As mentioned earlier, the variable PER differs from TIM in that PER is treated as a series of dummies, where as TIM is treated as a continuous variable to yield the production function of beef steers. The option sub= block*treatment produces a block-diagonal structure of variance-covariance for each experimental unit. The option type= specifies the variance-covariance structure of the data.

Apparently, the independent variables specified in model [3.7] are likely to be correlated. As a result, model [3.7] will tend to exhibit multicollinearity. Mathematically, the quadratic terms (SH*SH and TIM*TIM) are certainly correlated to their respective linear terms (SH and TIM). The interaction term SH*TIM will also be correlated to the linear terms SH and TIM. A correlation matrix was established to ascertain existence of multicollinearity among independent variables of model [3.7].

In view of the above, the partial Gram-Schmidt orthogonalization method was applied to overcome the problem of multicollinearity pertaining to model [3.7]. This method emphasizes orthogonalizing the independent variables that have higher-order terms or interactions. Orthogonalization can be viewed as a process of finding the residual of the variables that have higher-order terms or interaction. This is accomplished after the linear term and any lower-order terms are partialed out of the higher-order term variable or interaction variable. The residuals of the respective higher-order terms or interactions are then applied to gauge their relationship with the response variable. Consequently, every such variable correlates zero with all the lower-order variables, and may be thought of as a pure variable at its own level (Burrill, 1997). As the independent variables becomes independent (orthogonal) the estimates of the parameters will show directly which predictors contribute significantly to explaining variance on the dependent variable, and which do not. Hence, the advantages of the partial Gram-Schmidt orthogonalization method include clarity of tests of coefficients and efficiency of winnowing out uninformative independent variables in reducing a full model to a satisfactory reduced model.

The process of orthogonalizing the higher-order term and interaction variables was made possible by regressing these variables to the respective linear and lower-order terms using the GLM procedure. The specific equations regressed for each of the higher-order term variable or interaction variable were as follows

$$\mathrm{SH*TIM} = \beta_0 + \beta_1\mathrm{SH} + \beta_2\mathrm{TIM} + \mathrm{R\text{-}SH*TIM} \quad [3.8]$$

$$\mathrm{SH}^2 = \beta_0 + \beta_1\mathrm{SH} + \mathrm{R\text{-}SH}^2 \quad [3.9]$$

$$\mathrm{TIM}^2 = \beta_0 + \beta_1\mathrm{TIM} + \mathrm{R\text{-}TIM}^2 \quad [3.10]$$

The terms R-SH*TIM, R-SH^2, and R-TIM^2 are the residuals. Based on the GLM procedure, the syntax statements used to regress equation [3.8] through [3.10] were as follows

```
proc glm;
model (respective dependent variable) = (respective independent variable)
                                                    output  out = data r=Residual
```

The residuals obtained in equation [3.8] through [3.10] replaced the respective higher-order term variables SH^2, and TIM^2 and interaction variable SH*TIM in estimating model [3.7] using the Mixed procedure of SAS. Because the higher-order term variables are orthogonalized (a correlation matrix was established to confirm that the variables are independent) it was possible to decide on an appropriate reduced model after running only one regression. Once the relevant variables are identified, the actual variables (not the residuals) are used to obtain the parameters of the model.

3.4.2.1.4 Model validation

The word validate refers to exercises determining whether the estimates of the parameters of the model agree with the theories of the sciences involved. The theories of statistics, economics, and animal nutrition were applied. From a statistical point of view, the estimated parameters of the model were tested for statistical significance to see whether their respective independent variables have influence on the dependent variable. The theory of production functions was also verified. Specifically, verifying whether the production function exhibits increasing, constant or decreasing marginal productivities of factors of production. This exercise was done by checking the sign of estimated parameters to see whether they have economic logic. The theory of animal nutrition was applied in the interpretation of statistical and economic validations. Finally, the validated model was used in testing the third and fourth null hypotheses of the study (chapter 1).

3.4.2.1.5 Estimating the growth response function with ADG data

Further estimation of the production function was carried out using ADG as the dependent variable and SH, TIM, SH*TIM, SH^2, and TIM^2 as independent variables. The function form can be expressed as

$$Y = \beta_0 + \beta_1 SH + \beta_2 TIM + \beta_3 SH^*TIM + \beta_4 SH^2 + \beta_5 TIM^2 + e \qquad [3.11]$$

where Y is ADG of steers, SH is the percentage level of soy hulls fed, TIM is time measured in days, SH*TIM is the interaction between SH and TIM, while SH^2 andTIM^2 are quadratic terms for SH and TIM respectively. The ADG data, as was reported earlier, are repeated measurement data. Therefore, their random error terms exhibits one of the structures described for repeated measurement data. Basically, the variance-covariance structure for ADG found during the statistical analysis is applicable for this analysis. The reason is that the data still retain their same structural characteristic as when they were analyzed during the statistical analysis. The only thing that has changed is the specification of the independent variables; the classification variables are now replaced by the continuous variables. Thus, the random variable e in [3.11] is postulated to behave as $e \sim \text{iid } N(0, \Sigma)$, where Σ assumes one of the structures available in the SAS program.

The procedures used to estimate the production function using weight as a dependent variable were also applied in estimating the production function [3.11]. In summary, the procedures were: First, the extent of multicollinearity among the independent variables was explored. Second, high order terms were orthogonalized to address the problem of multicollinearity. Third, ADG was regressed with all uncorrelated independent variables to determine which among them contribute to the variability of the dependent variable, ADG. Last, ADG was regressed with all variables found to explain its variability.

3.4.2.2 Linear programming analysis

3.4.2.2.1 Ration formulation for beef steers

Least-cost receiving rations for beef cattle steers were formulated using linear programming in SAS. Following the structure of linear programming introduced in Chapter 2, the elements of the linear function F(X) were the feed ingredients and their prices. The linear constraints or restrictions G(X) constituted the feed ingredients and the input-output coefficients. The input-output coefficients or technical coefficients represented the quantity of nutrient per unit of feed ingredient. The set S_1 contained nutrient and restriction requirements. The vector X represented feed ingredients as decision variables that fall into non-negative restriction set S_2.

There were four rations formulated each representing one of the treatments used in the experiment. Like the treatments, the rations were classified based on the content of soy hulls. They contained 0 %, 25 %, 50 % and 75 % of soy hulls for ration 1, 2, 3, and 4 respectively. The main diet for ration 1 contained cracked corn grain and cottonseed hulls and the supplements were soybean meal, limestone, dicalcium phosphate, sodium chloride, trace minerals, Rumensin®and Tylan®. For rations 2 and 3, cracked corn grain, cottonseed hulls, and soy hulls composed the main diet while for ration 4 they were cottonseed hulls and soy hulls. The supplements for rations 2, 3 and 4 were the same as for ration 1.

The rations formulated included energy, protein, mineral and other restriction requirements. As reported in the data section of this chapter, the requirements were obtained from the NRC tables (NRC, 2000). Energy requirements reflected body weight and ADG of the animal. The rations targeted animals weighing 771 lbs (350 kg). The weight was near the average of 790 lb for animals that participated in the experiment. The ADG used was 4.4 lb/d for rations 1 and 2 representing their averages of 4.7 and 4.6 lb/d, recorded during the experiment, respectively. For rations 3 and 4, the ADG used was 3.3 lb/d showing representation of their experimental results of 3.4 lb/d. The minimum energy requirements for rations 1 and 2 were 6.23 Mcal/d for maintenance and 8.84 Mcal/d for growth. For rations 3 and 4, the minimum energy requirements were 6.23 Mcal/d for maintenance and 6.45 Mcal/d for growth (Appendix 3.6; NRC, 2000).

Protein requirement was restricted at a minimum level of 13.5 %. Animal minimum daily ration consumption was assumed to be at 3.156 % of their body weight; it reflected the average rates used during the experiment. Based on this estimate, the minimum daily amount needed to feed an animal weighing 771 lb (350 kg) was about 24.33 lb (11 kg).

Mineral requirements for calcium and phosphorus are also tied with body weight and ADG of the animal (Appendix 3.6; NRC, 2000). For rations 1 and 2, the minimum requirements were 50 g/d and 24 g/d respectively while for rations 3 and 4 were 41g/d and 20g/d respectively. The other minerals requirements were formulated as stipulated in the NRC tables (Appendix 3.6; NRC, 2000).

3.4.2.2.2 Sensitivity analysis

The rations were first formulated using the average prices of feed ingredients for 1994-98; the results were saved as base rations. Average prices for 2000-2004 were introduced to observe the sensitivity of the objective function value while the solution of the decision variables remained optimal. Additionally, range analysis was applied to examine the range of each feed ingredient prices for which the solution of the decision variables remained optimal and to determine impacts on the objective function value.

3.4.2.2.3 Accounting for input-output coefficient variability

Linear programming assumes that the input-output coefficients are known with certainty. However, if the variability measures of the input-output coefficients are known it is possible to relax this assumption by introducing variance equations in the linear programming problem to account for variability of the input-output coefficients (Tozer, 1999; Rahman, et al., 1971). On average, solutions of least-cost formulation obtained by ordinary linear programming will meet the nutrient requirements only 50 % of the time, assuming normally distributed measures of input-output coefficients. Meeting the requirements at a higher confidence level can be attained only if the variability of the input-output coefficients, measured by the variance, is accounted for.

The NRC publication (2000) reports variability measures of protein for various feed ingredients (variability measures for energy are not consistently reported). In order to incorporate these measures in the linear program the variance equation of protein is approximated to a linear equation. This approximation can be explained as follows. First, we have to recognize the statistical properties of a linear function containing stochastic elements. When the input output coefficients of the protein constraint in a linear programming problem are stochastic, its linear inequality can be stated as [3.12].

$$a_{i1}x_1 + a_{i2}x_2 + \ldots.. + a_{in}x_n \geq \mathbf{b}_i \qquad [3.12]$$

where a_{ij} is a stochastic input-output coefficient representing the amount of protein supplied by a unit of the jth ingredient to the protein constraint (the ith nutrient constraint), x_j is a deterministic unknown quantity of the jth ingredient in the final ration mix, and $\mathbf{b}_i$ is a stochastic minimum protein requirement. This inequality can be represented as [3.13]

$$\begin{aligned}\mathbf{b}_i &= a_{i1}x_1 + a_{i2}x_2 + \ldots + a_{in}x_n \qquad [3.13]\\ &= \sum a_{ij}x_j\end{aligned}$$

The mean and variance of a linear function such as [3.13] can be summarized as follows

Mean: $$\begin{aligned}\mu_{bi} = E(\mathbf{b}_i) &= \sum x_j E(a_{ij})\\ &= \sum x_j \mu_{ij}\end{aligned}$$

Variance: $$\sigma_{bi}^2 = E\{[\mathbf{b}_i - E(\mathbf{b}_i)]^2\}$$

$$= \sum \sigma_{ij}^2 x_j^2 + 2 \sum \sum x_j x_k(\mathrm{Cov}(x_j x_k) \quad j \neq k$$

where μ_{bi} is the mean of protein (the ith nutrient) in the final ration mix, μ_{ij} is the mean of protein in the jth ingredient, σ_{bi}^2 is the variance of protein in the final mix, σ_{ij}^2 is the variance of protein in the jth ingredient, and the last term of the variance equation is the summation of the covariances between the jth and the kth ingredients. However, if the protein content of the ingredients are independent the last term of the variance equation collapses (Snedecor, 1989) and becomes as [3.14]. It is reasonable to assume that the content of protein in any ingredient is not influenced by the content of protein in another ingredient. For example, the content of protein in corn is not influenced by the content of protein in soy hulls.

$$\sigma_{bi}^2 = \sum \sigma_{ij}^2 x_j^2 \qquad [3.14]$$

$$\sigma_{bi} = \sum \sigma_{ij} x_j \qquad [3.15]$$

Linearization of equation [3.14] to [3.15] can be visualized as a relationship between equation [3.16], [3.17], [3.18] and [3.19]. Starting with a linear equation [3.16], if we square both sides we obtain equation [3.17]. Equation [3.17] and [3.18] are similar because the term $\sum \sigma_{ij}^2 x_j^2$ of equation [3.14] is the same as that of [3.17]. Equation [3.19] shows that $\sigma_{bi}^{*\,2} \geq \sigma_{bi}^2$ because the term $\sum \sum \sigma_{ij}\sigma_{ik} x_j x_k$ is positive; it is a sum of positive cross-products.

$$\sigma_{bi}^{*} = \sum \sigma_{ij} x_j \qquad [3.16]$$

$$\sigma_{bi}^{*\,2} = \sum \sigma_{ij}^{2} x_j^{2} + 2 \sum \sum \sigma_{ij}\sigma_{ik} x_j x_k \qquad j \neq k \qquad [3.17]$$

$$\sigma_{bi}^{*\,2} = \sigma_{bi}^{2} + 2 \sum \sum \sigma_{ij}\sigma_{ik} x_j x_k \qquad j \neq k \qquad [3.18]$$

$$\sigma_{bi}^{*\,2} \geq \sigma_{bi}^{2} \qquad [3.19]$$

Therefore, σ_{bi} is approximated by σ_{bi}^{*}. Although σ_{bi}^{*} is biased, its direction is known as is shown in [3.19]. The consequence of this approximation is that whenever you try to increase the minimum requirement level of protein (**b**$_i$) by adjusting with (adding) its standard deviation (σ_{bi}^{*}), results will always be equal or greater than its actual standard deviation (σ_{bi}).

Variability information (σ_{bi}) is introduced in the protein constraint by adding equation [3.16] as another constraint in the linear program. Equation [3.16] approximates equation [3.15] which is a linear approximation of equation [3.14]. You can link equation [3.12] and [3.16] in the linear program so that the calculated value σ_{bj}^{*} is added to the right hand side of equation [3.12]. Table 3.2 illustrates this procedure. The standard deviation constraint links the value of σ_{bj}^{*} to the protein constraint at a level of 0.8. Consequently, it increases **b**$_i$ to **b**$_i$ + $0.8s_1$, well over the stipulated minimum requirement.

Whenever you increase the level of protein in the ration above the minimum requirements you increase the probability of attaining that minimum requirement. Referencing equation [3.12] and assuming that its data follow a normal distribution, the normality assumption is reasonable since the NRC obtains the nutrient content of ingredients as sample mean averages, and using the example of Table 3.2 you can calculate the standard normal deviate and find out the probability of attaining that value as follows.

Table 3.2 Tableau for least cost ration for beef steers with variability information in an experiment at the University of Missouri, Columbia, MO., 1998

Cj	C_1	C_2	C_3	…	C_n	0	0		
Activities	x_1	x_2	x_3	…	x_n	s_1	s_2		RHS
Protein constraint	a_{11}	a_{12}	a_{13}	…	a_{1n}	-0.8	0	$\geq$	b_1
Standard deviation	a_{21}	a_{22}	a_{23}	…	a_{2n}	-1	0	=	0
Energy for mainte.	a_{31}	a_{32}	a_{33}	…	a_{3n}	0	0	$\geq$	b_3
Energy for growth	a_{41}	a_{42}	a_{43}	…	a_{4n}	0	0	$\geq$	b_4
Calcium minimum	a_{51}	a_{52}	a_{53}	…	a_{5n}	0	-1.2	$\geq$	0
Calcium maximum	a_{61}	a_{62}	a_{63}	…	a_{6n}	0	-2.0	$\leq$	0
Phosphorous trans.	a_{71}	a_{72}	a_{73}	…	a_{7n}	0	-1	=	0
Phosphorous min.	a_{81}	a_{82}	a_{83}	…	a_{8n}	0	0	$\geq$	b_8
CSH constraint	-.15	.85	-.15	…	-.15	0	0	=	0
SH constraint	-.25	-.25	.75	…	-.25	0	0	=	0
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
Amount of feed	a_{m1}	a_{m2}	a_{m3}	…	a_{mn}	0	0	$\geq$	b_m

Legend: Cj is the row for the objective function coefficients; activities represent feed ingredients; s_1 is an activity column for linking standard deviation and protein constraints; s_2 is an activity to link the calcium constraint rows and the phosphorous transfer row to form a calcium:phosphorous ratio of between the range 2:1 to 1.2:1.

$$Z = [\mathbf{b}_1 + 0.8s_1 - \mathbf{b}_1] / \sigma_{b1}$$

The values of this equation are identified as follows. The value of $\mathbf{b}_1$ is the minimum protein requirement (for this study the value was 13.5 %), s_1 is profiled out by the standard deviation constraint (see Table 3.2) and the value of σ_{b1} is found by first calculating σ_{b1}^2 by hand or spreadsheet using equation [3.14] and then taking its square root; using Table 3.2 it is calculated as

$$\sigma_{b1}^2 = a_{21}^2 x_{21}^2 + a_{22}^2 x_{22}^2 + a_{23}^2 x_{23}^2 + a_{24}^2 x_{24}^2 + a_{25}^2 x_{25}^2 + a_{26}^2 x_{26} + \ldots\ldots + a_{2n}^2 x_{2n}^2$$

where $a_{21}^2 = \sigma_{21}^2$, $a_{22}^2 = \sigma_{22}^2$, $a_{23}^2 = \sigma_{23}^2$, $a_{24}^2 = \sigma_{24}^2$, $a_{25}^2 = \sigma_{25}^2$, $a_{26}^2 = \sigma_{25}^2$, …, $a_{2n}^2 = \sigma_{2n}^2$.

After obtaining the Z-score you find the probability of attaining less than or equal to that value on any normal distribution table.

Most linear programming problems which do not incorporate variability information have solutions that are feasible if the protein constraint is met. That is, the left hand side is equal or greater than the right hand side. If the left hand side is equal to the right hand side, then the probability of attaining that level is 50 % most of the time. Using the Z-score equation it can be illustrated as follows.

$$Z = [\mathbf{b}_1 - \mathbf{b}_1] / \sigma_{b1}$$

Since $\mathbf{b}_1 - \mathbf{b}_1$ is zero; the value of Z is 0.5 which represent 50 %. Although not common, sometimes the left side is greater than the right hand side. If this happens, you calculate the Z-score accordingly and find the probability of attaining that value. You do not need to include variability if the probability you find is reasonable.

The percentages of ingredients in the final ration were specified by equating the ratio of the amount of the respective ingredient to the total amount of all ingredients equal to the desired percentage. For example, cottonseed hulls were specified to be 15 % in the final ration. This was done by equating the ratio of cottonseed hulls to the total ration equal to 0.15 [3.20]. Simplifying this equation yields equation [3.21]; this constraint appears in the linear programming tableau in Table 3.2

$$\{[x_2] / [x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + \ldots + x_n]\} = 0.15 \qquad [3.20]$$

$$-0.15x_1 + 0.85x_2 - 0.15x_3 - 0.15x_4 - 0.15x_5 - 0.15x_6 - \ldots - 0.15x_n = 0 \qquad [3.21]$$

3.4.2.2.4 Procedure of analyzing the competitiveness of soy hulls

The potential of soy hulls as a principal ingredient in formulating beef cattle receiving rations was also evaluated against other byproducts. These byproducts were corn gluten feed, dried distiller’s grain, rice bran, and brewer’s grain. There is a limitation on how much to feed these byproducts to animals (Lalaman, 2005; Lalaman, et al., 2005; Kubik, et al., 1996; Poore, 1994). For this study, a recommended rate of 25 % of the total ration dry matter for each of the byproducts was used. To compare with soy hulls, the same rate for soy hulls was also used.

Each byproduct was used to formulate a ration and the cost of that ration was compared to the cost of a ration formulated with soy hulls. This procedure was necessary to safeguard the recommendations attached to each of the byproducts when used in animal feeding. The general tendency of letting the computer choose the ingredients that formulate a ration was practically not feasible both from a nutritional and a mathematical point of view. First, the ration formulated contained ingredients that were either less than or more than their recommended rates. Such formulation may have an unwarranted combination of byproduct (most of them are fiber based ingredients) and corn yielding what is known as associative effects. Second, including all ingredients and their recommended limitations resulted in an infeasible solution. In order to avoid these problems, each byproduct was used alone in the ration formulation. Thus, the rations were labeled as 25 % CGF to symbolize that the ration is formulated with corn gluten feed. The other labels were 25 % DDG for dried distiller's grain, 25 % RB for rice bran, and 25 % BG for brewer's grain. For each ration formulated, as with the 25 % SH, the main diet contained cottonseed hulls at the rate of 15 % of the total dry matter of the ration; corn; and the byproduct at the rate of 25 %. The supplement ingredients were similar as those used for soy hulls.

CHAPTER 4

ANALYTICAL RESULTS

4.1 Introduction

This chapter presents the analytical results of evaluating soy hulls as a principal ingredient in beef cattle receiving rations. The results include statistical and economic analyses. The statistical analysis covers four sub-sections. First, the spread and pattern features of the data for weight, average daily gain and feed efficiency are revealed by examining their scatter plots. Second, analysis of the modeled variance-covariance structures of the data is reported. This analysis focuses on the selection of the variance-covariance structures for weight, average daily gain, and feed efficiency; as well as parameter estimation for the various structures. Third, analysis of the effects of treatments on animal performance is presented. This is carried out by comparing treatment effects at specific times and averaged for time periods. Fourth, the effect of time on animal performance is reported. The analysis is centered on comparing time effects within a treatment.

The economic analyses carried out were two. First, a production function analysis is presented. The areas covered include validation of the estimated model and derivation of optimal level of soy hulls. Second, a linear programming analysis is reported. The analysis focuses on evaluating soy hulls as a potential feed ingredient in the formulation of minimum cost receiving rations for beef cattle. Also, the impact of price changes on the use of soy hulls as a minimum cost receiving ration for beef cattle is presented. Lastly, the competitiveness of soy hulls if matched with other by products is analyzed.

4.2 Statistical analysis

4.2.1 Scatter plots for the raw data

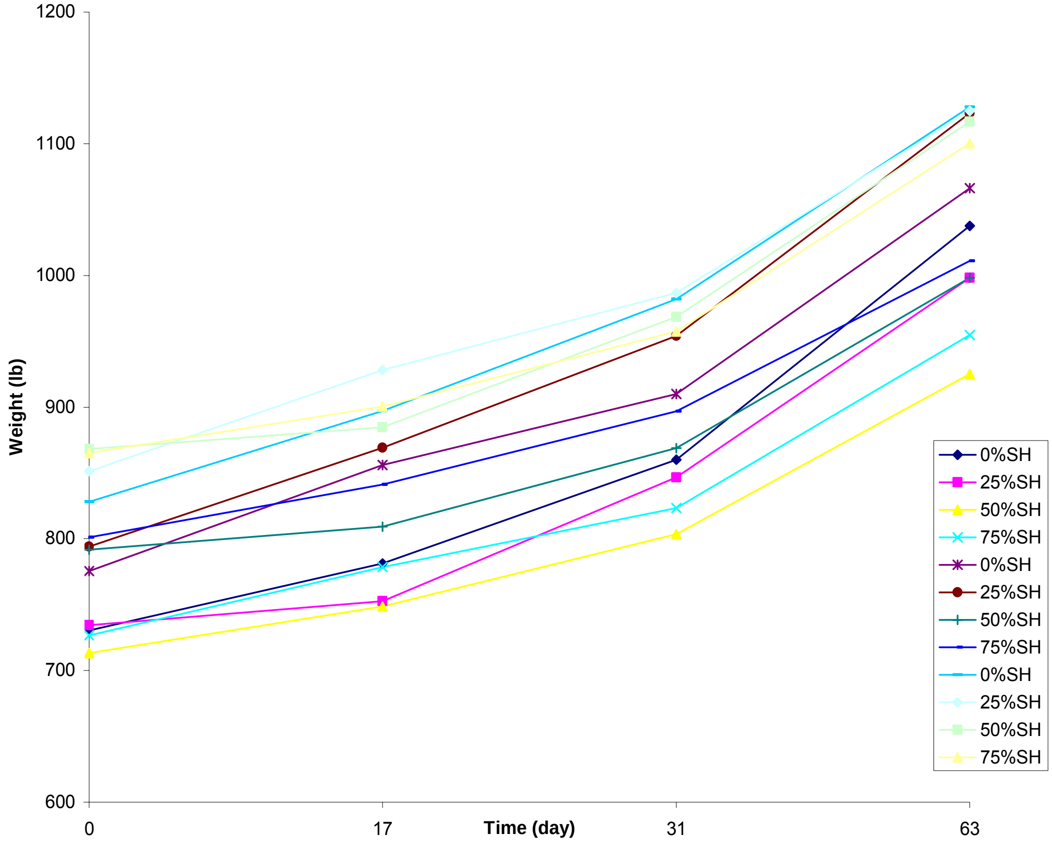
Figures 4.1 through 4.3 displays data graphically for weight, average daily gain, and feed efficiency. Lines connect the repeated observations taken on animals (pen averages). The graphs make apparent a number of important patterns.

For the weight data, Figure 4.1 shows that all animals are gaining weight. Many of the animals which were heaviest at the beginning of the experiment tend to be heaviest at the end of the experiment. The spread of the data is substantially uniform throughout the experimental period. This pattern suggests a uniform variance structure.

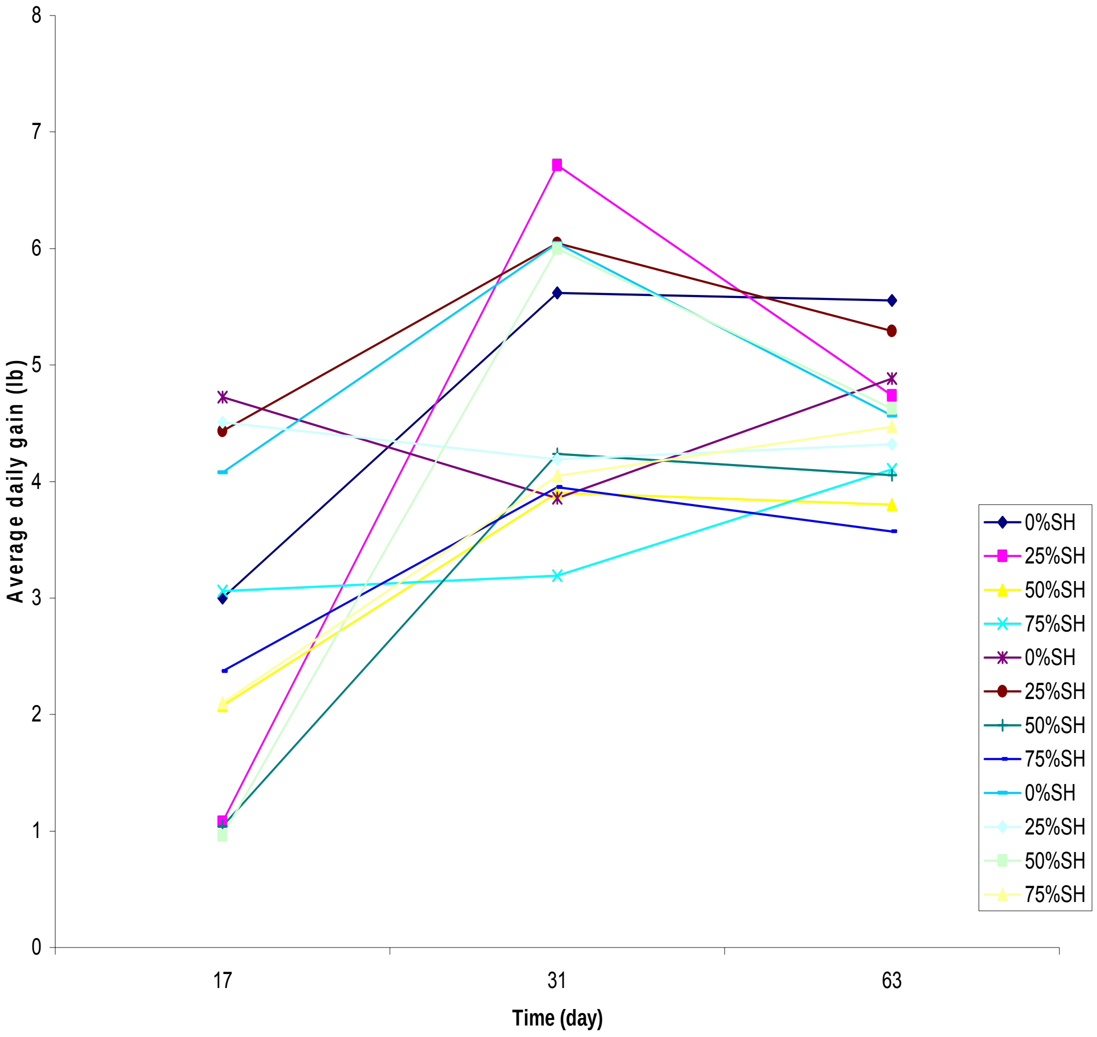
Figure 4.2 displays the average daily gain data. Some of the animals shows a decreasing trend at some point in time but increased later. For other animals, it increased sharply and decreased at the end of the feeding period. The figure shows that the spread of the data is not uniform; showing wider spread at the beginning, narrowing the second period and much smaller spread at the end the feeding period. The spread suggests a variable variance structure.

The display of feed efficiency data is shown in Figure 4.3. The figure indicates that some of the lines which connect measurements over time increased rapidly from day 17 to 31 and then decreased. Some lines increased steadily for the entire period. The spread of the data echoed that of the average daily gain. It shows wider spread at the beginning of measurement, lessening the second measurement and is comparably narrower at the end of the experiment. It seems to suggest a variable variance structure like that of the average daily gain data.

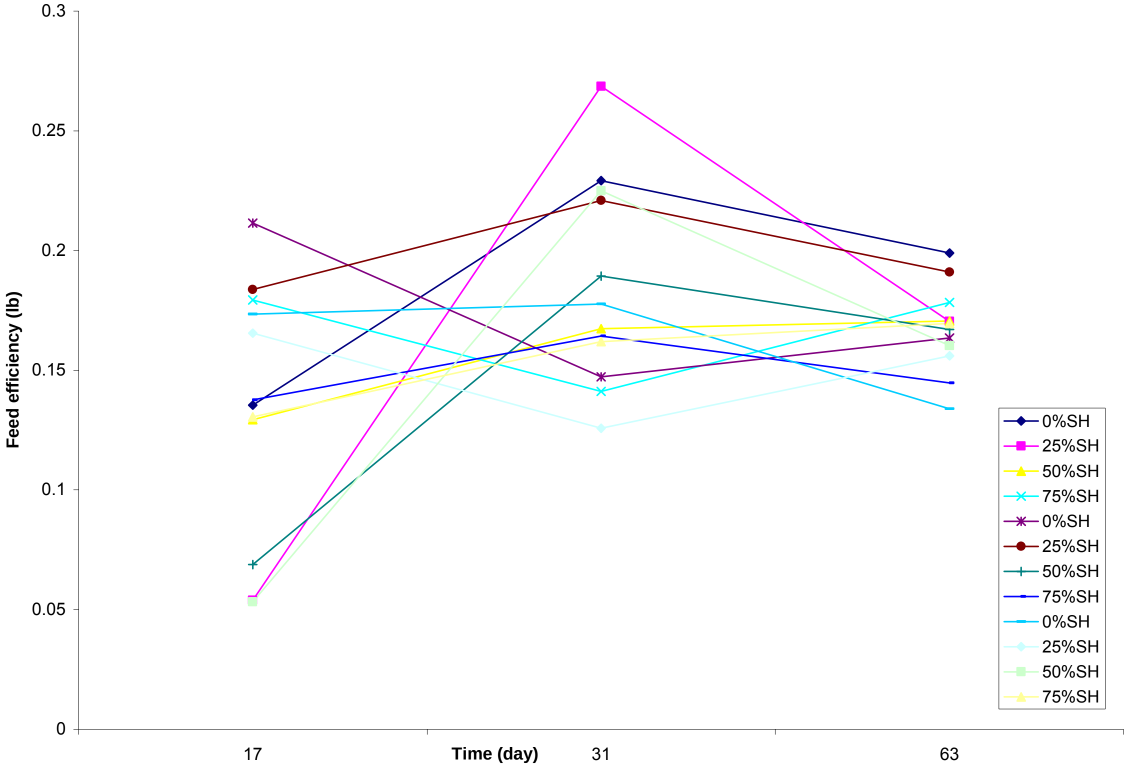
4.1 Plot of weight data of beef steers fed various rations in an experiment at the University of Missouri, Columbia, MO., 1998.



4.2 Plot of average daily gain data of steers fed various rations in an experiment at the University of Missouri, Columbia, MO., 1998.



4.3 Plot of feed efficiency data of steers fed various rations in an experiment at the University of Missouri, Columbia, MO., 1998.



4.2.2 Selection of variance-covariance structures

The search for the variance-covariance structure for weight, average daily gain, and feed efficiency was performed by fitting the data on several available structures. There were two procedures used to estimate the variance-covariance structure of each data (Chapter 3). The first procedure used the first set of SAS statements, while the second procedure used the second set of SAS statements.

As reported in Chapter 3, the variance-covariance structures fitted were unstructured (UN), compound symmetry (CS), heterogeneous compound symmetry (CSH, first-order autoregressive (AR(1)), heterogeneous first-order autoregressive (ARH(1)), first-order ante-dependence (ANTE(1)) toeplitz (TOEP), heterogeneous toeplitz (TOEPH) and the simple variance-covariance structure assumed by GLM procedure. All these structures were compared for goodness of fit statistics, determining which one seems to best fit the data. The criterion for selection, as reported in Chapter 3, was based on AIC.

4.2.2.1 The variance-covariance structure for weight

Table 4.1 reports the model fitting information for the various structures fitted to the weight data. The information includes values of AIC and the number of parameters for each of the respective variance-covariance structures. Each structure has its own formula for calculating the number parameters (SAS, 1996). The values of AIC were generated using the first set of SAS statements (Chapter 3). Of all structures fitted only AR (1) and ARH (1) met the convergence criteria for reaching the optimal solution. The fitting information for the simple variance-covariance structure of GLM is reported along with the other structures.

The choice of the best structure, as reported earlier, was based on AIC. A structure that has the smallest value of AIC is considered most desirable. Based on this criterion, the best structure selected by AIC is ARC (1). The AIC value for this structure is 303.8. It is the smallest value compared to other structures. The result shows that any attempt to improve the fit of the structure by reducing the parameters for estimation to 1 (GLM) or increasing to 5 (ARH (1)) is not supported by the fit statistics of AIC. Nevertheless, the structure selected will be compared to the structures estimated using the second set of SAS statements.

Table 4.1 Akaike's Information Criterion values for various variance-covariance structures fitted to weight data, using the second set of SAS statements for beef steers in an experiment at the University of Missouri, Columbia, MO; 1998.

Variance-covariance structures	Number of parameters	Fit Statistics (AIC)
First-order autoregressive, AR(1)	2	303.8
Heterogeneous first-order autoregressive, ARH(1)	5	304.8
Simple variance-covariance model, GLM	1	382.6

The fitting information for the various structures fitted to the weight data using the second set of SAS statements is presented in Table 4.2. The convergence criterion for realizing the optimal solution was met by all structures. A close look at the Table shows that AR(1) has the smallest AIC value of 314.7. This figure is bigger compared to the smallest value of 303.8 for AR(1) structure obtained in the first set of SAS statements. Based on these results, the best structure that best fit the data is AR(1) estimated using the first set of SAS statements. The results suggest that incorporation of the random statement improved estimation of the variance-covariance of the data.

The data were further evaluated for between subject heterogeneity to see whether treatments display different variability. This was done by including the GROUP = TRT option in the REPEATED statement (Chapter 3). Results showed that the value of AIC was 308.9. This figure was larger compared to 303.8 obtained without the option and using the first set of SAS statements. The implication of this result is that all treatments display similar variability represented by AR(1). In fact, plots of weight data for the individual treatments shows that the amount of variability appears to be roughly the same for all treatments (Appendices 4.1a through 4.1d).

Table 4.2 Akaike's Information Criterion values for various variance-covariance structures fitted to weight data, using the second set of SAS statements for beef steers in an experiment at the University of Missouri, Columbia, MO; 1998.

Structures	Number of parameters	Fit Statistics
		AIC
Unstructured, UN	10	321.1
Compound symmetry, CS	2	316.2
Heterogeneous compound symmetry, CSH	5	319.6
First-order autoregressive, AR(1)	2	314.7
Heterogeneous first-order autoregressive, ARH(1)	5	319.7
First-order ante-dependence, ANTE(1)	7	322.8
Toeplitz, TOEP	4	317.8
Heterogeneous Toeplitz, TOEPH	7	322

Thus, the variance-covariance matrix and the correlation matrix for subject 1 in treatment 1, displayed by the AR(1) structure, are reported below. The other subjects in different treatments show similar variance-covariance and correlation matrixes. For the variance-covariance matrix, result of the estimates appear as

$$\begin{bmatrix} 240.85 & 97.46 & 39.43 & 15.96 \\ 97.46 & 240.85 & 97.46 & 39.43 \\ 39.43 & 97.46 & 240.85 & 97.46 \\ 15.96 & 39.43 & 97.46 & 240.85 \end{bmatrix}$$

The first, second, third, and fourth columns or rows represent estimates for measurements taken on day 0, 17, 31 and 63 respectively. The diagonal elements represent the variances while the off diagonal elements are the covariances. The variances are constant supporting the amount of variability displayed in Figure 4.1. The covariance estimates provide evidence of decreasing trend, a desired characteristics for AR(1) structures.

Estimates of the correlation matrix for the AR(1) structure turned out to be

$$\begin{bmatrix} 1.000 & 0.405 & 0.164 & 0.066 \\ 0.405 & 1.000 & 0.405 & 0.164 \\ 0.164 & 0.405 & 1.000 & 0.405 \\ 0.066 & 0.164 & 0.405 & 1.000 \end{bmatrix}$$

The matrix shows a decreasing trend across times, a general pattern displayed by AR(1) structures and is formally expressed as ρ^t, where t is the number of time intervals between measurements. Thus, the correlation between measurements at times 1 and 2 is ρ which is 0.405; between measurements at times 1 and 3 is ρ^2 corresponding to 0.164; between measurements at times 1 and 4 is ρ^3 representing 0.066.

4.2.2.2 The variance-covariance structure for ADG

The results of fitting various variance-covariance structures to the ADG data showed that the structures UN, CS, AR(1), ARH(1), ANTE(1) and TOEP met the criteria of convergence when the first set of SAS statements were applied. However, each structure produced a non positive Hessian matrix. The structures CSH and TOEPH did not converge. Hence, these structures were not suitable for the ADG data.

Table 4.3 reports model fitting information for various structures fitted to the ADG data using the second set of SAS statements. All structures fitted met the convergence criteria for attaining the optimal solution. The best structure selected by AIC is ANTE(1).

Table 4.3 Akaike's Information Criterion values for various variance-covariance structures fitted to average daily gain data, using the second set of SAS statements for beef steers in an experiment at the University of Missouri, Columbia, MO; 1998.

Structures	Number of parameters	Fit Statistics
		AIC
Unstructured, UN	6	77.9
Compound symmetry, CS	2	80.1
Heterogeneous compound symmetry, CSH	4	79.5
First-order autoregressive, AR(1)	2	80.9
Heterogeneous first-order autoregressive, ARH(1)	4	80.1
First-order ante-dependence, ANTE(1)	5	76.0
Toeplitz, TOEP	3	82.1
Heterogeneous Toeplitz, TOEPH	5	81.5
Simple null model, GLM	1	80.4

The value of AIC for this structure turned out to be 76. This is the smallest value among all structures fitted using the second set of SAS statements including the GLM procedure.

Further evaluation of the data for between subject heterogeneous variability showed AIC value as 86.3. This value was larger compared to 76 obtained without the option. The result implies that all treatments have similar variability displayed by ANTE(1) structure. Appendices 4.2a through 4.2d plot the profiles of ADG data for the individual treatments. The plots indicate that the amount of variability do not considerably vary among treatments.

Estimates of the variance-covariance parameters for subject 1 in treatment 1 for ADG data, displayed by the ANTE(1) structure are reported below. All other subjects across treatments have the same variance-covariance matrix.

$$\begin{bmatrix} 1.31 & -0.80 & -0.16 \\ -0.80 & 1.14 & 0.22 \\ -0.16 & 0.22 & 0.22 \end{bmatrix}$$

The first, second, and third row or column represents estimate measurements for day 17, 31 and 63 respectively. The structure shows heterogeneous variances and heterogeneous covariances. The variances showed a decreasing trend, with the largest value of 1.31 on day 17 and the smallest, 0.22, on day 63. The sign of the covariance shows ADG negatively associated between measurements on day 17 and 31, as well as 17 and 63. However, ADG measured on day 31 and 63 is positively associated.

The estimates of the correlation matrix were mirrored by the estimates of the variance- covariance matrix. The correlations produced were heterogeneous.

$$\begin{bmatrix} 1.000 & -0.657 & -0.294 \\ -0.657 & 1.000 & 0.447 \\ -0.294 & 0.447 & 1.000 \end{bmatrix}$$

4.2.2.3 The variance-covariance structure for feed efficiency

As in the other data set, average daily gain, the structures UN, CS, AR(1), ARH(1), ANTE(1) and TOEP did not meet the criteria of convergence as they were fitted to the feed efficiency data with the first set of SAS statements. Also, their Hessian matrices were non-positive.

Table 4.4 presents results of the second set of SAS statements. All structures met the convergence criteria for achieving the optimal solution. The structures with the smallest AIC values were UN and ANTE(1).

Table 4.4 Akaike's Information Criterion values for various variance-covariance structures fitted to feed efficiency data, using the second set of SAS statements for beef steers in an experiment at the University of Missouri, Columbia, MO; 1998.

Structures	Number of parameters	Fit Statistics AIC
Unstructured, UN	6	-77.5
Compound symmetry, CS	2	-72.6
Heterogeneous compound symmetry, CSH	4	-72.1
First-order autoregressive, AR(1)	2	-72.7
Heterogeneous first-order autoregressive, ARH(1)	4	-72.4
First-order ante-dependence, ANTE(1)	5	-77.5
Toeplitz, TOEP	3	-71.0
Heterogeneous Toeplitz, TOEPH	5	-70.4
Simple null model, GLM	1	-72.2

The value of AIC for these structures was -77.5. Further evaluation of the data for between subject heterogeneous variability indicated that the value of AIC was -86.8 when ANTE(1) was included. However, when UN was included the result yielded a non-positive Hessian matrix and the optimization process stopped. Therefore, results favor modeling the feed efficiency data with between subject heterogeneous variability displayed by the ANTE(1) structure. Indeed, plots of feed efficiency data for each treatment show substantial differences in the amount of variability among treatments (Appendices 4.6a through 4.6d). Since the feed efficiency data showed treatments to have heterogeneous variability displayed by ANTE(1) structure, estimates of variance-covariance matrix for each treatment are reported below.

Treatment 1: $$\begin{bmatrix} 0.00144 & -0.00156 & -0.00081 \\ -0.00156 & 0.00171 & 0.00089 \\ -0.00081 & 0.00089 & 0.00106 \end{bmatrix}$$

Treatment 2: $$\begin{bmatrix} 0.00494 & -0.0034 & -0.00047 \\ -0.0034 & 0.00529 & 0.00073 \\ -0.00047 & 0.00073 & 0.00031 \end{bmatrix}$$

Treatment 3: $$\begin{bmatrix} 0.00161 & -0.00104 & 0.00019 \\ -0.00104 & 0.00085 & -0.00015 \\ 0.00019 & -0.00015 & 0.00003 \end{bmatrix}$$

Treatment 4: $$\begin{bmatrix} 0.0007 & -0.00033 & 0.00034 \\ -0.00033 & 0.00016 & -0.00017 \\ 0.00034 & -0.00017 & 0.0003 \end{bmatrix}$$

The estimates show that the variances varied across treatments. The data for treatments 1 and 2 were more spread compared to treatments 3 and 4. For all treatments, the spread of the data were smallest on day 63 compared to day 17 or 31. These observations are echoed with the data plot of individual treatments (Appendix 4.3a through 4.3d).

For treatments 1 and 2, the estimates of covariances indicate that feed efficiency on day 17 is negatively associated with day 31 and 63. However, the covariance between day 31 and 63 is positive. For treatments 3 and 4, estimates of feed efficiency on day 17 were negatively associated with day 31, but positively associated with day 63. The covariance between day 31 and 63 is negative.

The correlation matrices for treatment 1 through 4 are reported below. For treatment 1 and 2, the estimates indicate that feed efficiency on day 17 is negatively correlated with feed efficiency on days 31 and 63 and the strength of correlation decreased over time. The correlation between day 31 and 63 is positive, indicating that relatively large values of feed efficiency in day 31 are associated with a relatively large value in day 63. For treatment 3 and 4, feed efficiency on day 17 is negatively correlated with day 31, but positively correlated with day 63. The correlation of feed efficiency between day 31 and 63 was negative implying that relatively larger values of feed efficiency in day 31 are associated with relatively small value in day 63. The estimate of the correlation matrices are:

Treatment 1:
$$\begin{bmatrix} 1.0000 & -0.9889 & -0.6558 \\ -0.9889 & 1.0000 & 0.6631 \\ -0.6558 & 0.6631 & 1.0000 \end{bmatrix}$$

Treatment 2:
$$\begin{bmatrix} 1.0000 & -0.6649 & -0.3817 \\ -0.6649 & 1.0000 & 0.5741 \\ -0.3817 & 0.5741 & 1.0000 \end{bmatrix}$$

Treatment 3: $$\begin{bmatrix} 1.0000 & -0.8942 & 0.8937 \\ -0.8942 & 1.0000 & -0.9994 \\ 0.8937 & -0.9994 & 1.0000 \end{bmatrix}$$

Treatment 4: $$\begin{bmatrix} 1.0000 & -0.9739 & 0.7459 \\ -0.9739 & 1.0000 & -0.7659 \\ 0.7459 & -0.7659 & 1.0000 \end{bmatrix}$$

4.2.3 Effect of treatment on animal performance

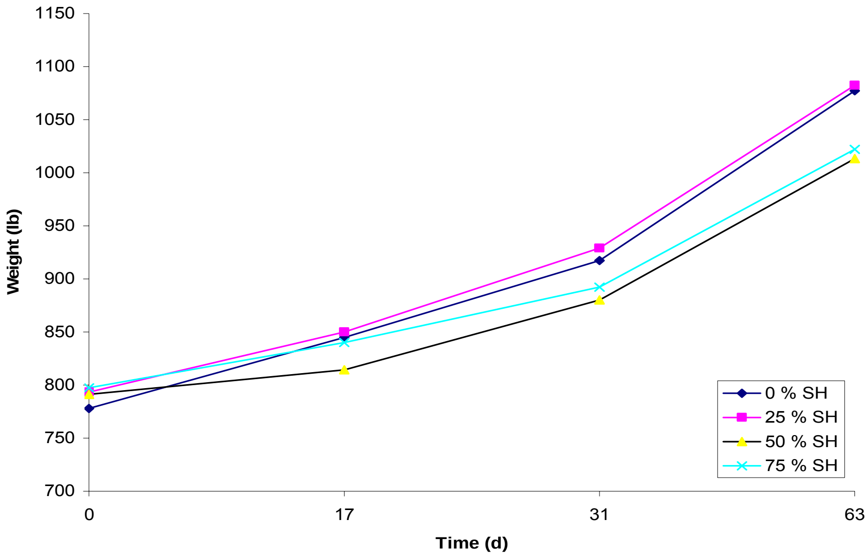
This subsection reports the effect of treatments on the beef steers' performance. As reported earlier, the experimental variables used to measure the performance of beef steers were weight, average daily gain, and feed efficiency. The effect of treatment on beef steer performance was evaluated at specific days whenever the test of the fixed effect TRT*TIM (interaction effect between treatment and time) was significant. However, whenever the test of the interaction (TRT*TIM) was insignificant, evaluation of treatment on performance of beef steers was carried out on treatment means averaged over the feeding period. The reason behind is that whenever the interaction is significant it masks the effects of treatments and their mean evaluations may be misleading.

4.2.3.1 Weight performance

The mean weight profiles of beef steers for each treatment over the time period are plotted in Figure 4.1. The figure shows that weight of beef steers increased for all treatments. The profile of beef steers fed 25 % SH shows increases in weight surpassing animals fed other diets before day 17. The profile for treatment 0 % SH indicates that the weight of beef steers increased rapidly from the start of the experiment, exceeding weight of steers fed 50 % SH or 75 % SH before day 17. The weight of beef steers fed 50 % SH increased relatively slowly between day 0 and 17, increased slightly between days 17 and 31, and started increasing at relatively the same rate as steers fed 75 % SH after day 31.

The test of fixed effects indicated that the interaction term TRT*TIM was significant (P = 0.0072). Test of TRT was insignificant (P = 0.1139) likely due to masking by the interaction, and TIM was highly significant (P = 0.0001). Because the interaction term is significant, statistical inferences for the comparison of treatment effects on weight of beef steer is reported at specific days (Table 4.5).

Figure 4.4 Mean weight profiles of beef steers for four treatments over time in an experiment at the University of Missouri, Columbia, MO., 1998.



For day 0, weight of beef steers assigned 0 % SH was not different from beef steers allotted to 25 % SH (P>.38), 50 % SH (P>.44) or 75 % SH (P>.26). For steers assigned 25 % SH, their weight did not differ from those allocated 50 % SH (P>.9) or 75 % SH (P>.8). Similarly, the weight of beef steers allocated 50 % SH and 75 % SH did not differ (P>.7). Because weights of beef steers on day 0 were measured prior to the start of the experiment, the observed weight differences do not reflect treatment effects.

On day 17, the weight of beef steers fed 0 % SH was not different from beef steers fed 25 % SH (P>.76), 50 % SH (P>.09) or 75 % SH (P>.78). Weight of beef steers fed 25 % SH was not statistically different from beef steers fed 50 % SH (P>.05), or 75 % SH (P>.57). The weight of steers fed 50 % SH was statistically not different from steers fed 75 % SH (P>.14).

Animals fed 0 % SH or 25 % SH started performing better than those fed 50 % SH on day 31. The statistical analysis shows that weight of steers fed 0 % SH did not differ from those fed 25 % SH (P>.49) or 75 % SH (P>.16), but differed from those fed 50 % SH (P<.05). Similarly, weight of steers fed 25 % SH differed from steers fed 50 % SH (P<.014) or 75 % SH (P<.051). The weight of beef steers fed 50 % SH did not differ from those fed 75 % SH (P>.4).

For day 63, the beef steers fed 0 % SH and 25 % SH continued to perform better compared to those fed 50 % SH or 75 % SH. Weight of steers fed 0 % SH did not differ from those fed 25 % SH (P>.7), but differed from steers fed 50 % SH (P<.003) or 75 % SH (P<.007). Also, the weight of steers fed 25 % SH differed from steers fed 50 % SH (P<.002) or 75 % SH (P<.004). The animals fed 75 % SH performed the same as those fed 50 % SH (P>.6).

As expected, the increase in weight for steers fed 0 % SH on day 31 and 63 echoed previous research results on cereal grain supplementation (Cole et al., 1976b; Galyean et al., 1976; Brown et al., 1981; Chase and Hibberd, 1987; Hibberd and Chase, 1986). Similarly, a study to evaluate the use of cracked corn or wheat bran as supplements for steers grazing endophyte-free fescue pastures found that steers supplemented with corn gained more than those fed bran-supplements (Hess et al., 1996).

The increase in weight of beef steers fed 25 % SH is probably due to the role of soy hulls altering the fermentation activity in the rumen, resulting in less digestive disturbances (Anderson et al., 1988a; Galloway et al., 1993; Grigsby et al., 1992). The weights of steers fed 0 % SH or 25 % SH were statistically similar the entire feeding time period. These results support research work of Hibberd and Chase (1986), Hibberd et al. (1987), and Anderson et al. (1988a). They reported that when soy hulls were fed at low inclusion rates in forage based beef cattle diets, the nutritive value of soy hull was estimated to be similar to that of corn. Hence, this is evidence that soy hulls, when fed in the proper proportions, can play an important role in several beef cattle rations.

Animals fed 75 % SH performed numerically better than those fed 50 % SH, this is probably due to the negative associative effects of feeding a mixture of feedstuffs (Byers et al., 1976; Mertens et al., 1980; Joaning et al., 1981). For diets containing corn, the starch part of corn depresses fiber digestion (Mertens et al., 1980; Joaning et al., 1981). The extent of the negative associative effect is dependent on the level of corn in the diet. The largest negative associative effects have been reported for diets containing 50 % corn and 50 % pelleted soy hulls (McDonnel et al., 1982). Therefore, the poor performance of steers fed 50 % SH is likely due to negative associative effects.

Table 4.5 Treatment comparison on mean weight (pounds) at specific days for beef steers in an experiment at the University of Missouri, Columbia, MO; 1998.

Treatments[1]	Day 0	Day 17	Day 31	Day 63
0 % SH	778.00	844.89	917.33^{a}	1077.33^{de}
25 % SH	793.22	850.00	929.11^{bc}	1082.22^{fg}
50 % SH	791.11	814.22	880.22^{ab}	1013.33^{df}
75 % SH	797.56	840.22	892.44^{c}	1022.00^{eg}

[1] Comparison is across treatments for each day; weights with same superscripts are statistically different.

4.2.3.2 Average daily gain performance

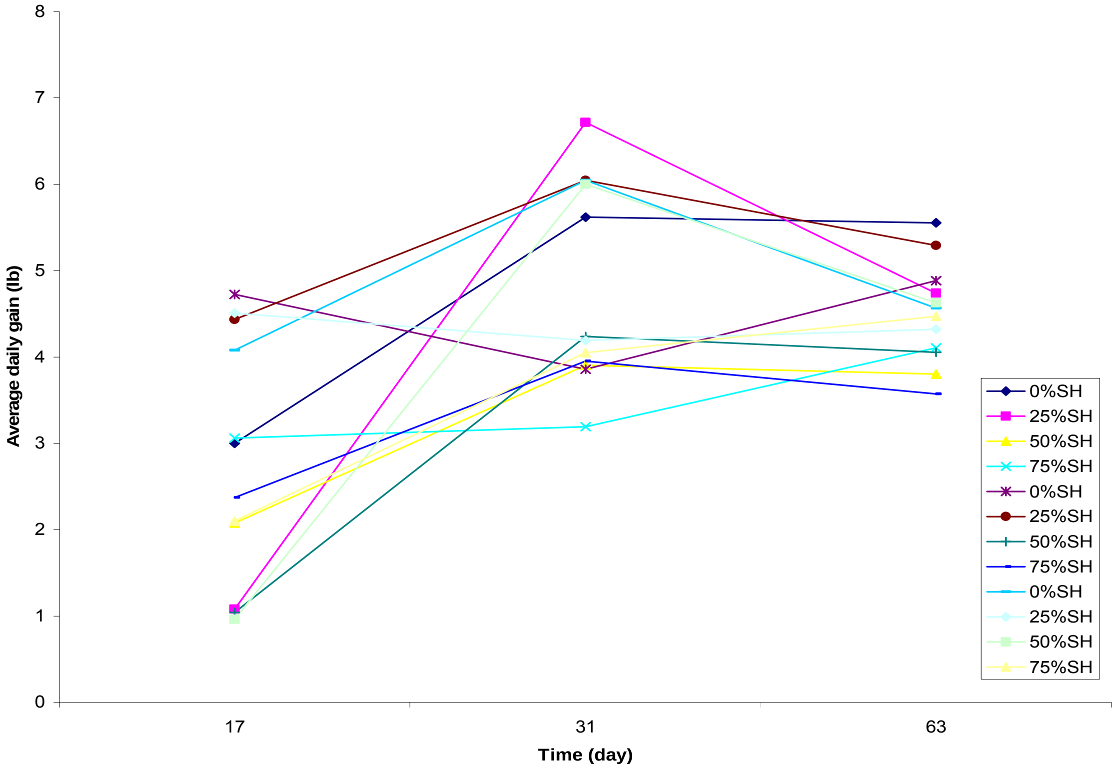
Figure 4.2 presents the mean profiles of ADG for beef steers fed various receiving rations. The figure indicates that ADG increased for all treatments, but started to decline after day 31 for all animals except for those animals fed 75 % SH. The ADG for 0 % SH was highest on day 17 compared to other treatments, but it was surpassed by 25 % SH before day 31 and regained the lead again before day 63. The ADG for 50 % SH increased sharply between day 17 and 31, but started declining thereafter.

Test of fixed effect showed that TRT and TIM were significant at P<.0016 and P<.0044 respectively. However, the interaction term TRT*TIM was insignificant (P>.46). Therefore, comparison of mean ADG across treatments averaged over the feeding period is relevant and is shown in Table 4.6.

Treatment comparisons on ADG averaged over the feeding days shows that beef steers fed 0 % SH did not differ from steers fed 25 % SH (P>.5), but differed significantly from steers fed 50 % SH (P<.003) or 75 % SH (P<.0035). Also, the ADG for steers fed 25 % SH differed from steers fed 50 % SH (P<.0065) or 75 % SH (P<.0078). Lastly, no differences in ADG were observed between steers fed 50 % SH and 75 % SH (P>.9).

Anderson et al. (1988a) reported that ADG of calves grazing low-quality bromegrass pasture was enhanced equally by corn or soy hull supplementation. Their report supports the finding of this study that ADG for steers fed 0 % SH or 25 % SH over the feeding period is similar. Horn et al. (1995) studied the effects high-starch (corn) or high-fiber (soy hulls) energy supplements on performance of fall-weaned steer calves grazing winter wheat pasture and subsequent feedlot performance. Their study found that ADG increase was not influenced by the type of energy supplement. However, subsequent feedlot ADG was decreased by supplementation.

Figure 4.5 Mean average daily gain profiles of beef steers for four treatments over time in an experiment at the University of Missouri, Columbia., MO., 1998.



Hsu et al. (1987) fed 25 % SH and 50 % SH of diet dry matter (DM) in beef cattle diets and observed slight decreases in ADG. Ludden et al. (1995) reported that replacing corn with SH linearly decreased ADG and increased dry matter intake (DMI). The result of this study shows that ADG started decreasing after day 31 for steers fed 0 % SH, 25 % SH, and 50 % SH (Figure 4.5).

Table 4.6 Effect of treatments on mean ADG (pounds/day) averaged over the feeding period for beef steers in an experiment at the University of Missouri, Columbia, MO; 1998.

Treatments[1]	Day 17	Day 31	Day 63	Average
0 % SH	3.93	5.17	5.00	4.75^{ac}
25 % SH	3.33	5.65	4.78	4.59^{bd}
50 % SH	1.35	4.71	4.16	3.53^{ab}
75 % SH	2.51	3.73	4.05	3.56^{cd}

[1] Comparison is made across treatments only on the last column, the ADG means are averaged over time; ADG with the same superscripts differ statistically.

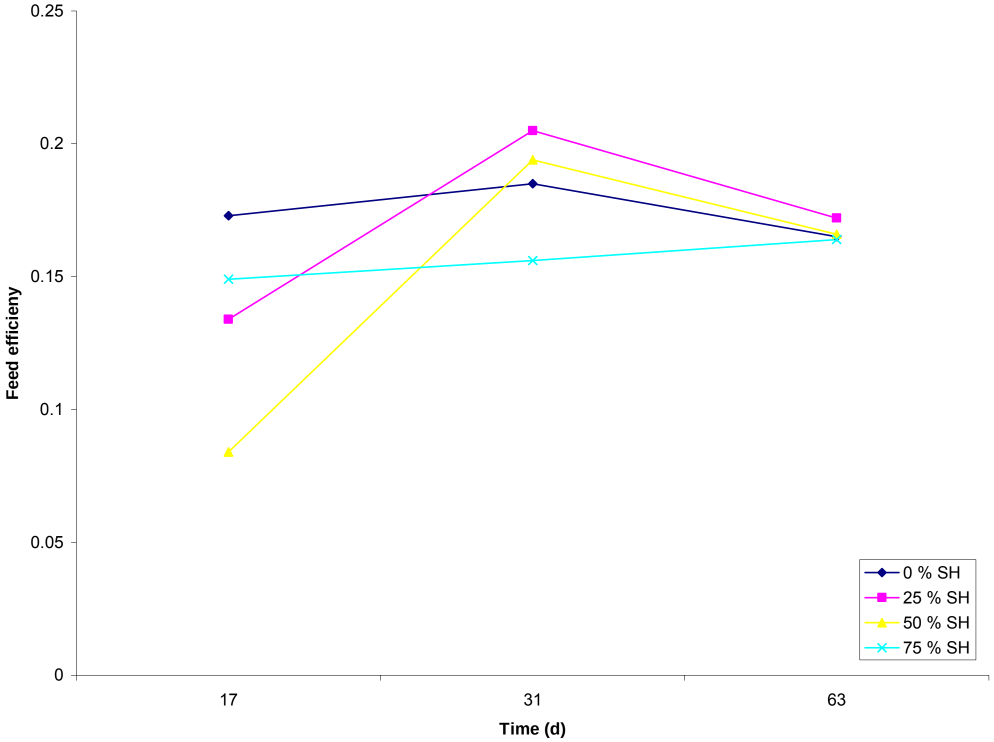
4.2.3.3 Feed efficiency performance

The mean profiles of feed efficiency are presented in Figure 4.6. The profile for 0 % SH increased slowly between day 17 and 31 and started declining thereafter. The profiles for 25 % SH and 50 % SH increased sharply between day 17 and 31 before they started declining the rest of the feeding period. The profile for 75 % SH shows feed efficiency increasing slowly over the feeding period.

Fixed effects TRT, TIM, and TRT*TIM were all insignificant at P>.08, P>.2, and P>.2 respectively. Due to the fact that TRT*TIM was insignificant, treatment comparison on mean feed efficiency averaged over time is reported (Table 4.7).

On average, feed efficiency for steers fed 0 % SH did not differ with those fed 25 % SH (P>.8) or 75 % SH (P>.1), but differed with animals fed 50 % SH(P<.04). The feed efficiency for 25 % SH was similar with 50 % SH (P>.19) and 75 % SH (P>.3). Also feed efficiency for animals fed 50% SH or 75 % SH did not differ (P>.2).

Figure 4.6 Mean feed efficiency profiles of steers for four treatments over time in an experiment at the University of Missouri, Columbia, MO., 1998.



A study by Ludden et al. (1995) to determine the value of soy hulls as a replacement for corn in concentrate diets formulated with or without added fat showed that replacing corn with soy hulls decreased feed efficiency. However, Faulkner et al. (1994) found no differences in feed efficiency for steer calves fed corn or soy hulls. Their findings support the results of this study.

Table 4.7 Treatment comparison on mean feed efficiency averaged over time for beef steers in an experiment at the University of Missouri, Columbia, MO; 1998.

Treatments[1]	Day 17	Day 31	Day 63	Average
0 % SH	0.173	0.185	0.165	0.1745^a
25 % SH	0.134	0.205	0.172	0.1706
50 % SH	0.084	0.194	0.166	0.1479^a
75 % SH	0.149	0.156	0.164	0.1564

[1] Comparison is made across treatments on the feed efficiencies averaged over time; feed efficiencies with the same superscripts differ statistically.

4.2.4 Effect of time on animal performance

One of the objectives of the study was to examine the effect of time on beef steer performance. This objective was addressed by analyzing the effect of time on weight, ADG, and feed efficiency of beef steers within a particular treatment. Therefore, the influence of time at a particular point is compared with another point in time within a treatment.

4.2.4.1 Weight performance

The effect of time on weight of beef steers within a particular treatment is reported in Table 4.8. The Table shows that pairwise comparisons of time within a particular treatment were significant at P =.0001 for 0 % SH and 25 % SH, P<.0029 for 50 % SH and P<.003 for 75 % SH. These results were as expected since these were all growing cattle. Over time, all animals increased their feed intake considerably (Appendix 4.1 through 4.4).

Table 4.8 Comparison of time on mean weight of beef steers (pounds) within a treatment in an experiment at the University of Missouri, Columbia, MO; 1998.

Treatments[1]	Time			
	Day 0	Day 17	Day 31	Day 63
0 % SH	778.00^{a}	844.89^{a}	917.33^{a}	1077.33^{a}
25 % SH	793.22^{b}	850.00^{b}	929.11^{b}	1082.22^{b}
50 % SH	791.11^{c}	814.22^{c}	880.22^{c}	1013.33^{c}
75 % SH	797.56^{d}	840.22^{d}	892.44^{d}	1022.00^{d}

[1] Comparison is made across time for each treatment; weights with the same superscripts differ statistically.

4.2.4.2 Average daily gain performance

Comparison of time on mean ADG within a treatment is reported in Table 4.9. For steers fed 0 % SH, ADG in day 17 did not differ from day 31 (P>.3), or day 63 (P>.2). ADG on day 31 and 63 was also significantly similar (P>.75). For steers fed 25 % SH, ADG on day 17 did not differ from day 31 (P>.08) or day 63 (P>.09). Similarly, ADG on day 31 and 63 did not differ (P>.15). For steers fed 50 %, ADG on day 17 differed from day 31 (P<.03) and day 63 (P<.007). However, ADG on day 31 did not differ from day 63 (P>.34). For steers fed 75 % SH, ADG on day 17 did not differ from day 31 (P>.3) or day 63 (P>.08). On day 31 and 63, ADG also did not differ (P>.57).

The fact that only ADG in day 17 for animals fed 50 % SH was statistically different from day 31 and 63, numerically ADG for the other treatments showed relative differences over time. The failure of the statistical test to detect these differences is likely due to the small size of the sample which in turn reduced the power of the statistical test.

Table 4.9 Comparisons of time on mean ADG (pounds/day) within a treatment for beef steers in an experiment at the University of Missouri, Columbia, MO; 1998.

Treatments	Time		
	Day 17	Day 31	Day 63
0 % SH	3.93	5.17	5.00
25 % SH	3.33	5.65	4.78
50 % SH	1.35^{cd}	4.71^{c}	4.16^{d}
75 % SH	2.51	3.73	4.05

[1] Comparison is made across time for each treatment; ADG with the same superscripts differ statistically.

4.2.4.3 Feed efficiency performance

Table 4.10 compares time on mean feed efficiencies within a treatment. Steers fed 0 % SH had feed efficiency in day 17 not different from day 31 (P>.8), or day 63 (P>.8). Also, feed efficiency on day 31 and 63 did not differ (P>.3). For steers fed 25 % SH, feed efficiency on day 17 did not differ from day 31 (P>.4) or day 63 (P>.4). Similarly, day 31 and 63 did not differ (P>.4). For steers fed 50 %, feed efficiency on day 17 did not differ with day 31 (P>.1), but differed with day 63 (P<.06). On day 31 and 63 feed efficiency did not differ (P>.2). For steers fed 75 % SH, feed efficiency on day 17 did not differ from day 31 (P>.7) or day 63 (P>.2). Also, on day 31 and 63, feed efficiency did not differ (P>.6).

Results indicate that animals utilized total feed for growth and maintenance the same in each time period except for animals fed 50 % SH. These animals showed differences in feed efficiency between day 17 and 63. These animals had the lowest ADG on day 17 attributed presumably by the negative associative effect on the earlier days of the experiment and improved slightly over time.

Table 4.10 Comparisons of time on mean feed efficiency within a treatment for beef steers in an experiment at the University of Missouri, Columbia, MO; 1998.

Treatments	Time		
	17 days	31 days	63 days
0 % SH	0.173	0.185	0.165
25 % SH	0.134	0.205	0.172
50 % SH	0.084[a]	0.194	0.166[a]
75 % SH	0.149	0.156	0.164

[1] Comparison is made across time for each treatment; feed efficiency with the same superscripts differ statistically.

4.3 Economic analysis results

4.3.1 Results of production function analysis

The procedure of estimating the parameters of the growth response function for beef steers started by exploring the correlation of the independent variables. The process was deemed necessary to uncover the problem of multicollinearity. In addition, the response variable, weight, was added in the correlation matrix of the independent variables to establish the extent of linear association with them. Table 4.11 presents results of the correlation matrix, using the correlation procedure of SAS. In reference to model [3.7] of Chapter 3, the variable SH (percentage of soy hulls), was highly correlated with the higher order variable SH^2 and moderately correlated with the interaction term SH*TIM; however it was not correlated with TIM or TIM^2. The variable TIM also showed a similar pattern of higher correlation with its higher order term and low with the interaction term. Thus, the results confirm the anticipated relationship between variables and their interactions and higher order terms. When independent variables are highly correlated it becomes difficult to isolate the true relation between them and the response variable because one masks the other. The association between Y (weight of animals) and SH or SH^2 was low, but high with TIM or TIM^2. The interaction, SH*TIM, was moderately related with Y.

Confirming that the lower order terms of model [3.7] are highly correlated, the next step was to orthogonalize the high order terms by removing the lower order terms from them. Table 4.12 present results of orthogonalization. All lower term variables are not correlated with the upper term variables. Then Y was regressed with SH, TIM, r-SH*TIM, r-SH^2, and r-TIM^2 to determine which of the independent variables are significantly contributing to the variability of the response variable.

Table 4.11 Partial correlation among independent variables and between the response variable for weight data in an experiment at the university of Missouri, Columbia, MO; 1998.

	Y	SH	TIM	SH*TIM	SH^2	TIM^2
Y	1.0000	-0.0855	0.8450	0.4511	-0.0794	0.8298
SH	-0.0855	1.0000	0.0000	0.5828	0.9583	0.0000
TIM	0.845	0.0000	1.0000	0.6515	0.0000	0.9592
SH*TIM	0.4511	0.5828	0.6515	1.0000	0.5585	0.6249
SH^2	-0.0794	0.9583	0.0000	0.5585	1.0000	0.0000
TIM^2	0.82975	0.0000	0.9592	0.6249	0.0000	1.0000

Table 4.12 Partial correlation among independent variables including orthogonalized ones and the response variable for weight data in an experiment at the University of Missouri, Columbia, MO; 1998.

	Y	SH	TIM	r-SH*TIM	r-SH^2	r-TIM^2
Y	1.0000	-0.0855	0.8450	0.4511	-0.0794	0.8298
SH	-0.0855	1.0000	0.0000	0.0000	0.0000	0.0000
TIM	0.845	0.0000	1.0000	0.0000	0.0000	0.0000
r-SH*TIM	0.4511	0.0000	0.0000	1.0000	0.0000	0.0000
r-SH^2	-0.0794	0.0000	0.0000	0.0000	1.0000	0.0000
r-TIM^2	0.82975	0.0000	0.0000	0.0000	0.0000	1.0000

Results of tests of significance of the parameters estimated by regressing Y with SH, TIM, r-SH*TIM, r-SH^2, and r-TIM^2 are reported in Table 4.13. The Table shows that the variables TIM and the residuals representing SH*TIM and TIM^2 are highly significant. However, the variable SH and the residual representing SH^2 are insignificant. Therefore, the true variables that explain the variability of the response variable are TIM, SH*TIM, and TIM^2. These are the variables which will be used to model the growth response function for beef steers. However, the variable SH was also included because SH*TIM cannot exist without the presence of SH. It is necessary to include all lower order terms whenever their respective higher order terms are shown to be significant.

Table 4.13 Tests of significance of parameters for the independent variables used to estimate the growth response function for beef steers in an experiment at the University of Missouri, Columbia, MO; 1998.

variable	t-Value	Pr > | t |
SH	-1.55	0.1653
TIM	38.98	< 0.0001
r-SH*TIM	- 4.7	0.0003
r-SH^2	0.11	0.9171
r-TIM^2	3.71	0.0008
n = 48		

Note: n represents number of observations

The final step in modeling the growth response function for beef steers was to regress Y with SH, TIM, SH*TIM and TIM^2, the variables found to be important in explaining the variability of the response variable. Results of this process are presented in Table 4.14 and in equation form as [4.6].

$$Y = 783.19 + 0.1576SH + 3.6796TIM - 0.01786SH*TIM + 0.01747TIM^2 \quad [4.6]$$

where Y is weight of beef steers in pounds, SH is percentage of soy hulls in the ration mix, TIM is time measured in days, SH*TIM is the interaction term between time and percentage of soy hulls in the ration mix, TIM^2 is the quadratic term for time.

Table 4.14 Parameter estimates for the independent variables estimating the growth response function for beef steers in an experiment at the university of Missouri, Columbia, MO; 1998.

Variable	estimate	standard errors	t-Value	Pr > | t |
Intercept	783.19	40.1588	19.50	0.0015
SH	0.1576	0.2311	0.68	0.5083
TIM	3.6796	0.3634	10.13	< 0.0001
SH*TIM	-0.01786	0.003792	- 4.71	0.0003
TIM^2	0.01747	0.004706	3.71	0.0008
n = 48				

Note: n represents number of observations.

The results indicate that the intercept is positive and significant; its estimate (783.19 lb) represents weight of steers at the beginning of the experiment. The variable SH is insignificant and it provides us no evidence to reject the null hypothesis that 'weight of beef cattle steers will not increase as the rate of soy hulls in the ration increases.' In fact the statistical analysis has already confirmed this. It was reported that weights of beef steers fed 0 % SH and 25 % SH were the same, but decreased as levels of soy hulls increased to 50 % SH and 75 % SH.

The variable TIM as expected was positive and highly significant and it confirms the statistical results which showed time to have influence on weight of beef steers. The interaction term, SH*TIM, which moderate the effect of the linear term SH on Y is significant and negative. The sign is negative to imply that the weight of an animal is weakened over time as is fed higher levels of soy hulls.

The variable TIM^2 was significant and positive confirming results of the data plot which showed weight to increase and showed no sign of a plateau. Because the variable SH^2 was dropped out for being insignificant, we have no basis to reject the hypothesis which stated that 'weight of beef cattle steers will not decrease as the rate of higher levels of soy hulls in the ration increases.' The weight data showed no sign of decreasing or leveling like a plateau.

Referring to model [3.7], estimate of the parameter for the random variable b turns out to be 4472.84 while that of w was 270.21. Parameter estimates for the random variable e represent the AR(1) structure and are presented below. Since the variance-covariance and correlation matrices are symmetric they are presented together. The upper shows half of the variance-covariance and the bottom represents correlations. The variances of the model are constant representing the uniformity in the spread of the weight data shown in the scatter plot in Figure 4.1. The correlation matrix also displays the AR(1) structure characteristics, decreasing over time. This trend confirms the earlier assertion that observations of repeated measurements close in time are correlated and the degree of association decreases with observations farther apart in time.

$$\begin{bmatrix} 291.19 & 104.41 & 37.4378 & 13.4238 \\ 0.3586 & 291.19 & 104.41 & 37.4378 \\ 0.1286 & 0.3586 & 291.19 & 104.41 \\ 0.0461 & 0.1286 & 0.3586 & 291.19 \end{bmatrix}$$

The production function [4.6] was expected to have both the necessary and sufficient conditions for determining the optimal levels of variable factors used in the production of beef steers. These factors were the levels of soy hulls in the ration and time used to feed the animals. Most important, the lower terms (SH and TIM) were expected to be significant and their parameters positive. The higher terms (SH^2 and TIM^2) were also expected to be significant and their parameters possessing negative signs. As already explained, the results showed that the lower term SH was positive and insignificant while TIM was positive and significant. The higher term TIM^2 was positive and significant while SH^2 was insignificant and dropped out. Even if SH^2 was included in the model, results for this scenario would be like [4.7]. This function also does not support the necessary and sufficient conditions of attaining optimal use of factors of production.

$$Y = 783.86 + 0.07869SH + 3.6791TIM - 0.01786SH*TIM + 0.01747TIM^2 + 0.001052SH^2 \quad [4.7]$$

Nutritional principles play a key role in explaining the outcome of the estimated growth response function for beef steers. Basically, both factors, soy hulls and time, had influence on the growth of beef steers, but in an opposing direction. First, as was reported in the statistical results, the animals continued growing over time. This indicated the vigorous growth of the animals as they were still young. The consequence of this effect likely resulted in a positive sign and strong statistical significance for both parameters of TIM and TIM^2. Second, the weight of the animals significantly decreased when higher levels of soy hulls were applied. Past research has shown that energy values for many feeds changes as the amount in the ration changes. This is especially true when replacing forage or roughage (fiber based ingredient) with concentrate (starch based ingredient). These changes in energy value are referred to as associative effects and can be positive or negative. Corn has been shown to have a negative associative effect on fiber utilization (Anderson et al. 1988; McDonnell, 1982). The impact of the effects is relative to the amount of corn fed as well as the type and quality of the forage. A mixture of half grain and half forage has a very large negative associative effect (Klopfenstein, et al. 1984). We infer from this literature that weight of beef steers decreased as high levels of soy hulls were applied due to associative effects of feeding a mixture of grain ingredient like corn and a fiber based ingredient like soy hulls; the effect was largest for the ration that contained 50 % soy hulls.

On the other hand the ration that contained 75 % SH had no grain (corn) in it and animals fed this ration had statistically similar weight gain performance like those fed 50 % SH. This could be due to reduced digestibility of soy hulls. The reduction in soy hulls digestibility is caused by a faster passage rate of small particles when little or no forage is included in the ration. Forage serves to slow passage and ruminal retention time, thereby increasing digestibility of soy hulls.

Therefore, the effect of the two factors (amount of soy hulls and time) which appeared in opposing direction as explained above resulted in a net effect as indicated in the estimates of parameters for SH, TIM, SH*TIM and TIM^2. Even if the higher term variable SH^2 were included in the model, the results would have shown a positive and statistically insignificant parameter estimate.

4.3.1.1 Results of estimating the growth response function with ADG data

The estimation of the growth response function using ADG as a dependent variable was carried out as an attempt to find out a function that can exhibit features conducive to determine the optimal level of soy hulls from an economical point of view. Table 4.15 reports results of exploring the extent of multicollinearity among the independent variables applied in estimating the growth response function [3.11]. All lower order terms, as was expected, are correlated with the higher order terms. Table 4.16 shows result of orthogonalizing the higher order terms; all terms are now orthogonal.

Table 4.15 Partial correlation among independent variables and between the response variable ADG in an experiment at the university of Missouri, Columbia, MO; 1998.

	Y	SH	TIM	SH*TIM	SH^2	TIM^2
Y	1.0000	-0.40345	0.40389	-0.05531	-0.37995	0.33601
SH	-0.40345	1.0000	0.0000	0.75418	0.95831	0.0000
TIM	0.40389	0.0000	1.0000	0.5265	0.0000	0.99168
SH*TIM	-0.05531	0.75418	0.5265	1.0000	0.72274	0.52212
SH^2	-0.37995	0.95831	0.0000	0.72274	1.0000	0.0000
TIM^2	0.33601	0.0000	0.99168	0.52212	0.0000	1.0000

Table 4.16 Partial correlation among independent variables including orthogonalized ones and ADG in an experiment at the University of Missouri, Columbia, MO; 1998.

	Y	SH	TIM	r-SH*TIM	r-SH^2	r-TIM^2
Y	1.0000	-0.40345	0.40389	0.09254	0.02339	-0.50110
SH	-0.40345	1.0000	0.0000	0.0000	0.0000	0.0000
TIM	0.40389	0.0000	1.0000	0.0000	0.0000	0.0000
r-SH*TIM	0.09254	0.0000	0.0000	1.0000	0.0000	0.0000
r-SH^2	0.02339	0.0000	0.0000	0.0000	1.0000	0.0000
r-TIM^2	-0.50110	0.0000	0.0000	0.0000	0.0000	1.0000

Results of regressing the dependent variable ADG with the orthogonalized variables are reported in Table 4.17. The results show that SH, TIM, and the residual for TIM^2 are significant. This implies that the variables SH, TIM and TIM^2 contribute in explaining the variability of the dependent variable. Thus, these variables should be included in modeling the growth response function for beef steers using ADG as the dependent variable. However, the residuals for SH*TIM and SH^2 were insignificant indicating that they were not a factor in explaining the variability of the ADG; including them in the model would only be justified if there was overriding nutritional or economic logic.

Table 4.17 Tests of significance of parameters for the independent variables used to estimate the growth response function for beef steers using ADG data in an experiment at the University of Missouri, Columbia, MO; 1998.

variable	t-Value	Pr > | t |
SH	-4.56	0.0014
TIM	4.37	0.0003
r-SH*TIM	1.42	0.1714
r-SH^2	0.65	0.5348
r-TIM^2	-3.31	0.0033
n = 36		

Note: n represents the number of observations.

Table 4.18 presents result of regressing ADG with SH, TIM and TIM^2. The table shows that the intercept is insignificant and the other variables are significant as were observed earlier. The parameter estimate for SH is negative implying that a unit increase in SH results in a decrease of ADG by a magnitude represented by the slope of SH (0.01701 lb/day). However, a unit increase in TIM increases ADG by 0.3069 lb/day. A close look on the function [4.8] indicates that its first derivative with respect to SH is negative and will not have a second derivative with the same variable. Thus, this function will not be valuable in determining the optimal level of soy hulls. The parameters for the random variable e were estimated as follows: $\sigma_1^2 = 1.5035$, $\sigma_2^2 = 1.0235$, and $\sigma_3^2 = 0.1910$; $\rho_1 = -05101$ and $\rho_2 = 0.3839$. As expected, ANTE(1) displays heterogeneous variances on the main diagonal and heterogeneous correlations and covariances.

Table 4.18 Parameter estimates for the independent variables estimating the growth response function for beef steers in an experiment at the University of Missouri, Columbia, MO; 1998.

Variable	estimate	standard errors	t-Value	Pr > | t |
Intercept	-0.8198	1.5437	-0.53	0.6058
SH	-0.01701	0.003745	-4.54	0.0003
TIM	0.3069	0.08892	3.45	0.0054
TIM^2	-0.00337	0.001019	-3.31	0.0070
n = 36				

Note: n represents number of observations.

$$Y = -0.8198 - 0.01701SH + 0.3069TIM - 0.00337TIM^2 \qquad [4.8]$$

Attempts to include all variables specified in [3.11] resulted to equation [4.9]. The intercept of this model as in [4.8] was declared insignificant. The variables SH*TIM and SH^2 were found to be insignificant confirming the test made earlier when their residuals were regressed with ADG. The model also is not favorable for determining the optimal level of soy hulls using economical principles.

$$Y = -0.3159 - 0.03686SH + 0.2982TIM + 0.000232SH*TIM + 0.00011SH^2 - 0.00337TIM^2 \qquad [4.9]$$

Realizing that the production function analysis could not yield the expected results of finding the exact level of soy hulls that maximize production of beef steers in economic terms, an alternative method was applied to determine and compare economic performance of the treatments. This method applied is the partial budget analysis. According to Heady, et al. (1963), if a production function fails to provide an exact level of input that maximizes production, then the alternative method is to isolate each treatment and calculate its net benefits. The net benefits are then compared among the treatments, a procedure explained in the next section.

4.3.2 Results of partial budget analysis.

The partial budget analysis for this study represents a method of organizing the experimental data in terms of variable costs and benefits per animal for each ration (treatment). It is a partial budget because only costs that varied in each ration are included in the analysis. The variable costs included were cost of buying the animals and feed ingredients used to formulate the rations. The benefits were for selling the animals. Average prices for 2000/04 were used to reflect current situations. In addition, net benefits per pound of gain were calculated by dividing the net benefit per animal by weight gain of the animal. Because the initial weights of the animals for each treatment were numerically different, the costs of buying the animals were also different even for animals priced at the same level and this gave unfair comparison of net benefit per animal across treatments. Thus, net benefit per pound gain which adjusts net benefit by weight gain was used as an additional parameter of comparing treatments.

Table 4.19 presents a summary of the partial budgets by treatments for days 17, 31, and 63. The detail of the analysis is shown in Appendices 4.4, 4.5 and 4.6 for day 17, 31 and 63 respectively. For day 17, animals fed 0 % SH had the highest net benefit followed by those fed 25 % SH. In fact the ratio of net benefits for animals fed 0 % SH and 25 % SH was 1:0.59. During this feeding period, this ratio simply implies that net benefit realized by animals fed 25 % SH was only 55 % compared to that earned by animals fed 0 % SH. The reason is that animals fed 25 % SH consumed more feed (Appendix 4.4) compared to those fed 0 % SH because corn contains more energy per unit of measurement compared to soy hulls. As a result, feed costs for animals fed 0 % SH were $21.459, slightly lower than $21.64 per animal for animals fed 25 % SH. This was also due to the fact that the ADG and feed efficiency for animals fed 0 % SH were numerically higher than those fed 25 % SH. More important, the cost of purchasing the animals fed 0 % SH was $684.64, less than the $698.034 per animal for those fed 25 % SH. The net benefit per pound of gain for animals fed 0 % SH was also higher compared to those fed 25 % SH. The lower net benefits and net benefits per pound of gain obtained by animals fed 50 % SH or 75 % SH is a reflection of the lowest ADG and numerically the lowest feed efficiency obtained by these animals compared to those fed 0 % SH or 25 % SH. Indeed, animals fed 50 % SH showed negative net benefit and net benefit per pound of gain. These animals gained the least weight as was reported in section 4.2.3.1, probably attributed to the negative associative effect of feeding a combination of fiber based and starch based ingredients.

On day 31, animals fed 0 % SH continued to perform better than those fed 25 % SH. However, animals fed 25 % SH improved as the net benefit ratio for animals fed 0 % SH and 25 % SH changed to 1:0.89. The ratio means that net benefit for animals fed 25 % SH was 88 % compared to those fed 0 % SH. The ADG and feed efficiency for animals fed 25 % SH improved, and was numerically higher than those fed 0 % SH (Tables 4.6

and 4.7). Thus, the feed costs for animals fed 25 % SH were $43.042, less than the $43.475 per animal for animals fed 0 % SH. Again, the purchase cost of the animals played a major factor in realizing the net befit per animal. The net benefits per pound of gain were lower for animals fed 25 % SH compared to those fed 0 % SH. Net benefits and net benefits per pound of gain for animals fed 50 % SH or 75 % SH were the lowest compared to those fed 0 % SH or 25 % SH. Animals fed 50 % SH continued to have negative net benefit and net benefit per pound of gain probably for the same reason mentioned above, the negative associative effect of feeding a combination of fiber based and starch based ingredients.

On day 63, animals fed 0 % SH had slightly higher net benefits than those fed 25 % SH. A close look on Table 4.19 indicates that the ratio of net benefits for animals fed 0 % SH and 25 % SH was 1:0.98. The ratio says that net benefits for animals fed 25 % SH were 97 % compared to those fed 0 % SH. Animals fed 0 % SH also had numerically higher ADG. However, their feed efficiency was numerically lower compared to those fed 25 % SH. As a result, feed costs for animals fed 0 % SH were $99.206, higher than the $91.307 per animal for those fed 25 % SH. Thus, the contributing factor for the lower net benefit for animals fed 25 % SH compared to those fed 0 % SH is the cost for purchasing the animals. The net benefit per pound of gain for animals fed 0 % SH was slightly lower compared to those fed 25 % SH. This implies that one pound of gain for animals fed 25 % SH earned more than a pound earned from animals fed 0 % SH. Animals fed 50 % SH or 75 % SH had lower net benefits and net benefits per pound of gain compared to animals fed 0 % SH or 25 % SH. The higher ADG for animals fed 0 % SH or 25 % SH compared to those fed 50 % SH or 75 % SH contributed to these differences. The net benefits for animals fed 50 % SH were 54 % compared to 0 % SH while animals fed 75 % SH were 59 %. This was mainly due to lower ADG which was in turn attributed with negative associative effects for 50 % SH and reduced digestibility for 75 % SH.

Table 4.19 Partial budget for beef steers fed various receiving rations in an experiment at the University of Missouri, Columbia, MO., 1998.

Items	Day 17			
	0 % SH	25 % SH	50 % SH	75 % SH
Gross Benefits ($/animal)	728.295	732.700	701.858	724.270
Total variable costs ($/animal)	706.099	719.674	710.743	716.305
Net Benefit ($/animal)	22.196	13.026	-8.885	7.965
Net Benefit ($/lb gain)	0.332	0.229	-0.384	0.187
	Day 31			
Gross Benefits ($/animal)	756.797	766.516	726.182	736.263
Total variable costs ($/animal)	728.115	741.076	728.385	733.231
Net Benefit ($/animal)	28.683	25.440	-2.203	3.032
Net Benefit ($/lb gain)	0.206	0.187	-0.025	0.032
	Day 63			
Gross Benefits ($/animal)	867.251	871.010	815.731	822.710
Total variable costs ($/animal)	783.846	789.341	770.706	773.213
Net Benefit ($/animal)	83.405	81.669	45.025	49.497
Net Benefit ($/lb gain)	0.279	0.283	0.203	0.221

4.3.3 Results of linear programming

4.3.3.1 Least cost receiving rations for beef steers

Least cost receiving rations for beef steers formulated without and with inclusion of variability information using 1994/98 average prices are reported in Table 4.20 and 4.21 respectively. Included in the tables are ingredients levels in percentage, amount of ration in pounds per day per animal, cost in dollars per day per animal, increase in cost in percentage (only Table 4.21), and probability of attaining the specified protein requirement. The inclusion of variability information, as was reported in chapter 3, was to enhance the probability of attaining the minimum requirement of protein.

The percentages of ingredients reflect the ways the rations were formulated. While the percentages of cracked corn grain were determined by the computer to fulfill nutrient requirements, the levels of soy hulls and cottonseed were predetermined. Rations formulated with variability information had higher levels of soybeans. Inclusion of variability information required adding a portion of the standard deviation to the minimum requirement of protein levels and this demanded more soybean meal. The costs of rations per day per animal decreased as the level of soy hulls in the ration increased. In addition, costs of rations with variability information were higher, attributed to the incorporating of variability information. The increase in cost due to inclusion of variability information was small for the three rations 0% SH (0.059 %), 25 % SH (0.063 %) and 50 % SH (0.068 %). However, for 75 % SH the increase was 3.922 % attributed to an increased amount of feed compared to other rations.

The probability of attaining the recommended level of protein at 13.5 %, as expected, was 50 % for rations formulated without variability information (Table 4.20). On the other hand, inclusion of variability information elevated the level of protein requirement. Consequently, probability levels increased (Table 4.21). The probability levels were adjusted to around 80 % to keep increase in cost as low as possible.

Table 4.20 Receiving rations for beef steers formulated without variability information and using 1994/98 average prices in an experiment at the University of Missouri, Columbia, MO., 1998.

Items	0 % SH	25 % SH	50 % SH	75 % SH
INGREDIENTS (%)				
Cracked corn grain	69.582	45.908	22.233	0.0
Cottonseed hulls	15.0	15.0	15.0	15.0
Soy hulls	0.0	25.0	50.0	75.0
Soybean meal	11.681	10.272	8.863	6.857
Limestone	1.906	1.536	1.166	0.0
Dicalcium phosphate	0.611	1.064	1.518	1.938
Sodium chloride	0.20	0.2	0.2	0.197
Trace minerals	1.0	1.0	1.0	0.999
Rumensin	0.014	0.014	0.014	0.014
Tylan	0.006	0.006	0.006	0.006
Total	100.00	100.00	100.00	100.00
AMOUNT (lb/d/animal)	24.25	24.25	24.25	24.56
COST ($/d/animal)	1.684	1.578	1.472	1.377
PROBABILITY (%)	50	50	50	50

Table 4.21 Receiving rations for beef steers formulated with inclusion of variability information and using 1994/98 average prices in an experiment at the University of Missouri, Columbia, MO., 1998.

Items	0 % SH	25 % SH	50 % SH	75 % SH
INGREDIENTS (%)				
Cracked corn grain	68.752	45.04	20.967	0.0
Cottonseed hulls	15.0	15.0	15.0	15.0
Soy hulls	0.0	25.0	50.0	75.0
Soybean meal	13.344	12.01	11.398	8.382
Limestone	1.655	1.274	0.784	0.0
Dicalcium phosphate	0.029	0.456	0.631	0.490
Sodium chloride	0.2	0.2	0.2	0.185
Trace minerals	1.0	1.0	1.0	0.924
Rumensin	0.014	0.014	0.014	0.013
Tylan	0.006	0.006	0.006	0.006
Total	100.0	100.0	100.0	100.0
AMOUNT (lb/d/animal)	24.25	24.25	24.25	26.24
COST ($/d/animal)	1.685	1.579	1.473	1.431
COST INCREASE (%)[1]	0.059	0.063	0.068	3.922
PROBABILITY (%)	82	82	81	81

[1] Cost increase was calculated relative to costs of ration without variability information.

4.3.3.2 Sensitivity analysis

The sensitivity of the least cost receiving rations formulated using 1994/98 average prices to changes in the objective function coefficients were evaluated using 2000/04 average prices. Further analysis was carried out by introducing variability information to enhance the probability of meeting the minimum requirement of protein. Tables 4.22 and 4.23 report on least cost rations formulated without and with inclusion of variability information, respectively. The composition of ingredients remained relatively similar with rations formulated with 1994/98 average prices; this was due to the way the ingredients were formulated. In all rations, cottonseed hulls were restricted to 15 % of the amount in the final mix and soy hulls was programmed at 0 %, 25 %, 50 %, and 75 % for 0 % SH, 25 % SH, 50 % SH and 75 % SH rations, respectively.

Costs of rations per day per animal decreased across rations (Table 4.22 and 4.23). They were lower compared to costs of rations prepared with 1994/98 average prices. The reason behind this is that average prices for the main ingredients: cracked corn grain, soy hulls, and soybean meal for 2000/04 were lower compared to 1994/98 (Appendix 3.2 and 3.3). Table 4.23 shows that inclusion of variability information resulted in a modest increase in feed cost by 0.066 % for 0 % SH, 0.068 % for 25 % SH, 0.143 % for 50 % SH and relatively higher cost by 3.558 % for 75 % SH.

Table 4.22 Receiving rations for beef steers formulated without variability information and using 2000/04 average prices in an experiment at the University of Missouri, Columbia, MO., 1998.

Items	0 % SH	25 % SH	50 %SH	75 % SH
INGREDIENTS (%)				
Cracked corn Grain	70.833	47.291	23.656	0.0
Cottonseed hulls	15.0	15.0	15.0	15.0
Soy hulls	0.0	25.0	50.0	75.0
Soybean meal	11.445	10.011	8.594	6.857
Limestone	0.881	0.402	0.0	0.0
Dical. phosphate	0.622	1.076	1.53	1.938
Sodium Chloride	0.2	0.2	0.2	0.197
Trace minerals	1.0	1.0	1.0	0.988
Rumensin	0.014	0.014	0.014	0.014
Tylan	0.006	0.006	0.006	0.006
Total	100.0	100.0	100.0	100.0
AMOUNT (lb/d/animal)	24.25	24.25	24.25	24.56
COST ($/d/animal)	1.526	1.463	1.401	1.349
PROBABILITY (%)	50	50	50	50

Table 4.23 Receiving rations for beef steers formulated with variability information using 2000/04 average prices in an experiment at the University of Missouri, Columbia, MO., 1998.

Items	0 % SH	25 % SH	50% SH	75 % SH
INGREDIENTS (%)				
Cracked corn Grain	69.706	46.114	21.92	0.0
Cottonseed hulls	15.0	15.0	15.0	15.0
Soy hulls	0.0	25.0	50.0	75.0
Soybean meal	13.169	11.811	11.22	8.338
Limestone	0.87	0.391	0.0	0.0
Dical. phosphate	0.035	0.464	0.64	0.532
Sodium Chloride	0.2	0.2	0.2	0.185
Trace minerals	1.0	1.0	1.0	0.926
Rumensin	0.014	0.014	0.014	0.013
Tylan	0.006	0.006	0.006	0.006
Total	100.0	100.0	100.0	100.0
AMOUNT (lb/d/animal)	24.25	24.25	24.25	26.19
COST ($/d/animal)	1.527	1.464	1.403	1.397
COST INCREASE (%)[1]	0.09	0.098	0.156	3.56
PROBABILITY (%)	81	82	81	80

[1] Cost increase was calculated relative to costs of ration without variability information.

4.3.3.3 Range analysis

Range analysis was carried out to examine the range of values the objective function coefficients can assume without changing the basic feasible ingredients in the solution. The analysis was limited to rations formulated using 2000/04 prices to represent recent prices and covered rations formulated with variability information.

Results are shown in Tables 4.24 through 4.27. The tables indicate the original prices of ingredients used in obtaining the basic feasible solution; the marginal value of each ingredient; the minimum and maximum prices the ingredient can vary without affecting the basic ingredients (set of ingredients that are in the plan); the minimum and maximum value of the objective function corresponding to the minimum and maximum price changes; and the blocking or limiting constraints that would enter the basis if prices at the indicated minimum or maximum range would further change.

Table 4.24 indicates that the original prices for cracked corn grain, cottonseed hulls, soy hulls, soybean meal, limestone, and dicalcium phosphate were 0.05, 0.072, 0.111, 0.06 and 0.22 $/lb respectively. The marginal values for cracked corn grain, cottonseed hulls, soy hulls, soybean meal, limestone, and dicalcium phosphate are zero because all activities that are in the basis have zero marginal values. Table 4.24 further indicates that price of cracked corn grain can vary within a range of $0.017 to $0.055 without changing the basic feasible ingredients in the solution, assuming all other coefficients remain constant. Consequently, if the cost of cracked corn grain were to decrease by 66 % from 0.05 to 0.017 $/lb, the objective function will be $0.978, down by $0.549 compared to the original optimal value of $1.527 and the constraint amount of feed will enter the basis if the cost were to decrease further; however, if its costs were to increase by 10 % from

0.05 to 0.055 $/lb, the objective function will be $1.612, up by $0.085 and the constraint protein level will enter the basis if price were to increase beyond the upper level. Observing the price trend for corn from 1994 to 1998 and from 2000 to 2004, it seems the price of cracked corn grain will likely not decrease beyond 0.017 $/lb (0.952 $/bu), warranting it to be in the basis. However, its price may increase past the limit of 0.055 $/lb (3.08 $/bu). Even if this happens, cracked corn grain will still remain in the basis because it was programmed as the major source of energy for this ration.

For cottonseed hulls, its price can decrease from $0.072 to zero and not to the negative value (-0.163) indicated in the table. Note that prices are not permitted to be negative. The price of cottonseed hulls can increase from $0.072 to infinity resulting to infinity maximum value of the objective function, assuming all other coefficients remain constant. Results confirm the way this ingredient was programmed. It was restricted to be exactly 15 % of the final ration mix regardless of price change.

Soybean meal price can fall by 2.7 % from 0.111 $/lb (222 $/ton) to 0.108 $/lb (216 $/ton) resulting in a decrease in the ration cost by 0.65 % compared to its original cost of $1.527, assuming all other coefficients remain constant. Price also can increase to a limit of 0.278 $/lb (556 $/ton) representing 150 % increase. This will result in an increase in the cost of ration to $2.06, up by 35 % from its original price. Price of soybean meal from 1994 to 1998 and from 2000 to 2004 ranged from 167.5 to 271.65 $/ton. Thus, it is possible for the price of soybean meal to fall beyond the minimum range, warranting it to be in the basic feasible solution; however, it is unlikely that the maximum range can be exceeded.

Price of limestone is allowed to fall from its original level of 0.06 \$/lb (3 \$/50 lb bag) to 0.038 \$/lb (1.9 \$/50 lb bag) representing a decrease of 37 %. These changes adjust the cost of ration downward by 0.3 % from its current level of \$1.527. Its price can also increase to 0.591 \$/lb (29.55 \$/50 lb bag), resulting in an increase in the cost of the ration to \$1.639, assuming all other coefficients remain constant. Since this is a very wide range, limestone is likely to always be included in the basic feasible solution.

Dicalcium phosphate is allowed to vary its price within the range of 0.035 \$/lb (1.75 \$/50 lb bag) to 0.23 \$/lb (11.5 \$/50 lb bag) without changing the basic feasible solution and assuming all other coefficients remain constant. Outside the lower bound, dicalcium phosphate will still remain in the basic feasible solution because it is relatively cheaper; however, when its price increases beyond the upper range, assuming all other coefficients stay constant, it will likely be out of the basic feasible solution. The reason is that the range between its optimal price of \$0.22 and the upper bound \$0.23 is very small.

Table 4.24 Price range analysis for ration containing 0 % SH, using 2000/04 average prices with variability information.

0 % SH[1]	Original price Marginal value	Minimum price Maximum price	Min. objective Max. objective	Constraint – at min Constraint – at max
INGREDIENTS				
CCG	0.05	0.017	0.978	Amount of feed
	0	0.055	1.612	Protein level
CSH	0.072	-0.163	0.674	Amount of feed
	0	infinity	infinity	.
SBM	0.111	0.108	1.517	Protein level
	0	0.278	2.060	Amount of feed
LIM	0.06	0.038	1.522	Calcium level
	0	0.591	1.639	Protein level
DPH	0.22	0.035	1.526	Sulfur level
	0	0.230	1.527	Protein level

[1] optimal solution was \$1.527

Legend: CCG = cracked corn grain, CSH = cottonseed hull, SBM = soybean meal, LIM = limestone, DPH = dicalcium phosphate.

Price range analysis for rations containing 25 % SH is presented in Table 4.25. The table shows that cracked corn grain has an allowable price change from 0.011 $/lb (0.616 $/bu) to 0.055 $/lb (3.08 $/bu) without changing the basic feasible solution. From these changes the corresponding cost for producing the ration decrease by 29.4 % for the lower bound and increase by 3.9 % for the upper bound. The constraints amount of feed and protein level will be added when price changes beyond the lower and upper limits respectively. These changes happen when all other coefficients remain constant. Moreover, even if price of cracked corn grain changes beyond the allowable bounds, it will still remain part of the basic feasible solution because it was programmed as a main ingredient to supply energy.

Cottonseed hulls can decrease from its current price of 0.072 $/lb to zero causing the cost of the ration to go down by 55 % from its original level of $1.464. Price can also increase to infinity resulting in infinity cost of the ration. The implication of these changes is that cottonseed hulls will remain in the basic feasible solution regardless of price change.

The allowable price decrease for soy hulls is zero. The price can also increase to infinity resulting in infinity cost of the ration. Results further indicate that the constraints amount of feed and protein level will be added if price changes past the allowable limits. These changes will only occur when all other coefficients remain constant.

The price of soybean meal can decrease as much as $0.108 reducing the cost of the ration by 0.61 % from its current level of $1.464 or increase as much as $0.257 making the ration more costly by 28.7 %. These changes happen assuming all other coefficients remain constant. The constraints amount of feed and protein level will be added to the basic feasible solution if price change beyond the lower and upper limits respectively.

Limestone is allowed to decrease as low as 0.038 $/lb reducing the cost of the ration to $1.462 (down by 0.137 %) or increase to 0.591 $/lb leading to increased cost of $1.515 (up by 3.48 % from the original cost of $1.464), assuming prices of other ingredients remain constant. The constraints calcium level and protein level will be added when price change past the lower and upper limits respectively.

The price of dicalcium phosphate can decrease by as much as 0.035 $/lb lowering the cost of the ration to $1.444 (down by $0.02) or increase by as much as 0.23 $/lb (up by $0.01) without changing the basic feasible solution, assuming prices of all other ingredients stay constant. The constraints sulfur level and protein level will enter the basis when price change beyond the lower and upper bound respectively.

Table 4.25 Price range analysis for ration containing 25 % SH, using 2000/04 average prices with variability information.

25 % SH[1]	Original price Marginal value	Minimum price Maximum price	Min. objective Max. objective	Constraint – at min Constraint – at max
INGREDIENTS				
CCG	0.05	0.011	1.034	Amount of feed
	0	0.055	1.521	Protein level
CSH	0.072	-0.145	0.658	Amount of feed
	0	infinity	infinity	.
SH	0.04	-0.090	0.658	Amount of feed
	0	infinity	infinity	.
SBM	0.111	0.108	1.455	Protein level
	0	0.257	1.884	Amount of feed
LIM	0.06	0.038	1.462	Calcium level
	0	0.591	1.515	Protein level
DPH	0.22	0.035	1.444	Sulfur level
	0	0.230	1.466	Protein level

[1] optimal solution was $1.464

Legend: CCG = cracked corn grain, CSH = cottonseed hull, SH = soy hull,
SBM = soybean meal, LIM = limestone, DPH = dicalcium phosphate.

Table 4.26 reports on price range for the 50 % SH ration. The price associated with cracked corn grain can decrease by as much as 0.0001 $/lb (0.0056 $/bu), lowering the cost of the ration to $1.138 or increase by as much as $0.055 leading to increased cost of ration to $1.43, assuming the coefficients of other ingredients are constant. If price changes beyond the lower or upper bound, the amount of feed and protein level constraints will enter the basis respectively. Cracked corn grain will still be part of the basic feasible solution to supply energy.

The price of cottonseed hulls is allowed to decrease to zero. It is also allowed to increase to infinity resulting in infinity cost of the ration. Consequently, cottonseed hulls will be retained as part of the basic feasible solution regardless of price change. This is assuming other coefficients of ingredients remain constant.

The original price of soy hulls of 0.04 $/lb can decrease to zero resulting I a cheaper ration by 52 % compared to its original cost of $1.403. Its price can also increase to infinity resulting in infinity cost of the ration. When price changes beyond the allowable levels, soy hulls will still be part of basic feasible solution and the constraint amount of feed will enter the basis.

Soybean meal price is allowed to decrease as much as 0.108 $/lb resulting in a cheaper ration of $1.393, or increase by as much as 0.242 $/lb leading to a more costly ration of $1.758. These changes assume the price of all other ingredients remain constant. If price changes outside the allowable lower and upper bounds, the protein level and amount of feed constraints will enter the basis respectively. Soybean meal may not be part of the basic solution when its price changes past the upper bound because it will be too costly.

The price of limestone can decrease to 0.038 $/lb or increase to infinity and the ration will cost the same ($1.403), assuming all other coefficients remain constant. When price decreases beyond the lower bound, more limestone levels will enter the basis. Thus, limestone will be part of the basic feasible solution all the time.

The original price for dicalcium phosphate is allowed to decrease by as much as 0.036 $/lb producing a cheaper ration of $1.374 or increase by as much as 0.23 $/lb and increasing cost to $1.404 without changing the basic feasible ingredients, assuming all other coefficients remain constant. The constraints sulfur level and protein level will enter the basis when price changes past the allowable lower and upper limits respectively.

Table 4.26 Price range analysis for ration containing 50 % SH, using 2000/04 average prices with variability information.

50 % SH[1]	Original price Marginal value	Minimum price Maximum price	Min. objective Max. objective	Constraint – at min Constraint - at max
INGREDIENTS				
CCG	0.050	0.0001	1.138	Amount of feed
	0	0.055	1.430	Protein level
CSH	0.072	-0.129	0.673	Amount of feed
	0	infinity	infinity	.
SH	0.04	-0.020	0.673	Amount of feed
	0	infinity	infinity	.
SBM	0.111	0.108	1.393	Protein level
	0	0.242	1.758	Amount of feed
LIM	0.06	0.038	1.403	Limestone level
	0	infinity	1.403	.
DPH	0.22	0.036	1.374	Sulfur level
	0	0.230	1.404	Protein level

[1] optimal solution was $1.403

Legend: CCG = cracked corn grain, CSH = cottonseed hull, SH = soy hull, SBM = soybean meal, LIM = limestone, DPH = dicalcium phosphate.

Table 4.27 shows that the original price of cottonseed hulls can vary between zero and infinity justifying it to be in the basic feasible solution, assuming all other coefficients stay constant. When prices drop below the lower bound, more protein will enter the basis.

Soy hulls price can decrease to 0.001 $/lb resulting in a cheaper ration of $0.625 or increase to infinity resulting in a ration of infinity cost, assuming all other coefficients remain constant. Soy hulls will be part of the basic feasible solution regardless of price change because it was assumed to be the main source of energy.

The original price of soybean meal is allowed to vary between $0.015 and $0.313. The cost of ration will be $1.187 for the lower bound and $1.837 for the upper bound, assuming no changes appears in the other coefficients. Protein level and limestone level constraints enter the basis when price changes past the lower and upper bounds respectively.

Limestone did not feature in the basic feasible solution. Thus, the price of limestone can decrease by as much as zero or increase by as much as infinity leading to no change in the cost of the ration of $1.397, assuming prices of other ingredients remains constant. Consequently, limestone will always not be in the basic feasible solution regardless of price change.

The price of dicalcium phosphate can decrease to zero or increase to 0.363 $/lb producing a more costly ration of $1.417. These changes assume all other coefficients remain constant. The binding constraint for the lower bound is sulfur level and the upper bound is protein level. When price changes beyond the upper bound protein level constraint will enter the basic feasible solution.

Table 4.27 Price range analysis for ration containing 75 % SH, using 2000/04 average prices with variability information.

75 % SH[1]	Original price Marginal value	Minimum price Maximum price	Min. objective Max. objective	Constraint – at min Constraint – at max
INGREDIENTS				
CSH	0.072	-0.125	0.623	Protein level
	0	infinity	infinity	.
SH	0.04	0.001	0.625	Protein level
	0	infinity	infinity	.
SBM	0.111	0.015	1.187	Protein level
	0	0.313	1.837	Limestone level
LIM	0.06	-0.056	1.397	Limestone level
	0	infinity	1.397	.
DPH	0.22	-0.082	1.355	Sulfur level
	0	0.363	1.417	Protein level

[1] optimal solution was $1.397

Legend: CSH = cottonseed hull, SH = soy hull, SBM = soybean meal, LIM = limestone, DPH = dicalcium phosphate.

4.3.3.4 Competitiveness of Soy hulls

Least cost rations for corn gluten feed, dried distiller's grain, rice bran, and brewer's grain formulated using 2000/04 average prices are reported in Table 4.28 for rations without variability information and Table 4.29 for rations with variability information. These rations, as reported previously, were labeled as 25 % CGF, 25 % DDG, 25 % RB, and 25 % BG referencing corn gluten feed, dried distiller's grain, rice bran, and brewer's grain respectively. The results were compared to the 25 % SH ration prepared using 2000/04 average prices.

Results indicate that all rations formulated required the same amount of ration (24.25 lb/day). The same amount was required by 25 % SH (Table 4.22 and 4.23). The composition of the ingredients in these rations differed with that of 25 % SH. While 25 % SH contained cracked corn grain at 47.291 % and 46.114 % for ration without and with variability information, respectively, rations prepared with 25 % CGF, 25 % DDG and 25 % BG needed more than 50 % of the same ingredient. However, rations prepared with rice bran (25 % RB) had almost similar cracked corn grain as 25 % SH. The three rations, 25 % CGF, 25 % DDG and 25 % BG, also contained less soybean meal compared to 25 % SH. The content of soybean meal in 25 % RB was comparable with that of 25 % SH. The content of nutrients (input-output) on each of the byproducts contributed to the composition of ingredients in the final mix of their rations. For example, corn gluten feed, dried distiller's grain, and brewer's grain all contain protein at more than 20 % (Appendix 3.5) compared to 14.4 % for rice bran and 12.2 % for soy hulls. Consequently, corn gluten feed, dried distiller's grain, and brewer's grain required less amount of soybean meal compared to rice bran and soy hulls. All byproducts required no dicalcium phosphate in the final mix of their rations while soy hulls contained 1.076 % and 0.464 % for without and with variability information respectively.

Despite having relatively higher unit prices of 0.045 $/lb for corn gluten feed, 0.056 $/lb for dried distiller's grain, and 0.044 $/lb for rice bran compared to 0.04 $/lb of soy hulls, the cost of 25 % CGF, 25 % DDG, 25 % RB, or 25 % BG rations was lower compared to that of 25 % SH. This was due to the fact that 25 % SH required more soybean meal compared to the three rations 25 % CGF, 25 % DDG, and 25 % BG. Rations containing brewers grain were not only cheaper compared to that containing soy hulls, but it was the cheapest among all rations due to its lower price of 0.023 $/lb.

For rations formulated without variability information, the probability of meeting the minimum requirements for protein was 50 % for 25 % CGF and 25 % RB. The implication of such level is that these rations contain 13.5 % protein in their final mix.

However, the probability of meeting the minimum requirements for protein was 92 % for 25 % DDG and 51 % for 25 % BG implying that their rations often contained more than 13.5 % protein in the final mix.

Rations formulated with variability information increased their probability of meeting the minimum requirement for protein (Table 4.29). Note that the ration 25 % DDG was not formulated with variability information because its probability level was above 80 % when it was formulated without variability information (Table 4.28). Therefore, the ration 25 % DDG formulated without or with variability information is the same.

Table 4.28 Competing receiving rations for beef steers formulated without variability information and using 2000/04 average prices in an experiment at the University of Missouri, Columbia, MO., 1998.

Items	25 % Corn Gluten Feed	25 % Corn Dried Distillers Grains	25 % Rice Bran	25 % Brewers Grain
INGREDIENTS (%)				
Cracked corn grain	54.326	55.845	47.904	57.792
Cottonseed hulls	15.0	15.0	15.0	15.0
Competing[1]	25.0	25.0	25.0	25.0
Soybean meal	3.081	1.808	8.833	0.0
Limestone	1.373	1.127	2.043	0.988
Dicalcium phosphate	0.0	0.0	0.0	0.0
Sodium chloride	0.2	0.2	0.2	0.2
Trace minerals	1.0	1.0	1.0	1.0
Rumensin	0.014	0.014	0.014	0.014
Tylan	0.006	0.006	0.006	0.006
Total	100.0	100.0	100.0	100.0
AMOUNT (lb/d/animal)	24.25	24.25	24.25	24.25
COST ($/d/animal)	1.345	1.397	1.43	1.166
PROBABILITY (%)	50	92	50	51

Note: [1] Competing ingredient for 25 % Corn Gluten Feed is Corn Gluten Feed; 25 % Corn Dried Distillers Grain is Corn Dried Distillers Grains; 25 % Rice Bran is Rice Bran and 25 % Brewers Grain is Brewers Grain

Table 4.29 Competing receiving rations for beef steers formulated with variability information and using 2000/04 average prices in an experiment at the University of Missouri, Columbia, MO., 1998.

Items	25 % Corn Gluten Feed	25 % Corn Dried Distillers Grains	25 % Rice Bran	25 % Brewers Grain
INGREDIENTS (%)				
Cracked corn grain	52.833	55.845	46.334	51.112
Cottonseed hulls	15.0	15.0	15.0	15.0
Competing[1]	25.0	25.0	25.0	25.0
Soybean meal	4.571	1.808	10.4	6.668
Limestone	1.376	1.127	2.046	1.0
Dicalcium phosphate	0.0	0.0	0.0	0.0
Sodium chloride	0.2	0.2	0.2	0.2
Trace minerals	1.0	1.0	1.0	1.0
Rumensin	0.014	0.014	0.014	0.014
Tylan	0.006	0.006	0.006	0.006
Total	100.0	100.0	100.0	100.0
AMOUNT (lb/d/animal)	24.25	24.25	24.25	25.152
COST ($/d/animal)	1.367	1.397	1.453	1.265
COST INCREASE (%)[2]	1.64	0	1.61	8.5
PROBABILITY (%)	81	92	82	81

Note: [1] Competing ingredient for 25 % Corn Gluten Feed is Corn Gluten Feed; 25 % Corn Dried Distillers Grain is Corn Dried Distillers Grains; 25 % Rice Bran is Rice Bran and 25 % Brewers Grain is Brewers Grain

[2] Cost increase was calculated relative to costs of ration without variability information.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Introduction

This chapter presents a summary and conclusions of the study. It is organized as follows. First, the summary of the study is presented; the major issues covered in the study are highlighted. Second, the conclusions of the study are revealed based on the results. Third, research implications are mentioned; they cover among other things issues that surfaced during the statistical and economic analyses and their effects on the fed beef sector and soybean crop enterprise. Fourth, the limitations of the study are spelled out. Lastly, recommendations on issues that came up during the study are presented.

5.2 Summary

The concern of the fed beef sector of the beef cattle industry is to get cattle started on feed. Adjusting cattle to grain based diets from predominately forage disrupts the normal microbial environment of the animal. In essence, grain rations contain starch which is broken down quickly by organisms giving off lactic acid as a byproduct. Lactic acid can increase very rapidly in cattle moved to rations high in grain. The presence of lactic acid affects the animal's metabolism mechanism resulting in side effects such as acidosis, founder and bloat.

Past research has suggested that soy hulls are promising feed ingredients that can overcome the side effects cattle experience when started on feed. They are moderate in crude protein (12.2 %), energy for maintenance (0.84 Mcal/lb), and energy for growth

(0.55 Mcal/lb). Their energy content is derived primarily from the fiber component of the feed (67 % NDF), which is unlignified (2 % lignin) and thus, highly digestible. Recognizing the potential of this byproduct, the present study was initiated with an overall objective of evaluating soy hulls as the principal variable ingredient in a beef cattle receiving ration. The specific objectives were (1) examine the effect of different treatments (receiving rations) fed to beef cattle steers on body weight, average daily gain, and feed efficiency, (2) compare the effect of different treatments (receiving rations) at specific times and averaged over time on body weight, average daily gain, and feed efficiency, (3) examine the effect of time on body weight, average daily gain, and feed efficiency within a treatment, (4) estimate beef cattle steers' growth response and derive the optimal level of soy hulls in a ration based on economic conditions (if a production function exhibits a plateau), and (5) formulate a least cost receiving ration based on average daily gain for beef cattle steers and determine the amount of soy hulls in such a ration.

Two methods of analysis were carried out to realize the objectives, statistical and economic analysis. The statistical method used was a mixed model procedure. This procedure handles repeated measurement data. By definition, repeated measurement refers to multiple observations taken in sequence on the same experimental unit or subject. These types of data are normally correlated because they originate from the same subject. In addition, observations on the same subject close in time tend to be more highly correlated than measures far apart in time. Moreover, wherever data departs from these phenomena the general linear procedure is appropriate.

Economic analysis methods used were production function analysis and linear programming. A growth response function for beef steers using weight as a dependent variable was estimated to summarize information concerning performance of the animals as they were fed feed rations. The function was envisaged to review weight of beef steers before they were given the rations, the highest weight which can be achieved as successive levels of soy hulls are increased, and whether weight gain gets less and less as the steers are fed successive levels of soy hulls. Further estimation of the production function was carried out using ADG as a dependent variable. For all responses estimated, the independent variables used were the linear term of soy hulls and time, interaction between soy hulls and time and the quadratic terms for soy hulls and time.

Another method, partial budget analysis, was introduced to further carry out economic analysis. Specifically, this method enabled calculation of net benefit and net benefit per pound of gain for each treatment. The net benefits and net benefits per pound of gain were compared across treatments.

Linear programming analysis was applied to formulate least-cost receiving rations for beef steers. The main feed ingredients used were corn, cottonseed hulls and soy hulls. Supplement ingredients were soybean meal, limestone, dicalcium phosphate, sodium chloride, trace mineral salt, Rumensin®, and Tylan® . Average prices for 1994/98 adjusted for haulage costs were used in formulating feed rations. The right hand restrictions included nutrient minimum requirements for energy, protein, and minerals; levels of some ingredients, soy hulls, and cottonseed hulls. Other restrictions were calcium and phosphorous ratio in the final ration. Corn gluten feed, dried distiller's grain, rice bran and brewer's grain were introduced as competing ingredients with soy hulls. The levels of these ingredients were restricted to their suggested recommendations.

The sensitivity of the least cost rations to changes in the objective function ingredient prices was evaluated using average prices for 2000/04 adjusted for haulage costs. Finally, variability information was included in the formulation of rations to account for variability in input-output coefficients relating feed ingredients as inputs and protein as output.

Statistical results showed that weight of beef steers fed 0 % SH and 25 % SH were statistically similar throughout the feeding period. Weight of animals fed 0 % SH was higher than those fed 50 % SH in day 31 and 63; it was also higher compared with animals fed 75 % SH in day 63. For animals fed 25 % SH, they had higher weights than those fed 50 % SH or 75 % SH in day 31 and 63. The ADG averaged over time for animals fed 0 % SH and 25 % SH was higher compared to animals fed 50 % SH and 75 % SH. On average, feed efficiency for all animals was similar except for animals fed 0 % SH and 50 % SH.

Comparison of time effects within treatments indicated that weight data for all animals differed between time points. For ADG, time effects were the same for all rations except 50 % SH where ADG in day 17 differed with day 31 and 63. Comparison of time effect on feed efficiency within a ration indicated no differences except for ration 50 % SH which showed differences between day 17 and 63.

Results of the analysis of the growth response function showed no evidence to reject the hypothesis that weight of beef cattle steers will not increase as the rate of soy hulls in the ration increases. The lower term variable SH was shown to be insignificant to influence variability of weight of beef steers. The null hypothesis ‘weight of beef cattle steers will not decrease as the rate of higher levels of soy hulls in the ration increases’ was not rejected. The variable SH^2 which was to be used to test this hypothesis was not even included in the model because it was insignificant.

Results of estimating the growth response function for beef steers using ADG as a dependent variable yielded an unfavorable model for determining the optimal level of soy hulls. The variable SH was significant, but negative. The higher order term SH^2 was insignificant and when allowed to enter the model its sign was positive implying that the second order condition for profit maximization can not be satisfied.

The partial budget analysis in day 17 showed that feeding animals with 0 % SH had the highest net benefit followed by those fed 25 % SH. The cost of purchasing the animals was a major factor for the difference in net benefit between animals fed 0 % SH and 25 % SH. Net benefit per pound of gain for animals fed 0 % SH was also higher compared to those fed 25 % SH. On day 31, the highest net benefit and net benefit per pound of gain continued to come from animals fed 0 % SH followed by those fed 25 % SH. In day 63, animals fed 0 % SH yielded the highest net benefits followed closely with animals fed 25 % SH. Essentially, the ratio of net benefits between animals fed 0 % SH and 25 % SH improved consistently from 1:0.59 in day 17, 1:0.89 in day 31 and 1:0.98 in day 63. In fact, the net benefit per pound of gain for animals fed 25 % SH was higher compared to those fed 0 % SH in day 63. Producers normally adjust their animals for the feedlot phase in about three weeks (21 days). This period is close to the 31 days used in the experiment. Thus, the outcome of analysis pertaining to day 31 reflects what producers practice.

The linear programming results indicated that the rations formulated increased in cost with increasing levels of corn or decreasing levels of soy hulls in the ration. Conversely, it decreased with decreasing levels of corn or increasing levels of soy hulls. The average cost per animal per day for rations formulated using 1994/98 average prices and without protein variability information were \$1.684 for 0 % SH, \$1.578 for 25 % SH, \$1.472 for 50 % SH, and \$1.377 for 75 % SH. When variability information was introduced to increase the probability of attaining the minimum protein requirements to around 80 %, costs of rations increased slightly for 0 % SH (0.059 %), 25 % SH (0.063 %), and 50 % SH (0.068 %), but increased more for 75 % SH (3.922 %). Rations formulated using 2000/04 average prices and without variability information had lower costs per day per animal than those formulated using 1994/98 average prices and without variability information. They were \$1.526 for 0 % SH, \$1.463 for 25 % SH, \$1.401 for 50 % SH, and \$1.349 for 75 % SH. This happened because average prices for corn, soy hulls, and soybean meal was lower in 2000/04 compared to 1994/98. When variability information were introduced (protein minimum met around 80 % of the time) costs increased moderately by 0.066 % for 0 % SH, 0.068 % for 25 % SH, 0.143 % for 50 SH and relatively higher by 3.558 % for 75 % SH.

5.3 Conclusions

The results of this study have illustrated the potential of soy hulls as a principal ingredient in a beef cattle receiving ration. Beef steers fed 25 % SH showed similar performance as those fed 0 % SH on weight and ADG. Results also showed that 0 % SH and 25 % SH performed better than 50 % SH and 75 % SH. Statistically, we can conclude that the use of soy hulls at up to 25 % of a ration mix is equivalent to corn; demonstrating the potential of soy hulls as one of the principal ingredients in a beef cattle receiving ration.

The effect of time within treatment on animal performance indicated that weight of animals continued to grow the entire feeding period for all rations; however, ADG and feed efficiency were statistically the same. For each treatment, the data for ADG were numerically lower at day 63 compared to day 31, though statistically they were the same. This suggests that the process of adjusting cattle to a grain based diet is mostly accomplished in the first 31 days. The animals do not gain much in performance if you continue adjusting them past day 31.

Results of the growth response function analysis showed that the data displayed a pattern that would not permit economic analysis. In terms of net befits, the partial budget analysis showed 0 % SH as the most economic ration followed by 25 % SH. A major factor contributing to the differences in net benefit between rations 0 % SH and 25 % SH was the cost of purchasing the animals. Net benefits for 25 % SH improved consistently over time nearing that of 0 % SH on day 63. On the other hand, 25 % SH was the most economic ration in terms of net benefit per pound of gain on day 63.

Linear programming analyses showed that soy hulls is a potential feed ingredient to be used in the formulation of beef cattle receiving rations. Rations with 25 % SH were cheaper compared to 0 % SH. Although rations with 50 % and 75 % SH formulated the cheapest rations, these rations are unrewarding from a nutritional point of view. Ration 50 % SH is constrained with negative associative effects while 75 % SH reduces digestibility of the soy hulls. The ration with 25 % SH enabled animals to perform comparable to rations containing corn (0 % SH); its fiber composition ensures animals experience less digestive disturbances compared to 0 % SH. Therefore, it prepares the animal better for the feedlot environment.

The competitiveness of soy hulls was evaluated against corn gluten feed, dried distiller's grain, rice bran, and brewer's grain. Rations prepared from these rations were cheaper compared to soy hulls, though prices for corn gluten feed, dried distiller's grain, and rice bran (in dollars per pound) were higher compared to soy hulls. All these byproducts contained more protein hence they required less soybean meal in their rations, lowering the overall cost. The byproduct brewer's grain had the cheapest ration among all byproducts because it was the cheapest.

Inclusion of protein variability information in feed formulation increases the minimum requirement of nutrients in the ration. By increasing the minimum requirement of the nutrient in the ration it raises the probability of attaining the minimum requirement. Although this procedure increases the probability of satisfying the minimum requirements it also increases cost.

5.4 Research implications

Research implications for this study cover issues that surfaced during statistical and economic analyses. In fact, both methods of analysis yielded contrasting research implications and are narrated below based on these grounds.

The statistical analysis has demonstrated that rations formulated with 25 % SH are comparable with rations containing 0 % SH. Statistically, weights and ADG of animals fed 0 % SH or 25 % SH were the same and performed better than those fed 50 % SH or

75 % SH. Thus, based on statistical evaluation and assuming that producers are not concerned with economic decisions during the adjustment period (receiving period), the study has demonstrated that soy hulls is a potential alternative choice in the formulation of beef cattle receiving rations and its implications both in the fed beef sector and soybean crop enterprise can be narrated as follows.

First, we have to recognize that there is potential for large amounts of soybean hulls to be available for use in the beef cattle industry. Referencing statistics from the American Soybean Association (2005), soybeans were planted on 75.2 million acres (30.4 hectares) producing a record 3.141 billion bushels (85.49 million metric tons) in 2004. The crop provides about 80 % of the edible consumption of fats and oils in the United States. The domestic crush level was 1,650 million bushels or 44.9 million metric tons. Since soy hulls are a byproduct of rolling or cracking soybeans before the seeds are processed for other uses, increased production and use of soybean seed implies that large amounts of soy hulls can be produced domestically.

Second, as farmers become responsive with the use of soy hulls, there will be some challenges ahead especially to the soybean industry. First, demand for soy hulls may increase, opening a market for soy hulls as the principal ingredient of beef cattle receiving rations. High demand for soy hulls could also increase its price which in turn could provide incentive to dehull more soybeans. Consequently, the soy hulls could become a driver of farm-gate soybean prices received by farmers, hence bringing an economic impact.

Third, as soy hulls become part of an array of ingredients, the fed beef sector of the beef cattle industry will have greater flexibility of choosing ingredients for making receiving rations. Prices and availability of byproducts are not certain, therefore, if farmers have a wider choice it will help them adjust feed costs accordingly.

The production function analysis resulted in an estimation of the growth response function that was unfavorable to determine the optimal amount of soy hulls using the economic principles of profit maximization. None of the production functions estimated using either weight data or ADG data showed key features to warrant fulfillment of necessary and sufficient conditions for profit maximization. It is possible that the time period allotted for the experiment was not enough to allow the animals to reach a growth phase that exhibits diminishing marginal rate of returns with respect to variable inputs. The continued growth of animals over time without showing a plateau was evident with the weight data. On the other hand, ADG data showed a turning point after day 31; however, the estimation process used only three data records, day 17, 31 and 63. It is difficult to obtain a smooth curve if variability of values of the independent variables is limited.

The partial budget analysis showed that animals fed 0 % SH were the most economic by recording the highest net benefits over the feeding period. However, animals fed 25 % SH improved impressively over time. The net benefit per pound of gain indicated 25 % SH to be the most economic ration compared to 0 % SH in day 63. Thus, research implications based on economic analysis are presented as follows. First, the design of the experiment needs to be revised to accommodate the feedlot phase. It is important to know the effect of rations in the feedlot phase. As was shown in the partial budget analysis, the net benefits for 25 % SH improved tremendously over time and net benefit per pound of gain was slightly higher than that of 0 % SH in day 63. In addition, extending the experiment to the feedlot phase will allow the evaluation of animals' performance at a period where producers are concerned with economic decisions. It should be recalled here that the major markets for beef cattle are evident during or after the cow-calf phase and the finishing phase. Thus, this suggests that producers are probably concerned with economic decisions during these periods of marketing. Second, the experiment needs to increase the factor levels, i.e., increase treatment levels and frequency of measuring the animals. This will increase the variability of the independent variables which is important for obtaining a smooth function. Also number of animals should be increased in order to improve statistical analysis.

5.5 Limitations of the study

The analysis of the growth response function for the beef steers did not feature as expected, as levels of soy hulls increased weight gain of animals decreased. This phenomenon or pattern of growth was explained clearly using the principles of animal nutrition. Although ADG data showed a turning point on day 31, attempts to establish a response curve using this data did not produce useful results either. Thus, the growth pattern limited application of economic principles to derive optimal use of soy hulls.

Another limitation of the study was related to the application of the linear programming in formulating rations that incorporated variability information. There is no clear knowledge on probability levels of attaining minimum requirements of nutrients and costs of rations. Given variability information of nutrients, the limitation is like this: Is an 80 % or 85 % probability reasonable to formulate a least cost ration that ensures animals meet or attain the minimum requirements of nutrients?

Last, the application and interpretation of results for this study is limited to conditions and situations that prevailed during this time period. The volatility of feed ingredients prices may alter the interpretation and application of results of this study.

5.6 Recommendations

The statistical analysis has demonstrated that soy hulls can serve as principal ingredients in a beef cattle receiving ration. In addition, economic analysis has generated information that is important for future work. Thus, the findings of this study will be disseminated via various publications so that a wider audience in academia, science and industry becomes informed. Similar information will be communicated with extension professionals who can help share the findings as interim recommendations to various stakeholders including beef cattle producers, feed producers, and soybean growers. Such contacts will facilitate feedback in the future by letting other stakeholders become aware of the research developments.

To understand the effect of adjusting animals with a receiving ration containing 25 % soy hulls in the feedlot phase, this study recommends another experiment that will trace and monitor effects of using a receiving ration containing 25 % SH to the feedlot phase. Understanding the potential of soy hulls beyond the receiving stage will enhance its potential of being one of the ingredients to be used in the formulation of receiving rations.

APPENDIX

Appendix 3.1 Layouts of a randomized complete block design-split plot in time design in an experiment at the University of Missouri, Columbia, MO., 1998.

BLOCK 1: PEN 1: TREATMENT 1 (3 ANIMALS)
BLOCK 1: PEN 2: TREATMENT 2 (3 ANIMALS)
BLOCK 1: PEN 3: TREATMENT 3 (3 ANIMALS)
BLOCK 1: PEN 4: TREATMENT 4 (3 ANIMALS)

BLOCK 2: PEN 5: TREATMENT 1 (3 ANIMALS)
BLOCK 2: PEN 6: TREATMENT 2 (3 ANIMALS)
BLOCK 2: PEN 7: TREATMENT 3 (3 ANIMALS)
BLOCK 2: PEN 8: TREATMENT 4 (3 ANIMALS)

BLOCK 3: PEN 9: TREATMENT 1 (3 ANIMALS)
BLOCK 3: PEN 10: TREATMENT 2 (3 ANIMALS)
BLOCK 3: PEN 11: TREATMENT 3 (3 ANIMALS)
BLOCK 3: PEN 12: TREATMENT 4 (3 ANIMALS)

Appendix 3.2 Raw data for weight and feed intake in pounds for beef steers by pen, block, treatment and date in an experiment at the University of Missouri, Columbia, MO., 1998.

Blk	trt	7/20/1998	7/21/1998	8/7/1998	8/21/1998	9/22/1998	9/23/1998	FI1	FI2	FI3	FI4
1	1	690	664	704	776	960	932	0	1130	1030	2680
1	1	766	744	854	946	1164	1160	.	.	.	
1	1	768	750	786	858	1004	1006	.	.	.	
1	2	718	680	740	844	938	956	0	1020	1050	2670
1	2	770	744	768	844	1048	1042	.	.	.	
1	2	744	750	750	852	1008	998	.	.	.	
1	3	666	700	712	762	890	890	0	820	980	2140
1	3	742	714	748	808	936	924	.	.	.	
1	3	728	730	786	840	958	952	.	.	.	
1	4	686	698	786	820	978	990	0	870	950	2210
1	4	754	724	756	806	916	926	.	.	.	
1	4	734	764	794	844	962	956	.	.	.	
2	1	772	754	804	890	1036	1040	0	1140	1100	2870
2	1	796	792	878	920	1100	1116	.	.	.	
2	1	776	764	886	920	1056	1050	.	.	.	
2	2	788	822	882	980	1130	1104	0	1230	1150	2660
2	2	782	754	842	924	1154	1058	.	.	.	
2	2	794	824	884	958	1158	1136	.	.	.	
2	3	804	796	812	854	980	976	0	770	940	2330
2	3	778	764	814	868	1000	994	.	.	.	
2	3	808	800	802	884	1020	1020	.	.	.	
2	4	768	752	806	872	1012	1004	0	880	1010	2370
2	4	784	766	806	848	952	962	.	.	.	
2	4	876	860	912	970	1062	1074	.	.	.	
3	1	794	818	872	960	1188	1116	0	1200	1430	3270
3	1	820	826	892	950	1080	1078	.	.	.	
3	1	836	874	928	1036	1160	1146	.	.	.	
3	2	848	846	906	964	1130	1102	0	1390	1400	2660
3	2	864	836	930	992	1184	1078	.	.	.	
3	2	860	854	948	1004	1110	1146	.	.	.	
3	3	858	838	846	948	1072	1064	0	920	1120	2770
3	3	864	882	912	978	1194	1142	.	.	.	
3	3	884	884	896	980	1108	1120	.	.	.	
3	4	842	828	862	926	1056	1066	0	820	1050	2530
3	4	908	870	920	980	1158	1144	.	.	.	
3	4	874	868	920	966	1092	1086	.	.	.	

Legend: blk = block; trt = treatment; FI1, FI2, FI3, and FI4 = feed intake for period 1, 2, 3 and 4 respectively.

Appendix 3.3 Prices of feedstuff for the period 1994-1998.

Feedstuff	1994	1995	1996	1997	1998
Corn ($/bushel)	2.503	2.674	3.763	2.596	2.199
CSH ($/ton)	62.5	51.095	102.47	112.88	99.53
SH ($/ton)	73.31	73.34	108.04	73.72	61.57
SBM ($/ton)	187.21	173.26	249.27	271.65	167.5
LIM ($/50 lb bag)					2.30
DPH ($/50 lb bag)					11.00
SCH ($/50 lb bag)					2.15
TMS ($/50 lb bag)					5.00
RUM($/50 lb bag)					276
TYL($/50 lb bag)					73

Source: 1. Prices for CSH, SH, SBM, were obtained from University of Missouri, Division of Animal Sciences and Commercial Agriculture Program, Bulletin Publication.

2. Prices for LIM, DPH, SCH, TMS were collected from Missouri Farmers Association, Agri-Services, 2420 Paris Road, MO., Columbia. (573)474-6123.

3. Prices for RUM and TYL were obtained from Scholfied Veterinary Supply Inc., Columbia, Highway 54. (573)581-7880.

4. Prices for corn were obtained from Missouri Department of Agriculture and US Department of National Agricultural, National Agricultural Statistics Services. Farm Facts. Compiled by Missouri Agricultural Statistics Services

Legend: CSH = cottonseed hulls; SH = soy hulls; SBM = soybean meal; LIM = limestone; DPH = Dicalcium phosphate; SCH = sodium chloride; TMS = trace mineral salt; RUM = Rumensin® ; TYL = Tylan®.

Appendix 3.4 Prices of feedstuffs and beef steers for the period 2000-2004.

Feedstuff	2000	2001	2002	2003	2004
Corn ($/bushel)	1.96	1.899	2.16	2.406	2.498
CSH ($/ton)	100.86	139.23	96.9	139.04	111.77
SH ($/ton)	53.02	65.47	69.23	72.46	74.9
SBM ($/ton)	177.69	175	179.07	206.89	243.81
CGF ($/ton)	56.84	66.06	63.41	73.77	78.22
DDG ($/ton)	83.5	96.3	93.19	100.38	108.27
RB ($/ton)	45.93	58.3	51.45	79.28	101.63
BG ($/ton)	25.77	23.64	25.11	25.32	41.41
LIM ($/50 lb bag)					3.00
DPH ($/50 lb bag)					11.0
SCH ($/50 lb bag)					4.20
TMS ($/50 lb bag)					5.35
RUM($/50 lb bag)					310
TYL($/50 lb bag)					75
BEEF STEERS ($/cwt)					
750 – 799 weight range	85.057	85.202	79.344	87.283	103.15
800 – 849 weight range	83.866	83.566	77.018	86.01	100.492
850 – 899 weight range	82.808	81.058	76.573	82.949	99.351
900 and above	77.388	78.526	74.709	78.816	92.941

Source: 1. Prices for CSH, SH, SBM, CGF, DDG, RB, and BG were obtained from University of Missouri, Division of Animal Sciences and Commercial Agriculture Program, Bulletin Publication.

2. Prices for LIM, DPH, SCH, TMS were collected from Missouri Farmers Association, Agri-Services, 2420 Paris Road, MO., Columbia. (573)474-6123.

3. Prices for RUM and TYL were obtained from Scholfied Veterinary Supply Inc., 4720 E.Liberty St. (573)581-7880.

4. Prices for corn were obtained from Missouri Department of Agriculture and US Department of National Agricultural, National Agricultural Statistics Services. Farm Facts. Compiled by Missouri Agricultural Statistics Services

5. Prices for beef steers were obtained from University of Missouri, College of agriculture, Food & Natural Resources, Commercial Agriculture Program and MU Extension. Agricultural Electronic Bulletin Board.

Legend: CSH = cottonseed hulls; SH = soy hulls; SBM = soybean meal; CGF = corn gluten feed; DDG = dried distiller's grain; RB = rice bran; BG = brewer's grain; LIM = limestone; DPH = Dicalcium phosphate; SCH = sodium chloride; TMS = trace mineral salt; RUM = Rumensin® ; TYL = Tylan®.

Appendix 3.5 Feedstuff nutrient composition

	CGC	CSH	SH	SBM	CGF
Dry matter (%)	90	90.4	90.3	90.9	90
NE_m(Mcal/kg)	2.24	0.68	1.86	2.06	1.94
NE_g(Mcal/kg)	1.55	0.15	1.22	1.4	1.3
C. Protein (%)	9.8	4.2	12.2	51.8	23.8
St.D of CP (%)	1.06	0.74	2.51	3.45	1.68
Calcium (%)	0.03	0.15	0.53	0.46	0.07
Phosphorus (%)	0.32	0.09	0.18	0.73	0.95
Magnesium (%)	0.12	0.14	0.22	0.32	0.4
Potassium (%)	0.44	0.88	1.29	2.42	1.4
Sulfur (%)	0.11	0.08	0.11	0.46	0.47
Copper (mg/kg)	2.51	13.3	17.8	19.1	6.98
Iron (mg/kg)	54.5	131	409	277	226
Manganese (mg/kg)	7.89	119	10	48.3	22.1
Molybden (mg/kg)	0.6	0.02		6.67	1.8
Selenium (mg/kg)	0.14	0.09	0.14	0.46	
Zinc (mg/kg)	24.2	22	48	67.9	73.3

Source: National Research Council. 2000. Nutrient Requirements of Beef Cattle, 8th rev. Ed., National Academy Press, Washington, DC.

Legend: CCG = cracked corn grain; CSH = cottonseed hulls; SH = soy hulls; SBM = soybean meal; CGF = corn gluten feed.

NE_m = net energy for maintenance; NE_g = net energy for growth; St.D of CP = standard deviation of crude protein.

Appendix 3.5 Feedstuff nutrient composition (Continued).

	DDG	RB	BG	LM	DPH
Dry matter (%)	90.3	90.5	90.2		
NE_m(Mcal/kg)	2.18	1.63	1.51		
NE_g(Mcal/kg)	1.5	1.03	0.91		
C. Protein (%)	30.4	14.4	29.2		
St.D of CP (%)	2.19	1.42	13		
Calcium (%)	0.26	0.1	0.29	34	22
Phosphorus (%)	0.83	1.73	0.7	0.02	19.3
Magnesium (%)	0.33	0.97	0.27	2.06	0.59
Potassium (%)	1.08	1.89	0.58	0.12	0.07
Sulfur (%)	0.44	0.2	0.4	0.04	1.14
Copper (mg/kg)	10.6	12.2	11.3		10
Iron (mg/kg)	358	229	221	3500	14400
Manganese (mg/kg)	27.6	396	44		300
Molybden (mg/kg)	1.8	1.53	3.16		
Selenium (mg/kg)		0.44			
Zinc (mg/kg)	67.8	33	82		100

Source: National Research Council. 2000. Nutrient Requirements of Beef Cattle, 8th rev. Ed., National Academy Press, Washington, DC.

Legend: DDG = dried distiller's grain; RB = rice bran; BG = brewer's grain; LIM = limestone; DIPH = Dicalcium phosphate; NE_m = net energy for maintenance; NE_g = net energy for growth; St.D of CP = standard deviation of crude protein.

Appendix 3.6 Nutrient requirements for growing and finishing cattle (for 771 lb or 350 kg body weight animals).

	Minimum	Maximum
NE_m(Mcal/kg) ADG of 1.5 kg/day ADG of 2.0 kg/day	 6.23 6.23	
NE_g(Mcal/kg) ADG of 1.5 kg/day ADG of 2.0 kg/day	 6.45 8.84	
C. Protein (%)	13.5	
Calcium (kg/day) ADG of 1.5 kg/day ADG of 2.0 kg/day	 41 50	
Phosphorus (kg/day) ADG of 1.5 kg/day ADG of 2.0 kg/day	 20 24	
Magnesium (%)	0.1	0.40
Potassium (%)	0.6	3.0
Sulfur (%)	0.15	0.4
Copper (mg/kg)	10.0	100
Iron (mg/kg)	50	1000
Manganese (mg/kg)	20	1000
Molybden (mg/kg)	-	5
Selenium (mg/kg)	0.10	2.0
Zinc (mg/kg)	30	500

Source: National Research Council. 2000. Nutrient Requirements of Beef Cattle, 8th rev. Ed., National Academy Press, Washington, DC.

Legend: NE_m = net energy for maintenance; NE_g = net energy for growth

Appendix 3.7 Display of various variance-covariance structures applied in the study

Unstructured (UN)

$$\begin{bmatrix} \sigma_{11}^2 & \sigma_{21} & \sigma_{31} & \sigma_{41} \\ \sigma_{12} & \sigma_{22}^2 & \sigma_{32} & \sigma_{42} \\ \sigma_{13} & \sigma_{23} & \sigma_{33}^2 & \sigma_{43} \\ \sigma_{14} & \sigma_{24} & \sigma_{34} & \sigma_{44}^2 \end{bmatrix}$$

Compound symmetric (CS)

$$\begin{bmatrix} \sigma^2+\sigma_1^2 & \sigma_1^2 & \sigma_1^2 & \sigma_1^2 \\ \sigma_1^2 & \sigma^2+\sigma_1^2 & \sigma_1^2 & \sigma_1^2 \\ \sigma_1^2 & \sigma_1^2 & \sigma^2+\sigma_1^2 & \sigma_1^2 \\ \sigma_1^2 & \sigma_1^2 & \sigma_1^2 & \sigma^2+\sigma_1^2 \end{bmatrix}$$

Heterogeneous compound symmetric (CSH)

$$\begin{bmatrix} \sigma_1^2 & \sigma_1\sigma_2\rho & \sigma_1\sigma_3\rho & \sigma_1\sigma_4\rho \\ \sigma_2\sigma_1\rho & \sigma_2^2 & \sigma_2\sigma_3\rho & \sigma_2\sigma_4\rho \\ \sigma_3\sigma_1\rho & \sigma_3\sigma_2\rho & \sigma_3^2 & \sigma_3\sigma_4\rho \\ \sigma_4\sigma_1\rho & \sigma_4\sigma_2\rho & \sigma_4\sigma_3\rho & \sigma_4^2 \end{bmatrix}$$

First-order autoregressive (AR(1))

$$\sigma^2 \begin{bmatrix} 1 & \rho & \rho^2 & \rho^3 \\ \rho & 1 & \rho & \rho^2 \\ \rho^2 & \rho & 1 & \rho \\ \rho^3 & \rho^2 & \rho & 1 \end{bmatrix}$$

Heterogeneous first-order autoregressive (ARH(1))

$$\begin{bmatrix} \sigma_1^2 & \sigma_1\sigma_2\rho & \sigma_1\sigma_3\rho^2 & \sigma_1\sigma_4\rho^3 \\ \sigma_2\sigma_1\rho & \sigma_2^2 & \sigma_2\sigma_3\rho & \sigma_2\sigma_4\rho^2 \\ \sigma_3\sigma_1\rho^2 & \sigma_3\sigma_2\rho & \sigma_3^2 & \sigma_3\sigma_4\rho \\ \sigma_4\sigma_1\rho^3 & \sigma_4\sigma_2\rho & \sigma_4\sigma_3\rho & \sigma_4^2 \end{bmatrix}$$

Toeplitz (TOEP)

$$\begin{bmatrix} \sigma^2 & \sigma_1 & \sigma_2 & \sigma_3 \\ \sigma_1 & \sigma^2 & \sigma_1 & \sigma_2 \\ \sigma_2 & \sigma_1 & \sigma^2 & \sigma_1 \\ \sigma_3 & \sigma_2 & \sigma_1 & \sigma^2 \end{bmatrix}$$

First-order ante-dependence (ANTE(1))

$$\begin{bmatrix} \sigma_1^2 & \sigma_1\sigma_2\rho_1 & \sigma_1\sigma_3\rho_1\rho_2 & \sigma_1\sigma_4\rho_1\rho_2\rho_3 \\ \sigma_2\sigma_1\rho_1 & \sigma_2^2 & \sigma_2\sigma_3\rho_2 & \sigma_2\sigma_4\rho_2\rho_3 \\ \sigma_3\sigma_1\rho_2\rho_1 & \sigma_3\sigma_2\rho_2 & \sigma_3^2 & \sigma_3\sigma_4\rho_3 \\ \sigma_4\sigma_1\rho_3\rho_2\rho_1 & \sigma_4\sigma_2\rho_3\rho_2 & \sigma_4\sigma_3\rho_3 & \sigma_4^2 \end{bmatrix}$$

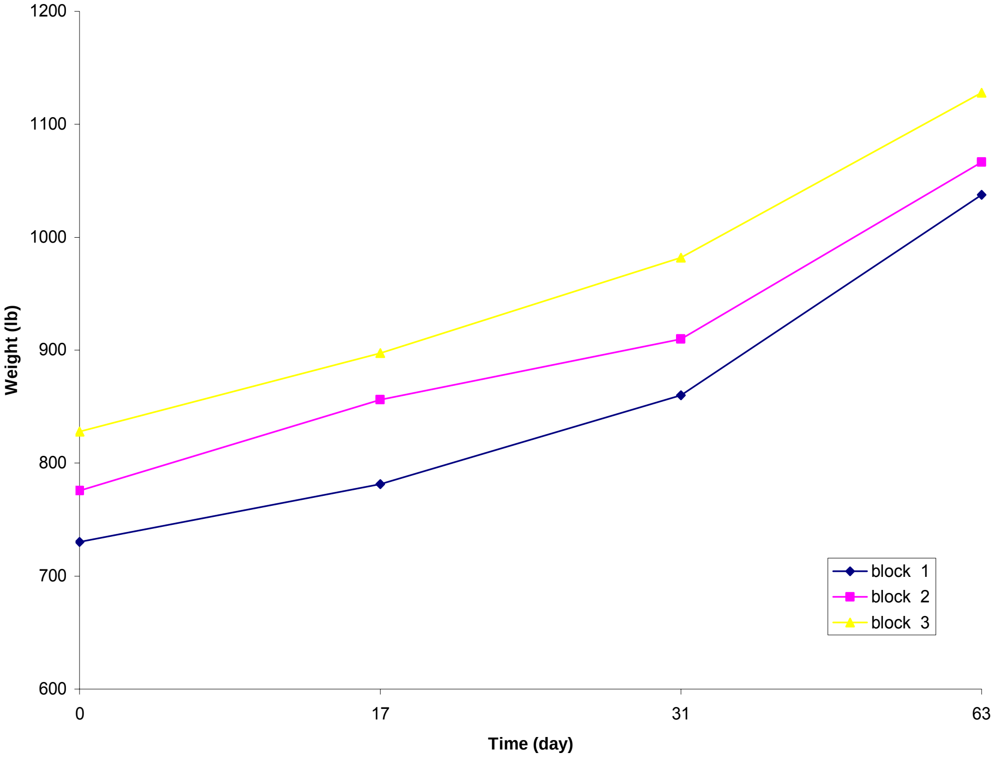
Heterogeneous toeplitz (TOEPH)

$$\begin{bmatrix} \sigma_1^2 & \sigma_1\sigma_2\rho_1 & \sigma_1\sigma_3\rho_2 & \sigma_1\sigma_4\rho_3 \\ \sigma_2\sigma_1\rho_1 & \sigma_2^2 & \sigma_2\sigma_3\rho_1 & \sigma_2\sigma_4\rho_2 \\ \sigma_3\sigma_1\rho_2 & \sigma_3\sigma_2\rho_1 & \sigma_3^2 & \sigma_3\sigma_4\rho_1 \\ \sigma_4\sigma_1\rho_3 & \sigma_4\sigma_2\rho_2 & \sigma_4\sigma_3\rho_1 & \sigma_4^2 \end{bmatrix}$$

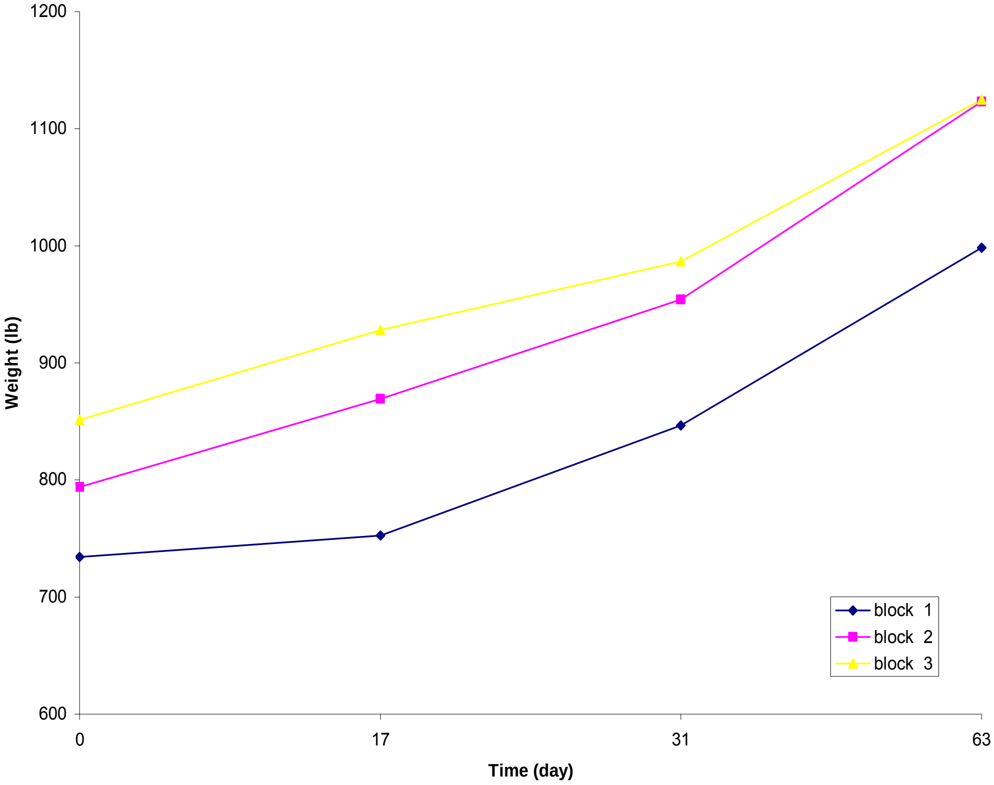
Simple variance-covariance

$$\begin{bmatrix} \sigma^2 & & & \\ & \sigma^2 & & \\ & & \sigma^2 & \\ & & & \sigma^2 \end{bmatrix}$$

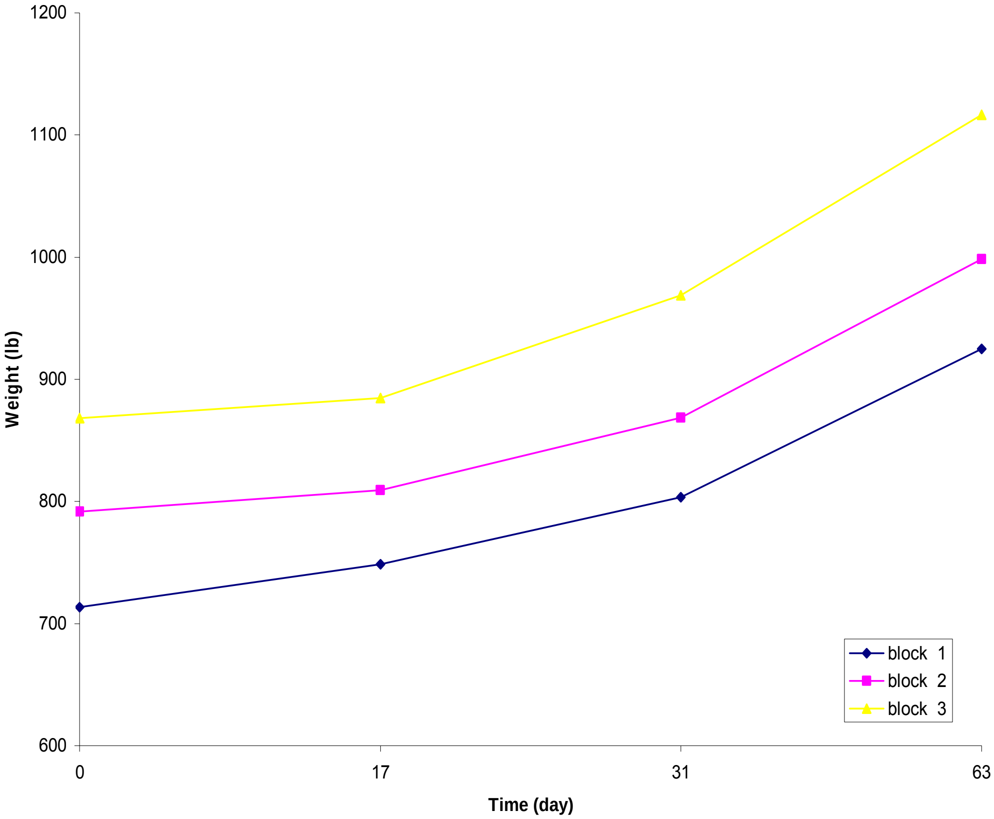
Appendix 4.1a Plot of weight data of beef steers fed 0 % SH ration in an experiment at the University of Missouri, Columbia, MO., 1998.



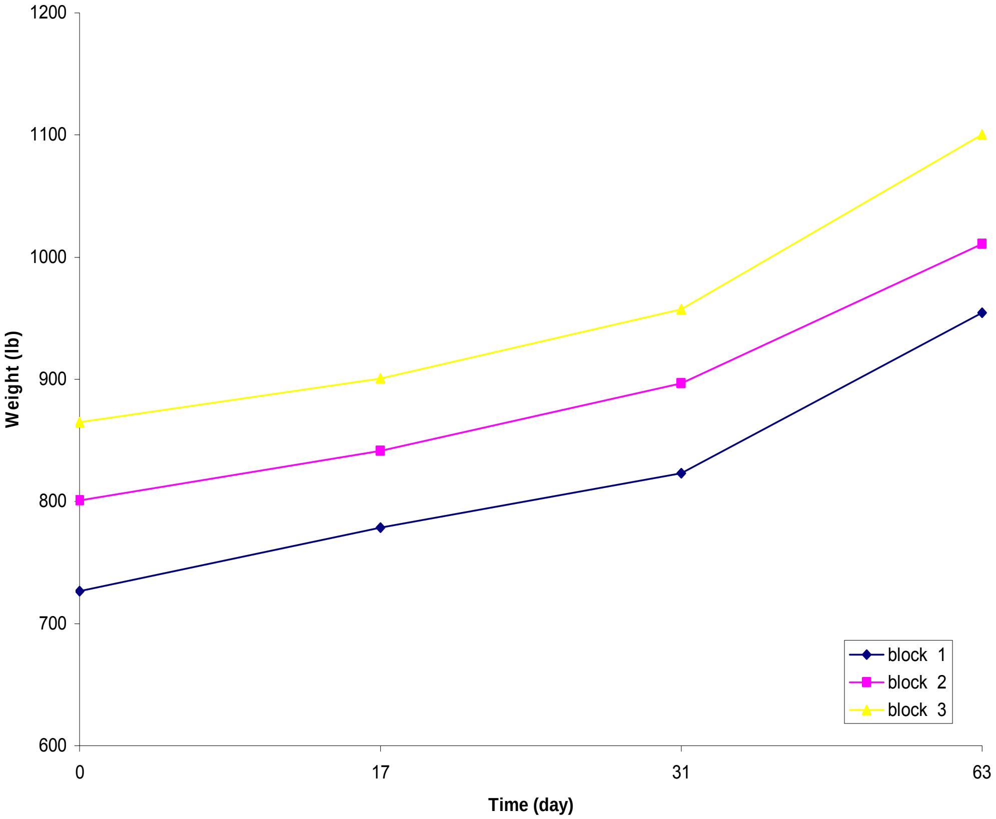
Appendix 4.1b Plot of weight data of beef steers fed 25 % SH ration in an experiment at the University of Missouri, Columbia, MO., 1998.



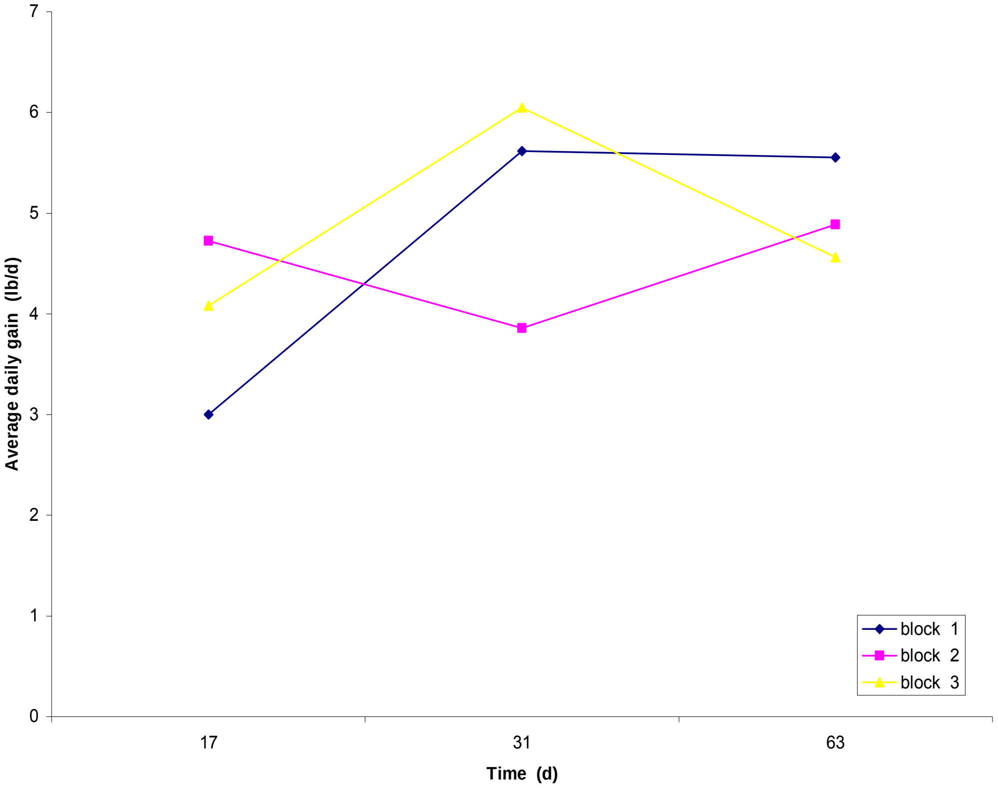
Appendix 4.1c Plot of weight data of beef steers fed 50 % SH ration in an experiment at the University of Missouri, Columbia, MO., 1998.



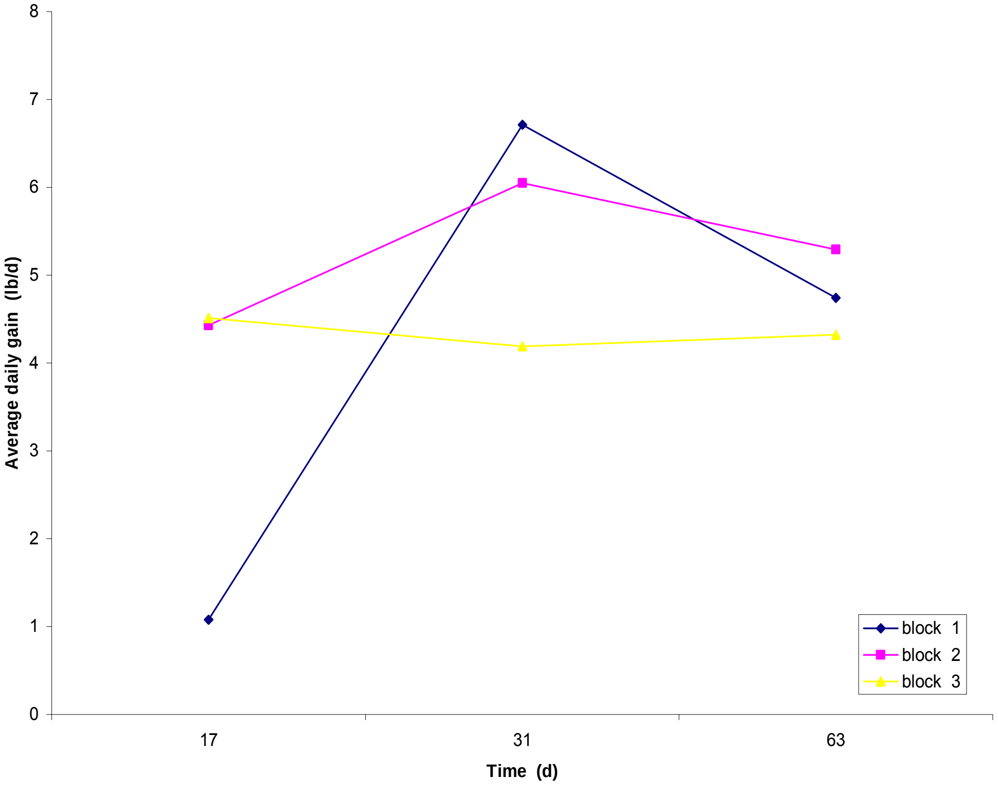
Appendix 4.1d Plot of weight data of beef steers fed 75 % SH ration in an experiment at the University of Missouri, Columbia, MO., 1998.



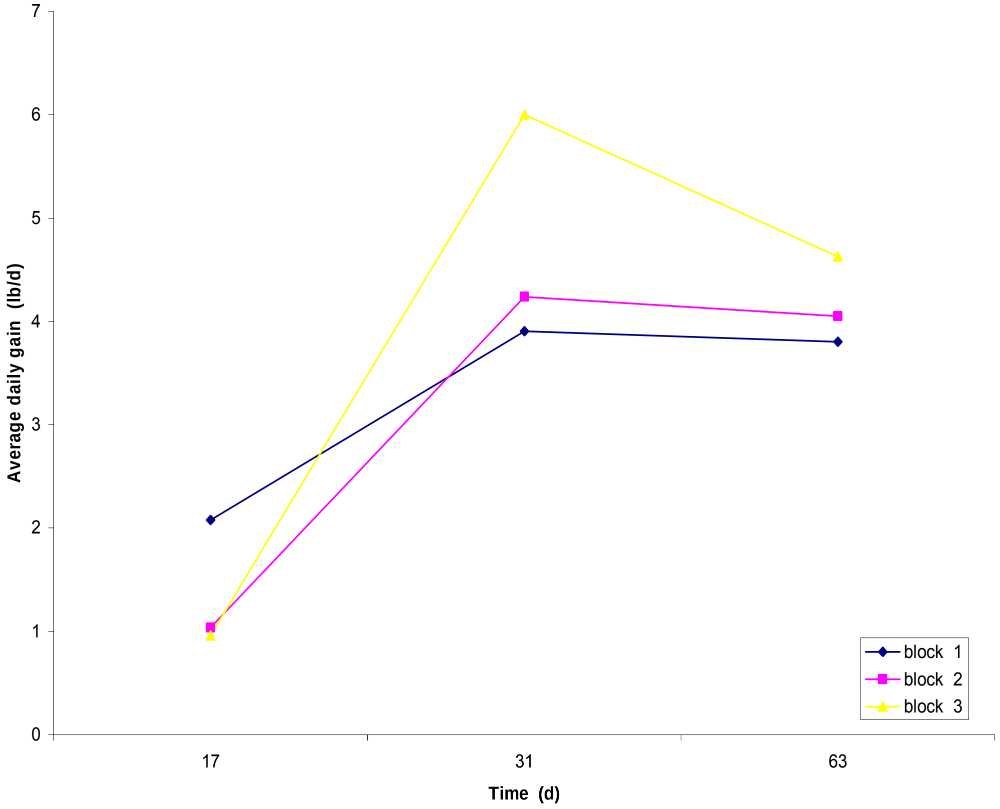
Appendix 4.2a Plot of average daily gain data of beef steers fed 0 % SH ration in an experiment at the University of Missouri, Columbia, MO., 1998.



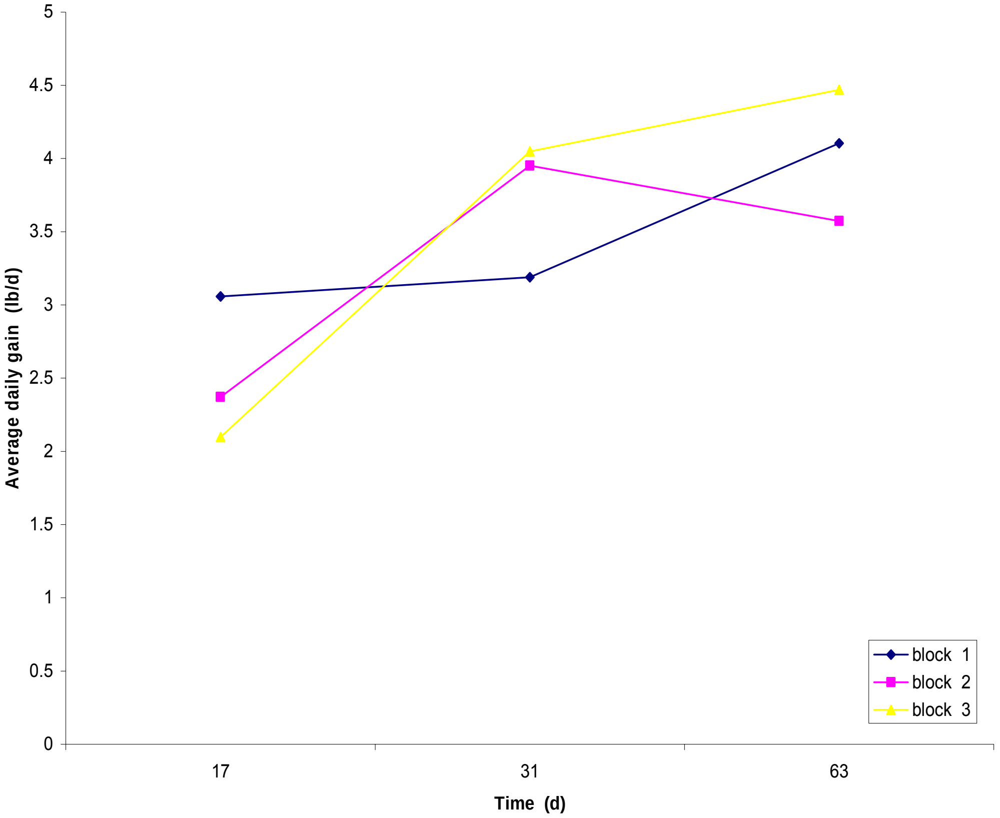
Appendix 4.2b Plot of average daily gain data of beef steers fed 25 % SH ration in an experiment at the University of Missouri, Columbia, MO., 1998.



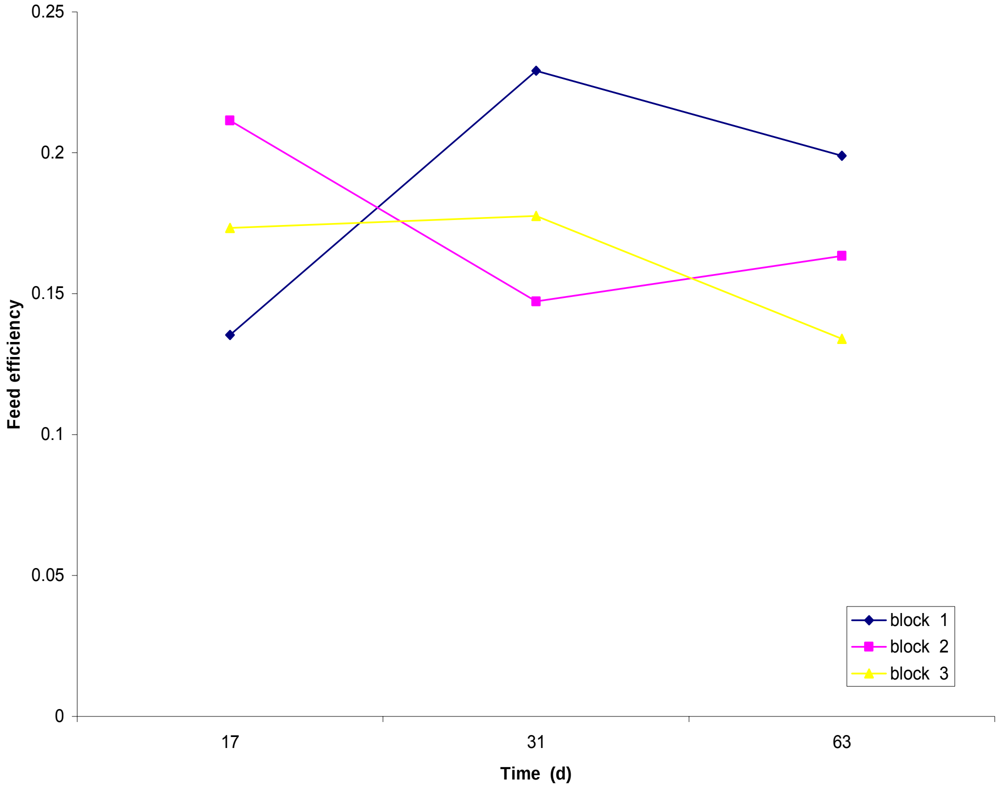
Appendix 4.2c Plot of average daily gain data of beef steers fed 50 % SH ration in an experiment at the University of Missouri, Columbia, MO., 1998.



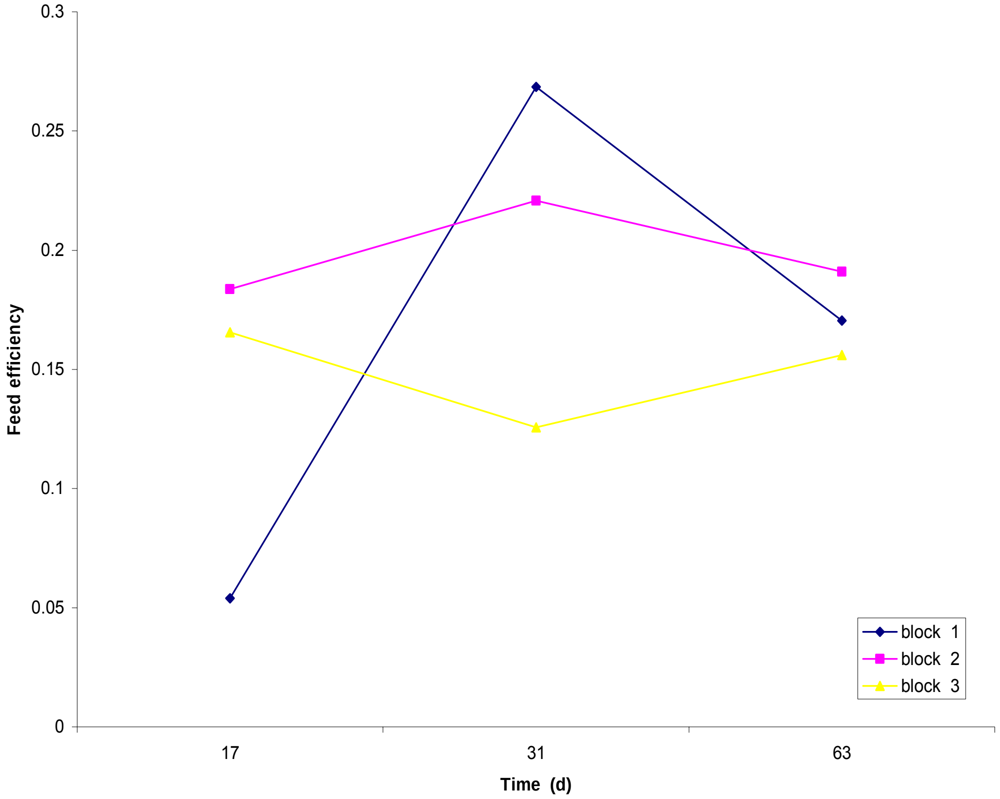
Appendix 4.2d Plot of average daily gain data of beef steers fed 75 % SH ration in an experiment at the University of Missouri, Columbia, MO., 1998.



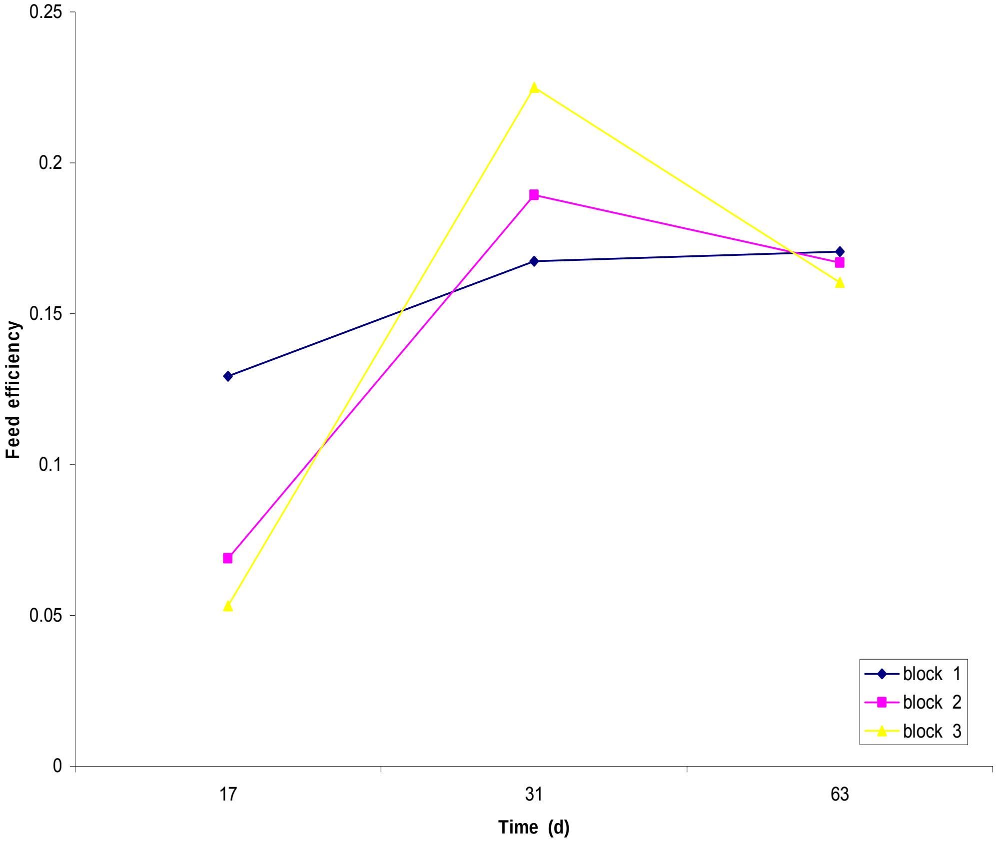
Appendix 4.3a Plot of feed efficiency data of beef steers fed 0 % SH ration in an experiment at the University of Missouri, Columbia, MO., 1998.



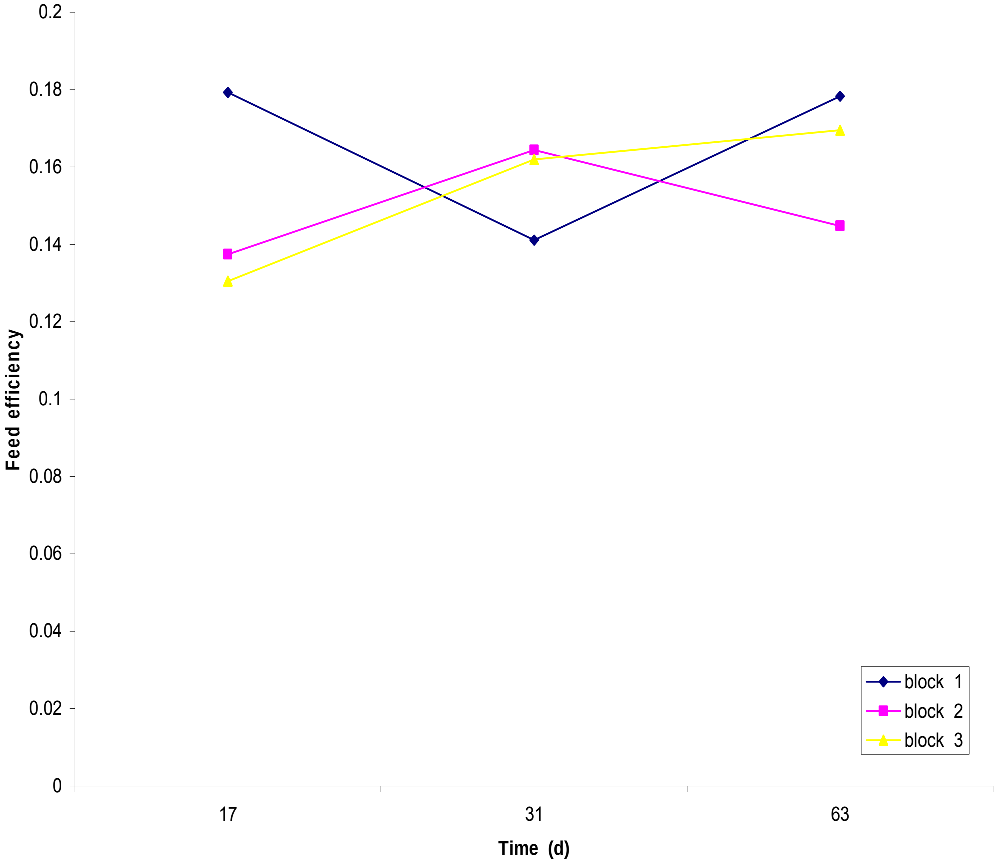
Appendix 4.3b Plot of feed efficiency data of beef steers fed 25 % SH ration in an experiment at the University of Missouri, Columbia, MO., 1998.



Appendix 4.3c Plot of feed efficiency data of beef steers fed 50 % SH ration in an experiment at the University of Missouri, Columbia, MO., 1998.



Appendix 4.3d Plot of feed efficiency data of beef steers fed 75 % SH ration in an experiment at the University of Missouri, Columbia, MO., 1998.



Appendix 4.4 Partial budget for beef steers fed receiving rations up to day 17 in an experiment at the University of Missouri, Columbia, MO., 1998.

Items	0 % SH	25 % SH	50 % SH	75 % SH
Benefits: *Animal live weight (lb)*	844.89	850	814.22	840.22
Live weight price ($/lb)	0.862	0.862	0.862	0.862
Gross Benefits: ($/animal)	**728.295**	**732.700**	**701.858**	**724.270**
Costs:				
Initial weight of animal (lb)	778	793.22	791.11	797.56
Price ($/lb)	0.88	0.88	0.88	0.88
Cost ($/animal)	**684.64**	**698.034**	**696.177**	**701.853**
Feed Intake	385.56	404.44	278.89	285.56
Corn (lb)				
Intake (lb)	259.87	182.40	60.24	0.00
Price ($/lb)	0.039	0.039	0.039	0.039
Cost ($/animal)	**10.135**	**7.114**	**2.349**	**0.00**
Cottonseed Hulls				
Intake (lb)	57.06	59.86	41.55	42.83
Price ($/lb)	0.065	0.065	0.065	0.065
Cost ($/animal)	**3.709**	**3.891**	**2.701**	**2.784**
Soy Hulls				
Intake (lb)	0.000	99.90	138.61	210.46
Price ($/lb)	0.037	0.037	0.037	0.037
Cost ($/animal)	**0.000**	**3.696**	**5.128**	**7.787**
Soybean Meal				
Intake (lb)	56.45	51.69	31.48	27.64
Price ($/lb)	0.108	0.108	0.108	0.108
Cost ($/animal)	**6.097**	**5.582**	3.400	**2.985**
Limestone				
Intake (lb)	6.20	4.85	2.46	0.000
Price ($/lb)	0.06	0.06	0.06	0.06
Cost ($/animal)	**0.372**	**0.291**	**0.148**	**0.000**
Dical. phosphate				
Intake (lb)	1.24	0.81	1.12	1.14
Price ($/lb)	0.22	0.22	0.22	0.22
Cost ($/animal)	**0.273**	**0.178**	**0.245**	**0.251**
Sodium Chloride				
Intake (lb)	0.77	0.81	0.57	0.57
Price ($/lb)	0.084	0.084	0.084	0.084
Cost ($/animal)	**0.065**	**0.068**	**0.048**	**0.048**
Trace minerals				
Intake (lb)	3.88	4.04	2.81	2.86
Price ($/lb)	0.107	0.107	0.107	0.107
Cost ($/animal)	**0.415**	**0.433**	**0.300**	**0.306**
Rumensin				
Intake (lb)	0.06	0.06	0.04	0.04
Price ($/lb)	6.2	6.2	6.2	6.2
Cost ($/animal)	**0.359**	**0.351**	**0.225**	**0.266**
Tylan				
Intake (lb)	0.02	0.02	0.01	0.02
Price ($/lb)	1.5	1.5	1.5	1.5
Cost ($/animal)	**0.035**	**0.036**	**0.021**	**0.026**
Total Cost ($/animal)	**706.099**	**719.674**	**710.743**	**716.305**
Net Benefits ($/animal)	**22.196**	**13.026**	**-8.885**	**7.965**
Weight gain (lb/animal)	**66.89**	**56.78**	**23.11**	**42.66**
Net Benefit ($/lb of gain)	**0.332**	**0.229**	**-0.384**	**0.187**

Appendix 4.5 Partial budget for beef steers fed receiving rations for day 31 in an experiment at the University of Missouri, Columbia, MO., 1998.

Items	0 % SH	25 % SH	50 % SH	75 % SH
Benefits: *Animal live weight (lb)*	917.33	929.11	880.22	892.44
Live weight price ($/lb)	0.825	0.825	0.825	0.825
Gross Benefits ($/animal)	**756.797**	**766.516**	**726.182**	**736.263**
Costs				
Initial weight of animal (lb)	778	793.22	791.11	797.56
Price ($/lb)	0.88	0.88	0.88	0.88
Cost ($/animal)	**684.64**	**698.034**	**696.177**	**701.853**
Feed Intake	781.111	804.44	616.67	620
Corn (lb)				
Intake (lb)	526.47	362.80	133.20	0.00
Price ($/lb)	0.039	0.039	0.039	0.039
Cost ($/animal)	**20.532**	**14.149**	**5.195**	**0.00**
Cottonseed Hulls				
Intake (lb)	115.60	119.06	91.88	93
Price ($/lb)	0.065	0.065	0.065	0.065
Cost ($/animal)	**7.514**	**7.739**	**5.972**	**6.045**
Soy Hulls				
Intake (lb)	0.000	198.70	306.48	456.94
Price ($/lb)	0.037	0.037	0.037	0.037
Cost ($/animal)	**0.000**	**7.352**	**11.34**	**16.907**
Soybean Meal				
Intake (lb)	114.36	102.81	69.61	60.01
Price ($/lb)	0.108	0.108	0.108	0.108
Cost ($/animal)	**12.351**	**11.103**	**7.518**	**6.481**
Limestone				
Intake (lb)	12.57	9.65	5.44	0.000
Price ($/lb)	0.06	0.06	0.06	0.06
Cost ($/animal)	**0.754**	**0.579**	**0.326**	**0.000**
Dical. phosphate				
Intake (lb)	2.52	1.61	2.47	2.48
Price ($/lb)	0.22	0.22	0.22	0.22
Cost ($/animal)	**0.553**	**0.354**	**0.543**	**0.546**
Sodium Chloride				
Intake (lb)	1.57	1.61	1.27	1.24
Price ($/lb)	0.084	0.084	0.084	0.084
Cost ($/animal)	**0.132**	**0.135**	**0.107**	**0.104**
Trace minerals				
Intake (lb)	7.86	8.04	6.20	6.20
Price ($/lb)	0.107	0.107	0.107	0.107
Cost ($/animal)	**0.841**	**0.861**	**0.664**	**0.663**
Rumensin				
Intake (lb)	0.12	0.11	0.08	0.09
Price ($/lb)	6.2	6.2	6.2	6.2
Cost ($/animal)	**1.726**	**0.698**	**0.497**	**0.577**
Tylan				
Intake (lb)	0.05	0.05	0.03	0.04
Price ($/lb)	1.5	1.5	1.5	1.5
Cost ($/animal)	**0.070**	**0.072**	**0.046**	**0.056**
Total Cost ($/animal)	**728.115**	**741.076**	**728.385**	**733.231**
Net Benefit ($/animal)	**28.683**	**25.439**	**-2.203**	**3.032**
Weight gain (lb/animal)	**139.33**	**135.89**	**89.11**	**94.88**
Net Benefit ($/ lb of gain)	**0.206**	**0.187**	**-0.025**	**0.032**

Appendix 4.6 Partial budget for beef steers fed receiving rations up to day 63 in an experiment at the University of Missouri, Columbia, MO., 1998.

Items	0 % SH	25 % SH	50 % SH	75 % SH
Benefits: *Animal live weight (lb)*	1077.33	1082	1013.33	1022
Live weight price ($/lb)	0.805	0.805	0.805	0.805
Gross Benefits: ($/animal)	**867.251**	**871.01**	**815.731**	**822.71**
Costs				
Weight of animal (lb)	778	793.22	791.11	797.56
Price ($/lb)	0.88	0.88	0.88	0.88
Cost ($/animal)	**684.64**	**698.034**	**696.177**	**701.853**
Feed Intake	1761.11	1692.22	1421.11	1410
Corn (lb)				
Intake (lb)	1186.99	763.19	306.96	0.00
Price ($/lb)	0.039	0.039	0.039	0.039
Cost ($/animal)	**47.480**	**30.528**	**12.278**	**0.00**
Cottonseed Hulls				
Intake (lb)	260.64	250.45	211.75	211.5
Price ($/lb)	0.065	0.065	0.065	0.065
Cost ($/animal)	**16.942**	**16.279**	**13.763**	**13.748**
Soy Hulls				
Intake (lb)	0.000	417.98	706.29	1039.17
Price ($/lb)	0.037	0.037	0.037	0.037
Cost ($/animal)	**0.000**	**15.465**	**26.133**	**38.449**
Soybean Meal				
Intake (lb)	257.84	216.27	160.41	136.47
Price ($/lb)	0.108	0.108	0.108	0.108
Cost ($/animal)	**27.847**	**23.357**	**17.325**	**14.739**
Limestone				
Intake (lb)	28.34	20.31	12.53	0.00
Price ($/lb)	0.06	0.06	0.06	0.06
Cost ($/animal)	**1.700**	**1.218**	**0.752**	**0.000**
Dical. phosphate				
Intake (lb)	5.67	3.38	5.68	5.64
Price ($/lb)	0.22	0.22	0.22	0.22
Cost ($/animal)	**1.248**	**0.745**	**1.251**	**1.241**
Sodium Chloride				
Intake (lb)	3.54	3.38	2.93	2.82
Price ($/lb)	0.084	0.084	0.084	0.084
Cost ($/animal)	**0.297**	**0.284**	**0.246**	**0.237**
Trace minerals				
Intake (lb)	17.72	16.92	14.30	14.1
Price ($/lb)	0.107	0.107	0.107	0.107
Cost ($/animal)	**1.896**	**1.811**	**1.530**	**1.509**
Rumensin				
Intake (lb)	0.26	0.24	0.18	0.21
Price ($/lb)	6.2	6.2	6.2	6.2
Cost ($/animal)	**1.638**	**1.469**	**1.145**	**1.311**
Tylan				
Intake (lb)	0.11	0.10	0.07	0.08
Price ($/lb)	1.5	1.5	1.5	1.5
Cost ($/animal)	**0.158**	**0.152**	**0.107**	**0.127**
Total Cost ($/animal)	**783.846**	**789.341**	**770.706**	**773.213**
Net Benefit ($/animal)	**83.405**	**81.669**	**45.024**	**45.497**
Weight gain (lb/animal)	**299.33**	**288.78**	**222.22**	**224.44**
Net Benefit ($/lb of gain)	**0.279**	**0.283**	**0.203**	**0.221**

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