DEVELOPMENT OF OPTIMAL COW-CALF STRATEGIES IN A DYNAMIC FRAMEWORK

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CHAPTER I

INTRODUCTION

The raising of cows and the production of calves, collectively referred to as the cow-calf system, plays an important role in Oklahoma's agricultural economy. In 1990, cattle and calves contributed 1.46 billion dollars of gross income to the coffers of the state. In terms of rank and value of production of principal crops and livestock commodities, beef cattle has maintained its lead as number one throughout the past decade. From a national perspective, beef cattle production in Oklahoma has experienced some growth over recent years. Prior to 1986, beef cattle oscillated between 5th and 6th positions, but has maintained its 4th position among the 50 states from 1986 through 1990 (Oklahoma Agricultural Statistics, 1990). These trends reflect the influence of several factors including economic pressures (changes in consumer demand, increasing population, changes in costs of production, etc.) and improved efficiencies and technology.

The beef cattle production system is typically divided into three stages: (1) cow-calf production, (2) an intermediate growing phase of forage-pasture, and (3) confined feedlot finishing. The cow-calf stage comprises the production of weaned calves. Producers breed the cows specifically to raise calves for sale or replacement at weaning. In the second stage, or stocker phase, the replacement calves are placed on high-quality pasture and roughage with or without feed concentrates administered for the duration of four to nine months. In the last stage (confined feedlot finishing), cattle are typically fed rations containing high proportions of grain and concentrates for a period of 100 days to 200 days, dependent upon their weights at placement, and thereafter slaughtered.

Trapp (1985) and Johnson et al. (1989) noted that cattle producers must increase productive efficiency in order to remain competitive with alternative meat sources. The production of beef cattle hinges on the ability to convert forage, grass, and grain crops into palatable and nutritious food for human consumption. A critical link in augmenting the efficiency of the cattle production sector is the cow-calf enterprise. Not only, does this phase contribute between one-third and one-half of an animals' final liveweight, but it also determines the quantity and quality of cattle entering subsequent stages of production. Therefore, cow-calf production is certain to play an important role in determining the sustainability and/or expansion of Oklahoma's beef production sector in future decades.

A major reason for Oklahoma's large and successful beef cattle production sector is the state's abundant forage resources. Nearly 46 percent of Oklahoma's total land area (19.6 million acres) constitutes the state's range resource base. Oklahoma also has a significant acreage of forestland utilized for livestock grazing (Bernardo, 1986). The native range of Oklahoma is characterized by a vast array of vegetative types and traverses across the state. The diversity in vegetation connotes diversity in ecology, productivity, and range quality. Oklahoma possesses large acreages of improved pasture land, covering about 7.1 million acres and requiring little (less than 1 percent) or no irrigation as a source of supplemental water. A final important forage resource is the state's winter and early spring wheat pasture. These forage resources all combine to create a unique comparative advantage for beef cattle production relative to other regions in the United States.

According to Fontenot and Blaser (1965), increased forage quantity generally increases animal performance because animals are allowed more opportunity to graze selectively and choose higher quality forages in their diets. Since there is a positive correlation between forage quantity and quality and livestock numbers, positive trends in livestock production in Oklahoma may be partially attributed to an abundance of improved pasture and high quality rangeland.

Successful cow-calf production requires integrating available forage resources with other feed sources to meet the cow's nutritional requirements. As stated by Price (1981), forage is the commodity that the rancher actually produces, and livestock are merely the method of marketing the forage. Although several forage resources are available to Oklahoma cattle producers, care must be exercised to assure that nutrition requirements are met throughout the year. The changing availability and quality of this forage makes this particularly challenging. As noted by Lusby (1989), the feeding strategy of the cow-calf is the single most important decision facing the cow-calf producer. These decisions have physical, biological (reproductive), and economic implications on the success or failure of a cow-calf system.

Reproduction (i.e., the production of calves) is the focal point of the cow-calf system. Cow-calf producers have large amounts of capital tied up in fixed factors of production, namely land and breeding livestock. If the animals fail to reproduce, the rancher will not have a product to sell and cannot cover these fixed costs. To forestall this situation, feeding programs must be developed to assure nutritive requirements are met and a high level of reproductive efficiency attained. Reproductive efficiency is related to the number of calves born from a given herd size; the higher the number, the more productive the cow herd.

However, there are some vital physical efficiency measures that a good beef cattleman should consider. These include:

- number of calves sold or marketed in relation to the number of cows bred (weaning percent).
- number of calves born compared with the number of cows bred (calving percent).
- number of calves that attain weaning age (weaning weight) in relation to the number of cows bred (Ensminger, 1987).

It is an accepted fact that weaning percentage is the most important single factor that affects profitability in cow-calf production, and the most common causes of a low calf crop are improper feeding and disease. Uniformity in the cow/herd is another important factor that adds to reproductive efficiency because herds of similar type and breed produce uniform calves. This facilitates sale of the offspring at a premium price at any age (Selk and Lusby, 1989).

Whereas physical efficiency is critical in assessing herd performance, economic efficiency ultimately determines the long-term profitability of the cow-calf enterprise. Economic efficiency requires that the dollar value of output per dollar's worth of resource input be maximized. Beef cow management is carried out under a variety of conditions that utilize the feed resources available given the existing environmental conditions. Cattle inherit certain genetic traits, but how well these traits develop depends upon the environment to which they are subjected. The most important factor defining this environment is the quantity and quality of available feed, noting that adequate feeding produces thick, well-conditioned animals, irrespective of the season of the year. Feed is also the highest single cost item of beef cattle production.

Determination of feeding programs are critical economic decisions facing the cow-calf producer. The production of saleable calf weight must increase relative to increased feed costs and nutrient requirements should be met at least costs. Also, feeding programs should change relative to the prevailing economic conditions, particularly cattle prices and feed costs. For example, if the market price for cattle is high, economic efficiency may dictate striving for a higher level of reproductive performance that will ensure a marginal value product from the added saleable weight that is higher than the marginal cost of the added feed. On the other hand, with lower market price, supplemental feeding levels may be reduced to reflect the lower marginal value product of the supplemental feed. Thus, beef producers should aspire for feeding strategies that are economically efficient, rather than develop feeding programs based on a criterion of physical efficiency.

In addition to supplementation programs, decisions on culling practices, weaning dates, and sale dates for calves may also affect the economic efficiency of the cow-calf production system. According to Price (1981) and several other researchers, early weaning seems to be most advantageous since it is inherently more efficient for a calf to consume and convert feed into growth directly rather than the cow consuming the feed, converting it into milk, and the calf consuming the milk. Early weaning consequently reduces the amount of cow feed required and also the amount of time a lactation ration needs to be fed. Economic efficiency is achieved when more beef is produced for consumption at least cost. To attain this objective, a complete cow-calf management plan including supplementation programs, grazing schedules, weaning dates, and marketing strategies should be developed.

Definition of Problem

Traditional cow-calf nutrition management strategies have been based upon target levels of reproductive performance. A review of several livestock research reports shows that reproductive efficiency is enhanced by monitoring physically-based criteria such as target levels of cow condition, calving percentages, and weaning weights. Pregnancy diagnosis is also a useful practice affecting reproduction. Shorter days of conception following breeding season is another indicator of herd efficiency since it reduces feed cost.

Rearing a cow-calf for beef is laden with environmental influences that are both dynamic and stochastic in nature. These changes, as well as changes in the economic environment, are bound to affect changes in objectives regarding reproductive efficiency. Dynamics and uncertainty are closely related. The major sources of uncertainty in beef production include price variability (feed costs and output prices) and environmental fluctuations (e.g. weather, insect infestation, and disease). These factors combined with changing rates of inflation, technological improvements, and institutional changes render the assumption of perfect knowledge of prices and input and output supplies extremely tenuous. Such changes may translate to changes in optimal production strategies, which in turn will affect the herd's weaning weights, reproductive performance, etc.

Increased knowledge of how various nutrition programs affect reproduction has provided guidelines for cattle producers to meet their objectives in terms of conception rates and optimal use of limited feed resources (Selk and Lusby, 1989). However, there is a paucity of knowledge concerning the interactions between nutrition and reproductive performance. To attempt to fill this gap in knowledge, numerous researchers have conducted experiments where beef cattle are fed to target levels of body condition and the resulting reproductive efficiency monitored.

Body condition score (BCS) (or fattening) of cows at calving have been linked to pregnancy rates and days from calving to next conception. Both are measures of reproductive efficiency. Several body condition scoring systems have been developed; however, the most accurate and accepted scheme assigns a rating ranging from 1 (very thin or emaciated) to 9 (very fat or obese). The concept of BCS is fundamental to the development of feeding programs that are economical and ensure that cows at calving are in condition for successful breeding and rebreeding.

Many research studies have been conducted to assess the relationship between body condition score and reproductive efficiency. Several of these are highlighted in Chapter II. Generally, this research has found that body condition score at calving is an important factor influencing reproductive performance of beef cows in the next breeding season. Given available knowledge concerning the influence of supplementation on BCS and the relationship between BCS and reproductive efficiency, how can this information be used in developing optimal cow-calf management strategies?

Decisions concerning calving season, supplementation, and weaning dates should be made by comparing marginal value products (MVP) with input costs to maximize economic returns. However, determination of MVPs of feed and other inputs is difficult given the complex dynamic interactions involved. This study will attempt to develop a method by which economic criteria can be introduced into some of the decisions that affect nutrition-reproduction management of cow-calf system. Specific attention will be focused on the development of body condition score as an observable measure on which to base supplementation decisions.

Objectives

The general objective of this research is to develop and apply a conceptual framework for determining optimal intra-seasonal cow-calf nutrition programs by taking into account the relationship between cow condition and reproductive performance.

The specific objectives are:

1. To quantify the interaction between supplementation, cow body condition score, and various measures of reproductive efficiency (e.g. weaning percent, pregnancy rates, weaning weight).
2. To develop several alternative supplementation programs for beef cows, and determine the influence of these programs on future body condition and reproductive performance.
3. To develop optimal intra-seasonal cow-calf supplementation strategies under alternative economic scenarios differing in terms of beef prices, feed costs, and forage conditions.
4. To evaluate body condition score as an observable measure from which to base cow-calf supplementation decisions over the productive season.

Procedures

This study involves the development of a bioeconomic simulation model programmed in Fortran language to evaluate alternative cow-calf supplementation strategies available to cow-calf producers of central Oklahoma. The model is constructed to combine a native range submodel with cow-calf intake/growth submodel and an economic submodel to represent a complete rangeland/cow-calf production system.

The model is constructed to estimate the physical and economic influences of alternative cow-calf supplementation strategies given differing environmental conditions. The cow-calf model uses a modified version of the National Research Council's net energy system to calculate daily estimates of forage intake, energy requirements, and available energy. Many of the relationships used to modify the net energy system to represent beef cow production were adapted from the Iowa State University Beef Cow Ration Analysis Spreadsheet (1985). Additional relationships were added to adjust cow body condition in response to energy deficits and surpluses, as well as estimate reproductive performance as a function of cow condition. These relationships were estimated based upon experiments conducted to determine changes in body condition score and reproductive performance under different supplementation programs.

A cow herd model is used to separate the cow herd into subgroups based upon cow condition and track the performance of each group under the prescribed supplementation program. Performance data from the cow-calf model are then input into the economic submodel to obtain estimates of annual net returns. From the economic submodel, enterprise budgets specific to the production practices and environmental conditions of the simulation run are generated.

The combined cow-calf forage model is used to evaluate various supplementation strategies available to stockmen in central Oklahoma. Supplementation programs may be based on fixed supplementation schedules that specify dates and quantities of supplemental feed or more sophisticated adaptive supplementation strategies. Adaptive supplementation strategies evaluate BSC at critical points in the season (e.g.,breeding, early winter, etc.) and adjust supplementation programs accordingly. Cows comprising the herd may be sorted according to condition and grouped for supplemental feeding over a specified time period.

Distributions of annual net returns are generated for each of the supplementation activities. Appropriate risk efficiency criteria, including first- and second-degree stochastic dominance and generalized stochastic dominance are used to rank the alternatives. An additional analysis, utilizing a value of information criterion is conducted to determine the value of body condition score information to cow-calf producers characterized by alternative risk preferences.

Organization of the Study

The biological, empirical, and economic literature relevant to the analysis is reviewed in Chapter II. First, a review of literature focusing on the relationship between reproductive performance and cow body condition score is conducted. Next, several of the economic issues involved in evaluating the economic efficiency of alternative supplementation strategies are discussed. Finally, several economic analyses which have focused on various management issues of cow-calf production are reviewed.

In chapter III, a detailed description of the bioeconomic simulation model is presented. This includes the conceptual framework and data development for this study,as well as the computational procedures used to estimate nutritional requirement, reproductive performance, and economic returns.

Chapter IV discusses the results from applying the simulation model to evaluate alternative supplementation strategies for a representative spring-calving cow herd. Probability distributions of annual net returns derived from the alternative supplementation strategies are estimated. The supplementation activities are then ranked utilizing various efficiency criteria.

Finally, Chapter V provides a summary of the results and major conclusions derived from the analysis. This chapter also contains a discussion of the limitations of the analysis and suggestions for further research.

CHAPTER II

ECONOMIC THEORY AND REVIEW OF LITERATURE

Economic Considerations In Cow-Calf Production

Cow-calf production is a complex system involving the conversion of coarse forage and grass to palatable and nutritious food for human consumption (Ensminger, 1987). Producers face several long-term and short-term decisions which greatly influence the productivity of their cow-calf enterprise. Long-term decisions concerning such factors as fertility, culling, and breed type define the production technology employed by the producer in the short run. The production technology dictates the maximum quantity of output (e.g., weaned calves) capable of being produced from a given set of production inputs (feed, veterinary services, labor, etc.).

The short-run decision environment can be framed in terms of attaining some economic objectives (e.g., maximizing profits) subject to a set of constraints facing the producer. One of these constraints is land through its ability and capacity to produce forage for feed. The single most important factor in beef cow production is reproduction, and cows must be supplied adequate nutrition levels to remain productive. Thus, the goal of the cattleman is to combine supplemental feed and available forage resources in a least-cost manner to attain some specified level of reproductive performance.

Breeding Season

A knowledge of the existing breeding seasons should precede any policies pertaining to the development of the cow-calf feeding and management programs. Thedford et al. (1989) developed a detailed and simplified beef cowherd calendar as a production and management guide for Oklahoma cattlemen. There are basically two production (reproduction) seasons – spring calving and fall calving; however, there is no fine line that divides these two strategies into two distinct periods. Choice of the calving period is broadly based on producing to meet certain sales target at minimum cost. Typically, any profit maximizing producer should choose a season based on the resources available to him/her, with adequate forage for grazing and a favorable weather condition.

Selk and Lusby (1989) discussed the pros and cons of both calving seasons. The duration of any calving season depends upon the length of the breeding season, which ranges from 45 days to running the bulls year-round with the cows. The year-round system poses a series of problems in terms of management of the herd. For example, cows and calves are in different stages, and therefore need at some point in time different veterinary services, weaning dates, feeding packages, etc. This introduces non-uniformity and often translates to higher management cost. Calves being in different stages introduces a large degree of variability in weaning weights which translates to a lack of coordination in marketing strategies.

A short breeding season with a short calving interval is advocated because it makes planning nutrition programs simple since cows are in similar stages of gestation or lactation. However, it also has its attendant problems.

For example, high pregnancy rates are difficult to achieve, since most cows capable to conceive do so in a 90-day breeding (Selk and Lusby, 1989).

The majority of cow-calf operators in the United States favor spring calving for several reasons. First, calving is done after severe winter weather (Gillian, 1984; Ensminger, 1987). Spring calves require less intensive and expensive management practices than fall calves. Also, forage is at its highest quality during the lactation phase and other period of high nutritive demands. Therefore, supplementation requirements are lower and feed costs are reduced (Ensminger, 1987). However, Selk and Lusby (1989) point out some significant advantages of fall calving over spring calving in Oklahoma. Most notably, fall cows usually calve in very good body condition because they calve at the end of the forage growing season. Also, experiments have shown that with proper management, fall calving herds can achieve the highest reproductive efficiency of any management program. Finally, fall-calving systems provide weaned calves for grazing during the summer grazing period.

Intra-Seasonal Dynamics

There are some distinct or vital times in beef cow-calf production, including events such as breeding, calving, dehorning, castrating, branding and weaning (Ensminger, 1987). These activities must be conducted despite the breeding season or calving season. Figure 1 illustrates the various types of the decisions made by the cow-calf producer over a production season. This schematic describes a typical spring calving process, assuming a 280-day gestation and 210-day weaning period. Spring calving cows are bred from early summer, say April, to end of July (that is 2 to 3 months or 90 days maximum). Calving takes place after a 280-day gestation period the following

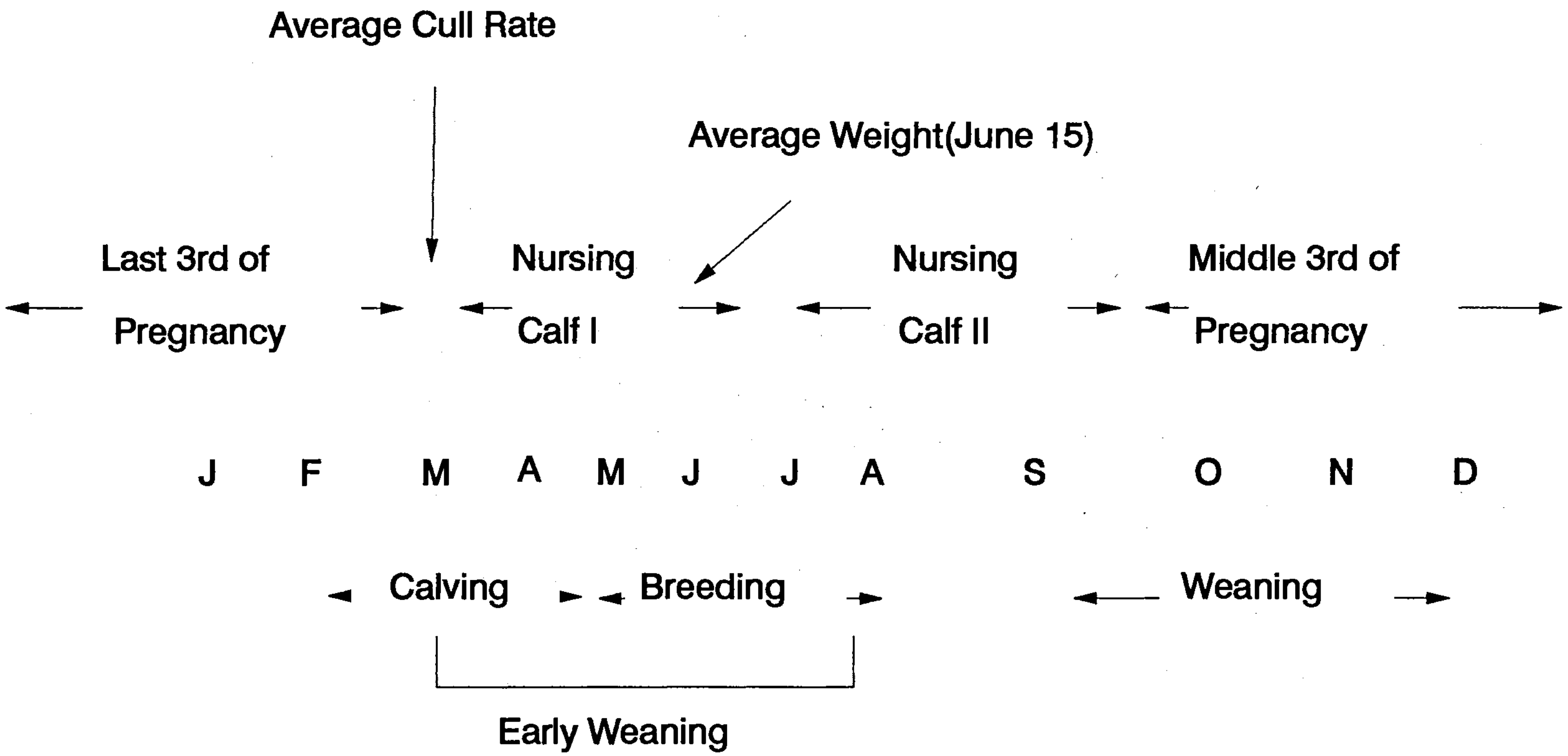


Figure 1. General Production Process of Spring Calving Cow-Calf Herd with 280-Day Gestation Period

spring. Spring-born calves are usually weaned in the fall. Cows or first calf-heifers normally should be ready to rebreed after three months.

While we may assume profit maximization as the ultimate goal, the producer needs to answer some pertinent questions relating to the production process. According to Saez et al. (1980) several questions must be answered irrespective of the calving strategy undertaken: How large should the breeding herd be? What is the best season for calves to calve? What is the value of attaining a higher conception rate? What is the best forage system? The overall objective from which to answer these questions centers on the improvement of reproductive efficiency of the cow herd. Selk and Lusby (1989) state that for a rancher to improve the reproductive efficiency of his/her beef cow herd he/she should emphasize three vital measures of efficiency: 1) number of calves sold per cow on the ranch; 2) cost of producing each pound of calf; and 3) uniformity of the calf crop at weaning and/or sale time. All three have direct impact on cash flow and profitability, and ultimately determine the stability and longevity of the operation.

Decisions on fertility (breeding), culling, calving dates, replacement, etc., are complex and made under imperfect knowledge and conditions often not controlled by the producer. In practice, the practical measure of animal's performance is, in the case of cow-calf ventures, the weaner calf, which is insulated to a certain degree from what is happening on the ground. A suckling calf inescapably supplements any forage it eats with milk, the mother cow at least partially making up any deficiencies in the forage crop. Nonetheless, in cow-calf enterprises utilizing rangeland as the principal forage resource, the calf weight is a reflection of range condition and availability (Smith, 1978).

In addition to reproduction decisions (e.g., culling, breeding, etc.), nutrition management plays a critical role in determining the reproductive efficiency of the cow herd. Nutrition management in rangeland cow enterprises involves simultaneously developing a grazing plan and supplementation program that meet nutritional goals. The grazing plan dictates where various groups of animals are to be grazed during periods of the production year. Formulation of supplementation programs requires three basic steps: (1) knowing the animal's requirements, (2) estimating what is available from the forage, and (3) providing nutrients to fill this gap, while making maximum use of forage resources. Of course, during some periods of the year cows are better able to convert feed to gain and store energy for future use. Conversely, in other periods, supplementing cows to fully meet energy requirements would require large quantities of high-energy supplements and is cost prohibitive. Anticipation of these periods will provide cows sufficient body condition to meet energy deficits when consumption alone cannot meet energy requirements.

The cow-calf production process therefore calls for an understanding of the nutrition dynamics and the herd response under alternative nutrition and management programs. The nature of the production process requires a dynamic analysis to reflect the true production process.

Inter-Seasonal Dynamics

Having identified some of the complexities of linkage within a production season, it is worthwhile to consider the possible linkages across seasons. These considerations might be termed the "inter-seasonal dynamics" of the cow-calf production system. Referring to Figure 1, starting from breeding to rebreeding, nutrition-reproduction programs are managed in a continuum with no breaks, and carry-over effects often determine management decisions in subsequent stages. More specifically, there exists an overlap of periods such that cow condition in the end of one production season becomes the cow condition of the initial portion of the subsequent season.

This situation differs from the traditional crop production example which involves identifiable and specific periods or stages for preplanting, planting, growing, harvesting, etc. Economic analyses are therefore based on the interactions between the major resources such as labor, land, and capital and the ultimate outputs accruing from the different crops. As a point of contrast, consider the classic inter-seasonal dynamic crop production problem of soil moisture carryover. The dynamic relationship in this production system links soil moisture content across production periods such that:

$$SM_{t+1} = f(SM_t) \tag{2.1}$$

where SM_{t+1} = soil moisture content in next planting season.

SM_t = soil moisture content in current planting season.

Normally, crop production involves a discrete time horizon and no overlapping of period to period management decisions. Ending soil moisture is tied to beginning soil moisture of the subsequent production period through an inactive (dormant) season. Variation in rainfall during the dormant season results in only a weak correspondence between ending and beginning soil moisture via the transition relationship.

Because of the overlap of production seasons, inter-seasonal dynamics are much stronger in the cow-calf production system. The cow's body condition prior to weaning is also the beginning condition for the following production season (i.e., breeding). Therefore, the impact of management decisions occurring over the current production season on the subsequent season's production is much more direct and certain than in most crop production examples. Upton (1986) noted that a breeding flock or herd of livestock at any point in time is the outcome of reproduction and growth in the past, and may be expected to survive into the future. This assertion appropriately fits the cow condition at any point in time.

Body Condition Score

Cow condition is measured by the fat content of the cow or how fleshy the cow is. As shown by many authors and researchers, cow body condition has a direct relationship with the nutrition status, and therefore the performance of the cow in terms of reproduction. Selk and Lusby (1989) maintain that there are relationships between body condition scores (numerical ranks or grades of fattening) and rebreeding efficiency of beef cattle. Condition scoring allows the herdman to appraise his nutritional strategy on an ongoing basis throughout the production year. By doing this at specified periods of the year, the cattleman is able to coordinate and combine the use of available forage and other nutritional needs in order to use less of the expensive feed needs such as protein supplements and hay.

Generally, researchers in the United States utilize a 9-grade system for cow condition scoring (Dunn et al. 1983; Wagner, 1985). Selk and Lusby (1989) described a 9-grade system ranging from 1 (very thin or emaciated) to 9 (very fat or obese). Extremely thin and emaciated condition and an overfat condition have been found by several researchers to be harmful from the standpoint of reproductive performance (Selk and Lusby, 1989). In another scoring system, also utilizing a 9-grade system, Fox and George (1986) described flesh condition and energy reserves in beef breeds. In this system grade 1 classified the extremely fleshy and blocky cows, whereas grade 9 described extremely emaciated and listless cows that could be regarded as being near death from starvation. Irrespective of the direction and content of grading, the concept of body condition score is fundamental to developing feeding programs that are economical and ensuring that cows at calving are in condition to assure successful breeding and rebreeding. Numerous production studies have been conducted to investigate the complex relationship between cow body condition scores and reproductive performance.

Review of Selected Production Studies

Fox and George (1986) reiterated the previously misplaced emphasis on beef cow-calf operation as a production system requiring only a minimum of management in order to generate a return from otherwise wasted resources. This approach, they cited, overlooked the cost-side effects (i.e. costs greater than returns) which resulted in loss of market shares to other more efficient meat producers such as poultry producers. There exists the need for producers "to identify their market, and then produce the most desirable type for that market so no sale price discount is absorbed". In the attempt to achieve this, producers should choose from their herd, the combination of cattle that "will optimize use of their forage resources while minimizing cost per unit of weight sold" (Fox and George, 1986).

Noting that cow body condition score relates to the fat content, it is therefore important that the cow-calf producer should strive to administer the nutrition packages subject to the broad range of environmental and management conditions he faces, for optimal body condition scores. Selk and Lusby (1989) state that a "better understanding of the relationship between body condition scores and rebreeding efficiency of beef cattle has added a powerful management tool to the cattleman's arsenal".

According to Selk and Lusby (1989) the logical times for the evaluation of cow body condition in spring calving herds are

- middle of summer
- fall weaning
- 60 days to calving
- at calving
- commencement of breeding in the spring.

The foregoing precautions are necessary because cow condition at calving and breeding are critical to next breeding cycle. Cows in thin condition are likely to have delayed conception into the season.

Appropriate times to evaluate cow conditions for fall calving cows are:

- commencement of summer
- at weaning, usually in July or August
- during calving
- commencement of breeding.

The general objective is that cows must calve in good body condition. If cows are in sound condition at normal weaning time, all areas of management will proceed normally (Selk and Lusby, 1989). Otherwise, adjustments in feeding, weaning weights, breeding, etc., will have to be made to improve the cow's performance.

Interest in the interactions between cow condition, nutrition and reproductive performance has prompted several researchers to conduct experiments where beef cattle are fed to target body condition scores and the associated reproductive efficiency monitored. Reproductive efficiency has been measured in terms of pregnancy rates, weaning weights, and days from calving to next conception. These measures have then been associated with body condition score.

Traditionally, several nutrition programs are available, each offering a different degree of reproductive efficiency. Studies on the effect of body condition score on reproductive performance have focused mainly on feeding different rations to cows to lose, maintain, or gain weight. Thus, cow body condition takes on both dependent and independent variable characteristics at various points of the year, irrespective of the multiple interactions that exist between BCS and other variables that influence reproductive performance.

The importance of BCS at calving on reproduction in beef cows is one area that has received considerable emphasis among animal scientists. Selk et al., (1986) related the importance of body condition score (1 = emaciated, 9 = obese) at calving to pregnancy rate and days from calving to subsequent conception in 110 hereford cows by subjecting the cows to different feeding programs. They concluded that pregnancy rates for cows that were BCS = 4 at calving decreased to 50 percent, whereas cows with BCS = 5, 6, and 7 had pregnancy rates of 81 percent, 88 percent and 90 percent, respectively. There was no significant difference in days from calving to next conception between cows that calved in BCS greater or less than 5.3 (89 and 100, respectively) even though their pregnancy rates were different (90 percent and 66 percent, respectively). Also the additional feed costs incurred in order to maintain body condition above 5.3 generated additional returns of $27.00 per cow, compensating for the added feed cost.

Godfrey et al. (1982) used a herd of fall calving Brahman X Hereford F-1 cows nursing calves and placed them on ryegrass - clover - bermuda grass pastures for a period of 130 days during early gestation. Two groups of cows were creep fed (CF) and placed on pasture to attain higher nutritional planes.

Cows were weighed and condition scored at 28-day interval during the grazing season. Weaned calves at the end of the grazing season were placed on bermudagrass paddocks. Cows were divided into two groups: weight loss (WL) and weight gain (WG) during the grazing season. The outcomes of this experiment (mean ± standard error are reported in parenthesis) are:

- WG cows had a higher mean condition score during the grazing season than WL cows (8.0 ± .63 vs 5.5 ± .36, respectively).
- There existed a close correspondence ($p < .01$) in calf birth weight between WG and WL cows (36.02 ± 4.10 kg vs 33.67 ± 4.52 kg, respectively).
- WG cows weaned heavier ($p < .01$) calves than WL cows (302.25 ± 33.90 kg vs 205.6 ± 15.18 kg, respectively).
- CF cows weaned the heaviest ($p < .0l$) calves of the WG group (319.27 ± 21.98 kg vs 290.09 ± 27.63 kg, respectively).
- WG cows weighed more at calving and had higher ($p < .01$) condition scores at calving than WL cows (596.98 ± 39.15 kg vs 531.59 ± 49.65 kg, and 7.9 ± .80 vs 6.4 ± .38, respectively).
- Postpartum interval was shorter ($p < .05$) for WG cows than for WL cows (31.76 ± 9.5 days vs 37.40 ± 5.4 days, respectively).

In other studies, parallel results were obtained irrespective of the experimental design (Cantrell et al., 1982; Renbarger et al., 1964; Godfrey et al., 1982 a, b; Dunn and Kaltenbach, 1980).

More recent studies seem to reinforce the results of earlier studies. Wetteman et al. (1987) evaluated two groups of 70 hereford and Angus X Hereford cows that calved in 1985 and 1986 between the months of February 11 and April 15. Postpartum nutritional treatments were given to these cows blocked by calving date, breed and BCS. These cows were fed under range conditions to maintain or gain weight during the first 85 days postpartum and were bred 90 days each year starting on May 1. One objective was to determine the influence of postpartum nutrition and BCS of cows at calving on reproductive performance. In some of their findings, BCS at calving and postpartum nutrition were shown to influence pregnancy rate. The rate of pregnancy improved for cows fed to gain weight rather than maintain. They held that there is an interaction between BCS at calving, postpartum nutrition and year of pregnancy. Furthermore, increasing postpartum feed intake of range cow that calve with a BCS of 5 in the spring will increase pregnancy rate (Momont and Pruitt, 1987a, b).

In a similar study with first calf heifers, Wettemann et al., (1986) tried to determine the influence of body energy reserves at calving and postpartum nutrition on reproduction and calf performance. Heifers were fed to gain or maintain. The study showed that reproductive performance is influenced by body condition score at calving and nutrient intake after calving. Weight gain after calving had an influence on pregnancy rate. Also, calf birth weight and weaning weight were not influenced by cow body condition score between 4 and 6, but reproductive performance may be altered.

Wettemann and Lusby (1987) examined the influence of BCS at calving on birth weight of calves, calving difficulty (dystocia) and rebreeding performance of heifers that calve at two years of age. Heifers were blocked by breed and BCS in two different years and fed to lose or gain weight restricting them to BCS of 4, 5, or 6 at calving. Body condition or body energy reserves at calving was identified as the most important factor that influences the length of the interval from calving until the first postpartum estrus. A reduced nutrient intake during the last months of pregnancy may reduce birth weights of calves, body energy reserves and delay rebreeding. A BCS of 6 was identified as a desirable amount of body energy reserves for first calve Hereford and Hereford x Angus heifers at parturition for good reproductive performance (Wetteman et al., 1986; Bell et al., 1990).

Tinker et al. (1989) conducted an experiment with crossbred cows, instead of singlebred type, in order to determine their response to supplementation treatments. The crossbred groups included Hereford X Angus, Simmental sires, Brown Swiss sires, and Jersey-sires. This research concluded that the body condition that will enhance reproductive performance may be different for cows of differing breeds and biological types. This result also reinforces the conclusion that BCS does have an effect on percentage of cows returning to estrous by 85 days after calving. Crossbreed did affect the percentage of cows with luteal activity, but there was no interaction between crossbred cow group and BCS. A greater percentage of the Jersey-cross cows exhibited luteal activity than the other two-breed combinations. Since cows of this breed type do not need to be in as high of BCS as other types of crossbred cows in order to cycle 85 days after calving, they would not need to be fed to the same body condition. Thus, feed costs could be reduced while attaining a desirable level of reproductive performance. Therefore some refinements of the BCS recommendations for enhancing reproductive performance may need to be investigated for cows of various breed combinations and biological types. This work disproves earlier studies that held the position that cows irrespective of breed, hence biological types, "perform the same at a similar body condition score" (Tinker et al., 1989).

Various studies have posited unequivocally that BCS, irrespective of the approach, is an important factor that influences reproductive performance in beef cows during the next breeding season. When a cow calves at low body condition, by implication both energy reserves for maintenance and production would be low. Feed intake post calving would be utilized first for maintenance and later for production (that is caloric needs for parturition, lactation, reproductive tract repair, rebreeding), prolonging the breeding season and consequently increasing the overall cost of production.

Most studies, if not all, showed that lower cow nutrition and body condition at calving decreases reproductive performance of the cow in addition to affecting the weaning weights of young calves, calf survival and reproductive performance of first calf heifers. Also, the birth weight of the calf does not appear to be influenced by body condition score between 4 and 6 at calving, but the reproductive performance may be altered.

The proposition that cows with the same body condition, irrespective of breed, perform similarly reproductively needs to be addressed. Changes need to be made to nutrition programs based on breed differences. Since weight gain is highly positively correlated with body condition and body condition positively related to reproductive performance up to a point, we would infer that at some point in the feeding regime, there would be a weight gain and BCS that would result in optimum reproductive performance at least cost, under adequate forage conditions, ceteris paribus.

Inferring from these studies, determining the single influence of body condition on reproductive performance is a difficult undertaking because its effects (i) are not outstandingly clear; (ii) are controlled by other factors like nutrition, calving rate, breed, season, weather, etc.; and (iii) interact with past and future body condition. The question then arises, how do we represent these relationships in a response function context for economic analyses of the various decision phases?

Economics of Body Condition Score

The traditional production function of the Neoclassical Theory of the Firm presupposes technical efficiency and states the maximum attainable output from each input combination. The function is represented mathematically as:

$$q = f(x_1, \ldots, x_n) \tag{2.2}$$

where q = output and $x_1 \ldots x_n$ represents a set of inputs. The inputs and output are rates of flow per unit of time, t_o, where t_o is sufficiently long that the technical processes are completed, and t_o is sufficiently short that the technology remains unchanged. In addition, t_o is a short enough period that entrepreneurs cannot vary inputs originally specified as fixed. If t_o is lengthened beyond this point, the analysis is shifted from the short run to the long run. Use of such a representation would dictate a static or comparative analysis in which the production process does not change during the time period, and does not incorporate time as an explicit factor. Such an analysis postulates that a change in an exogenous variable, say weather, will affect cow weight gain and traces the effect on other relevant variables (e.g., weaning percentage, weaning weights, etc.) "before" and "after" the change. The "before" and "after" situations are analyzed in a static manner assuming that the situation has prevailed a long time and other agents had fully adjusted, implying a long run equilibrium.

While the limitations of the NTF production function are well documented, several features make their application to cow-calf management particularly ineffective. Most notably, it is difficult to define a time period over which the production process is completed. As stated earlier, production seasons tend to overlap since breeding typically commences prior to the weaning of the previous period's calf. Also, output from the cow-calf production involves several processes and cannot be measured through a single variable. Output is influenced by several factors, including calving percent, weaning weights, and death loss. Thirdly, failure to explicitly represent the critical dynamic elements of feed response (e.g., timing of supplemental feeding, changing forage quality, etc.) renders the NTF production functions nearly useless in analyzing cow-calf management decisions.

Dynamics of BCS

The nature of cow-calf nutrition dynamics and cow body condition response, earlier highlighted, requires a multistage decision process. According to Burt and Allison (1963) a multistage decision process is characterized by the task of finding a sequence of decisions which maximizes (or minimizes) an appropriately defined objective function. The stage being the interval into which the process is divided; a decision being made at each stage in the sequence of stages comprising the decision process. The state of the process at a particular stage describes the condition of the process and is defined by the magnitudes of state variables and/or qualitative characteristics. Also decision at a given stage controls the state in which the process will be found in the following stage. States resulting from a given control may be either deterministic (outcomes are known with certainty) or stochastic (outcomes are uncertain and represented with a probability distribution).

Incorporating the temporal dimension of intra-seasonal cow-calf management can greatly complicate the conditions for profit maximization. To illustrate the influence of time considerations on the optimality conditions, a relatively simple example of time-dependent response is considered. This example will serve to illustrate the interdependency of the sequential decisions defining an optimal supplementation program.

For simplicity, it is assumed that the production year is comprised of n discrete subperiods. The management objective may be defined mathematically using the following separable objective function:

$$\text{Max} \sum_{i=1}^{n} NR_i \ (BC_i, F_i) \tag{2.3}$$

where NR_i = net returns from stage i

BC_i = the state vector describing the body condition status in period i

F_i = the quantity of supplement fed in period i

In the usual reverse order of dynamic programming, i is used to denote that period after which i-1 further runs of the response process are made. The producer seeks to maximize returns over the n periods by choosing supplementation quantities in each of the n periods ($F_1, F_2, \ldots, F_n$).

The body condition status in period i (BC_i) is defined by the body condition carried over into period i (R_i) and the level of supplementation in the period (F_i). Therefore, a response function relating output to body condition status in period i may be defined as:

$$f_i \ [\, BC_i \, (R_i, F_i) \,] \tag{2.4}$$

Note that output is a function of the state of the system (body condition) rather than the total physical quantity of feed used in the season. The function f_i is assumed to exhibit diminishing returns so that the required second-order conditions for optimality hold. In addition, the specification of f_i differs among subperiods, accounting for the changing marginal productivity of supplemental feed over time.

The optimization problem includes a transformation function (a recursion relation) that describes the transition of body condition status from the initial stage to the final stage. This expression may be written:

$$R_i = g_i\,(F_{i+1}, R_{i+1}) \tag{2.5}$$

Abstracting from any uncertainties in price or yield, recurrence equations of the usual dynamic programming form may be formulated. Net returns are determined by subtracting variable costs from total revenue. For the case with only one period remaining (i.e., n=1), the objective function may be defined as:

$$\max \theta_1(BC_1) = P_y \cdot f_1[BC_1,(R_1,F_1)] - rF_1 \tag{2.6}$$

Differentiating the expression with respect to the decision variable F_1, yields the final-period condition for profit maximization:

$$P_y - \partial f_1/\partial BC_1 \cdot \partial BC_1/\partial F_1 = r \tag{2.7}$$

Supplemental feed is fed to the level required to equate the MVP of the feed input in period 1 to its marginal factor cost. Continuing for the case with two periods remaining, the objective function becomes:

$$\max \theta_2(BC_2) = P_y \cdot f_2[BC_2(R_2,F_2)] - rF_2 + P_y \cdot f_1[BC_1(R_1,F_1^*)] - rF_1^* \tag{2.8}$$

The resulting second-period condition for optimality is:

$$P_y[(\partial f_2/\partial BC_2 \cdot \partial BC_2/\partial F_2) + (\partial f_1/\partial BC_1 \cdot \partial BC_1/\partial R_2 \cdot \partial R_2/\partial F_2)] = r \tag{2.9}$$

Equation 2.9 illustrates the interdependence of the sequential feeding decisions. This expression states that the sum of marginal value product of a unit of supplemental feed in period 2 and the impact on period 1 revenues resulting from feeding a unit of feed in period 2 must equal the marginal factor cost of the feed input in the second period. The interaction between the two periods is a consequence of the value of the additional body condition from F_2 carried over to period 1.

Arguing by induction, these results may be extended to the general case with m periods remaining. The objective function for the t-th period is:

$$\theta t = P_y \cdot f_t[BC_t(R_t, F_t)] - rF_t + \sum_{j=1}^{t-1} [P_y \cdot f_j\{BC_j[R_j(R_{j+1}, F_{j+1}), F_j^*]\} - rF_j^*] \tag{2.10}$$

Where the general condition for optimality is:

$$P_y[(\partial f_t/\partial BC_t \cdot \partial BC_t/\partial F_t) + \sum_{j=1}^{t-1} (\partial f_j/\partial BC_j \cdot \partial BC_j/\partial F_t)] = r \tag{2.11}$$

This formulation demonstrates the influence of time-price effects and the temporal aspect of response on cow-calf nutrition management. The current output effect, as well as the effect on the marginal productivity of feed in future subperiods, must be considered.

The intraseasonal management problem is actually much more complex than the situation represented above. The formulation can be modified to incorporate a greater array of decisions faced by the manager, a more complete representation of the state of the system, as well as the stochastic elements that affect changes in cow condition over time. Having defined the calving period, the production year can be divided into discrete subperiods. At the beginning of each subperiod, decisions concerning supplementation, weaning and sale of calves are made. Such decision will be made based upon the current state of the system, accounting for cow condition and its impact on future reproductive performance.

The "state" of the system is now defined using two variables -- cow body condition (BC) and calf weight (CW). The BC state variable represents an index of the reproductive efficiency of the cow herd and can take on s values BC (i = 1, 2, . . ., s). The state variable (CW) indicates the current weight of the calf, which has implications for cow nutrient requirements and calf sale weight. Delayed weaning dates also affect the level of body condition attainable in future time periods from a given feeding program.

Based on the cattle calendar, one could assume three types of controls. At the beginning of each period (month), the producer observes the state of the system that is cow body condition, forage condition, and calf weight. Based upon this information, a particular supplementation program is selected as well as whether the calves are weaned or sold in the period. The feed program variable can take on r possible values, N_i, $i = 1, 2, \ldots, r$. The latter two controls (weaning and sale of calves) are only considered in months when calves are present and may be represented using a zero-one decision variable.

Solution of the problem requires finding the optimal control rule that maps each state (combination of BC and CW) into a set of controls. Controls may be selected to maximize expected net returns. The pay-off function will give the current pay-off to the decision maker's control selection given the state of the system. In essence, returns in period t are a function of the state of the system (BC_t, CW_t) as well as the set of controls selected and may be expressed as $g(BC_t, CW_t, k_t)$.

Therefore, the multistage decision problem may be expressed as:

$$(1) \quad \max_{k_t} \; E \sum_{t=1}^{n} g(BC_t, CW_t, k_t) \qquad (2.12)$$

where k_t is the control set in period t and n is the length of the time horizon. This objective function is maximized subject to a set of relationships that define the transformation of states from one stage to the other. This can be done using Markov chains. The Markov assumption implies that body condition in period t+1, (BC_{t+1}), is a random variable and is dependent only upon state and control variables in period t, (k_t, BC_t). These interrelationships could be represented using a stochastic Markov process consisting of a unique transition matrix (P) for each feasible combination of controls. The P-matrix is a square matrix with an order equal to the number of possible states, m (all combinations of BC and CW). The probability with the subscript ij in the r^{th} P-matrix (P^r_{ij}) is the probability of moving from state i in period t to state j in period t+1, given that the r^{th} combination of controls is employed in t.

From the above explanation, the problem can be redefined by applying Bellman's Principle of Optimality. Let $f_n(i)$ be the expected return from n-stage decision process under an optimal policy with the initial stage given by the i^{th} combination of states BC and CW. The Principle of Optimality states that "an optimal policy has the property that whatever the initial state and decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision" (Bellman, p.63). Applying this principle to the cow-calf management problem yields the following recurrence relation:

$$(2) \quad f_n(i) = \max_k \; g(i,k) + \sum_{j=1}^{m} P^k_{ij} \, f_{n-1}(j), \qquad (2.13)$$

when the second term in the equation gives the expected value of net returns over the remaining n-1 months of the time horizon, given that an optimal policy is followed after selection of control k in period n.

Risk and Uncertainty in Cow-Calf Production

Livestock production in general, and cow-calf production in particular, is characterized by both environmental and economic influences that are dynamic and stochastic in nature. The control of production cost is very important to a profit-maximizing producer. However, decisions concerning fertility, culling, calving season, replacement, weaning weights, death loss, rate of gain, etc. are made under imperfect knowledge and conditions of uncertainty.

Environment and institutions constitute sources of risk and uncertainty in decision-making (Eidman, 1985). Many authors have defined risk and uncertainty in different ways. Generally, the concepts of risk and uncertainty have been applied interchangeably, cancelling the dichotomy assumed. Risk can be defined as an event in which the outcome is not certain but a mathematical probability can be assigned to alternative outcomes using a priori computations or estimations or statistical computations from historical or experimental data. Risky choices prevail when the decision maker has to choose between alternatives, some or all of which have consequences that are not certain and can only be described in terms of a probability distribution (Mapp, 1989). On the other hand, subjective probabilities can be assigned to uncertain events. There is no authenticated basis or premise for generating probability of events that occur, hence, does not call for any form of empirical measurement in absolute terms. Outcomes occur randomly and are not repeatable hence, given similar situations, events that are not uniform can occur. This implies that a decision maker cannot formulate a probability distribution of the outcomes. According to Robison and Barry (1987) events are uncertain if outcomes are not known with certainty.

Sources of Risk Facing the Cow-Calf Producer

The cow-calf producer, like any other agricultural producer, faces different types of risk and uncertainty from diverse sources. Some of the sources of risk faced by a cow-calf producer include weather variability (heat, cold, climatic conditions affecting feed supplies, etc.); diseases and pests (animal diseases, parasites, etc.); livestock and product prices (fluctuating prices received due to supply and demand factors); costs of operating inputs (fluctuating prices for feed, feeder livestock, etc.); cost of credit (unexpected variation in interest rates); cost of leverage (unexpected changes in vulnerability of cash flows and credit worthiness due to high leverage); government agricultural programs (unexpected changes in government programs affecting livestock producers, e.g. public land grazing fees, dairy program provisions); inflation (unexpected changes in prices, costs and investment returns).

Eidman (1985) identified three types of risk that affect farm businesses: production risk, price risk, and financial risk.

Production Risk. Production risk is described as output variability from one season to the next as a result of factors beyond the manager's control. Such factors include unfavorable weather conditions, pests, genetic variation, and changes in government regulations on pesticides and feed additive usage (Eidman, 1985). Some of the possible consequences on the cow-calf producer include variability in forage production, weaning weights, rate of gain, or death loss.

Price Risk. Eidman (1985) defines price risk as a situation which unpredictably shifts supply and demand for inputs and outputs. These shifts inevitably give rise to variability in both prices of inputs and outputs. In other words, there is an inherent variability in cost of production and price of output. Some of the causes of these shifts are fiscal and monetary policy, change in commodity programs and trade policy that relate to agricultural exports and imports, and weather-induced supply changes.

Financial Risk. Eidman (1985) defines financial risk as "the added variability of net returns to owner's equity that results from debt financing". The important issue here is that if the cow-calf enterprise is heavily leveraged, as implied by a high debt/equity ratio, the decision maker is obligated to meet a set of scheduled debt payments (interest and principal) annually. Financial risk is an embodiment of uncertain interest rates and uncertain loan availability and both increase the absolute and relative variability to owner's equity (Eidman, 1985).

The three forms of risk identified above, when acting together affect the net returns to the decision maker in a cow-calf production enterprise. These variations are translated ino variation in annual gross margins. Low or high gross margins coupled with expectations will influence all decisions made by the farmer or rancher. The rancher's attitude or response to risk will also greatly influence his decisions.

Risk Factors in the Cow Body Condition Problem

Several factors contribute to the level of risk present in the cow body condition problem. Obviously, the cow-calf producer faces many of the traditional sources of risk present in agricultural production. Production decisions are based upon input and output price expectations; however, uncertainty exists in prices actually paid and received by the producer. The unique aspects of risk in the body condition problem relate to uncertainty that exists in several of the underlying production processes. As identified earlier, two of the critical production relationships which define the body condition problem are the transition equation defining changes in BCS over time and the response function relating to BCS to reproductive performance. Significant sources of variability can be identified in each of these processes.

Body condition, as previously indicated, affects the productivity of the cow-calf unit. BCS_t may be expressed as a function of BCS_{t-1} through the transition equation which describes changes in body condition over time under a given feeding strategy. There is a certain degree of uncertainty in this process due to the influence of several environmental factors. The ability to increase body condition relies upon the presence of energy surpluses that allows the cow to store excess energy as fat. Therefore, any factors outside the manager's control which change the cow's energy requirements or nutritional value of the feed package will translate to production risk. Undoubtedly, the most important source of variability in the supply of energy relates to differences in forage quality. Although much is known about changes in the nutritional value of range forage over the year, considerable differences exist year to year as a result of climatic effects. Climatic events also affect the cow's energy requirements as a result of additional energy demands due to cold stress and/or muddy conditions.

The problem of fertility, after discounting genetic and phenotypic influences, is another area where risk enters into the body condition problem. Animal scientists have linked conception rates to BCS. Both are positively correlated up to the point prior to over fatness or obese situation. Inferring from several research results, this relationship could be summarized graphically in Figure 2. There exists, however, a certain degree of uncertainty in the relation ship between condition score a cow or first calf heifer and reproductive performance (conception rate, weaning weights, etc.). The process of converting body condition to reproductive performance is further complicated by factors such as breed effects. For example, NRC (1984) states that different breeds and individuals that mature at heavier weights, require more energy for maintenance. Since the animal satisfies energy for maintenance first before that of production, considerable uncertainty may be present in the process which converts BCS to reproductive performance.

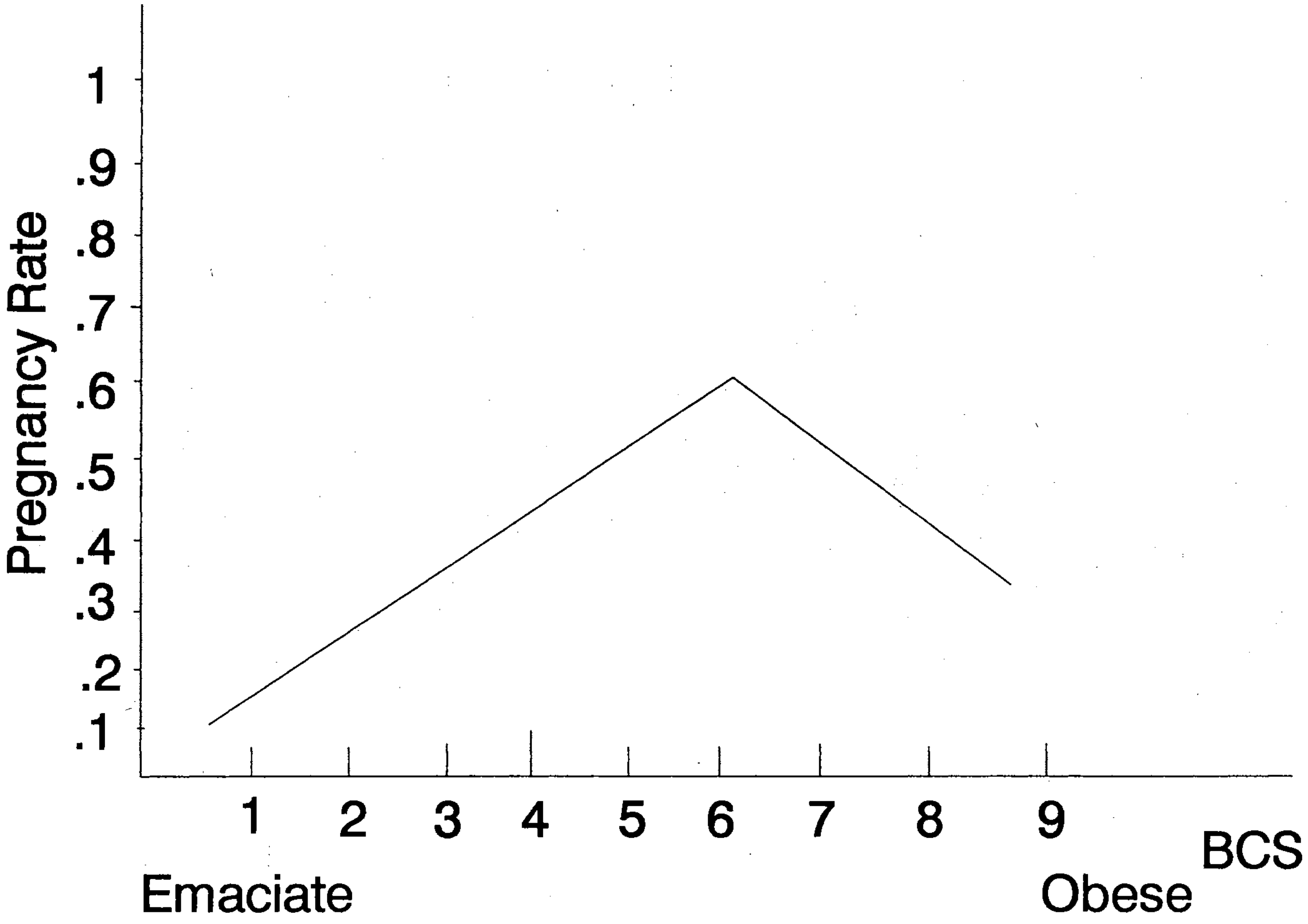


Figure 2. Relationship Between Pregnancy Rate and BCS

Clearly, significant levels of risk are present in cow-calf production, and risk can significantly impact decisions regarding body condition score and supplemental feeding. It is, therefore, justified at this point to review some of the studies done so far relating to cow-calf production risks.

Economic Studies of Cow-Calf Management

Many economic analyses have been conducted to evaluate the economic efficiency of various components of the cattle production system. This summary will focus on economic analyses of cow-calf production, particularly attempts to more completely represent some of the physical complexities of the cow-calf enterprise into economic models. Several studies have shown that cow-calf production is subject to various risky situations such as livestock and product prices, diseases and pests, and weather variability. Their primary focus has been the representation of these sources of risk in physical and economic models of the cow-calf production system.

Guitierrez (1985) demonstrated and implemented some modifications to the simulation model REPFARM, an earlier version of FLIPSIM V, to permit cattle ranch analysis within a stochastic framework. Using triangular distributions, modifications were made to represent stochastic steer calf prices, steer calf sale weights, and weaning percents for five cow-calf and five stocker enterprises. Selected management plans and economic scenarios were analyzed for a representative Oklahoma ranch. Alternative production and marketing strategies were evaluated based upon expected income, risk, and firm survivability. Estimates of risk preference intervals were applied to ending net worth levels to order the ranch simulation results utilizing stochastic dominance with respect to a function. The net worth distributions from the simulation experiments were compared for decision makers defined by their risk preferences employing the upper and lower bounds of the absolute risk aversion function.

In another study conducted by Vantassell (1987), three major business risks that confront Texas ranchers were analyzed. The three risk factors were brush encroachment, insufficient and unpredictable rainfall, and fluctuating livestock prices. These three factors operate concomitantly, and therefore render the decision making environment uncertain and burdensome, affecting the cattle cycle and consequently range improvement practices. Financial and production subroutines of FLIPSIM V were used to adapt a rangeland simulation model, RANGE. The simulation model is primarily driven by a climatic environment that affected cattle supplementation levels, cow and calf weights, weaning dates, and range conditions. Based upon cumulative environmental conditions at selected decision dates, decision criteria were developed and, assessed by this model. A new model evolved called RANSIM which is a combination of RANGE and FLIPSIM V models. Cash receipts, variable expenses and financial requirements were passed from RANGE to FLIPSIM V, with the overall financial conditions of the farm passed back to RANGE from FLIPSIM.

Rice et al. (1983) investigated the livestock component of the program SPUR (Simulation of Production and Utilization of Rangeland) to assess the short- and long-term effects of rangeland management decisions on economic returns. They designed a model component to simulate the dynamic impacts of grazing on rangeland and livestock response. Dynamic functions and operational requirements were specified. The quantity and quality of forage or range situation was shown to be not only important to the choice of calving seasons, but also instrumental in the planning of feeding strategies that are of great importance to the body condition,and hence, reproductive performance of the cow-calf unit. The variation in forage yield due to uncertain amounts of rainfall results in lower stocking rates, increased supplementation, and resulted in unexpected variations in production costs such as leasing extra land to make up for the declining forage quantity and quality.

Morris and Wilton (1975) adapted the method and assumptions of Wilton et al. (1974) to evaluate the influence of mature cow weight on the economic returns from different beef cattle operations under alternative management and input/output price scenarios. Under the average and low feed prices, returns were shown to increase with cow size; whereas, at high feed prices the combination of small cows and smaller operations were optimal. Furthermore, under average or high beef prices returns increase as cow weight increases, and the inverse occurs when the prevailing output is low.

In other studies, McMorris and Wilton (1986), and McMorris et al. (1986) used a deterministic framework and evaluated the biological and economic performance of herds having different cow weights and milk yield potentials. The breeding systems evaluated were a two purebred systems, a four-breed large rotational beef system, a four-breed small rotational dual purpose system, and a three-breed small rotational beef system. At average or high beef-to-feed price ratios (B:F), higher returns were linked to systems with high output; whereas,production of smaller calves at low B:F was slightly more profitable. The optimal cow weight was also highly dependent on the beef-to-feed ratio. Higher cow weights displayed a negative return at low B:F. Conversely, higher returns resulted as the B:F increased. Similarly, there is also a high correlation between milk yield and B:F. High milk yields were most profitable under high B:F, and vice versa. A decrease in feed costs makes an increase in calf weight gain via increased milk yield economically profitable.

Trapp (1986) identified the areas of production risks in livestock enterprises. These are death rates in calves and mature cows, calving and weaning percentages, variability in calf weights and rate of gain of the stocker cattle. Further, he developed an optimal flexible culling and replacement strategy, principally, for management of cyclical cattle prices. The underpinning assumption of this model was that the feeder cattle price cycle must be anticipated for a period, ranging between four to six years. This type of analysis benefits feeder cattle producers and cattle feedlot operators. He concluded that, irrespective of seasonal price variations, managers can improve on their marketing decisions with the knowledge of their business cycle position, be it downward, upward trend, or close to the peak of the cycle.

In another study, Rawlins, (1988) developed a multi-period MOTAD (Minimum of Total Absolute Deviation) model for analyzing efficient organizations of forage and livestock enterprises for an eastern Oklahoma ranch. The decision framework developed represents forage quality and intake considerations including the various sources of risk the livestock producers encounter. The model was specified to maximize expected net returns subject to parametric restrictions on the mean and absolute deviations in returns. The level of feed rations were endogeneously determined by constraining the animals intake and allowing varying combinations of supplements or forage capable of meeting livestock nutrient requirements within each period. The various risk levels were determined by measuring the mean absolute deviation from expected net returns resulting from variability in forage yields, livestock prices and purchased input. This study's results showed that efficient ranch plans are highly sensitive to the producer's degree of risk aversion. In addition, as the degree of risk aversion increases, a reduction in livestock numbers occurs and the more stable livestock enterprises are substituted for the more risky production alternatives. The study indicated that cow-calf enterprises are more desired as the degree of risk aversion increases and there is a positive correlation between reductions in level of risk and reductions in expected net returns.

Cartwright and Doren (1985) characterized the Texas A & M Beef Herd Simulation Model (TAMU) as a computer model, programmed in Fortran IV and designed to simulate the growth, reproduction and lactation of beef cattle. The TAMU model considers animals based on classes of sex and age. In addition to descriptive data of the livestock classes, the model requires input that define forage quality and availability by month. Some elements of stochasticity contained in the model are birth, death, estrus, conception, and removal.

Stokes et al. (1981) used the TAMU model to simulate preweaning and postweaning performance of nine different beef cattle genotypes. Estimates of enterprise net returns were calculated under various environmental and economic situations. The model was also used to evaluate alternative retained ownership strategies. From the results, selling weaned calves directly to the feedlot exhibited the highest average net returns per head, as compared to selling calves at weaning.

Whitson et al. (1976) studied the impact of risk on the returns that accrue by selling produced calves or retaining them through subsequent production stages. Multiperiod quadratic programming (QP) was used for modeling the vertical sequence of decision strategies and subsequently for the evaluation of the risk and returns under a value added premise. The E-V efficient growth plan was generated through the QP model. For all scenarios, income increased and income variability was reduced when vertical production alternatives were employed. In concluding, they affirmed that utilization of vertical production alternatives in ranch planning could be regarded as an effective response to risk, highlighting the fact that, vertical production alternatives should be evaluated simultaneously with other risk responses.

In two studies conducted by Stokes et al. (1981 and 1986), a method was developed for incorporating biological simulation results into an economic model for the evaluation of performance levels of spring calving cow herds differing in terms of potential cow size and milk production. In the latter study, the calves were sold using one of two weaning strategies: (1) wean all on November 1, or (2) wean some on October 1 and the remainder on December 1. These studies asserted that economic performance was improved during the study periods through a simultaneous decrease in milk production and increase in mature cow size in the herd. Several conclusions were inferred from the results. Conception rates increased moderately as mature size increased while milking potential declined. In addition, heavier milking cow types incurred increased feed costs; consequently, the benefits associated with higher production were offset by the higher cost of milk production.

Angirassa et al (1981) determined the effects of beef production of different marketing plans using a systems simulation approach. The results indicated that cow-calf enterprises dominated the profit-maximizing solutions, but only within a narrow price range. Also, moderately risk averse producers have a tendency to partially integrate through the stocker phase.

In another similar study, Little (1990) conducted an economic analysis of alternative cattle breeding systems with focus on retained ownership through the stocker and feeder phases. A linear programming model was used to generate estimates of residual returns to operator labor, management, equity, and risk for the profit-maximizing ranch plans for each system. He then generated residual returns to fixed production and marketing plans for selected systems. Further, he undertook a risk analysis using simulation modelling technique to generate a distribution of returns for selected breeding systems and ranch plans.

Several significant findings were provided by the analysis. First, the combined Hereford-Angus rotational-terminal sire system exhibited the highest returns in the profit-maximizing ranch plans, seconded by the combined rotational-terminal sire and rotational systems with Brahman in the rotation. Also, retained ownership showed the highest residual returns to the ranch's owned resources, and selling calves at weaning was the least profitable production and marketing plan. Finally, risk-averse producers were shown to prefer to sell calves at weaning or as wheat pasture stockers in order to avoid potential losses associated with feeding cattle. Risk-seeking producers opted for cattle retention as wheat pasture stockers for finishing, so as to capture potentially high returns from feeding cattle.

An important contribution of Little's study is that it quantifies the breed effect in cattle production and estimates its impact on net returns. Also the inherent risk in feeding cattle through various phases is estimated which is instrumental to the cattleman's decision making process and greatly influenced by his/her risk attitude.

CHAPTER III

MODEL DESCRIPTION AND DEVELOPMENT

This study utilizes simulation techniques to model physical and economic processes involved in cow-calf production. Anderson (1974) described simulation as an analytical process that contains several interrelated mathematical components which represent a complex real process. According to Trapp (1989), simulation analysis involves the study of a system, where a system is a set of interconnected elements (components) organized towards a goal or set of goals. He adds that in order to analyze a system, there is the need to define the interconnections (structures) of that system. According to Levine and Hohenboken (1982), the application of mathematical and computer modeling to livestock production systems has increased with greater efficiency and sophistication in recent years.

Simpson (1988) asserts that "the very purpose of simulation models, by their very nature, is generally not in forecasting or predicting, although some models of this type have been constructed. Rather, the purpose is predicting with an interpretation being, for instance, 'if X were to change, Y would be the result'. In effect, simulation is fundamentally a tool to describe a real world situation through a model." Mapp (1989) noted that many types of systems in agriculture such as plant and animal growth processes, growth and intergenerational transfers of the farm firm, risk and survival projects, supply and demand relationships, and multi-objective decision processes have been modeled using simulation.

The term system simulation depicts a situation in which real-life conditions are emulated and represented by simple models over time. In the case of cow-calf production, the basic concept surrounding the structure of such models is that each animal within the herd is propelled forward through time, calling for modifications of its status in accordance to the outcome of the different events and management decisions. The effects of various events and management decisions can be represented stochastically. This means that they could be generated as random samples based on appropriate probability distributions and not just fixed values. Such a process lends itself to a series of calculations which represents the biological and economic variability inherent in the system.

In this study, the main purpose is to evaluate the reproductive performance of a cow-calf operation based upon changes in body condition score and weight gain. The simulation model, written in the Fortran programming language, represents the biological behavior (breeding, gestation or pregnancy, parturition or calving) and economic effects of alternative management strategies on a cow-calf enterprise grazing on native range. The model was developed with the principal objective of developing management information concerning the effect of different supplementation strategies during periods of potential energy deficit.

Model Structure

The simulation model is comprised of four major interconnected submodels: (1) a forage production model, (2) a cow-calf production or growth model, (3) a cow herd model, and (4) an economic model. The hierarchical structure of the model is represented using a flow chart in Figure 3. The submodels are differentiated by dashed lines and linkages by thick lines. In the forage production submodel, the factors that determine the quantity and quality

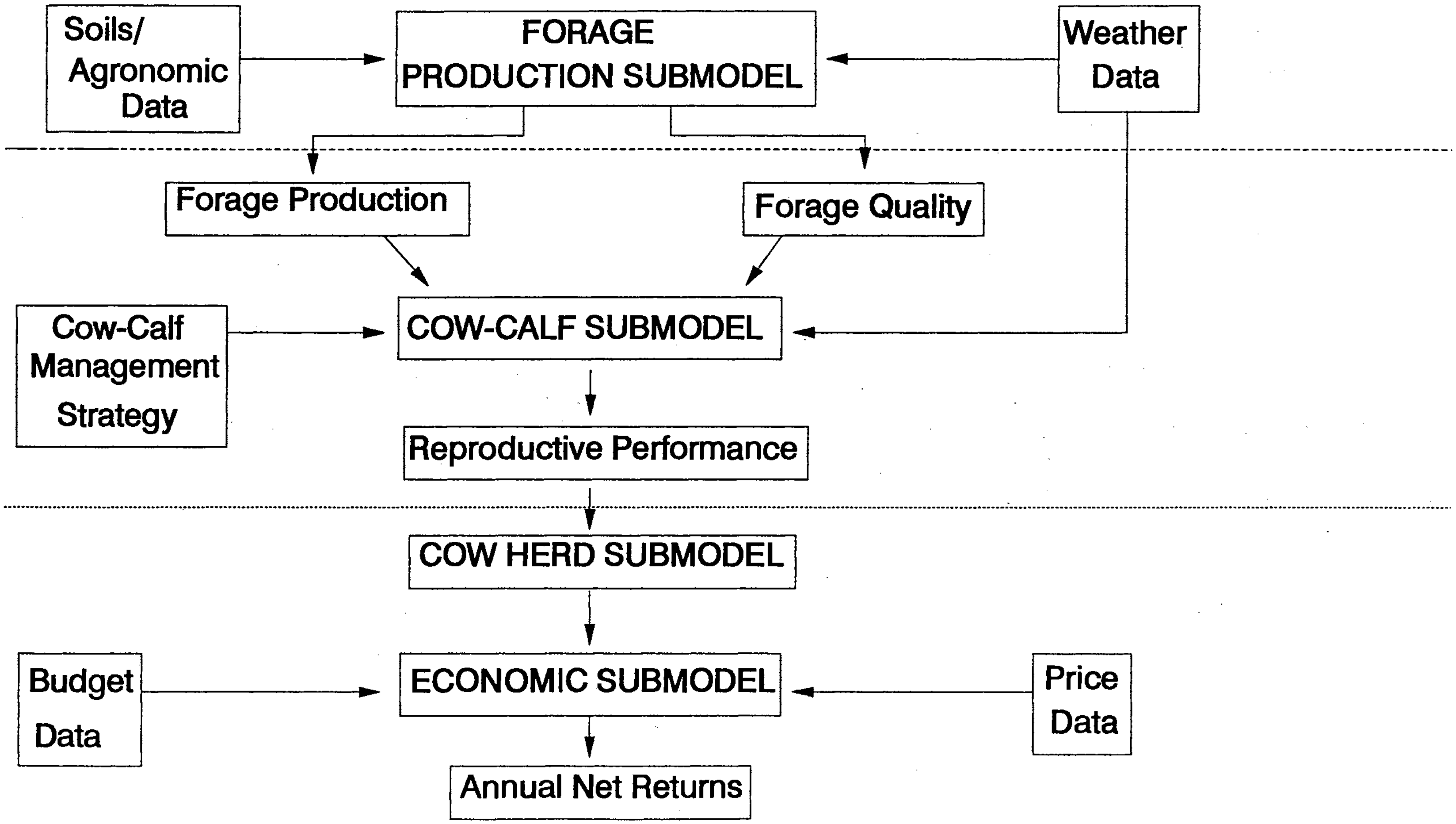


Figure 3. Flow Chart of Range Cow-Calf Simulation Model

of forage (e.g. climate and soils) are shown in the rectangles. Given the land quality, the forage model yields an estimate of annual forage production and changes in forage quality occurring over the year. The cow-calf submodel utilizes the forage production data to estimate livestock performance. Energy requirements and energy provided by consumption of forage and supplement are estimated daily. Energy deficits (surpluses) are then converted to weight loss (gain) and changes in cow condition. This information is then used to estimate cow reproductive performance.

The cow herd submodel is necessary because different groups of cows within the herd will be characterized by different conditions depending upon reproductive history. The cow herd submodel inventories the number of cows in various body condition states at the initiation of each production year. A separate simulation is run for each group of cows characterized by a particular body condition state. Economic data generated through deterministic and/or stochastic processes are then used in combination with performance data from the cow-calf model to determine annual enterprise net returns.

Forage Submodel

Forage Production

Seasonal forage production was estimated using a modified version of the ERHYM model developed by Wight (1987). This simulation model uses a two-step procedure to estimate the water use of a range site and impacts on forage production. First, daily simulation of soil water evaporation, transpiration, runoff, and soil water routing is conducted throughout the growing season. This procedure provides estimates of the portion of daily potential transpiration utilized by the range plants for crop growth and development. Next, results from the daily simulations are employed in water-stress yield models to estimate total annual forage production.

The ERHYM model utilizes a common approach for estimating crop water relationships from available climatic data. First, an estimate of potential transpiration (T_p) is derived. Potential transpiration represents the energy used by range plants when water is adequate for unrestricted plant growth. Next, factors which limit the attainment of T_p are considered in deriving an estimate of actual transpiration (T_a). This value approximates the consumptive use of the plant. The relationship between T_a and T_p is determined by whether water available in the soil is adequate to meet the atmospheric demand placed on the soil-plant system. Whenever available water is not sufficient to meet crop water demands, a water deficit occurs and T_a is less than T_p (Roddy, 1989).

The ratio of actual to potential yield is often referred to as relative transpiration and is directly related to crop yield (Wight). Daily estimates of T_a and T_p are summed over the growing season. These values are then used in a single equation forage production model which relates seasonal forage production to the aggregate transpiration deficit.

The ERHYM model was previously applied and validated to a central Oklahoma loamy prairie range site (Roddy, 1989). Input parameters for the model include several soil characteristics, vegetation parameters, and daily weather data. Weather data includes precipitation, maximum temperature, and minimum temperature. For a detailed description of input parameters and computational procedures, see Roddy (1989). A description of validation efforts is presented in Roddy (1989) and Bernardo and Roddy (1991).

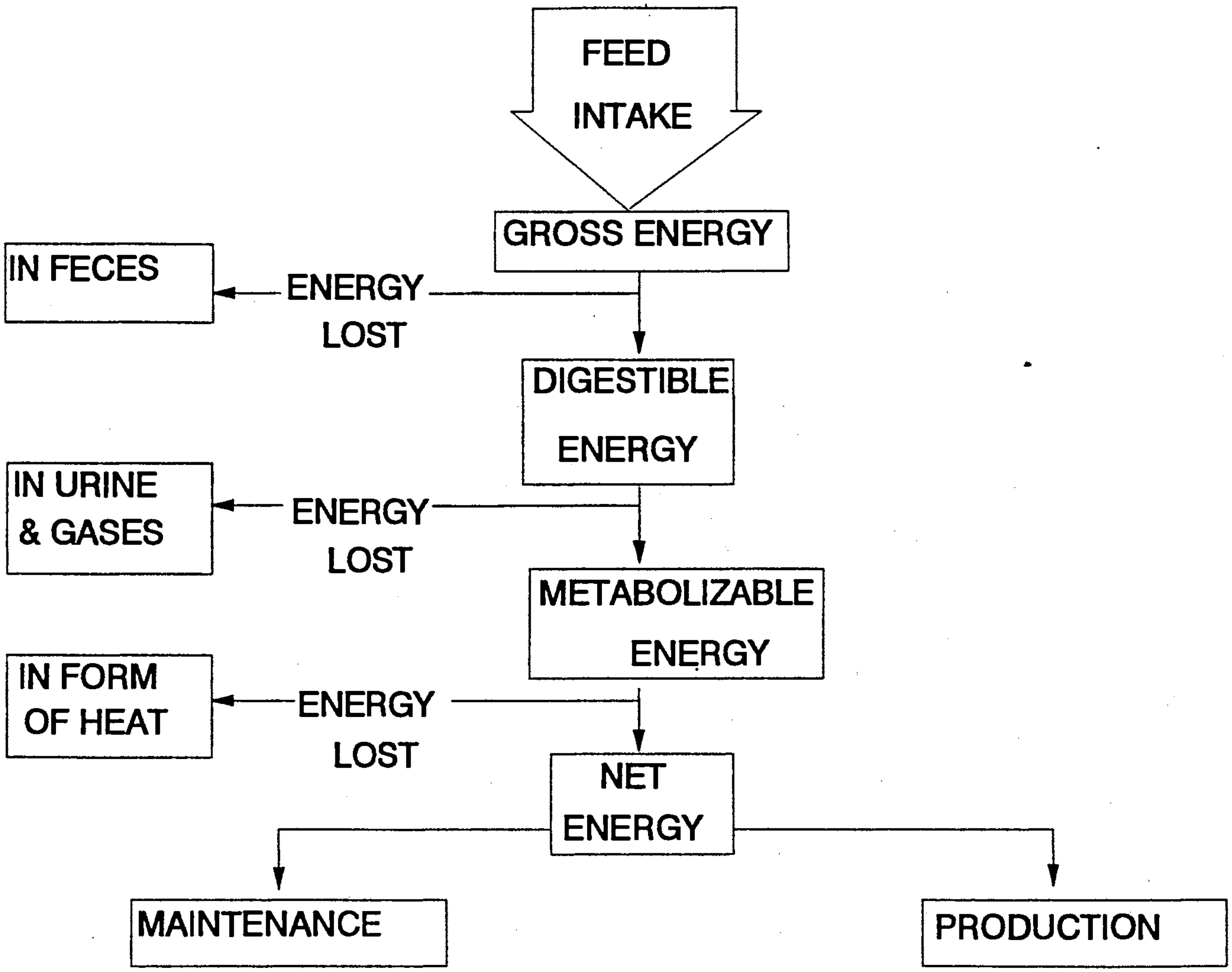
Forage Quality

Animals in general, and cows in particular, use energy for various body functions including essential muscular activity, maintenance of body temperature, growth, and milk production. The weight gained or lost by an animal relates directly to the positive or negative relationship between intake and energy expenditure. Forage quality is often measured in terms of the quantity of energy available from consumption of a unit of the feedstuff.

The energy in feeds can be expressed in terms of gross energy (GE), digestible energy (DE), metabolizable energy (ME), and net energy (NE). This nomenclature recognizes the ways the various energies are utilized by the animal. Figure 4 summarizes these measures of energy and energy utilization by cattle. GE is the amount of heat resulting from the complete oxidation of food, feed, or other substances. DE is GE minus fecal energy. In practice GE is measured over a period of time followed by collection of fecal excretion for a representative period. It is general knowledge that energy lost in the feces accounts for the single largest loss of ingested nutrients (Taylor, 1984). ME is defined as the GE of feed minus energy in the feces, urine, and gaseous products of digestion. A common expression used to estimate metabolizable energy is:

$$ME = DE*0.82 \tag{3.1}$$

NE_m (net energy for maintenance) and NE_g (net energy for gain) are more commonly used for formulating rations for cattle than any other energy system. NE_m is the amount of energy needed to maintain a constant body weight. Animals of known weight fed for zero energy gain, have a constant level of heat production. The NE_g measures the increased energy content of the carcass after feeding a known quantity of feed energy.



Source: Taylor, Robert E.

Figure 4. Measures of Energy and Energy Utilization by Cattle.

Since the ERHYM model does not address forage quality, a separate forage quality model had to be developed. The cow-calf submodel requires daily estimates of forage quality over the production year. Forage quality information of this level of detail is not available; however, a long-term study was conducted to evaluate the chemical composition of native grasses in central Oklahoma (Waller et. al., 1972). Based upon analysis of grass samples, monthly estimates of percent crude fiber (CF), crude protein (CP), nitrogen-free extract (NFE), ether extract (EE), and several other properties were determined. These estimates were collected from unpublished data for each year of the study, providing a 17 year data set of monthly chemical composition values. Chemical composition values were converted to monthly estimates of digestible energy (DE) using the following relationship (National Research Council, 1984):

$$DE = .0504CP + .077EE + .02CF + .011NFE + .00037NFE^2 - .152 \qquad (3.2)$$

Earlier attempts to develop a forage quality model by regressing these forage quality estimates and/or chemical composition values against observed weather data were not fruitful (Roddy, 1989). Therefore, it was decided to represent annual variability in forage quality using the actual monthly data. By pooling this data with eight additional years of forage quality data (McCollum, 1991; Bogle, et al. 1988), a 25-year data set of monthly forage quality measurements was derived. Forage quality in these studies was expressed in terms of percent digestibility and converted to DE using NRC procedures (National Research Council, 1984).

Average monthly forage quality over the 25 years is shown in Figure 5. Because native grasses in central Oklahoma grow vigorously in the spring and early summer, forage quality usually peaks in May or June and declines steadily through the summer and fall months. The vertical bars in Figure 5 illustrate the range of forage quality observations in each month. Clearly, the

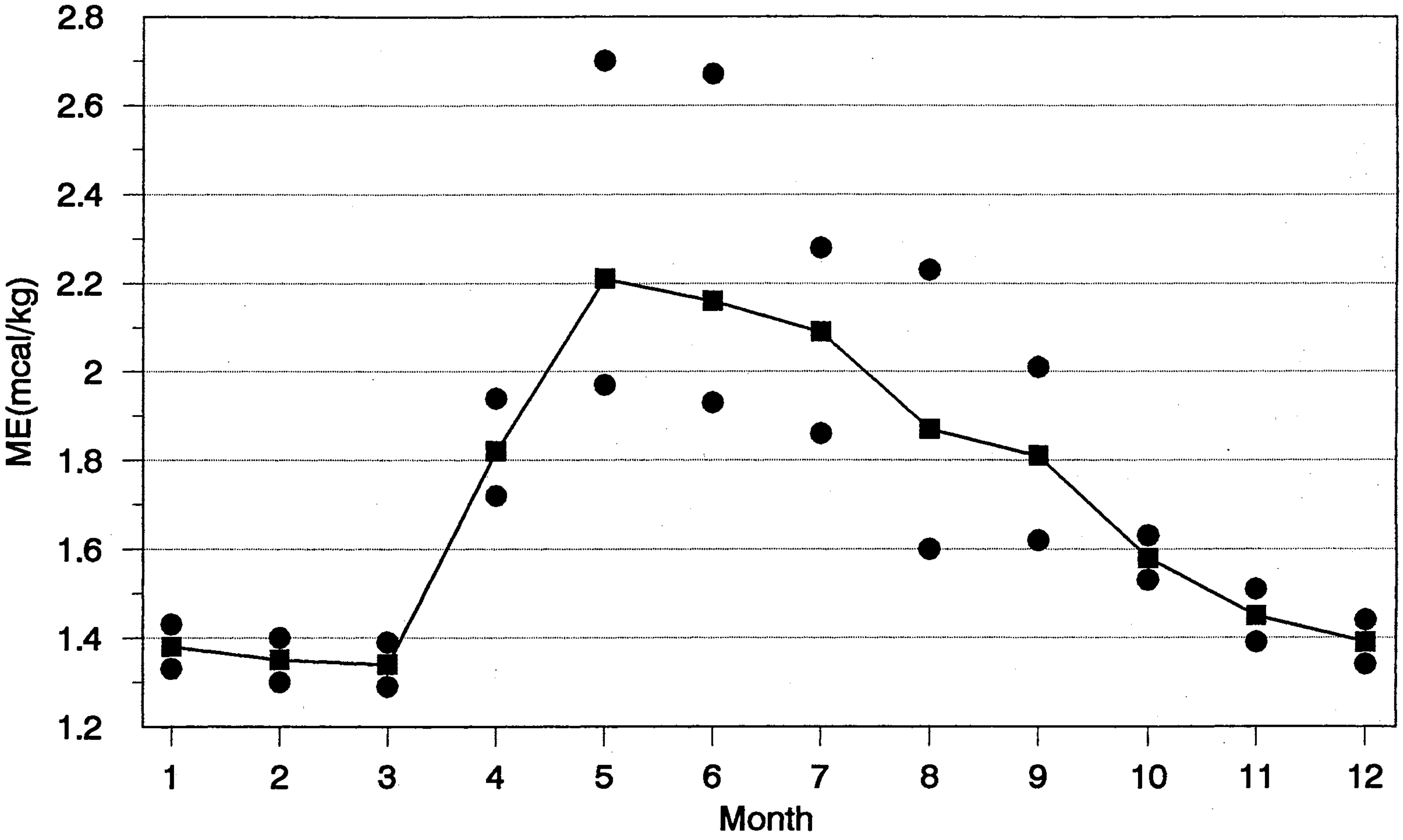


Figure 5. Average and Range of Monthly Forage Quality Variables

level of variability in each month is highest in the months of vigorous growth. In the late fall and winter months, little variability in forage quality is observed, since the grasses are dormant and are not responsive to weather conditions.

Each monthly DE estimate is assumed to represent forage quality at the midpoint of the month. Monthly estimates are converted to daily values through linear interpolation. Net energy for maintenance (NEM) and net energy for gain (NEG) are the forage quality measurements actually used in the cow-calf submodel. Digestible energy values were converted to metabolizable energy using equation 3.1. NEM and NEG were then estimated as polynomial functions of metabolizable energy (ME) as follows (National Research Council):

$$NEM = 1.37\,ME - .138ME^2 + .0105ME^3 - 1.12 \tag{3.3}$$

$$NEG = 1.42ME - .174ME^2 + .0122ME^3 - 1.65 \tag{3.4}$$

Cow-Calf Submodel

The cow-calf submodel uses the forage production data and simulates the daily energy balance of breeding cows. Energy requirements are calculated using a modified version of the California Net Energy System. Estimated energy deficits and surpluses are converted to changes in cow weight and body condition based upon published finding relating cow condition to energy deficits. Cow reproductive performance is then estimated as a function of cow condition based upon several years of body condition score experiments conducted at Oklahoma State University.

Many of the functional relationships built into the cow-calf submodel are derived from the Iowa State University (I.S.U.) Beef Cow Ration worksheet (Miller et al., 1985). The spreadsheet is a synthesis of current knowledge concerning the influence of environmental and physiological factors on cow-calf energy requirements. The spreadsheet's internal relationships were revised, where necessary, to suit the study's objectives and production setting. The I.S.U. spreadsheet is designed to evaluate rations fed to one beef cow or a whole herd of beef cows for one day or a multiple of days. The rations are calculated based upon expected energy intake, crude protein, calcium, phosphorus and vitamin A. Energy requirement projections are made for bred cows or heifers based on such factors as their current stage of production, condition score, milk production level, and environmental conditions. The program determines whether a ration is capable of meeting a cow's daily nutrient requirements, reveals both ration excesses or deficits, and projects the cow's weight gain or loss.

It is assumed that the relationships used in the I.S.U spreadsheet are a good representation of the relevant features embedded in this research, particularly, the physical (environment) and biological (gestation, feed intake, etc.) systems. The cow-calf submodel developed for this analysis transfers the principal components of the spreadsheet into an operative continuous simulation model with the relevant linkages. The cow-calf submodel was adapted to describe spring/fall calving cow-calf enterprise on native rangeland in central Oklahoma. Data from the Departments of Animal Science and Agronomy, Oklahoma State University, Stillwater were used to adapt several of the cow-calf submodel's subroutines to the study region.

The basic managerial assertion underlying the simulation model developed for this analysis is that producers would be able to evaluate the body condition of beef cows at one point or a series of points through the production year. Feeding strategies can then be developed based on the current stage of production, cow condition score, economic conditions, and expected environmental conditions.

The cow-calf submodel calculates cow-calf intake, energy available from intake, and energy requirements that would lead to weight gain or loss. In order to predict any form of gain or loss of a specific cow-calf unit, the intake capacity of the cow-calf must be predicted. Generally, intake is influenced by the quality and quantity of forage and other environmental factors accounted for by the cow-calf submodel . The cow-calf simulation model developed in this study gives a description of breeding cows (2 years of age and older) raised on native rangeland. In addition to consumption of range forage, seasonal allocations of supplemental feed are made to augment projected energy deficits. Supplementation strategies are developed based on certain physiological stages (e.g. pregnancy, lactation, etc.) and environmental factors (e.g. forage quality, temperature, etc.).

The cow-calf submodel is based on the assumption that energy is the limiting nutrient requirement. Efficient conversion of forage to energy requires the availability of proper amounts of protein, minerals, and vitamins. Supplementation programs and mineral packages are used that assure these factors are non-limiting.

Several energy systems have been developed for estimating the maintenance requirements and performance of livestock. An energy system frequently used to determine gain in cattle is the California Net Energy System (CNES). The National Research Council (NRC) has adopted the CNES as the base for its estimated energy requirements. The California Net Energy System has two parts, separately calculated: (1) net energy for maintenance (NEM) and net energy for gain (NEG). NEM is energy required to keep the animals in good condition, such that no gain or loss of weight occurs, implying no excess reserves. NEG implies excess energy exists for other productive processes above maintenance. Although the CNES has a built-in bias for high quality forage, it can be applied satisfactorily to evaluate energy requirements of cattle on high forage diet. By adapting the underlying relationships, the net energy system was deemed appropriate for energy requirement evaluation in this analysis. The basic approach to estimating energy requirements was to first estimate a base energy requirement for the cow; then adjust the requirement based upon lactation, pregnancy and environment.

Estimation of Cow Intake

Numerous literature suggest that feed represents the major cost to livestock production and the efficiency of its use exerts a considerable impact on the performance of the system. In order to predict voluntary feed consumption of different feeds, the intake capacity of the animal must be considered. The ease with which the organic matter of the forage can be removed from the rumen is the most important dietary characteristic determining forage intake. The capacity of the rumen is limited and the rate of entry of feed organic matter into the rumen (rate of feed intake) cannot exceed its rate of removal. Hence, the complex structure and function of the rumen, which obviate rapid removal of feed particles, can place a limit on the rate of feed consumption. It follows that forages with organic matter highly resistant to removal from the rumen are consumed in smaller amounts than those more readily degraded (Weston and Hogan, 1973).

The usefulness of intake predictions depends upon their applicability in evaluating alternative management practices. The general principle that underlies the physical control of feed intake is that undigested material in the digestive tract (ballast) limits the rate at which the feed passes through the digestive tract and consequently restricts feed consumption. Abstracting from this theory, dry matter intake (per kg liveweight) is inversely proportional to the nondigestible fraction when digestibility is less than 67%, whereas, the fecal dry matter output per kg liveweight remains constant (Conrad et al., 1974). Conrad et al.(1974) and Kahn (1982) state that physiological control becomes important when the feed is highly digestible (more than 67%). Feed intake will then be restricted by the animal's potential to absorb and utilize digestible nutrients, or alternatively, feed intake is controlled by energy requirements.

In this analysis, a base voluntary intake of the animal is considered, then adjustments are made based upon pregnancy, lactation and environmental conditions. Voluntary intake (VI) can be estimated as a function of forage quality and the animal's metabolic weight. The following equation from the NRC publication Nutrients Requirements for Beef Cattle (1984) is used to calculate VI:

$$VI = WT^{0.75}\,(0.1493NEM-0.046NEM^{2}-0.0196) \qquad (3.5)$$

where VI = voluntary intake (kg/head)

$WT^{.75}$ = metabolic weight of the animal (kg/head)

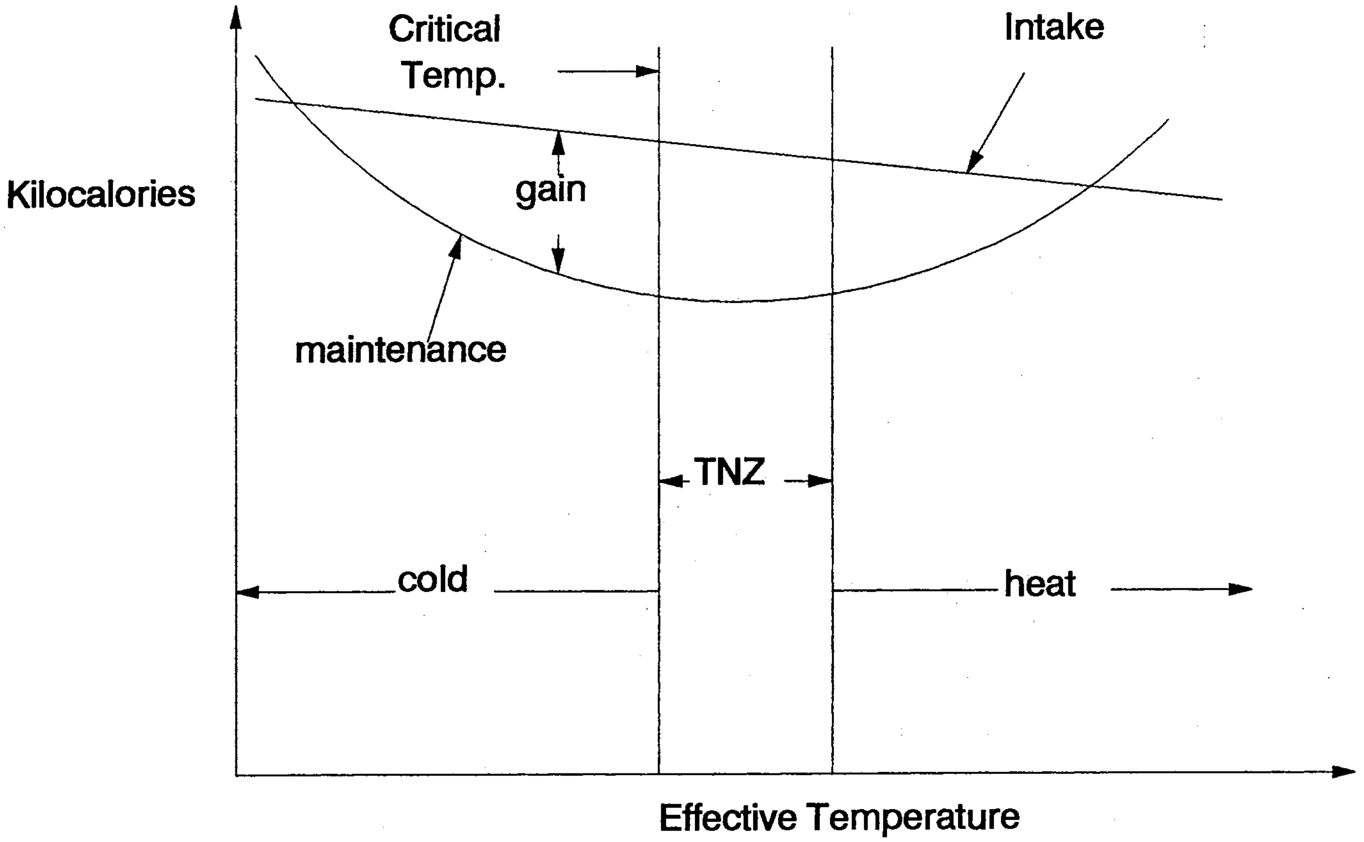
NEM = net energy for maintenance (mcal/kg)

According to Fox and George (1986) considerable variability exists within and between breeds in terms of such factors as milk production, growth rates of beef cows and nursing calves, and sensitivity to extreme temperatures. These factors directly influence the nutrient requirements at various stages of the cow's reproductive cycle. Also, this variability translates into differences in ability to withstand heat or cold stress. In order to account for these changing conditions, intake adjustment factors are developed for pregnancy, lactation, and temperature.

Temperature Adjustments. According to the NRC (1981), voluntary food intake is affected significantly by the external environment, especially when the effective ambient temperatures are outside the thermoneutral zone (TNZ). The thermoneutral zone is defined as the temperature range between 15 degrees to 25 degrees celsius (see Figure 6). Rate and efficiency of performance are maximized in the TNZ. The lower limit of the TNZ is identified as the critical temperature below which cattle performance starts declining as temperature gets colder. Also, energy required for maintenance increases more rapidly than rate of gain during the cold weather. Consequently, the following conditions prevail: "reduction of gain, more feed required per pound of gain which typically causes cost per pound of gain to be higher" (Taylor, 1984). Similarly, Rittenhouse et al. (1970) indicated that intake of forage by grazing cattle is reduced appreciably by short periods of cold weather with snow cover. Under this situation supplemental forage or concentrate feeding is inevitable, so as to avoid detrimental weight reduction. It is worth noting that certain supplements to forage of low quality can lead to declining forage intake (Forbes et al.,1976; Lusby et al., 1976; Umoh and Holmes, 1974); whereas, some supplements give the opposite result, that is, increase forage intake (Blaxter and Wilson, 1963; Clanton and Zimmerman, 1970).

In order to adjust for temperature in this study, the current temperature in Fahrenheit is converted to a temperature adjustment factor. This factor ranges between .95 and 1.11, and scales voluntary intake up or down to reflect conditions outside the thermoneutral zone. For temperatures below 60 degrees, the adjustment factor (TVI) is estimated as:

$$TVI = 1.11 - 0.0019\ TEMP \qquad (3.6)$$



Source: Taylor, Robert E. 1984

Figure 6. Effect of Temperature on Rate of Feed Intake, Maintenance Energy Requirement and Gain. (Ames, 1980)

If daily average temperature is greater than 75 degrees, the adjustment factor is .95. Intake is not adjusted if the daily temperature is between the 60 and 75 degree range.

Lactation Effects. Cows/heifers face a standard lactation curve that represents milk production levels over time. After calving, milk production increases for a period of four to ten weeks. It is within this time that peak milk yield is attained. The length of time required to meet this peak depends upon condition score, breed, nutrition and production level. Milk production for Hereford cows on native range was estimated as a function of the number of days lactating based upon data of Lusby et. al. (1989). For the first 30 days, milk production was assumed to remain at peak levels (8.16 kg/day); production decreased over the remainder of the lactation period according to the relationship:

$$MP = [18-(0.05*(DL-30))]/2.205 \qquad (3.7)$$

where MP = milk production (kg/day)

DL = days lactating

At peak lactation, additional feed intake is required, so that milk production is maintained and body condition restored. The model uses the following relationship to estimate additional intake required for lactation (LVI):

$$LVI = MP*0.20 \qquad (3.8)$$

where MP = milk production (kg/day)

Actual Intake. Actual intake is estimated by adjusting voluntary intake for temperature and lactation effects. Daily dry matter intake (INTK) is calculated as follows:

$$INTK = (VI*TVI)+LVI \qquad (3.9)$$

Supplementation

Livestock intake can be described from the relative availability of energy and protein in the feed as well as the capacity of the animal to use both. The cow-calf submodel is designed to account for effects of feeding protein supplements on animal's net gain which bears directly on animal's gain. Prior to feeding supplement, the intake equation developed earlier holds; however, at the commencement of supplementation, intake is recalculated to reflect the current feed composition.

A built-in interative process determines total digestibility based upon the proportion of forage and supplement comprising intake. First, the percentage composition of each feed comprising total intake is determined. Then using these weights, the net energy for maintenance and gain are estimated. The following equations are used to estimate the energy provided by a combination of forage and protein supplement:

$$\mathrm{PCTP} = \mathrm{SUPL/INTK} \tag{3.10}$$

$$\mathrm{PCTG} = 1\text{-}\mathrm{PCTP} \tag{3.11}$$

$$\mathrm{NEM} = (\mathrm{PCTP}^{*}\mathrm{NEMP})+(\mathrm{PCTG}^{*}\mathrm{NEMG}) \tag{3.12}$$

$$\mathrm{NEG} = (\mathrm{PCTP}^{*}\mathrm{NEGP})+(\mathrm{PCTG}^{*}\mathrm{NEGG}) \tag{3.13}$$

where PCTP = percentage of total intake comprised of supplement
SUPL = quantity of supplement fed (kg/hd)
INTK = total intake (kg/hd)
PCTG = percentage of total intake comprised of forage
NEMG = net energy for maintenance in forage (Mcal/kg)
NEMP = net energy for maintenance in supplement (Mcal/kg)
NEGG = net energy for gain in forage (Mcal/kg)
NEGP = net energy for gain in supplement (Mcal/kg)

Through this procedure, the complementary effects of protein supplementation are represented. The nitrogen content of forages is an important factor affecting digestion. Supplementation of nitrogen to cows on a diet of high fiber forages that have a low nitrogen content results in increased intake and associated changes in digestion and passage (McCollum and Galyean, 1985).

The primary objective of this analysis is to identify the effects of alternative supplementation programs on BCS, and hence, reproductive performance. To evaluate the ability to monitor body condition and respond with alternative supplementation strategies (adaptive supplementation strategies), added supplementation criteria were employed based upon BCS. For example, Lusby et al. (1989) noted that by evaluating BCS at strategic points of the year, it is possible to coordinate use of forage resource with nutritional needs of the cattle. Good BCS in the winter depends upon nutritional programs initiated in the summer. If cows are thin on July 1, it is unlikely that large gains can be attained through winter supplementation. In these cases, supplementation should be initiated in late-summer months.

The cow-calf submodel is programmed to trigger supplementation during a specified period if BCS falls below a particular level. The combination of time period, type and level of supplementation, and BCS trigger level defines the supplementation strategy. For example, the model may be programmed to feed 1.5 lb/day of protein supplement in the July-October period, if BCS falls below 5.5 during the period. By varying the time period and trigger point, alternative strategies for bringing cows up an acceptable level of body condition at calving can be evaluated.

The cow-calf submodel may also be programmed to feed hay in the event of a shortage of standing forage. Twenty-five percent of standing forage is assumed available for intake (Kothmann, 1984). If total consumption exceeds the quantity, hay is fed to compensate for forage deficits. This feature eliminates the need to consider complexities relating to how voluntary intake is affected by forage availability.

Energy Requirements

As mentioned before, the basic approach used to estimate energy requirements is to first estimate a base energy requirement for the cow, then adjust the requirement based upon lactation, pregnancy and environment.

Several authors have developed relationships to estimate energy requirements as a function of animal weight. This study employs the NRC (1984) relationships to describe energy requirements of beef cattle as a function of metabolic weight (body weight raised to the .75 power). The base net energy requirement is represented by the following equation:

$$NERB = 0.077^{*}(WT/2.205)^{0.75} \tag{3.14}$$

where NERB = base net energy required (Mcal/head)

In sum, the animal's weight and the physiological status are determinants of energy utilization from feed intake. Crooker et al. (1991) identified sources of variability among beef cows in terms of their ability to gain weight or maintain body condition. This variation could be due to differences in the feed intake, parasite load, activity, environment or other factors not easily observed by the beef producers. Furthermore, they showed that factors that affect body composition most likely also affect an animal's ability to utilize available energy.

Net Energy Required for Cold Stress.

Earlier discussion noted that temperature affects intake, and implicitly nutrients from the feedstuffs as well. This effect inherently affects energy required for maintenance. Due to the effect of temperature on feed intake, the need exists to evaluate the efficiency of conversion of metabolizable energy to net energy for utilization by the body tissues. The procedure used to calculate NE for cold stress is to first calculate the total insulation value based upon cow condition and coat description, then use these values to project the rate of heat loss and energy requirements for cows exposed to heat stress. This procedure was adapted from the Iowa State University Beef Cow Ration Analysis spreadsheet (Miller et al., 1985).

In order to calculate effective temperature (wind chill) the model uses the following equation:

$$ETF = (.00857WS^2 - 1.154WS - .017 + TEMP) \qquad (3.15)$$

where ETF = effective temperature in Fahrenheit (degrees Fahrenheit)
WS = windspeed (m.p.h.)
TEMP = expected temperature (degrees Fahrenheit)

The effective temperature in Fahrenheit (ETF) is then converted to a celsius scale (ETC).

In calculating effective temperature, the surface area associated with muscular activity of the beef cow is calculated as:

$$SURF = 0.12(WT/2.205)^{0.6} \qquad (3.16)$$

where SURF = surface area of beef cow (m^2/kg)

Calculations of the internal and external insulation are made separately, and then converted to a total insulation value as follows:

$$IINS = 2.4+(1.2*BCS) \qquad (3.17)$$

$$EINS = 18.5-(0.1781JDAY)+(0.0005JDAY^2) \qquad (3.18)$$

$$INSUL = (EINS*EAF)+IINS \qquad (3.19)$$

where EINS = external insulation ($C/Mcal/m^2$)
IINS = internal insulation ($C/Mcal/m^2$)
JDAY = julian day of the year
INSUL = total insulation ($C/Mcal/m^2$)

EAF = an external adjustment factor based on the coat description value (dry condition = 1 and muddy or wet condition = 2).

The critical temperature is the temperature at which the animal must increase rate of heat production in order to maintain constant body temperature (Church and Pond, 1988). The lower critical temperature is calculated as:

$$\mathrm{LCT} = (-1.46 * \mathrm{INSUL}) + 29.3 \tag{3.20}$$

From these relationships, net energy for cold stress is estimated if ETC is less than LCT. First, beginning with the metabolizable energy relationship:

$$\mathrm{MEC} = [(\mathrm{LCT}-\mathrm{ETC}) * \mathrm{SURF}]/\mathrm{INSUL} \tag{3.21}$$

where MEC=metabolizable energy for cold stress (Mcal/head)

Finally, net energy required for cold stress is calculated as a function of MEC using the following polynomial function:

$$\mathrm{NERC}=1.37\mathrm{MEC} - 0.138\mathrm{MEC}^2 + 0.0105\mathrm{MEC}^3 - 1.12 \tag{3.22}$$

where NERC=net energy required for cold stress (Mcal/head)

Net Energy for Fetal Growth. Daily energy requirements for fetal growth will continue to increase as the pregnancy period progresses. Two variables, the length of the pregnancy period and calf weight, are used to calculate the net energy required for fetal growth and pregnancy maintenance requirements. Energy requirements increase exponentially over the pregnancy period, reflecting the growth and development of the calf.

$$\mathrm{NERF} = (\mathrm{CW} * (0.0149-(0.000407\mathrm{DP}) * \mathrm{EXP}(0.05883\mathrm{DP}- 0.0000804\mathrm{DP}^2)/1000 \tag{3.23}$$

where NERF = net energy required for fetal growth(Mcal/head)

CW = expected birth weight of calf (kg/head)

DP = days pregnant

Net Energy Required for Lactation. A milk adjustment factor is used to calculate the net energy required for lactation. Kahn (1982) defined lactation potential as a function of the genetically defined maximum potential daily milk yield, the number of days to peak yield, the lactation stage and the age of the animal. A lactating cow needs the appropriate level of net energy to produce maximum milk based on the genetical potential and other relevant factors. Daily milk production is converted to net energy required for lactation using the relationship:

$$NERL = MP*((0.1*3.5)+0.35 \qquad (3.24)$$

where NERL = net energy required for lactation (Mcal/head)

Total Energy Requirements. Assuming efficiency of conversion, the total net energy required for maintenance is estimated as the sum of all four subcomponents. That is,

$$TNERM = NERB+NERF+NERC+NERL \qquad (3.25)$$

where TNERM = total energy required for maintenance (Mcal/head)

Weight Gain or Loss

This section considers the estimation of the net energy available for gain and its conversion to weight gain or loss. In order to estimate a cow's/heifer's production (for example, milk, growth, and calf), comparisons are made between intake and energy available for gain or loss in liveweight. If energy intake is in excess of production needs, (i.e., above maintenance requirements) then fat deposition occurs, and the animal gains weight. However, weight loss occurs if energy available for gain is below maintenance requirements.

During the grazing period, the main objective is to maintain the cows on a specific nutritional plane consistent with reproduction performance objectives.

This can only be achieved with proper grazing management that will ensure a continuous supply or availability of the necessary quality of forage. In addition, supplementary feeding is administered when forage quality is low, to maintain the specified target growth rate.

The following procedures are used to calculate net energy available for gain and average daily weight gain or loss. First, dry matter required for maintenance, adjusted for temperature and forage quality (DMRM) is estimated as:

$$DMRM = (TNERM^{*}CADJ)/NEM \qquad (3.26)$$

where DMRM = dry matter required for maintenance (kg/head)

CADJ = body condition adjustment factor

The cold stress adjustment (CADJ) is calculated as:

$$CADJ = 1.099\text{-}0.18\ BCS \qquad (3.27)$$

Dry matter available for gain (DMAG) is then calculated as the portion of intake not used for maintenance. That is,

$$DMAG = INTK\text{-}DMRM \qquad (3.28)$$

DMAG is next converted to net energy available for gain (NEAG) by multiplying by NEG (a measure of forage quality). That is,

$$NEAG = DMAG^{*}NEG \qquad (3.29)$$

where NEAG = net energy available for gain (Mcal/head)

Finally, average daily gain (kg/hd) was estimated based upon the following relationship from Miller et al. (1985):

$$ADG = NEAG/6.2 \qquad (3.30)$$

Therefore, 6.2 Mcal are required per pound of gain. The above procedure yields reasonable and consistent weight gain and loss estimates over virtually all forage quality levels that are feasible in this application. However, at extremely low forage quality levels ($ME < 1.30$), the slope of the relationship between ME and NEG reaches a local minimum and NEG estimates from equation 3.4 actually begin to increase as forage quality continues to decline. Therefore, the model was modified to estimate weight loss (or negative weight gain) under large energy deficits. In cases where the net energy deficit exceeds 2, the following equation is used to estimate weight loss:

$$ADG = (0.018-(.515*LOG(NED)))/2.205 \qquad (3.31)$$

Maintenance requirements of the cow herd are crucial in the calculation of maximum voluntary feed intake. Increases in intake of dry matter are possible due to increases in the rate at which dry matter is absorbed by the animal. Since dry matter available for gain is derived after dry matter required for maintenance is absorbed, intake is fundamentally regulated by energy requirements.

Estimation of Body Condition Score

As indicated in the previous chapter, several research studies have analyzed the relationship between body condition score and cow reproductive performance. Often, these experiments are designed so that the cow/heifer may gain, lose or sometimes maintain weight to reach a target BCS at parturition or at the commencement of the breeding season. The main goal is to improve cow/calf reproductive performance through the manipulation of the BCS, since there is a linkage between reproductive performance and BCS or body energy. Randel (1990) concluded that body weight and condition score, even though imprecise or subjective, are functional indicators of energy and rebreeding performance after calving.

Two alternative methods were considered for estimating changes in body condition in response to energy deficit (surplus). In the first method, body condition score changes were estimated as a function of changes in cow weight gain. Crooker et al. (1991) reported a set of relationships expressing BCS as a function of cow weight. Based upon these equations, a frame score 5 cow should weigh 452, 533, and 580 kg when BCS is 3, 5, and 7, respectively. Therefore, a weight gain of 81 kg is required to increase BCS from 3 to 5, but only a 47 kg increase is needed to increase BCS from 5 to 7. Using these equations, the model was programmed to update BCS based upon daily projections of cow weight. BCS changes estimated from this procedure did not correspond well to changes in BCS observed in BCS experiments conducted using spring-calving cows in Oklahoma.

In the second approach, changes in BCS over time were estimated based upon calculated daily energy deficit or excess. Based upon the Cornell Beef Production Manual, at a 10% energy deficit (surplus), it takes 150 days to decrease (increase) BCS by 1 point. Similarly, for a 20% deficit (surplus), 75 days are required to decrease (increase) BCS by 1 point. Abstracting from this information, BCS decreases .00067/day/percent energy deficit. The daily energy deficit was calculated as follows:

$$\%\ \text{Energy Deficit} = \text{NED}/\text{TNERM} \qquad (3.32)$$

Application of this approach provided BCS estimates that more closely corresponded to changes observed in the experimental data.

Reproductive Performance as a Function of BCS

BCS at time of calving has been related to reproductive performance of cows. It has been identified as a determining factor for the re-establishment of cyclic ovarian activity in the beef cow. Selk and Lusby (1989) and other researchers have shown a significant relationship between a cow's/heifer's body condition at the time of calving and subsequent reproductive performance. Various physiological stresses occur during the processes of fetal development, including delivering a calf, milking, and repair of the reproductive tract. These stresses require the availability and use of large quantities of energy to enable cows to be rebred in a punctual manner. Providing all of the required energy through grain or forage consumption would be extremely costly. In order to alleviate this problem, some of the additional energy is provided by stored body energy or fat (condition). Assuming a balanced nutrient intake after calving, cows/heifers with extra body reserves at calving will meet the extra caloric needs of giving birth, milking, reproductive tract repair, and rebreeding more readily than thin cows.

Weaning percent is associated with body condition score and may be expressed as a function of BCS at calving. Published data relating the reproductive performance of spring calving cows grazed on central Oklahoma rangeland to body condition score was collected from several studies referenced in Chapter II. Based upon six years of data, weaning percent was estimated as a function of BCS at calving as:

$$W\% = -124.08+62.15BCS-4.5BCS^2 \tag{3.33}$$

Approximately 75 percent of the variation in weaning percent in the data was explained by this relationship. This function reaches a maximum at a BCS of 6.9, and an associated weaning percent of 91%. Therefore, for all BCS>6.9, weaning percent is assumed at the maximum level of 91%.

Several functional forms that approach a maximum asymptotically (e.g., Cobb-Douglas, logarithmic) were evaluated; however, the quadratic form best fit the data, particularly over the range of the BCS variable to be encountered in this study. Actually, the quadratic form does fit the maintained hypothesis about the relationship of BCS to weaning percent, since reproductive performance has been shown to be adversely affected by obesity. It was not possible to represent this phenomenon in the estimated relationship because of an absence of observations at high BCS levels.

The estimation of relationship describing weaning weight as a function of BCS was based upon the studies referenced above reporting weaning weights along with weaning percent. To account for variation in weaning weights and cow herds, the weaning weight observations were expressed in terms of the maximum weight observed in each experiment. The estimated relationship is:

$$WWT = (.274+.20245BCS-.01412BCS^{2})*WWMX \qquad (3.34)$$

where WWMX = maximum weaning weight (kg/head)

Therefore, the expression in parenthesis provides an estimate of the weaning weight as a proportion of some specified maximum (or potential) weight. This function is maximized at a BCS level of 7.1. At this point a maximum weaning weight is achieved, and WWT=WWMX for all BCS > 7.1.

Cow Herd Submodel

DiCostanzo et al. (1990) described substantial within herd variation of maintenance requirements and efficiency of energy utilization. Despite the various factors that may influence the ability of a beef cow to maintain or to gain body condition, some animals in a herd produce heavy calves at weaning and maintain adequate body condition, whereas other animals in the same herd produce calves of similar weaning weight and are in thin body condition. This is often referred to as the theory of "easy keepers" and "hard doers" (Crooker et al.,1991). Based on these findings, it is necessary to take into account the fact that in every breeding herd, assuming all factors equal, not all of the cows/heifers are characterized by the same body condition or conceive at the end of the breeding season.

Accounting for this variability is critical to the representation and evaluation of alternative cow-calf management practices. A tree diagram (Figure 7) is used to illustrate some of the variabilities in the cow herd and the resulting implications. The tree diagram considers a two-year production period. The underlying assumption of the tree diagram is that the initial cow herd is characterized by all cows having the same BCS at breeding, and factors like breed, weight, age, etc. are held constant.

Cows/heifers are bred to produce calves; however, a portion of the herd will not be bred during the breeding season. If a cow/heifer tests negative to pregnancy at the end of breeding season, then the pregnant cow/heifer should be separated from the open cows/heifers, thereby establishing two groups. At the end of the breeding period in year one, two groups are identified (pregnant vs open). Each group should be fed a different supplementation program, since energy requirements will differ considerably between the two groups. Assuming that body condition is not the initial problem, a feed package should be developed such that the animal will convert the feed into the largest amount of productive energy without storing unwanted fat/condition. In year two, only a portion of each group will be pregnant at the end of the breeding period. Potentially, four groups of cows would be present at the conclusion of year 2, each differing in terms of body condition and/or pregnancy status.

In order to assess use of BCS as a management tool, evaluation must be done on a whole herd basis. However, the BCS of individual members of the herd will differ depending upon their reproductive history. Tracking the BCS status of different groups of cows within the herd is therefore necessary. Feeding of the individual groups (e.g., pregnant vs open at end of year one)

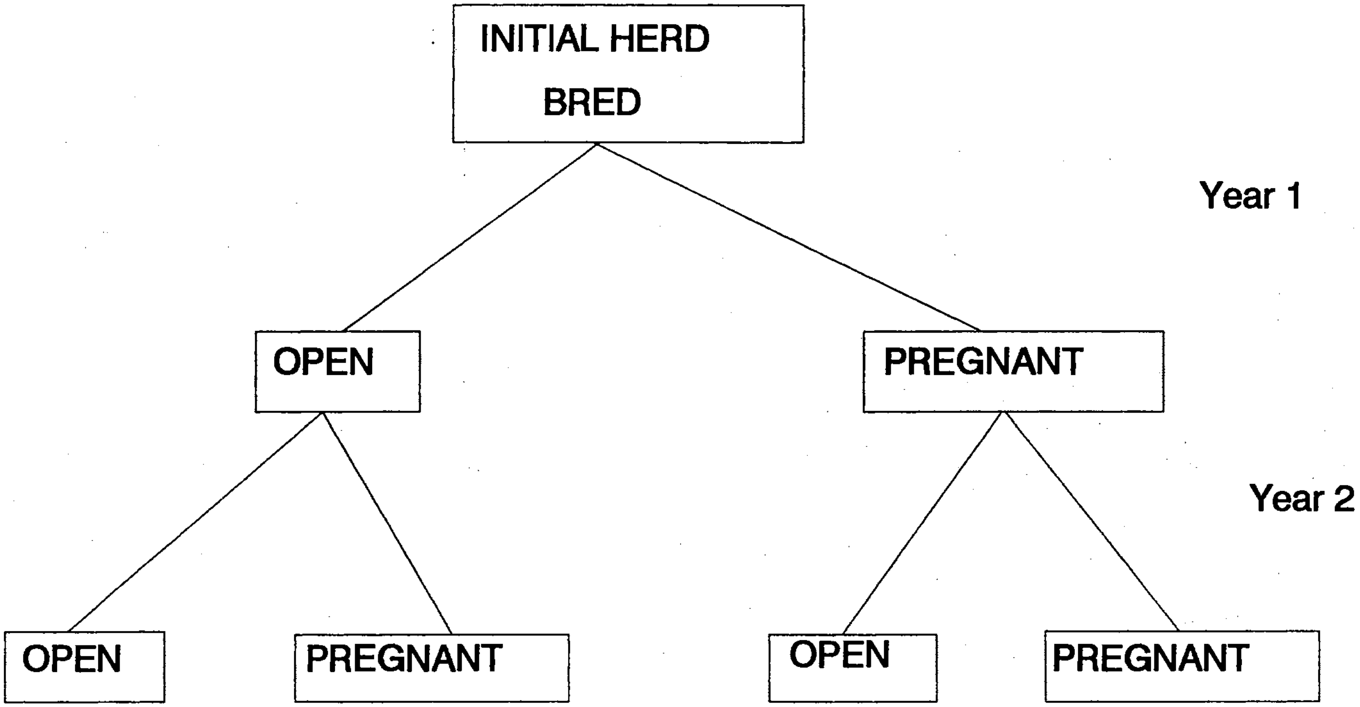


Figure 7. Tree Diagram Representing Cowherd Dynamics

would call for different feeding strategies. The first group would require a feeding strategy developed to maintain the cows on a high enough nutritional plane to meet energy requirements and achieve some target level of BCS at the next breeding season. On the other hand, the open cows would require lower levels of supplementation, since energy demands prior to breeding would not include pregnancy and lactation requirements.

To represent BCS diversity within the herd, each cow could be modeled independently, but this is computationally intractible. In addition, separation of individual cows based upon BCS is not practical from a management perspective. Instead, cows are grouped based upon their body condition score at the beginning of each production year (defined as the day following calving). Considering BCS as a state variable, ten states are identified based on .5 intervals of body condition score. Cows may be bred or open at this time, dictating a second state variable. This state variable is a 0-1 variable; therefore, there are a total of 20 possible states. All cows are inventoried at the beginning of each production year and placed in one of the 20 groups.

For each state containing cows at the initiation of the production year, the cow model is run for a one year period, from one day following calving to the next calving date. BCS is tracked through the year; however, some percentage of the group of cows will not become pregnant during the breeding season. This percentage is determined by the calving percent, which is in turn influenced by BCS at the time of breeding. Therefore, two simulations are necessary - one for bred cows and one for open cows. Simulations for these two groups are identical up to the breeding season; however, the trajectory of BCS over the remainder of the year will differ because of difference in energy requirements due to pregnancy and lactation. The ending BCS state for each group becomes the initial BCS state for the following year. At the beginning of the next year, the number of cows in each BCS state are inventoried. For all states containing cows (as determined by the ending BCS of the previous year's runs), an annual simulation is again initiated.

Economic Submodel

The economic submodel uses basic enterprise budgeting procedures to estimate annual receipts and costs from cow-calf production. Based upon the average weaning weight, weaning percentage, and other outputs generated from the cow-calf submodel, annual net returns are calculated for each year of the simulation.

The economic submodel is constructed to simulate the effect of random events upon the system. The price of steer calves, cull cows, prairie hay, and protein supplement can be input by the model user or generated within the system to represent a source of randomness. The procedure for generating these random prices is reported in Clements et al. and rests on the correlation between the four prices. In this application, prices are input by the user and variability introduced by random prices is not considered.

Estimation of Livestock Receipts

Receipts from livestock production reflect the sale of all livestock classes included in the herd. Therefore, receipts reflect income earned from the sale of weaned calves, as well as income from the sale of cull cows, aged bulls, etc.

Receipts from the sale of calves are separately calculated for each group of cows for which a simulation is conducted in the cow herd submodel. Each calf crop is assumed evenly split between steer calves and heifer calves. The estimated weaning weight is applied to the steer calves, and heifer weights are assumed to be 95 percent of steer weights. Receipts from each group of cows are then summed to estimate total receipts from the sale of calves at the herd level. Total receipts are then adjusted to reflect any heifer calves retained as replacements, as well as income earned from the sale of other livestock classes (cull cows, aged bulls, etc.).

Estimation of Operating Costs

Operating costs in the economic submodel include all outlays for purchased inputs that are used over the production year. The generated cow-calf budgets reflect returns above operating costs for the specified herd size.

Salt and Minerals. The price and quantity of salt and minerals are input provided by the user. The total per head cost of salt and minerals is determined by multiplying the input cost by the amount fed over the grazing season.

Hauling and Marketing Charges. The hauling charge per head is determined by multiplying the quantity of livestock hauled by the hauling charge. The quantity hauled is determined by adding the sale weight of all livestock classes sold (steer calves, heifer calves, cull calves, and aged bulls). A marketing charge is also assessed based upon the total quantity of livestock sold.

Veterinary Medicine and Supplies. Veterinary and medical costs are input provided by the user and assumed constant across all the production activities. Vet-med expenses result from routine veterinary calls. The vet-med supplies cost include a charge for expendable items as well as reusable equipment. The charge for expendable items includes syringe needles, ear taggers, wormer guns, implant guns, thermometers and other supplies. The charge for reusable equipment consists of assessed cost of pliers, hammers, tools, branding equipment, horse, tack, ropes, refrigerator, clippers, knives, and dehorners. Many of these items have several years of useful life but, replacement items are purchased each year and represent a regular expense (Walker et. al., 1987).

Supplemental Feed. Annual protein supplement and hay requirements are determined within the cow-calf model based upon the specified supplementation strategy. The quantity of supplement and hay fed during the year is aggregated over the entire herd, and this information is transferred to the economic submodel to determine the cost of supplementation. Hay charge is determined by multiplying the hay cost ($/lb) by the total quantity of hay fed. Total protein supplement cost is determined by multiplying the quantity of protein by the cost of the supplement ($/lb).

Interest on Operating Capital. Interest costs are computed in the model by using the interest factor approach (Boehjle and Eidman, 1984). Interest on operating capital is dependent upon the number of days each of the outlays is held. To determine the interest cost, each expense is weighted by the fraction of a year elapsing between when the expense was incurred and the sale date. The sum of all operating interest expenses are then multiplied by the interest rate to determine the total interest cost.

Labor. Per-head labor requirements such as purchasing, treatment for sickness, and normal observation of cattle are considered fixed across all strategies. The equations for determining labor required for feeding consider the quantity of supplement fed and a coefficient which reflects labor requirements per pound of supplement fed. The coefficients and equations used in the labor calculation are based upon labor requirements used in existing budgets and previous studies (Roddy, 1989; Walker et al., 1987). Labor charge is found by multiplying the appropriate labor quantity by the labor cost per hour.

Machinery and Equipment Operating Costs. Machinery and equipment fuel, lubrication, and repair costs are input provided by the user and expressed on a per-head basis. These charges are calculated outside the model using standardized equations for estimating fuel, lubrication, and repairs (Walker et al., 1987).

CHAPTER IV

MODEL APPLICATION AND RESULTS

The stochastic simulation model was applied to evaluate the physical and economic performance of a typical central Oklahoma spring calving enterprise under alternative supplementation strategies. The principal objective is to evaluate the economic implications of using alternative supplementation strategies to affect cow reproductive performance and body condition in accordance with annual fluctuation in forage quantity and quality, as well as other environmental variables. Alternative protein supplementation strategies are evaluated using various criteria, including maximizing expected returns, first- and second-degree stochastic dominance, and generalized stochastic dominance. In addition, the economic value of various levels of cow body condition score information is estimated.

The unit of analysis is a 100 cow herd of spring-calving English crossbred cows. Calving is assumed to be centered on March 1, and calves are weaned at an age of 210 days on October 1. An average gestation period of 280 days is assumed. The breeding herd is maintained through rotational crossing, and the herd raises its own replacements.

Description of Alternative Supplementation Strategies

To represent the range of supplementation strategies available to cow-calf producers, twenty supplemental feeding activities are evaluated. These strategies differ in terms of the quantity of supplement fed and the ability of the manager to supplement in response to changing cow body condition. All supplementation strategies utilize soybean meal as a protein supplement. The first two strategies (10 activities) are termed "fixed supplementation strategies" in that the quantity fed daily is predetermined and remains constant across years. The next 10 activities involve adjusting supplementation levels in response to changes in cow condition.

Strategy I: Baseline

This set of activities constitutes the baseline supplementation strategy. Five basic levels of supplementation are developed. Relating to the work of Lusby and Wetteman (1988), spring calving cows on native range require supplementation during November through mid-April. Also, supplementation levels should be increased in January to meet demands of fetal growth and lactation. A fixed quantity of supplement is fed daily to all cows during the supplementation periods as follows:

BS-1: 11/1 - 12/31 = 0.8 lb/day, 1/1 - 4/10 = 1.2 lb/day
BS-2: 11/1 - 12/31 = 1.0 lb/day, 1/1 - 4/10 = 1.5 lb/day
BS-3: 11/1 - 12/31 = 1.5 lb/day, 1/1 - 4/10 = 2.25 lb/day
BS-4: 11/1 - 12/31 = 2.0 lb/day, 1/1 - 4/10 = 3 lb/day
BS-5: 11/1 - 12/31 = 3.0 lb/day, 1/1 - 4/10 = 4.5 lb/day

where, BS-1 is the base strategy at the first (lowest) level of supplementation, BS-2 is the base strategy at the second level of supplementation, etc. These supplementation programs were based upon quantities fed in body condition experiments conducted on native range in Oklahoma (Richards et al., 1986; Lusby and Wetteman, 1988; Fleck et al., 1987).

This strategy is considered naive in that cows are fed the same level of supplemental feed, regardless of body condition. Therefore, the manager is unable to separate cows and adjust the level of supplementation based upon the cow's current body condition. A detailed description of the five baseline activities is as follows:

(a) BS-1: this activity represents the lowest level of supplementation available. Cows are fed a quantity of 0.8 lb/day during November and December, then increased to a level of 1.2 lb/day over the remainder of the supplementation period. These quantities are often used to represent low levels of supplementation in O.S.U. body condition score experiments, and is often termed the "negative control" (Lusby et al., 1988; Fleck et al., 1987).

(b) BS-2: this is an intermediate level of supplementation between low (BS-1) and moderate (BS-3) levels.

(c) BS-3: this activity represents a moderate level of supplementation that provides adequate energy under average forage quality conditions.

(d) BS-4: this activity is representative of a moderate to high level of supplementation used in body condition score experiments conducted at O.S.U (Fleck et.al., 1987; Hibberd et.al., 1986; Lusby et.al., 1988). In these experiments, this level of supplementation is often termed the "positive control."

(e) BS-5: this level is developed to assure a high level of reproductive performance. Supplementation levels are sufficient that energy is not a limiting factor of production in the fall-winter period.

Strategy II: Late-Summer Supplementation

This strategy utilizes fixed supplementation levels as in Strategy I, but with one important adjustment: late-summer supplementation is provided for cows with low body condition. The difference between Strategy I and II is that thin cows are separated in mid-July and started on supplement. This adjustment is based on several of the body condition experiments noted above which recommend initiation of supplementation of thin cows in late summer to allow them to gain BCS by calving. The producer, here, is able to separate cows into two groups ("thin" and "not thin").

To distinguish strategy I from II, another acronym is used where LS (late-summer) substitutes for BS in the activity name. The same levels of supplementation used in the baseline strategies are also used in these activities. Thus, activity LS-1 refers to a low supplementation level (.8 lb/day in November-December and 1.2 lb/day in January-April 10) that allows for additional supplementation (1 pound/day) of thin cows from mid-July through October.

Strategy III: Variable Supplementation

In this set of activities, two decision points are introduced, as opposed to one under Strategy II. Again, fixed supplementation rates are employed for late-summer supplementation of cows in low body condition. As in Strategy II, thin cows are separated in mid-July and started on supplement to improve body condition at calving. Additionally, the level of supplemental feeding during the primary supplementation period (November-April) is determined by the cow's body condition on November 1. On this date, the producer is able to separate cows into groups ("thin" and "not thin") and provide an appropriate level of supplementation. Cows classified as "thin" are provided a high level of supplementation to increase the probability of attaining a satisfactory body condition at calving. Cows in good condition are fed the base level of supplemental feed.

By combining different supplementation levels for the two groups of cows with different definitions of "thin" cows, copious activities could be developed under this strategy. Several combinations of supplementation levels were evaluated, along with several cow condition classification criteria. Based upon a criteria of maximizing expected net returns, six alternative supplementation activities were selected. These activities differ in terms of supplementation rates and the cow body condition designating a "thin" (or poor) body condition in November. Variable supplementation (VS) activities are:

(a) VS-1A: this activity uses low supplementation levels (.8 and 1.2 lb/day) as a base, and supplements with moderate levels (1.5 and 2.25 lb/day) when needed. That is, cows are fed the higher level during the November-April period if the BCS on November 1 is below the "trigger" level. A trigger BCS of 5.0 is employed.

(b) VS-1B: this activity utilizes the same supplementation rates as VS-1A, but employs a lower "trigger" to initiate the higher level of supplementation during November-April. A trigger BCS of 4.5 is used.

(c) VS-1C: this activity also employs low supplementation levels as a base, but supplements with higher levels (2.0 and 3.0 lb/day) when cows are in thin condition in November. A BCS of 5.0 is used to initiate the higher level of supplementation.

(d) VS-2A: this activity applies supplementation rates of 1.0 and 1.5 lb/day as a base, and supplements with rates of 1.5 and 2.25

lb/day when cows are identified as "thin" on November 1. A trigger BCS of 5.0 is used.

(e) VS-2B: this activity utilizes the same supplementation rates as VS-2A, but employs a lower trigger (BCS = 4.0) to initiate increased supplementation in the November-April period.

(f) VS-2C: this activity uses the 1.0 and 1.5 lb/day schedule as a base, and supplements with higher rates (2.0 and 3.0 lb/day) when cows are classified as "thin" (BCS=5.0) on November 1.

Strategy IV: Flexible Supplementation

This set of activities make the greatest use of body condition information and are termed "flexible supplementation" strategies. The strategy is termed "flexible" in that at each decision point over the year, several alternative supplementation programs are available. This differs from the "variable supplementation" strategy where only the base or a higher level of supplementation is available. Under this strategy, supplementation levels can be selected that more closely correspond to the energy requirements of the cow. The activities selected might be considered approximations of supplementation strategies that could be derived from a dynamic optimization framework similar to the one discussed in Chapter III.

The four activities primarily differ in terms of the number of times body condition score information is utilized throughout the year. Each time BCS is evaluated during the year an appropriate supplementation strategy is determined. The revised level is used until the next decision point. Four flexible supplementation activities are considered:

(a) FS-A: this activity uses low supplementation levels (.8 and 1.2 lb/day) as a base, but initiates one of three alternative supplementation levels depending upon the BCS on November 1. This activity is identical to VS-1A, with the exception that two additional supplementation programs are available on November 1.

(b) FS-B: this activity is identical to FS-A, with the exception that the base rates of supplementation are higher (1.0 and 1.5 lb/day).

(c) FS-C: this activity again uses the low supplementation levels as a base, but evaluates BCS at three points during the production year. BCS is evaluated and feeding adjustments are made in late-summer, at the initiation of the fall supplementation period (November 1), and at breeding.

(d) FS-D: this activity is identical to FS-C, with the exception that BCS is assessed at one additional point in the production season. BCS is evaluated and feed adjustments are made at breeding, late-summer, November 1, and January 1.

Base Enterprise Budget

Standard enterprise budgeting procedures were used to develop the production cost and receipt estimates for the representative cow-calf enterprise. Many of the underlying assumptions developed in the cow-calf enterprise budgets of Walker et al. (1987) were employed. Cost and return calculations used in the budgets were then programmed into the economic submodel to estimate annual return above operating costs under alternative supplementation strategies.

The culling and replacement strategy employed by the manager is similar to that proposed by Walker et al. (1987). Twelve heifers are retained annually and placed on a nutritional plane that will allow them to weigh 900 pounds when they first calve. Ten cows are culled annually and a 2 percent cow death loss is assumed. During the breeding season, one bull is kept for every 25 cows, and one bull is culled and replaced annually. Annual production cost estimates reflect the cost of maintaining all livestock classes, including the replacement heifers and bulls.

A representative enterprise budget for the cow-calf enterprise is shown in Table I. All items denoted with an asterisk are endogenous, that is, they are calculated within the model and will change across production strategies and years. The remaining costs are considered constant.

Input Requirements and Production Costs

Supplemental Feed. The sample budget includes a cost for three forms of supplemental feed: hay, 41-45% protein supplement. and 20% protein cubes. The protein cubes are fed to the replacement heifers and assumed constant across years. The quantity of hay fed annually is determined within the cow-calf model and increases in years when forage is limiting. A minimum of 135 pounds per cow unit is included to account for bad weather days. The quantity of soybean meal fed is constant across years for the fixed supplementation strategies; however, it will vary based upon the built-in decision rules under the variable and flexible supplementation strategies.

The cost of soybean meal and prairie hay reflects the average price paid by Oklahoma cattlemen over the past 10 years. A 10-year series of each feed cost was developed and expressed in 1992 dollars (Oklahoma Department of

TABLE I

COMPONENTS OF OPERATING INPUTS IN A COW-CALF SPRING CALVING ENTERPRISE USING AVERAGE PRICES

Operating Costs				
Item	Units	Cost	Quantity	Total Cost ($/Cow)
Hay	lbs.	.030	135.000	4.05
41-45% Prot.Sup.	lbs.	.160	316.500	50.64*
20% Protein Suppl.	lbs.	.050	502.000	25.10
Salt and Minerals	lbs.	.150	30.000	4.50
Vet Medicine	hd.	14.650	1.000	14.65
Vet-Med-LS Supp.	hd.	2.780	1.000	2.78
Marketing Expens	cwt.	1.720	4.350	7.48*
Hauling and Marketing	cwt.	.350	4.350	1.52*
Annual Operating Capital	dol.	.130	72.562	9.43
Livestock Labor	hr.	4.650	6.33	29.43*
Machinery Fuel,Lube,Rep.	dol.			31.62
Equipment Fuel,Lube,Rep.	dol.			0.76
Total Operating Cost				174.48
Production	Units	Price	Quantity	Value ($/Cow)
Str.Calves(4-5)	cwt.	98.00	1.9206	188.22*
Hfr.Calves(4-5)	cwt.	88.00	1.305	111.41*
Commercial Cows	cwt.	49.00	0.873	42.78
Aged Bulls	cwt.	60.00	0.136	8.15
Total Receipts				350.56
Returns Above Total Operating Costs				$176.08

* Values that change with supplementation activity.

Agriculture, 1991). The cost of hay is $60.00 per ton, and soybean meal is valued at $16.00 per cwt.

Salt and Minerals. Salt and minerals constitute a small portion of operating costs and are assumed constant. Two pounds of a salt and mineral mix per animal unit month were allocated for each animal unit month. Therefore, a total requirement of 30 pounds per cow unit was estimated.

Veterinary Expenses. Medical expenses are assumed constant across supplementation strategies. Included in this expense category are a $14.65 per head expense for veterinary services and a $2.78 per head expense for expendable items.

Marketing Charge. A marketing charge of $1.72 per cwt. is assessed on the weight of all livestock sold. This expense will vary as a function of the average annual weaning percent and weaning weights.

Hauling Charge. A custom charge of $.35 per cwt. is used to estimate the cost of hauling cattle. A 50 mile haul at $2.75 per mile was used to derive this value (Walker et al., 1987). The hauling charge is assessed on the total weight of livestock sold.

Interest on Operating Capital. Interest on operating capital is estimated based upon an annual interest rate of 12 percent.

Labor. Labor requirements are comprised of two components: (1) a fixed quantity that does not change across supplementation strategy, and (2) labor required for supplemental feeding. A base labor requirement of 6.33 hours per cow unit is used, and livestock labor is valued at $4.65 per hour. Additional labor required to feed protein supplement is valued at $2.00 per cwt fed.

Machinery and Equipment Costs. Machinery and equipment costs reflect the cow enterprises' share of fuel, lubrication, and repair costs. Variable costs are assumed constant at $31.62 per head and were estimated using standardized machinery cost equations (Kletke, 1979).

Livestock Receipts

Livestock receipts reflect the sum of sale revenues from all livestock classes. All calves are sold through an auction market in October. Other sales, such as aged bulls and cull cows, are permitted in other months. A 3 percent shrink on all livestock is assumed. Revenues from the sale of cows and bulls will remain constant across all years and strategies. Revenues from the sale of calves will vary depending upon the weaning percentage and weaning weights. Weaning weights estimated in the cow-calf submodel are used for the steer calves, heifer weights are adjusted by a factor of 0.95.

Livestock prices used in the analysis are assumed constant. Historical monthly average prices for livestock were obtained from the Oklahoma City Livestock Market. Four price series were developed--October steer and heifer calves (400-500 pounds), October commercial cows, and July aged bulls. Each price series was indexed to 1992 dollars. In the baseline economic situation, steer calves are valued at $95.00/cwt, heifer calves at $79.00/cwt, cull cows at $47.00/cwt, and aged bulls at $55.00/cwt.

Comparison of Physical Simulation Results

Three key physical variables, weaning percent, weaning weight and supplementation quantity, account for the principal sources of production risk represented in the model. Analysis of how each of these variables changes in response to different supplementation strategies will aid in interpreting the economic results of the analysis. A review of the 20 supplementation activities is provided in Table II.

Baseline

Changes in average weaning percentages and weaning weights across the five base activities are shown in Figures 8 and 9. As expected, average weaning percent and weaning weights increase as the supplementation rate increases. Average weaning percent and weights are not affected significantly by moving from the first level of supplementation (BS-1) to the second (BS-2). However, each additional increment in supplementation increases the weaning percent by an average of about 4 percent and weaning weight by an average of 6 pounds.

In general, reproductive performance under the base strategies is lower than expected. For example, the average annual weaning percent under BS-4 is only 85 percent, lower than that observed in several experiments conducted on Oklahoma rangeland where a comparable level of supplementation was fed (Lusby and Wetteman, 1988; Fleck et al., 1987; Hibberd et al, 1986). This result can probably be explained by the naive nature of the baseline supplementation strategy. All cows are fed a fixed supplementation quantity, and the producer does not possess the ability to change supplementation levels in response to cow condition. Also, the average, particularly under low supplementation

TABLE II

SUMMARY OF TWENTY SUPPLEMENTATION ACTIVITIES

Suppl. Activity	Base Quantity Fed' First Period	Base Quantity Fed' Second Period	Suppl. Decision Pts. Nov	July	Jan.	May
	-----------LBS----------					
BS-1	0.8	1.2	X			
BS-2	1.0	1.5	X			
BS-3	1.5	2.25	X			
BS-4	2.0	3.0	X			
BS-5	3.0	4.5	X			
LS-1	0.8	1.2	X	X		
LS-2	1.0	1.5	X	X		
LS-3	1.5	2.25	X	X		
LS-4	2.0	3.0	X	X		
LS-5	3.0	4.5	X	X		
VS-1A	0.8*	1.2*	X	X		
VS-1B	0.8*	1.2*	X	X		
VS-1C	0.8*	1.2*	X	X		
VS-2A	1.0*	1.5*	X	X		
VS-2B	1.0*	1.5*	X	X		
VS-2C	1.0*	1.5*	X	X		
FS-A	0.8#	1.2#	X	X		
FS-B	0.8#	1.2#	X	X		
FS-C	0.8#	1.2#	X	X	X	
FS-D	0.8#	1.2#	X	X	X	X

' Base quantity of supplement fed (pounds/day). First period=Nov.1-Dec.31,Second period=Jan1-Apr.10.

* Base quantity fed; higher supplementation rates are used when cows are in "thin" condition on Nov.1.

Base quantity fed; four alternative supplementation rates available at each decision point.

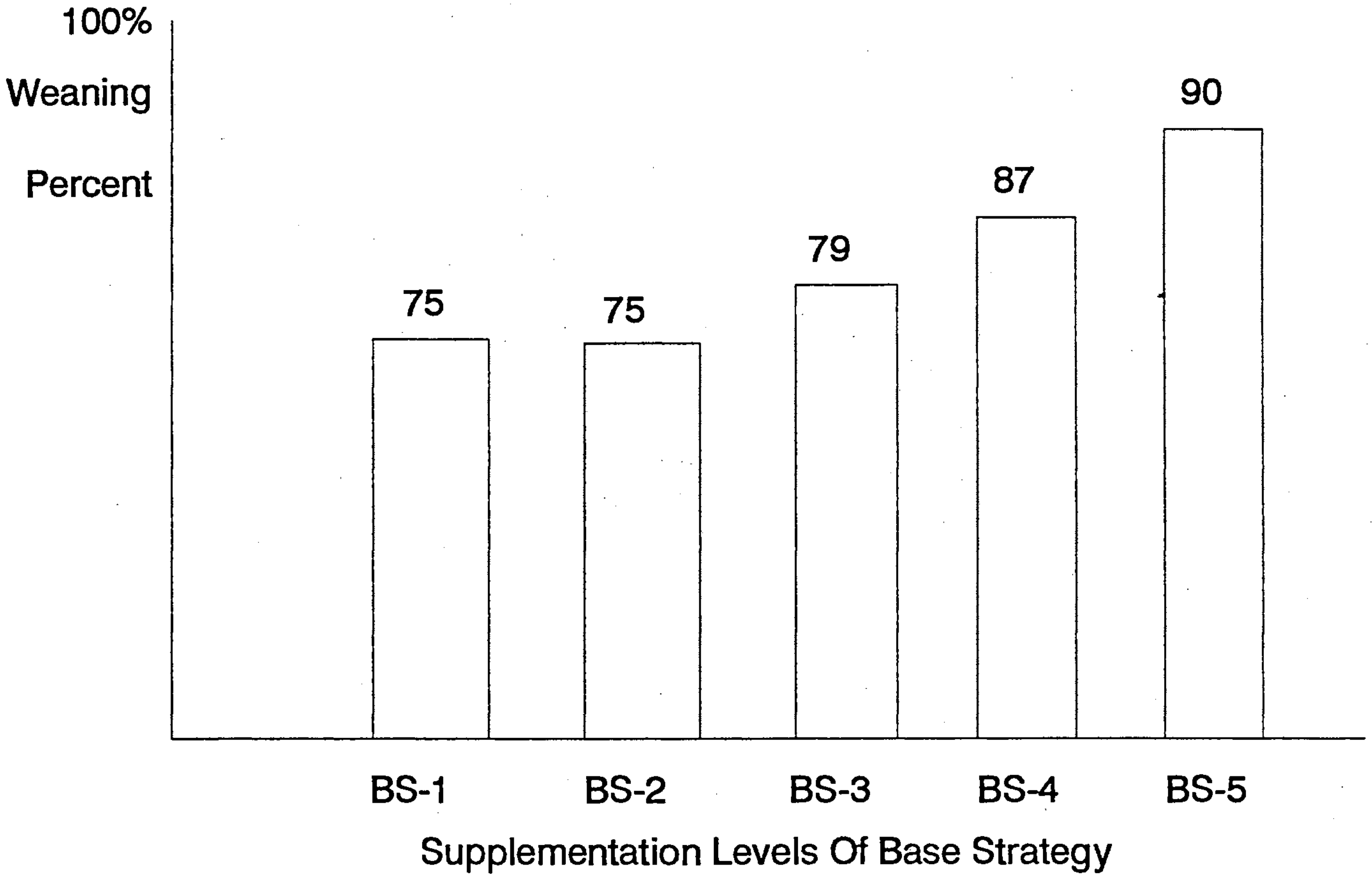


Figure 8. Weaning Percent of Base Activities

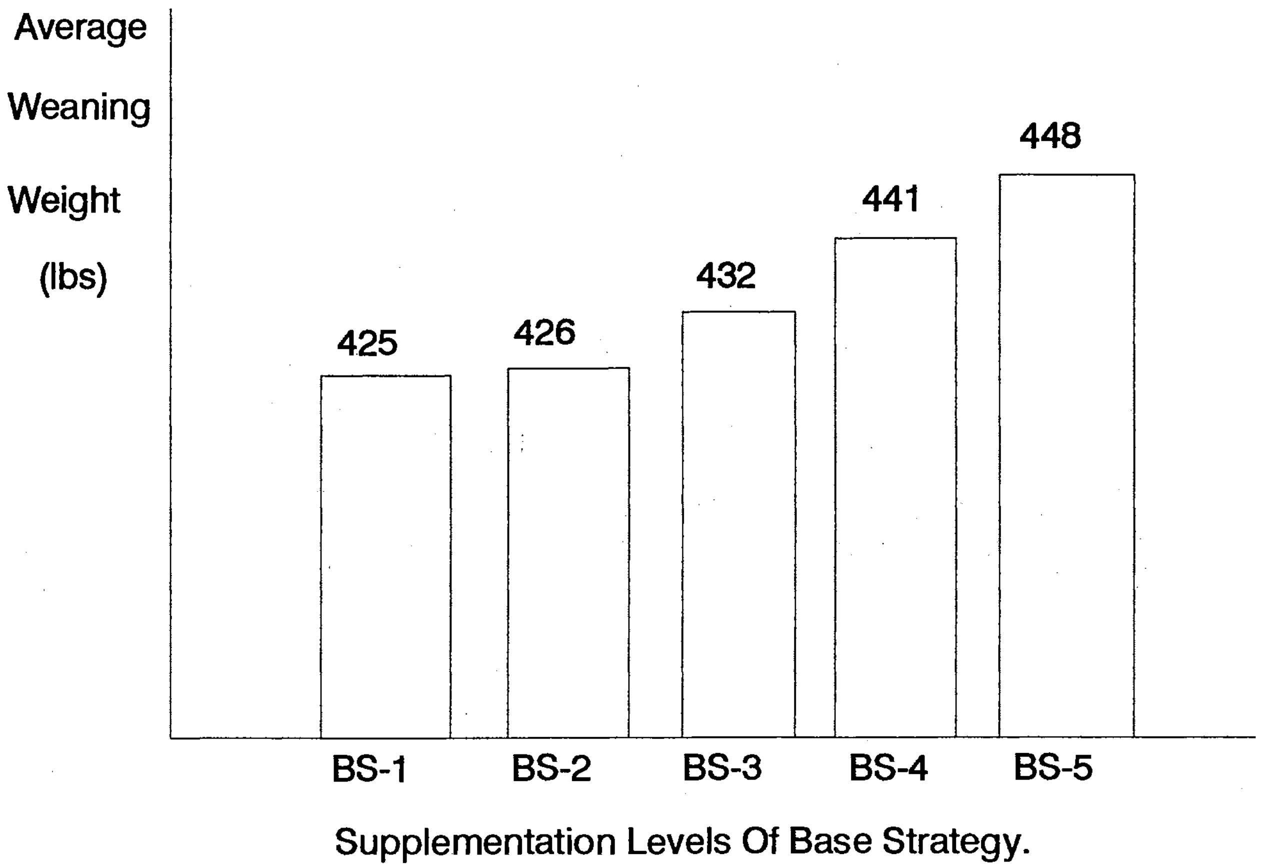


Figure 9. Average Weaning Weight of Base Activities

activities, is affected by a small number of low annual weaning percents and weaning weights observed in years of large energy deficits. The median of the 25-year distributions on weaning percent and weaning weights is somewhat higher.

The level of supplementation not only affects the mean value of weaning percentage, but the shape of the distribution, as well. Approximations of the distributions of annual weaning percentage for two of the important baseline activities (BS-1 and BS-4) are shown in Figure 10. The respective shape of distribution of the weaning percent variable, that is the variance and degree of skewness between low and high supplementation activities, changes considerably in moving to higher levels of supplementation. Clearly, increases in supplementation levels translate to reductions in the variability of average annual weaning percentage and weaning weights. Also, due to improved reproductive performance in years of low forage quality, the skewness of the distribution increases as supplementation levels are increased. The distribution of average annual weaning weight behaves in a similar manner to changes in supplementation quantities.

Late-Summer Supplementation

The effects on the average annual weaning percent and weaning weights of adjusting the base strategies are summarized in Table III. Average weaning percent and weaning weights only increase slightly as a result of late-summer supplementation. Generally, for the five supplementation levels, the average weaning percent increases 0.2, 0.7, 1.0, 1.6 and 2.2 percent in favor of the late-summer supplementation strategies, for LS-5, LS-4, LS-3, LS-2, and LS-1, respectively. Since the increase is not substantial, it could be inferred that any

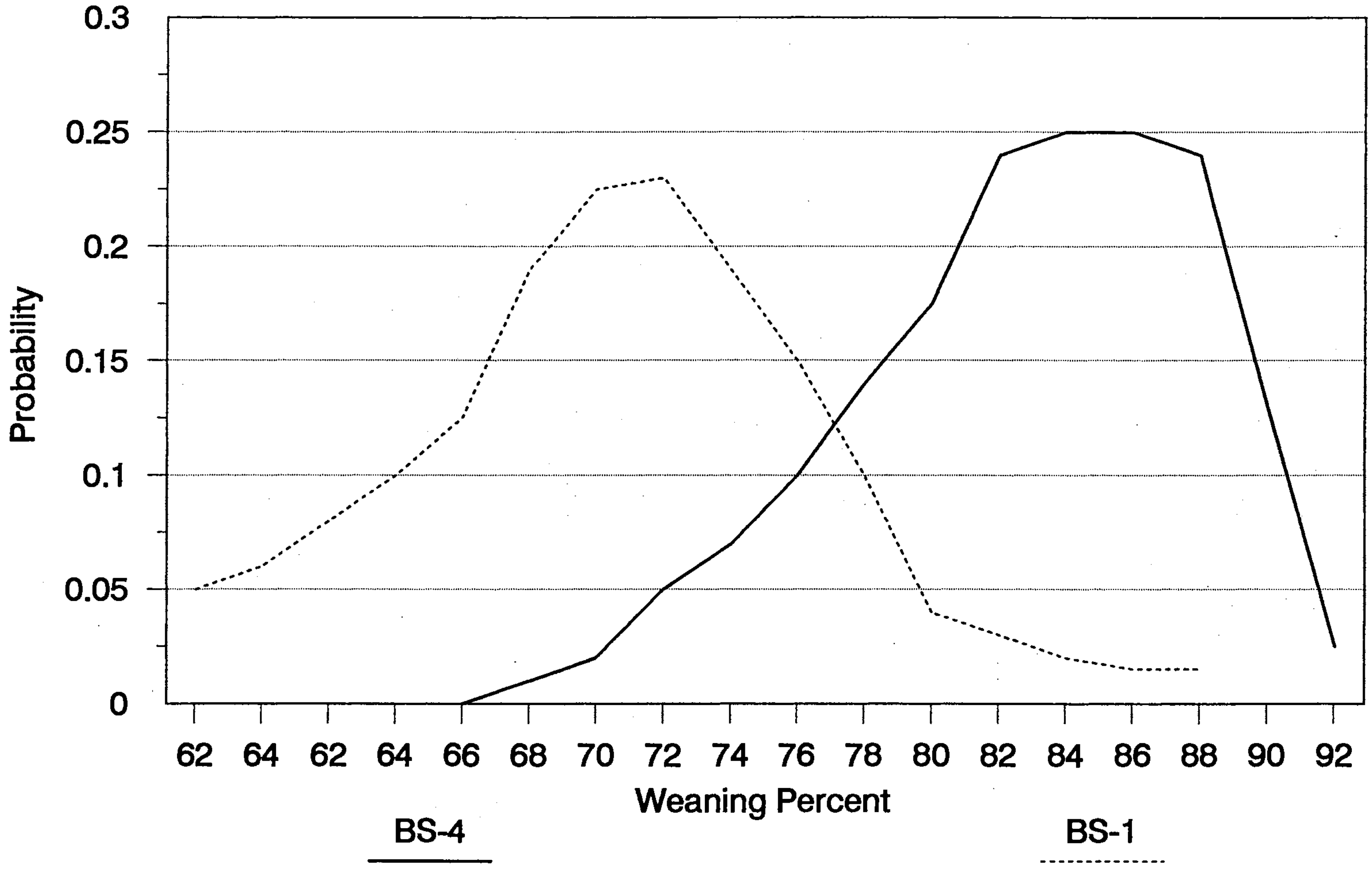


Figure 10. Probability Distribution of BS-4 and BS-1

TABLE III

AVERAGE ANNUAL WEANING PERCENT AND AVERAGE WEANING WEIGHT FOR ALTERNATIVE SUPPLEMENTATION ACTIVITIES

Supplementation Activity	Weaning Percent	Weaning Weight
Baseline Activity		
BS-5	90.1	448.4
BS-4	85.0	440.9
BS-3	79.2	432.2
BS-2	75.7	426.4
BS-1	74.9	425.3
Late-Summer Supplementation		
LS-5	90.3	448.6
LS-4	85.7	441.6
LS-3	80.2	433.4
LS-2	77.3	428.7
LS-1	77.1	428.1
Variable Supplementation		
VS-1A	82.2	438.9
VS-1B	83.2	437.5
VS-1C	83.7	437.6
VS-2A	82.8	436.9
VS-2B	80.6	433.6
VS-2C	83.9	438.1
Flexible Supplementation		
FS-A	84.0	438.1
FS-B	85.8	441.0
FS-C	86.1	440.9
FS-D	86.4	441.5

benefit of additional late-summer supplementation is minimal, particularly when used in combination with high levels of supplementation in the fall and winter. In these cases, supplementation rates are sufficient to bring body condition to satisfactory levels by calving; therefore, late-summer feeding is often superfluous.

Variable Supplementation

Comparison is made between the base strategies and the six variable supplementation strategies (VS-1A through VS-2C)). Variable supplementation provides an increase in annual weaning percent of between 5 and 9 percent of the comparable fixed supplementation activities (BS-1 and BS-2). Similarly, increases in weaning weights range between 8 and 13 pounds. There also is significantly less variation across years within this group than within the baseline activities in terms of both the average weaning percent and weaning weights. For example, the standard deviation of annual weaning percent for BS-1 was 12.5 percent, while the standard deviation under VS-1C was reduced to 7.1 percent. Variable supplementation was not able to eliminate low reproductive performance years, but it did greatly reduce the probability of their occurrence. Body condition problems could still occur in years when November 1 BCS levels did not trigger a higher supplementation program, but high energy requirements prevailed in the fall-winter period.

Flexible Supplementation

The use of flexible supplementation activities resulted in further improvements to average weaning percentage and weaning weights. Increases in average annual weaning percentage range between 8 and 12 percent of those observed in BS-1 and BS-2. In addition, further reductions in the variability of reproductive performance are achieved. Modification of supplementation during the fall-winter period further reduces the probability of poor reproductive performance.

Total Quantity of Supplement Fed

The effect of late-summer supplementation on annual feed requirements is shown in Table IV. Under high supplementation rates (LS-5), additional feed is required in only 16 percent of the years. However, under low fall-winter supplementation levels (BS-1), late-summer supplementation becomes much more important, occurring 92 percent of the time. Average annual supplementation rates under the variable and flexible strategies are similar to the intermediate levels of the baseline strategy. Under variable supplementation, the average quantity of supplement fed annually ranges from 16.4 to 19.6 tons. The average annual supplemental feed requirement ranges between 16.6 and 18.4 tons under the four flexible supplementation activities. Although these levels compare to those used in BS-3, physical and economic productivity measures are much higher in the BCS-based activities. This result reflects the improved productivity of the feed input when supplementation is better coordinated with nutritive demands.

Comparison of Net Return Distributions

Baseline

The mean, standard deviation, range, and skewness of each of the 20 net return distributions are reported in Table V. For the five baseline supplementation strategies, average annual net returns range from $12,291

TABLE IV

DISTRIBUTION OF ANNUAL SUPPLEMENTATION REQUIREMENTS FOR THE FIVE LATE SUMMER SUPPLEMENTATION ACTIVITIES

Year	LS-5	LS-4	LS-3	LS-2	LS-1
	lbs				
1	64,550	45,700	34,275	22,850	18,825
2	64,550	45,700	35,003	24,443	20,851
3	64,550	45,700	34,275	32,535	28,476
4	64,550	45,700	36,800	29,433	25,433
5	65,222	51,901	41,058	32,468	30,033
6	66,111	53,218	43,507	33,097	29,284
7	65,877	53,077	44,444	34,315	30,299
8	64,550	52,102	41,342	33,423	29,106
9	64,550	51,240	41,403	30,483	26,580
10	64,550	47,676	37,300	26,696	22,855
11	64,550	46,330	35,911	27,051	23,153
12	64,550	45,700	34,275	22,883	18,825
13	64,550	45,700	34,275	22,850	18,825
14	64,550	45,850	35,831	25,063	21,096
15	64,550	45,700	34,275	22,949	19,004
16	64,550	46,258	37,370	27,389	23,253
17	64,550	46,444	37,740	27,979	24,729
18	64,550	45,755	35,274	25,888	21,909
19	64,550	45,700	34,976	23,964	20,059
20	64,550	46,532	41,328	31,454	28,435
21	64,550	45,957	39,763	30,566	26,821
22	64,550	45,867	39,136	32,070	28,520
23	64,550	48,854	41,395	30,539	26,953
24	66,900	53,619	40,751	30,803	26,747
25	64,550	47,599	37,720	27,261	22,588

TABLE V

MEAN, STANDARD DEVIATION AND RANGE OF NET RETURNS UNDER ALTERNATIVE SUPPLEMENTATION STRATEGIES, BASELINE PRICE SCENARIO

Supplementation Activity	Mean	Standard Deviation	Highest	Lowest	Skewness
Baseline					
BS-5	12,291	878	12,740	9,853	-1.80
BS-4	13,309	2,803	16,133	7,666	-0.80
BS-3	12,590	2,858	17,979	7,548	+0.08
BS-2	13,034	3,414	19,969	7,829	+0.26
BS-1	13,408	3,390	20,746	8,328	+0.28
Late-Summer Supplementation					
LS-5	12,326	793	12,740	10,428	-1.62
LS-4	13,203	2,984	16,133	6,867	-0.93
LS-3	12,389	3,431	18,189	6,131	-0.17
LS-2	12,729	3,035	20,035	7,841	+0.31
LS-1	13,333	4,016	20,746	6,925	+0.13
Variable Supplementation					
VS-1A	14,151	3,971	20,680	7,054	-0.09
VS-1B	14,278	3,962	19,909	6,675	-0.22
VS-1C	14,663	3,998	20,803	7,187	-0.25
VS-2A	13,584	3,583	19,229	6,418	-0.21
VS-2B	13,731	4,188	20,724	6,049	+0.01
VS-2C	13,814	3,504	19,032	7,204	+0.24
Flexible Supplementation					
FS-A	14,844	3,971	20,723	7,025	-0.24
FS-B	15,224	3,935	20,925	6,497	-0.27
FS-C	15,267	3,948	20,757	7,458	-0.25
FS-D	15,394	3,790	20,566	8,244	-0.21

under the highest supplementation level (BS-5) to $13,408 under the lowest level (BS-1). Therefore, average net returns are not greatly influenced by the level of supplementation under the baseline strategy. This result again reflects the rather naive nature of the fixed supplementation strategy. Benefits of high rates of supplementation in years where environmental conditions dictate large energy requirements from supplemental feed are offset by the excessive feed costs and low net returns in years of favorable environmental conditions (e.g., favorable weather and high forage quality). Conversely, average annual net returns under low levels of supplementation are adversely affected by poor reproductive performance in years of unfavorable environmental conditions.

Despite similarities in average net returns, significant differences in the variability of net returns do occur in moving across supplementation levels. The standard deviation of net returns increases monotonically over the range of supplementation levels and increases nearly four-fold in moving from BS-5 to BS-1. In addition, the range increases from $2,887 to $12,418. Income variability is greatly affected by supplementation decisions. As noted above, high rates of supplementation tend to negate the possibility of high net returns in years of favorable environmental conditions, but also insulate the producer from low outcomes. This result can be illustrated by assessing the high and low net returns reported in Table V. The highest outcome in each distribution decreases monotonically as supplement is increased; however the lowest outcomes tend to move in the opposite direction.

It is difficult to rank the five baseline activities based upon a simple mean-variance criteria. While BS-1 would be selected based upon a criteria of maximizing expected returns, low levels of supplementation would be less preferred under a criteria of minimizing income variability. BS-5 is clearly preferred when ranking the activities based upon standard deviation or coefficient of variation.

The level of supplementation also has interesting implications on the shape of the net return distribution. Under high supplementation levels, the income distribution is negatively skewed, and the majority of observations fall in the \$12,000 to \$12,700 range. Under moderate feeding levels net returns become more normally distributed, and the distribution becomes positively skewed under low levels of supplementation. These findings are illustrated in Figure 11 where the cumulative distributions of net returns under BS-1, BS-3, and BS-5 are depicted.

Late-Summer Supplementation

Average net returns are not significantly improved as a result of late-summer supplementation. As noted earlier, only small improvements in reproductive performance (weaning percentage and weaning weights) occur as a result of the ability to initiate the supplementation of "thin" cows in the late-summer. In general, additional feed costs tend to exceed the value of additional pounds of calves produced. As in the case of the five baseline activities, average net return is maximized under the lowest supplementation level (LS-1), and is lowest under LS-5.

Variable Supplementation

Activities comprising the third set of supplementation strategies are generally characterized by higher average net returns than the baseline activities. Through improved nutrition management, both improved reproductive performance and reduced feed costs are attained. All of the

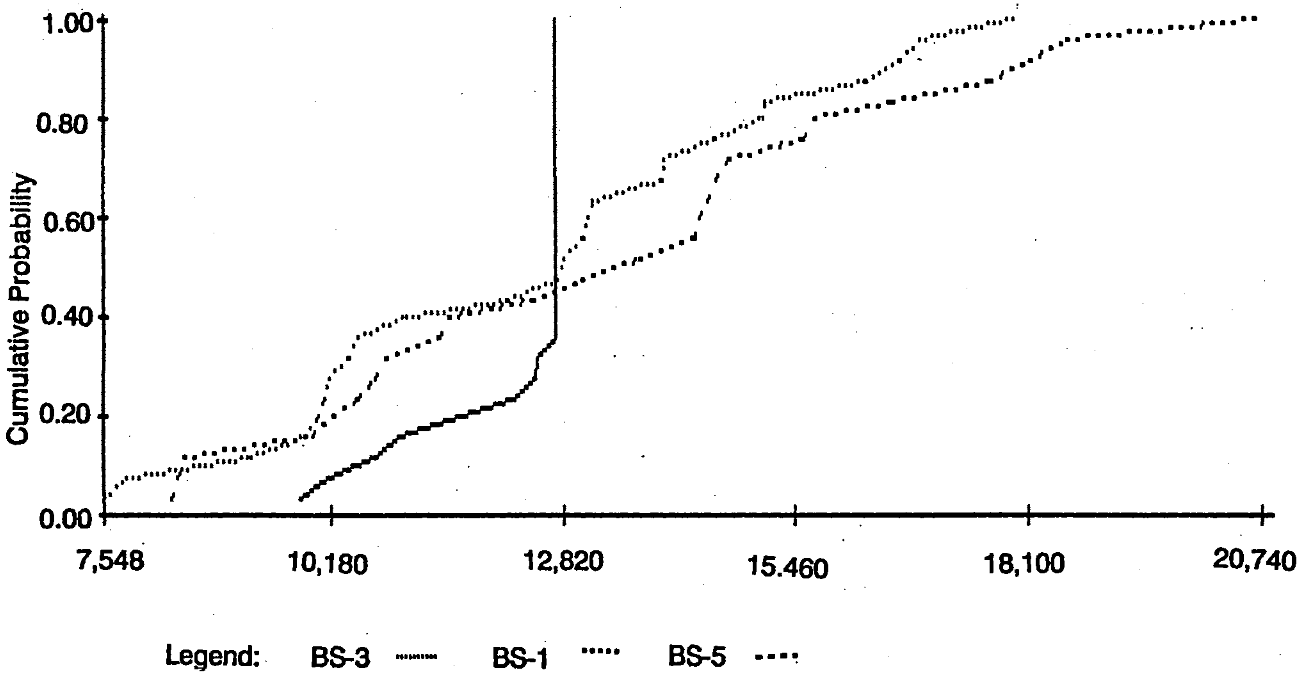


Figure 11. Cumulative Distributions of Net Returns Under BS-5, BS-3, BS-1

variable supplementation activities provide an average annual net return above each of the ten fixed supplementation activities. VS-1A, VS-1B, and VS-1C all feed the low supplementation rates under base conditions, and hence, can be compared to BS-1. Increases in average net returns from variable supplementation range between $742 and $1,254. VS-2A, VS-2B, and VS-2C feed base rates comparable to BS-2. In these cases, variable supplementation increases net returns between $406 and $550. In addition to higher expected income levels, income variability (as measured by the standard deviation) is also increased relative to the baseline activities. However, when scaled to account for increases in the mean, income variability (i.e., the coefficient of variation) is comparable to BS-1 and BS-2.

Flexible Supplementation

Average annual net returns are highest under the activities using flexible supplementation strategies (FS-A, FS-B, FS-C, and FS-D). Each improved level of management employing body condition score information results in an incremental increase in expected net returns. Net return increases can be attributed to both improvements in reproductive performance as well as a reduction in feed costs due to better matching supplementation programs with nutritive demands. Net return variability is also decreased in moving from FS-A to FS-D. The primary benefit of this additional information occurs as a result of increasing reproductive performance in years of unfavorable environmental conditions (e.g., poor weather and/or low forage quality.) While the additional information has little affect on the high end of the net return distribution, minimum returns are increased with each improvement.

Description of Stochastic Dominance Criteria

Stochastic dominance is a quantitative technique that can be used to investigate if one strategy completely or partially dominates another. A repeated iteration of the simulation model provides a probability distribution of annual net returns under each supplementation level alternative. The derived distributions provide an estimate of the relative expected profitability and risk associated with adopting each of the supplemental feeding alternatives. The decision maker faces the problem of selecting the supplementation strategy that generates levels of expected returns and risk consistent with his/her risk attitudes (or preferences).

In order to overcome the fallacies and/or common misconceptions regarding the direct elicitation of utility functions that classify attitudes of decision makers towards risk, efficiency criteria may be used. Efficiency criteria provide a means of dividing risky alternatives into efficient and inefficient sets. According to King and Robison (1981), an efficiency criterion is a decision rule that provides a partial ordering of choices for decision makers whose preferences conform to a specified set of conditions. An efficient set contains the preferred choice for every individual whose preferences conform to the restrictions associated with the criterion. As an illustration, one may restrict preferences such that everyone has positive marginal utility for money. Individuals with this positive marginal utility for money will be limited in their choices of preferred alternatives; these activities will comprise the efficient set. Actions comprising the inefficient set will not be chosen as members of the efficient set, implying mutual exclusivity of the sets.

A sizeable number of risk efficiency models have been developed to incorporate various risk attitudes into the evaluation of production practices.

The efficiency criteria used in this analysis are first-degree stochastic dominance (FSD), second-degree stochastic dominance (SSD), and generalized stochastic dominance (GSD).

First-Degree Stochastic Dominance (FSD). First-degree stochastic dominance is based on the assumption that a decision maker prefers more to less. FSD holds for all individuals having positive marginal utility for money. Under this criterion, an alternative with an outcome distribution described by a cumulative distribution function (CDF) F(y) is preferred to a second alternative with CDF G(y), if $F(y) \leq G(y)$ for all possible values of y, and if the strict inequality holds for some value of y. By FSD, the dominant distribution lies nowhere above the dominated distribution.

Second-Degree Stochastic Dominance. Another popular efficiency criterion is second degree stochastic dominance (SSD), as presented by Hadar and Russel (1969) and Hanock and Levy (1969). The additional assumption of SSD is that the decision maker is risk averse and possesses a utility function that is positive with a non-increasing slope. Under SSD, an alternative with CDF F(y) is preferred to an alternative with CDF G(y) if $F(y) \leq G(y)$ for all values of y with at least one strong inequality. Illustrating with areas under the CDF, the decision maker should be able to identify F as the dominant CDF if:

$$\int_{-\infty}^{\infty} F(y)\,dy \leq \int_{-\infty}^{\infty} G(y)\,dy \tag{4.1}$$

for all possible values of y, and if strict inequality exists for some value of y (King and Robison, 1984). Employing SSD necessitates separating the set of production alternatives into efficient and inefficient sets such that all actions within the efficient set are unanimously preferred by all risk averse producers to any action in the inefficient set (King and Robison, 1984).

Generalized Stochastic Dominance. Generalized stochastic dominance (GSD) is an evaluative criterion that orders uncertain choices based upon decision makers attitudes as well as expectations concerning the probability outcomes under each action choice (King and Robison, 1981). Generalized stochastic dominance provides a practical means of applying expected utility theory to decision problems. The expected utility model is the foundation of the majority of economic risk analysis and is based upon the assumption that decision makers choose actions to maximize their expected utility. Expected utility is a single-valued index of satisfaction that not only accounts for the expected value of an action, but the probability of alternative outcomes as well. The expected utility of a particular action j may be represented as $EU_j = f(u_j, sj^2, m_{3j},...)$, where uj, sj^2, m^3j,... represent the mean, variance, skewness, and higher moments of the probability distribution of outcomes for action j (Young, 1984). In this case, the outcome of importance is the annual net return generated from the feeding of various supplementation strategies. The feeding strategies are ranked according to their expected utility, with the highest level being most preferred.

Risk is measured in the expected utility model by the moments of the probability distribution of outcomes. A decision maker's attitudes are exhibited in the shape of his utility function, and consequently, the relative weights assigned to the various moments of the probability distribution. As an illustration, the utility function of producers with a strong aversion toward risk would be specified to penalize actions that are prone to high probability of low income occurrence. Hence, decision makers with different risk preferences will assign different levels of expected utility to actions, resulting in the possibility of different preferred actions.

Decision makers are categorized according to their risk attitudes as risk averse, risk preferring, or risk neutral (Robison et.al. 1984). Risk averters are described as cautious individuals with preferences for less risky sources of income. In general, this group of individuals will sacrifice some amount of expected income to reduce the probability of less income or loss. Whereas, risk preferrers desire more risky production alternatives with some probability of a higher income, even though they are bound to accept some probability of a lower income. Risk neutrality refers to the intermediate case where individuals prefer the alternative with the highest return, despite the probabilities of gain or loss

GSD orders uncertain choices for decision makers whose absolute risk aversion function lies within specified upper and lower bounds. GSD looks for a utility function $U_o(y)$ that minimizes:

$$\int_{-\infty}^{\infty} [G(y) - F(y)]\, u'(y)\, dy \tag{4.2}$$

subject to the constraint:

$$r_1(y) \leq - \frac{u''(y)}{u'(y)} \leq r_2(y) \tag{4.3}$$

for all y for a given class of decision makers. If the minimum difference between G(y) - F(y) is greater or equal to zero for all y, then F(y) > G(y) and F(y) is preferred to G(y) by all decision makers in that class. If the minimum is zero, decision makers are indifferent and cannot order the choices. On the other hand, if the minimum difference is negative, then the expression is flipped around to:

$$\int_{-\infty}^{\infty} [F(y) - G(y)]\, u'(y)\, dy \tag{4.4}$$

to look for a a new minimum difference. This would determine if G(y) dominates F(y) and is preferred (King and Robison, 1981).

FSD and SSD are special cases of GSD. In the case of FSD, the bounds on the absolute risk aversion coefficient are extremely large, ranging from negative to positive infinity (i.e., $r_1(y) = -\bullet$, $r_2(y) = \bullet$). To apply SSD, the lower bound is set at zero and the upper bound is positive infinity (i.e., $r_1(y) = 0$ and $r_2(y) = \infty$).

The primary advantage of generalized stochastic dominance, or stochastic dominance with respect to a function, over first-degree, second-degree, and third-degree stochastic dominance is that it is more discriminating in ranking alternative strategies (Meyer). By specifying lower and upper bounds on the absolute risk aversion function, a more precise description of the decision maker's risk preferences can be represented.

Results of Stochastic Dominance Analysis

Stochastic dominance procedures are applied to the net return distributions to identify risk efficient supplementation strategies for decision makers with different risk preferences. The microcomputer program of Cochran and Raskin (1988) was used to conduct the stochastic dominance analysis. Risk efficient sets are first identified for the fixed supplementation strategies, then the set of alternatives is augmented to include the remaining activities.

First-and Second-Degree Stochastic Dominance

Stochastic dominance procedures were first applied to the ten fixed supplementation activities. By ignoring strategies that use cow condition information to make supplementation decisions, the effect of risk preferences on the quantity of supplement fed can be isolated. Risk efficient sets of supplementation alternatives derived from application of first-degree stochastic dominance (FSD) and second-degree stochastic dominance (SSD) to rank the ten activities are shown in Table VI.

The first-degree stochastically efficient set includes 9 of the 10 alternatives. This criterion is not capable of eliminating any significant number of the activities from the efficient set, reflecting its low discriminating power. As illustrated in Figure 11, the cumulative distributions of net returns under alternative supplementation levels tend to differ in shape and often cross; therefore, FSD is not capable of ranking the alternatives.

Under the more restrictive assumptions of second-degree stochastic dominance, only three activities, BS-1, BS-4, and LS-5, remain in the risk efficient set. Recall that the second-degree stochastically efficient set contains those strategies that risk averse producers prefer over those not in the efficient set. Second-degree stochastic dominance eliminates all of the intermediate supplementation levels. This result appears to be driven by the extreme years. In years of high supplementation requirements (i.e., poor forage quality and/or poor weather), intermediate levels are not adequate to provide large improvements in reproductive performance. Conversely, in years of low supplementation needs, intermediate levels are excessive and high feed costs reduce net returns. LS-5 is the least risky or variable among the set, even though it does not have the highest potential of net returns. Comparison of the moments of the net return distribution indicates that this activity is characterized by the highest minimum net return and the lowest standard deviation. BS-4 and BS-1 have potential for higher net returns, but also have a higher probability of generating low returns.

TABLE VI

RISK EFFICIENT SETS UNDER FIRST- AND SECOND- DEGREE STOCHASTIC DOMINANCE, BASELINE PRICE SCENARIO

First-Degree	Second-Degree
BS-5	BS-4
BS-4	BS-1
BS-3	LS-5
BS-2	
BS-1	
LS-5	
LS-4	
LS-2	
LS-1	

Generalized Stochastic Dominance

The advantages of generalized stochastic dominance over FSD and SSD are apparent. It is a more powerful and discriminating tool because decision maker risk preferences may be more precisely represented. Optimal feeding strategies are derived for producers characterized by a broad range of risk preferences, as described earlier. Once the risk preferences have been specified, an ordering of two strategies can be made strictly on the basis of the properties of their probability distributions. With such an ordering, one alternative will dominate the other, or the criterion will not be able to order the two alternatives and both will be considered efficient. Through a series of pair-wise comparisons, an optimal set of supplemental feeding alternatives may be derived.

Raskin and Cochran (1986) provided a detailed analysis of the implications of Pratt-Arrow coefficients for generalized stochastic dominance analysis. According to these authors, the Pratt-Arrrow measure of absolute risk aversion can be defined in several equivalent ways represented by the following equations:

$$r(x) = \frac{u''(x)}{u'(x)} \tag{4.5}$$

$$= \frac{(du'/dx)}{u'} \tag{4.6}$$

$$= \frac{d}{dx} \log u' \tag{4.7}$$

$$= \frac{(du'/u')}{dx} \tag{4.8}$$

The last of these expressions indicates that the Pratt-Arrow coefficient can be interpreted as the percent change in marginal utility per unit of outcome space, implying that r(x) has associated with it the reciprocal of the unit with which the outcome space is measured. As an illustration, suppose with outcomes measured in dollars, r(x) is elicited as .0001. This value is actually .0001/$, and would more appropriately be specified with its units intact. It shows that near the outcome level at which the elicitation was made, the decision maker's marginal utility is dropping at the rate of .01% per dollar change in income. Likewise, if r(x) is known only to lie in the interval (.00004/$, .00006/$) then marginal utility is falling at a rate between .004% and .006% per dollar (Raskin and Cochran, 1986). Therefore, it is important that the Pratt-Arrow coefficients employed in an analysis correspond to the outcome range observed in the net return distributions.

For this analysis, four different risk interval sets are used to represent risk preferring, risk neutral, slightly risk averse, and strongly risk averse decision makers. The risk interval boundaries are presented in Table VII. Results from applying generalized stochastic dominance procedures to the net return distributions of the 10 fixed supplementation activities are presented in Table VIII. The optimal supplementation activities are reported for the four risk classifications. The efficient set includes the strategies that maximize expected utility for decision makers whose risk preferences conform to the restrictions for that criterion. A comparison of the efficient sets derived for each set of risk preferences provides insight as to the influence of risk preferences on preferred supplemental feeding strategies.

Only a single supplementation activity, LS-1, is identified as comprising the risk efficient set for risk preferring decision makers. As expected, this activity is characterized by a wide range of net return outcomes. Under high forage

TABLE VII

PRATT/ARROW RISK AVERSION COEFFICIENTS

	Lower Bounds	Upper Bounds
Risk Preferring	-.0008	-.0001
Risk Neutral	-.0001	+.0001
Slightly Risk Averse	+.0001	+.0004
Strongly Risk Averse	+.0004	+.001

TABLE VIII

OPTIMAL SUPPLEMENTATION LEVEL STRATEGIES FOR DECISION MAKERS CHARACTERIZED BY ALTERNATIVE RISK PREFERENCES

Classification of Decisionmaker	Risk Efficient Sets
Risk Preferring	LS-1
Risk Neutral	BS-4,BS-1,LS-1
Slightly Risk Averse	BS-4,BS-1,LS-5
Strongly Risk Averse	LS-5

quality conditions, feed costs are minimized and high net returns occur. However, extremely low returns occur when supplementation levels are not adequate to maintain cow condition in low forage quality years. As indicated in Table V, LS-1 has both the largest and smallest annual net return outcomes of the ten fixed supplementation activities.

Under the assumptions of risk neutrality, the optimal set of strategies includes BS-4, BS-1, and LS-1. None of these strategies completely dominate the others in terms of a basic mean-variance criteria (i.e., highest expected returns and lowest standard deviation). As indicated by the range and standard deviations of net returns, these strategies are characterized by large amounts of income variability. Risk neutral decision makers are willing to accept the high level of risk associated with these strategies

For the slightly risk averse decision makers, BS-1 and BS-4 remain in the efficient set; however, LS-5 replaces LS-1 in the efficient set. Although acceptable to the risk preferring and risk neutral decision makers, the level of risk associated with LS-1 is not compatible with risk averse preferences, hence its exclusion from the efficient set. This trade-off between expected returns and risk is consistent with the preferences of the risk averter.

The optimal set of supplementation activities adopted under strong risk aversion differs considerably from those identified under alternative risk preferences. A single supplementation feeding strategy (LS-5) is identified as efficient by strongly risk averse decision makers. Strongly risk averse producers are not willing to accept the probability of low net returns associated with low-level supplementation activities. While minimizing feed costs, and providing high net returns in years characterized by favorable environmental conditions, low level supplementation can result in extremely low net returns in years of poor forage quality. The strategy comprising the efficient set is characterized by infrequent occurrences of low net returns, showing that producers having a strong aversion toward risk place a great deal of emphasis on avoiding low returns.

Price Sensitivity Analysis

As noted earlier, the variation inherent in input and output prices and quantity of agricultural production results in significant levels of income variability faced by cow-calf producers. Changes in market prices can cause substantial variation in producer income. However, the cow-calf producer does have the ability to make reasonable projections of the two economic variables which most dramatically impact returns--cattle price and feed costs. The choice of supplementation level, as well as the intended level of production, should be influenced by these price expectations. Of course, the expected sale prices may be different from the actual prices observed when the calf crop is ready for sale.

To evaluate the effect of the decision maker's price expectations on supplementation decisions, two additional price scenarios were developed. Under each of the price scenarios, the method of analysis was the same with the exception of the prices used for protein supplement, calves, and cull cows. Historical prices for the last ten years for protein supplement, calves, and cows were indexed to real dollars and ranked in descending order. To derive a "low" price, the three lowest prices in the series were averaged. Similarly, for the "high" price, the three highest prices in each category were selected and averaged. This approach generates a "low" and "high" cattle price and supplemental feed cost. To generate the two possible extreme price conditions, two price scenarios are developed as combinations of these two price extremes. That is,

Price Scenario 1: This is a combination of the low protein supplement price ($.13/lb) and the high cattle prices ($105/cwt for steer calves, $87.20/cwt for heifer calves, and $52.00/cwt for cull cows).

Price Scenario 2: This is a combination of the high protein supplement price ($.19/lb) and the low cattle prices ($81.00/cwt for steer calves, $67.50/cwt for heifer calves, and $40.00/cwt for cull cows).

Net returns under each of the alternative price scenarios are summarized in Tables IX and X. Under price scenario 1 (low supplement costs-high cattle prices), average net returns increase 35 percent above those generated under the baseline economic situation. Expected net returns are now larger under the activities using higher levels of supplementation. For the five baseline activities, returns are maximized under BS-4 (as opposed to BS-1 under the initial economic situation). The combination of a higher marginal value product and lower input costs increases the optimal input level by about 1 pound per day during the supplementation period. The cattle-to-feed price ratio is still not high enough to generate expected returns that are maximized under supplementation rates used in BS-5. Under price scenario 2 (high supplementation costs-low cattle prices), expected returns are again maximized under BS-1. Therefore, managers developing supplementation programs based on a criterion of maximizing expected net returns should adjust feeding levels in response to changes in cattle and feed prices.

Evaluation of the expected returns and variability of net returns under the different supplementation strategies is carried out via stochastic dominance

TABLE IX

MEAN, STANDARD DEVIATION, AND RANGE OF NET RETURN UNDER ALTERNATIVE SUPPLEMENTATION STRATEGIES PRICE SCENARIO 1

Supplementation Activity	Mean	Standard Deviation	Highest	Lowest	Skewness
Baseline					
BS-5	18,038	970	18,534	15,344	-1.80
BS-4	18,241	3,099	21,362	12,004	-0.88
BS-3	16,887	3,159	22,843	11,314	+0.08
BS-2	16,818	3,774	24,484	11,066	+0.26
BS-1	17,035	3,747	25,145	11,420	+0.28
Late-Summer Supplementation					
LS-5	18,089	857	18,534	15,979	-1.64
LS-4	18,224	3,166	21,362	11,488	-0.92
LS-3	16,846	3,643	23,076	10,246	-0.15
LS-2	16,750	3,281	24,557	11,468	+0.29
LS-1	17,230	4,259	25,145	10,381	+0.13
Variable Supplementation					
VS-1A	18,547	4,010	25,092	11,354	-0.10
VS-1B	18,789	3,986	24,392	11,117	-0.23
VS-1C	1,915	3,926	25,195	11,747	-0.25
VS-2A	18,157	3,671	23,942	10,799	-0.21
VS-2B	17,999	4,253	25,127	10,224	+0.01
VS-2C	18,483	3,496	23,724	11,883	-0.23
Flexible Supplementation					
FS-A	19,354	4,043	25,158	11,352	-0.31
FS-B	19,904	3,919	25,343	11,037	-0.41
FS-C	19,963	3,749	25,187	12,320	-0.28
FS-D	20,112	3,594	24,987	13,132	-0.25

TABLE X

MEANS, STANDARD DEVIATION, AND RANGE OF NET RETURNS UNDER ALTERNATIVE SUPPLEMENTATION STRATEGIES, PRICE SCENARIO 2

Supplementation Activity	Mean	Std. Dev.	Highest	Lowest	Skewness
Baseline					
BS-5	5,019	749	5,402	2,941	-1.80
BS-4	6,953	2,390	9,360	2,141	-0.88
BS-3	6,986	2,437	11,580	2,687	+0.08
BS-2	8,009	2,911	13,923	3,572	+0.26
BS-1	8,556	2,890	14,813	4,225	+0.28
Late-Summer Supplementation					
LS-5	5,036	699	5,402	3,387	-1.60
LS-4	6,746	2,698	9,360	1,035	-0.94
LS-3	6,605	3,099	11,760	904	-0.19
LS-2	7,439	2,684	13,979	3,132	+0.35
LS-1	8,171	3,634	14,813	2,411	+0.14
Variable Supplementation					
VS-1A	8,391	3,826	14,734	1,588	-0.07
VS-1B	8,381	3,834	13,900	1,056	-0.20
VS-1C	8,780	3,980	14,878	1,303	-0.25
VS-2A	7,635	3,391	12,972	876	-0.20
VS-2B	8,131	4,008	14,787	754	+0.01
VS-2C	7,748	3,425	12,804	1,298	-0.25
Flexible Supplementation					
FS-A	8,935	3,829	14,749	1,497	-0.15
FS-B	9,110	3,900	14,966	769	-0.13
FS-C	9,133	4,085	14,788	1,332	-0.22
FS-D	9,232	3,940	14,630	2,070	-0.18

analysis for the two alternative price scenarios. Again, the stochastic dominance criteria used are first-degree, second-degree, and generalized stochastic dominance. This process involves simultaneous comparison of the cumulative distribution functions of net returns summarized in Tables IX and X.

Table XI summarizes the results of applying first-and second-degree stochastic dominance to the net return distributions generated under the alternative price scenarios. Under price scenario 1 ("low feed-high cattle") all 10 activities are in the FSD efficient set. In price scenario 2 ("high feed-low cattle"), 9 out of the 10 levels appear in the efficient set. Second-degree stochastic dominance exhibits (relative to FSD) a higher level of discriminatory power. Only two activities, BS-4 and LS-5, are contained in the efficient set under price scenario 1; whereas, only one activity, BS-1, appears in the SSD efficient set derived under price scenario 2. Therefore, the selection of risk efficient supplementation activities by risk averse producers is sensitive to price conditions. However, under the less restrictive assumption of first-degree stochastic dominance, the price situation has little affect on the risk efficient set.

As discussed earlier, generalized stochastic dominance, poses additional restrictions upon producer risk preferences and may provide additional insight as to the influence of the price situation on supplementation decisions by producers characterized by different risk preferences. Efficient sets of the preferred supplementation levels for the specified price scenarios are given in Table XII.

The efficient set for risk preferring decision makers facing price scenario 1 ("low feed-high cattle") consists of BS-4, LS-4, and LS-1. Therefore, BS-4 and LS-4 are added to the efficient set derived under baseline economic conditions. These activities have the highest expected return of the baseline and late-summer supplementation strategies. For price scenario 2 ("high feed-low

TABLE XI

EFFICIENT SETS OF FIRST- AND SECOND- DEGREE STOCHASTIC DOMINANCE GIVEN BASE ACTIVITIES UNDER PRICE SCENARIOS 1 AND 2

Price Scenario	FSD Efficiency Set	SSD Efficiency Set
1	BS-5,BS-4,BS-3,BS-2,BS-1 LS-5,LS-4,LS-3,LS-2,LS-1	BS-4 LS-5
2	BS-5,BS-4,BS-3,BS-2,BS-1 LS-5,LS-4,LS-2,LS-1	BS-1

TABLE XII

EFFICIENT SETS OF GENERALIZED STOCHASTIC DOMINANCE GIVEN BASE ACTIVITIES UNDER PRICE SCENARIOS 1 AND 2

Classification of Decisionmaker	Risk Efficiency Set
Scenario 1	
Risk Preferring	BS-4,LS-4,LS-1
Risk Neutral	BS-4,LS-5
Slightly Risk Averse	LS-5
Strongly Risk Averse	LS-5
Scenario 2	
Risk Preferring	BS-1,LS-1
Risk Neutral	BS-1
Slightly Risk Averse	BS-1
Strongly Risk Averse	BS-1

cattle"), BS-1 and LS-1 comprise the efficient set. In this case, the efficient set derived under the baseline price situation is augmented by BS-1. Interestingly, LS-1 remains in the risk efficient set across all price scenarios. Under all three price situations, LS-1 has the largest range of annual net returns and provides the highest return outcomes. This is an indication that risk preferrers are willing to accept outcomes with a probability of low returns to realize a probability of generating large net returns.

The risk neutral decision maker will always choose outcomes with the highest returns regardless of the variability. Under price scenario 1, BS-4 and LS-5 are selected; whereas BS-1 comprises the efficient set under price scenario 2.

Efficient sets for both slightly and strongly risk averse decision makers are identical under each price scenario. Therefore, the degree of risk aversion does not affect the selection of the risk efficient supplementation strategy for risk averters. For risk averse decision makers facing price scenario 1 ("low feed-high cattle"), LS-5 is the only activity in the efficient set. Expected returns from this strategy are comparable or higher than the other activities, and the activity also has the least standard deviation. For price scenario 2 ("high feed-low cattle"), BS-1 comprises the efficient set. Therefore, the economic setting is extremely important in determining optimal supplementation levels for risk averse producers. Optimal levels range from the lowest to highest quantities, over the economic settings considered.

Stochastic Dominance Analysis of Complete Set of Supplementation Activities

To evaluate the effect of introducing body condition score information into decision making concerning supplementation of cow-calf enterprises, all 20 distributions reported in Table V were evaluated using stochastic dominance procedures. The set of 10 fixed supplementation activities was augmented with the ten BCS-based activities (six variable and four flexible supplementation activities) and compared using first-degree, second-degree, and generalized stochastic dominance. Risk interval boundaries used in the GSD analysis are reported in Table VII. Risk efficient sets under first- and second-degree stochastic dominance are reported in Table XIII, while GSD results are reported in Table XIV.

Under first-degree stochastic dominance, the risk efficient set is comprised of members of all four sets of the supplementation activities. As discussed earlier, FSD is the least discriminating of the efficiency criteria, and 9 of the 20 activities remain in the efficient set. Fixed supplementation activities comprising the set utilize high supplementation rates (either level 4 or 5). All four flexible supplementation activities are included in the FSD set, while only VS-2A is included from the set of variable supplementation activities. Flexible supplementation represents improved use of the BCS information, and with the exception of VS-2A, all of the net return distributions generated under the assumptions of flexible supplementation lie to the right of the variable distributions.

The risk efficient set is reduced to three activities as a result of applying second-degree stochastic dominance. Interestingly, the SSD criterion is not capable of eliminating the fixed supplementation activity from the risk efficient set. Under the general assumption of risk aversion, LS-5 remains in the efficient set because of the absence of low net return outcomes.

Generalized stochastic dominance is able to reduce the efficient set to three or fewer activities for each risk preference interval. The efficient set for the risk preferrer consists of three flexible supplementation activities. As noted

TABLE XIII

RISK EFFICIENT SETS UNDER FIRST- AND SECOND- DEGREE STOCHASTIC DOMINANCE FOR COMPLETE SET OF SUPPLEMENTATION ACTIVITIES BASELINE PRICE SCENARIO

First Degree Stochastic Dominance	Second Degree Stochastic Dominance
BS-5,BS-4	
LS-5,LS-4	LS-5
VS-2A	
FS-A,FS-B	FS-B
FS-C,FS-D	FS-D

TABLE XIV

OPTIMAL SUPPLEMENTATION LEVEL STRATEGIES FOR DECISION MAKERS CHARACTERIZED BY ALTERNATIVE RISK PREFERENCES USING GSD

Classification of Decision Makers	Risk Efficient Set
Risk Preferring	FS-B,FS-C,FS-D
Risk Neutral	FS-D
Slightly Risk Averse	FS-D
Strongly Risk Averse	LS-5,FS-D

earlier, net return distributions derived under the assumptions of flexible supplementation are comprised of both high and low net return outcomes. Decision makers falling under this category are willing to accept a higher probability of low net returns to have a chance of obtaining high net return outcomes.

The risk efficient set for the risk neutral and slightly risk averse decision maker consists of a single flexible strategy, FS-D. This is the most sophisticated strategy in terms of monitoring BCS information and adjusting supplementation levels accordingly. As a result, the activity provides the highest expected net return, but also avoids extremely low net return outcomes.

The strongly risk averse decision maker's efficient set is comprised of FS-D and LS-5. Review of the moments of each of these distributions (see Table V) indicates that they differ considerably in terms of mean, standard deviation, skewness and range of outcomes. Nonetheless, both enter the efficient set for the strongly risk averse decision maker. This result indicates that strongly risk averse decision makers may be just as well off feeding a high level of supplementation based upon a fixed schedule, than monitoring BCS and modifying their supplementation program.

Stochastic Dominance Analytic Approach To Valuing Information

Interest in ascertaining decision makers' willingness to pay for information has increased in recent years. Much of this research has focused on estimating the value of various forms of climate forecasts in making crop production decisions (e.g., Mjelde and Cochran, 1988; Sonka et al., 1987). Information value has been shown to be dependent upon the structure of the decision set, the structure of the payoff matrix, the decision maker's prior knowledge, and the nature of the information set. The assessment of supplementation strategies using body condition score information provides a unique application of value of information techniques. Like climate forecasts, BCS information provides a projection of future input requirements needed to attain some physical or economic objective. BCS information has potential economic value in making supplementation decisions given uncertain environmental conditions.

A decision maker's willingness to pay for information can be thought of as a premium, π. This analysis uses the approach of Cochran and Raskin (1988) to calculate the premium associated with body condition score information. This premium is the amount that a decision maker would be willing to pay (in each and every state of nature) before the decision maker is indifferent to buying the information (Cochran and Mjelde, 1988). This occurs when the expected utility associated with using the information and paying π is equivalent to the expected utility of selecting the action without the information.

The value of information or information premium (π) can be estimated using stochastic dominance procedures. Upper and lower bounds on the information premium can be estimated by comparing two distributions. The first distribution, F(x), is generated using the BCS information. The second distribution, G(x), is generated based upon a decision maker's prior knowledge of supplementation requirements. Such a distribution may reflect net returns earned under a fixed supplementation strategy. The lower bound on the value of information is the minimum value of the premium, π such that $F(x-\pi)$ no longer dominates G(x). The premium is subtracted from each element of F(x); therefore, this is equivalent to a parallel shift in F(x). The upper bound on the value of information is the minimum premium such that G(x) dominates $F(x-\pi)$. Therefore, the upper bound corresponds to the minimum shift in the dominant distribution that is required for it to be dominated by the comparison distribution.

The lower bound corresponds to the minimum shift in the dominant distribution that produces an efficient set with both the dominant and comparison distributions as members. Mathematically, the bounds on information value can be defined as:

upper: Min π such that $EU(F(x-\pi)) - EU(G(x)) < 0 \; \forall \; U \in \mu$ 4.6

lower: Min π such that $EU(F(x-\pi)) - EU(G(x)) \leq 0$ for at least one $U \in \mu$ 4.7

where π = information premium

EU = expected utility

μ = admissible set of utility functions

These bounds on the premium can be interpreted as estimates on the value of information contained in the dominant distribution. They are an indication of the decision makers' (represented by the preference interval) willingness to pay for the information.

Table XV gives upper and lower bounds on the value of BCS information associated with each of the four flexible supplementation strategies. Bounds on the risk preference function are identical to those used in the GSD analysis to reflect slightly risk averse preferences (i.e., $r_1(x) = .0001$ and $r_2(x) = .0004$). As indicated earlier, the level of information increases as one moves from FS-A to FS-D; each strategy reflects further refinement in the producer's ability to monitor body condition score and adjust supplementation levels accordingly. As expected, the value of the information increases as the ability to monitor BCS and make feeding adjustments improves. For example, in moving from FS-A to FS-D, the lower and upper bounds on the value of information increase an average of $883 and $628, respectively.

The value of information is also dependent upon the level of prior knowledge; that is, the fixed supplementation strategy that the dominant strategy is being compared with. For example, if prior knowledge dictates the

TABLE XV

LOWER AND UPPER BOUNDS ON THE VALUE OF BODY CONDITION SCORE ACTIVITIES USING GSD FOR A SLIGHTLY RISK AVERSE DECISION MAKER

Dominant Activity	Prior Knowledge Activity	r(x) Bound(.0001,.0004) Lower Bound	Upper Bound
FS-A			
	BS-5	0.00	1802.04
	BS-4	700.07	1582.95
	BS-3	322.11	1203.92
FS-B			
	BS-2	106.51	2209.17
	BS-1	658.27	1557.01
	BS-3	1039.28	2255.84
	BS-2	987.24	1972.66
	BS-1	609.13	1593.63
FS-C			
	BS-5	322.88	2252.50
	BS-4	874.94	1600.34
	BS-3	1255.80	2301.18
	BS-2	1203.46	2016.14
	BS-1	825.50	1637.27
FS-D			
	BS-5	739.44	2443.54
	BS-4	1291.20	1791.38
	BS-3	1672.21	2492.22
	BS-2	1619.57	2211.00
	BS-1	1241.46	1831.97

use of high supplementation levels (BS-5), then the value of the BCS information associated with FS-D ranges between $739 and $2,444. Conversely, if prior knowledge dictates the use of low levels (BS-1), then the information is valued between $1,241 and $1,832.

In interpreting the value of body condition score information obtained from the analysis, one must realize that no cost is assigned to monitoring cow condition or additional handling of livestock required under the flexible supplementation strategy. Therefore, the value of information might be considered to have two parts: (1) the true value of the information in increasing net returns, and (2) the additional cost of feeding and monitoring the cows. One can argue that the latter component represents mainly a management cost. Since this study assumes that producers make decisions to maximize returns to land, management and fixed costs of production, this additional cost would not impact the net return distributions being compared.

Table XVI reports estimates of the lower and upper bounds on the value of information represented by the most sophisticated strategy (FS-D) across risk preferences. Because the exact values for $r_1(x)$ and $r_2(x)$ are not known, comparison of these estimates of the values of information provides a form of sensitivity analysis. In addition, changing the values of $r_1(x)$ and $r_2(x)$ allows one to evaluate the relationship between risk preferences and the value of BCS information.

The value of BCS information is shown to be sensitive to both risk preferences and the level of prior knowledge assumed. For example, if prior knowledge dictates the use of BS-5, the BCS information takes on an extremely high value for the risk preferrer. The risk preferrer is interested in the possibility of high net return outcomes, even at the expenses of increasing the probability of low outcomes. As discussed earlier, the high supplementation levels

TABLE XVI

LOWER AND UPPER BOUNDS ON THE VALUE OF BODY CONDITION SCORE UNDER FS-D ACROSS RISK PREFERENCES BASELINE SCENARIO

Dominant Strategy	Prior Knowledge Activity	Lower Bound	Upper Bound
Risk Preferring FS-D			
	BS-5	3732.15	6098.33
	BS-4	2402.65	3776.24
	BS-3	3062.44	3666.08
	BS-2	1922.30	2638.86
	BS-1	1357.27	2306.21
Risk Neutral			
	BS-5	2443.54	3732.30
	BS-4	1791.23	2402.80
	BS-3	2492.37	3077.55
	BS-2	2189.33	2503.36
	BS-1	1802.98	2144.47
Slightly Risk Averse			
	BS-5	739.44	2443.54
	BS-4	1291.20	1791.38
	BS-3	1672.21	2492.22
	BS-2	1619.57	2211.00
	BS-1	1241.46	1831.97
Strongly Risk Averse			
	BS-5	0.00	739.44
	BS-4	1045.38	1291.20
	BS-3	1055.91	1672.36
	BS-2	971.38	1620.48
	BS-1	652.47	1242.98

associated with BS-5 tend to compress the net return distribution and eliminate the possibility of low or high annual net returns. Therefore, the risk preferrer will be willing to pay a large premium for the BCS information and the possibility of realizing large net return outcomes. He will be less willing to pay for the information if prior knowledge dictates the use of BS-1, since the possibility of high annual net returns exists under the fixed supplementation strategy. For the strongly risk averse producer, the reverse circumstance occurs. The BCS information has a much higher value to this individual if prior knowledge dictates the use of BS-1, since this activity may result in a low net return outcome. The decision maker has a high willingness to pay for avoiding these situations due to his/her strong aversion toward risk.

Information is often characterized as a risk-reducing input. However, as the decision maker becomes more risk averse, he/she will not always be willing to pay more for the information. Such a case can be illustrated by comparing the value of information across the four risk preferences when BS-5 is the prior knowledge activity. The value of information decreases monotonically as the level of risk aversion increases. In this case, BCS information provides the producer the opportunity to increase expected net returns primarily by realizing some high net return outcomes; however, some probability remains for low outcomes. Income risk can be minimized through the use of the fixed supplementation strategy; therefore, the BCS information has a much lower value to the risk averter. Changes in the value of BCS information across risk preference intervals are much lower when the dominant distribution is compared to BS-1. In this case, risk can be reduced by adopting the flexible supplementation strategy; therefore, the value of the information to the risk averter is higher than when BS-5 is the prior knowledge activity. However, the risk preferrer is still more willing to pay for the BCS information than the risk averse decision maker.

One can argue that the most relevant value of information under each risk classification corresponds to the base activity selected by the decision maker with similar risk preferences. That is, the appropriate prior knowledge activity would be the one identified as risk efficient under the generalized stochastic dominance criterion. These activities are noted with an asterisk in Table XVI. Basing the value of BCS information on the other activities overstates the information value since the decision maker would not select these activities from the set of fixed supplementation activities

The upper and lower bounds in Table XVII reflect the value of information under the three price scenarios considered in the analysis. As in Table XV the risk aversion coefficients employed are $r_1(x) = .0004$ and $r_2(x) = .0001$ and reflect slight risk aversion. With the exception of when BS-5 is the prior knowledge distribution, the value of BCS information increases as the cattle:feed price ratio increases. Lower and upper bounds on the value of BCS information average $1,357 and $920 more under price scenario 1 than under price scenario 2.

The sensitivity of the value of information to economic conditions is dependent upon which activity is used to represent the fixed supplementation strategy. If BS-5 is used as the prior knowledge activity, the value of information increases significantly as the cattle:feed price ratio decreases. The cost of excessive supplementation is high under this price scenario; therefore, the BCS information has a higher value in reducing feed costs and increasing returns. On the other hand, the value of BCS information declines as the cattle:feed price ratio decreases when the dominant distribution is compared to BS-1. BS-1 is a member of the efficient set for risk averse producers facing this price

TABLE XVII

LOWER AND UPPER BOUNDS ON THE VALUE OF BODY CONDITION SCORE FOR A SLIGHTLY RISK AVERSE DECISION MAKER UNDER ALL THREE PRICE SCENARIOS

Dominant Activity	Prior Knowledge Activity	Lower Bound	Upper Bound
Price Scenario 1			
FS-D			
	BS-5	0.00	1491.39
	BS-4	1505.74	1771.09
	BS-3	2565.16	3069.76
	BS-2	3069.76	3383.79
	BS-1	2855.22	3149.11
Baseline Price Scenario			
FS-D			
	BS-5	739.44	2443.54
	BS-4	1291.20	1791.38
	BS-3	1672.21	2492.22
	BS-2	1619.57	2211.00
	BS-1	1241.46	1831.97
Price Scenario 2			
FS-D			
	BS-5	1680.30	3489.84
	BS-4	894.47	1819.76
	BS-3	636.90	1777.34
	BS-2	0.00	866.09
	BS-1	0.00	314.48

scenario. The low value of gain translates to a low value of the information to be used in achieving additional gain.

CHAPTER V

SUMMARY AND CONCLUSIONS

Cow-calf production is an important component of Oklahoma's agricultural economy. Cattle and calves contributed approximately 1.46 billion dollars of gross income to the coffers of the state in 1990. The importance of beef production sector can be primarily attributed to the state's abundant forage resources, with native rangeland characterized by a vast array of vegetation types traversing across the state. This diversity of vegetation translates to diversity in ecology, productivity, and range quality.

In order to remain competitive, cow-calf producers must make production decisions in response to an ever-changing environment and prevailing uncertainties in production and prices. The producer must ensure the production of more beef per acre while simultaneously receiving a return that, at least, covers the variable cost of production. Undoubtedly, the most critical factor of production in cow-calf production is the feed input. Supplemental feed represents the largest production cost and has significant implications on the present and future reproductive performance of the cow herd. Reproduction is the focal point of any cow-calf system. The profitability of any cow-calf enterprise is primarily determined by the number of calves sold per cow, the weight of the calves, and the uniformity of the calf crop.

Problem Statement

Determination of feeding programs are critical economic decisions facing cow-calf producers. The beef cattleman should, therefore, aspire for feeding practices that are economically efficient and by implication physically efficient. Feeding programs, including supplementation levels, should also change relative to the prevailing economic conditions, particularly calf prices and feed costs. Economic efficiency dictates that feed inputs should be used to the point where the marginal value product of feed equals the marginal input cost. The problem with applying such a criterion is that the conversion of feed to output is a complex process. Dynamic and stochastic factors complicate the process of estimating the implicit value of the feed input.

Traditional cow-calf nutrition management strategies have been based upon target levels of reproductive performance, such as calving percentages and weaning weights. Based upon historical observation and limited scientific input, rules of thumb have been developed to aid producers in making supplementation decisions. However, raising a cow-calf for beef is laden with environmental influences which translate to variability in such factors as forage quality, forage availability, cow energy requirements, and death loss. These changes, coupled with those of the economic environment, are bound to affect changes in objectives regarding reproductive efficiency. These changes would then lead to changes in feed requirements, which in turn will affect weaning weight, weight gain, and other measures of reproductive performance.

Recent research efforts to better understand the relationship between cow body condition and reproductive performance has tremendous potential to improve the efficiency of the cow-calf production sector. Research has led to the further refinement of the concept of body condition score to quantify the nutritional status and reproductive potential of breeding cows. Results indicate that cow body condition score is unequivocally linked to pregnancy rates and days from calving to next conception. The BCS concept is based on developing feeding programs that ensure that cows at calving are in condition for successful breeding and rebreeding in the midst of all uncertainties.

The major purpose of this study is to develop a method by which economic criteria can be introduced into the nutrition-reproduction management of the cow-calf enterprise. The analysis will assess the use of body condition score to improve reproductive performance and integrate economic factors into supplementation decisions.

Model Development

A bioeconomic simulation model was developed to represent the primary components of the cow-calf production system, including forage production, supplementation, cow reproduction, and resulting economic returns. The simulation model, written in the Fortran programming language, represents the biological behavior (breeding, gestation or pregnancy, parturition or calving) of cow-calf enterprise grazing on native range. The model was developed with the intent of developing management information concerning different supplementation strategies during periods of energy deficit. The model structure consists of four major interconnected submodels: (1) a forage production submodel, (2) a cow-calf production or growth submodel, (3) a cow herd model, and (4) an economic submodel.

The forage model consists of a modified version of the ERHYM Model to provide estimates of annual forage production. A 25-year series of monthly forage quality was developed to represent the dynamic and stochastic characteristics of rangeland forage quality. The cow-calf model uses the forage production data to simulate the daily energy balance of breeding cows. Energy requirements are calculated using a modified version of the California Net Energy System, accounting for such factors as cold stress, lactation, pregnancy, and body condition effects. Estimated energy deficits and surpluses are converted to changes in cow weight and body condition based upon published finding relating cow condition to energy deficits. Cow reproductive performance is then estimated as a function of cow condition based upon findings from several years of body condition experiments conducted at Oklahoma State University.

When the feeding program is managed according to some specified objectives (such as maximizing expected returns from weight gain or weaning weight) then the question arises as to which feeding strategies are optimal. This creates the need to examine how the various feeding strategies are affected by environment and economic conditions, as well as how the level of returns is affected by these conditions.

The cow herd submodel inventories the number of cows in each body condition state at the initiation of each production year. A separate simulation is then run to estimate the physical performance of each group of cows characterized by a body condition state. The economic submodel was designed to calculate annual net returns based upon simulation results and existing enterprise budget data. Prices of inputs and outputs were based upon average prices for the relevant inputs in the area under study. Prices for the protein supplement, cows, and calves were calculated from historical data and were varied to represent different economic conditions. Other costs were assumed fixed.

Summary of Results

The model was applied to evaluate the physical and economic performance of a 100-head spring-calving cow herd under alternative supplementation strategies. Twenty alternative supplementation activities were developed to represent the range of alternatives available to producers. The supplementation strategies differ in terms of the quantity of supplement fed and the ability of the manager to change supplementation levels in response to changes in cow condition. Estimates of annual net returns were generated by the simulation model for each of 20 supplementation strategies over a period of 25 years.

Four sets of supplementation activities were developed: (1) baseline, (2) late-summer supplementation, (3) variable supplementation, and (4) flexible supplementation. In the baseline activities, a fixed quantity of supplement is fed during the supplementation period (November through mid-April). In this case, the manager is not able to monitor body condition score and adjust the supplementation program accordingly. Supplementation levels evaluated ranged from a low level (.8 to 1.2 pounds per day) to a level that virtually eliminates any significant energy deficits during the fall-winter period (3.0 to 4.5 pounds per day). Supplementation quantities are also fixed in the second set of activities, with the exception that supplementation is initiated prior November 1 if cows are in low body condition. In the third set of activities (variable supplementation) supplement levels fed in November through April are based upon the BCS on November 1. The flexible supplementation strategy represents further improvements in the use of body condition information. BCS is evaluated at several points during the year and feeding adjustments are made accordingly.

Significant differences in reproductive performance are observed across the 20 supplementation activities. Incremental increases in average annual weaning percentage and weaning weights occur as supplementation levels increase in the baseline activities. Increases in supplementation levels also translate to a reduction in the variability of annual weaning weights and weaning percent. Average weaning percent and weaning weights only increase marginally as a result of late-summer supplementation; however, significant improvements in reproductive performance occur under the variable and flexible strategies. The ability to adjust supplementation levels in accordance with body condition is shown to be a powerful tool in increasing the reproductive performance of spring-calving cow herds.

Under the baseline strategy, average annual net returns are not greatly affected by the level of supplementation, and range from $12,291 under high supplementation to $13,408 under the lowest level. Significant differences in the variability of net returns do occur across the five supplementation levels. Expected annual net returns are increased above baseline levels under the variable supplementation activities. As a result of improved reproductive performance and reduced feed costs, variable supplementation increases expected net returns an average of 11 percent above the comparable baseline activity. Average annual net returns are further increased under flexible supplementation. Therefore, decision makers employing a criterion of maximizing expected net returns do have an economic rationale for utilizing BCS information in making supplementation decisions.

Stochastic dominance procedures were applied to the net return distributions to identify risk efficient supplementation activities for decision makers characterized by alternative risk preferences. Risk efficient sets were identified based upon several efficiency criteria, including first-degree stochastic dominance (FSD), second-degree stochastic dominance (SSD), and generalized stochastic dominance (GSD). Stochastic dominance procedures were first applied to the 10 fixed supplementation activities, then the activity set was augmented to include activities which utilize BCS information in determining supplementation levels.

FSD and SSD exhibit a limited capability of reducing the number of activities comprising the efficient set; however, application of GSD reduces the efficient set to three or fewer activities for each risk preference interval considered. The results indicate that risk preferences play an important role in supplementation decisions. Generally, supplementation levels increase as decision makers become more risk averse. Risk preferrers select the lowest level of supplementation, which is also characterized by the greatest net return variability. In contrast, strongly risk averse individuals prefer the highest supplementation level, despite the fact that it provides a relatively low average net return.

To evaluate the effect of cattle and feed prices on supplementation decisions, net return distributions were developed under two alternative price scenarios. Under a combination of high cattle prices and low feed costs, the profit maximizing level of supplement fed in the fall-winter period is increased over one pound per day above the level derived under the baseline prices. Under low cattle and high feed prices, the profit maximizing supplementation level is identical to the baseline economic situation. Risk efficient sets of supplementation activities also change significantly under the alternative economic settings. Therefore, optimal input levels are sensitive to feed and cattle prices, and all managers, regardless of risk attitudes, should consider these factors in making supplementation decisions.

To evaluate the effect of introducing BCS information into supplementation decision making, all 20 activities were included in the stochastic dominance analysis. Flexible supplementation strategies dominated the risk efficient sets across all risk preference intervals. Strategies which monitor and adjust supplementation levels reduce the profitability of low reproductive performance in years of poor environmental conditions. In addition, net returns are maximized in years of favorable environmental conditions by reducing the quantity of supplement fed.

Based upon the dominance of the BCS-based criteria in the stochastic dominance results, it is apparent that BCS information has an implicit value to decision makers. By employing BCS information, managers can make better projections of the supplementation practices required to attain some physical and/or economic objective. The value of BCS information was estimated using stochastic dominance procedures outlined in Mjelde and Cochran. The decision maker's willingness to pay for BCS information can be thought of as the premium he/she is willing to pay before he/she is indifferent between buying the information and selecting the action without the information.

The value of BCS information is shown to be sensitive to both decision maker risk preferences and the level of prior knowledge assumed. The level of prior knowledge reflects the fixed supplementation strategy that the dominant strategy is being compared with. As expected, the value of information increases as the ability to monitor BCS and make feeding adjustments improves.

Although information is often characterized as a risk reducing input, the decision maker will not always be willing to pay for information as he/she becomes more risk averse. This circumstance prevails in the case where the dominant distribution is compared with a fixed supplementation activity feeding high levels of supplement. In this case, the risk preferrer is most willing to pay for BCS information, and the value of information decreases as the decision maker's level of risk aversion increases. The value of BCS information to the risk preferrer rests on its ability to match supplementation levels with nutritive demands and increase the probability of high net return outcomes. Conversely, risk averters place value on the information for its use in minimizing the probability of low net return outcomes.

General Conclusions

Results of the analysis indicate that body condition score is a useful observable measure from which to base cow-calf supplementation decisions over the production season. Monitoring body condition score and adjusting supplementation levels was shown to improve reproductive performance and increase expected net returns from cow-calf production. In addition, BCS-based supplementation activities were included in the risk efficient set across all risk preferences. By matching supplementation levels with nutritive demands, the use of BCS information tends to reduce feed costs, and hence increases net returns, in years of favorable environmental conditions. In addition the use of BCS information insulates the producer from low net returns in years of poor environmental conditions. Value of information estimates indicate that producers exhibit a high willingness to pay for body condition score information, regardless of risk preferences.

It is recognized that the specific results reported in this study are limited to cow-calf production in central Oklahoma due to the site specificity of the data employed. In addition, the findings are specific to the size and breed of the cow herd, as well as the loamy prairie range site represented in the forage quality and quantity data. However, the model structure does provide a means of representing cow-calf nutrition and body condition score relationships in supplementation decision making. In addition, the general strategies derived from the model provide insight into supplementation decision making in spring-calving enterprises throughout the region.

Limitations of Study and Need for Further Research

In the process of conducting this research several difficulties were encountered. These problems indicate several gaps in the current level of knowledge concerning reproductive performance of beef cows and the relationship between body condition score and reproduction. These shortcomings provide several opportunities for future research in the disciplines of animal science, range management, and applied economics.

Perhaps the most important area requiring additional research attention relates to simulating changes in the quality of rangeland forage over the production season The cow-calf model was shown to be relatively sensitive to forage quality data, and forage quality represented the principle source of variability present in the analysis. Limited data is available to model seasonal variation in the quality of rangeland, and attempts to relate changes in forage quality to climatic variables have not been successful. In addition, forage quality estimates used in the model are based upon forage clipping data, while the cow-calf model is based upon the quality of forage actually ingested by the animal. Additional research is needed to reconcile differences in the quality of standing forage and the quality of actual intake.

Considerable research has been conducted in Oklahoma assessing the effect of body condition score on reproductive performance. A literature search revealed that this topic has received considerably more attention in Oklahoma than any other region. Despite the numerous studies that have been conducted, additional research is needed to validate several of the underlying production relationships used in the model. Among the most important of these relationships are changes in cow weight in response to energy deficit, changes in body condition score, and the effect of body condition score on reproductive performance.

The model performed reasonably well in simulating changes in cow weight and body condition score over the production season. However, because data is not available indicating changes in forage quality during these experiments, it is difficult to validate the cow-calf model as to its ability to project changes in cow weight and/or body condition over time. To more precisely validate the various components of the cow-calf model it is necessary to conduct experiments where forage quality, cow weight, intake, and body condition score are measured at frequent intervals throughout the production season. Additional years of experimental data are also required to assess the ability of the model to predict changes in cow condition and body condition score under various environmental conditions.

The relationships estimated to relate weaning weights and weaning percentage to body condition are based on limited empirical data. Research indicates that the relationship is more complex than represented in the analysis, and successful rebreeding is also dependent upon whether the cow was gaining, maintaining, or losing weight prior to calving. Additional data could provide sufficient data to develop a more complex representation of the interactions between body condition and reproductive performance.

From an economic perspective, future research could focus on several improvements. Development of a forage quality model would increase the time horizon of the analysis and improve the robustness of the estimated net return distributions. Also, as indicated earlier, the body condition score problem is truly dynamic and has important inter-seasonal and intra-seasonal dynamic components. Improved insight into developing economically efficient supplementation strategies could be provided by applying a dynamic optimization approach. Application of stochastic dynamic programming would provide a mapping of optimal supplementation levels to various body condition states at various points in the production season.

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