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Simulation Studies on the Effects of Cow Size, Milk Production and Calving Season on the Bioeconomic Efficiency of Beef Production

by

Hang PANG ©

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled SIMULATION STUDIES ON THE EFFECTS OF COW SIZE, MILK PRODUCTION AND CALVING SEASON ON THE BIOECONOMIC EFFICIENCY OF BEEF PRODUCTION submitted by HANG PANG in partial fulfilment of the requirements for the degree of DOCTOR OF PHILOSOPHY in ANIMAL BREEDING AND GENETICS.

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ABSTRACT

A dynamic deterministic model, **Beef Production Simulation System (BPSS)**, was developed to evaluate the effects of cow size (mature cow weights of 450, 550 and 650 kg), milk production (peak milk yields of 5.4, 8.2 and 10.9 kg/d), calving season (spring and fall), market price (low, medium and high price), and their interactions on the bioeconomic efficiency of cow-calf production systems. The model is programmed using Stella II simulation software on PC/Windows or Macintosh platforms, and is composed of four major submodels: Herd Inventory, Nutrient Requirements, Forage Production, and Economic submodels. The results of simulations indicated that dry matter intake (DMI) and total cost per cow increased with increasing cow size. When comparisons were at constant weaning age (200 d), medium cow size had the highest bioeconomic efficiency at the low price level. Large cow size had the highest bioeconomic efficiency at the high price level. This indicates interaction between cow size and market price. Calf forage DMI decreased with higher milk production, but calf milk DMI, cow DMI and total cost per cow increased with higher milk production. The high milk production class had the highest bioeconomic efficiency because of heavier calves at weaning, regardless of the price level or the cow size. Fall-calving resulted in higher DMI and feed cost. Bioeconomic efficiency was higher in the spring-calving season group when the average weaning age was less than 200 days. However, at an average weaning age of 220 days, bioeconomic efficiency was higher in the fall-calving season group due to the higher market price of the fall born calves. In conclusion, BPSS provides a useful method for simultaneous consideration of many factors in an integrated system, which could be helpful to beef cattle extension specialists and cow-calf production managers, for

predicting the effects of different management and selection strategies on bioeconomic efficiency. Proper use of the model, when the factors which influence bioeconomic efficiency are well defined, will hopefully lead to a strategy which has a higher probability of success under a defined environment.

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Chapter 1

General Introduction

1.1. Introduction

Winter feeding of beef cows represents a major expenditure in cow-calf operations. Selection for growth rate and the use of large size continental breeds by commercial producers have resulted in larger cows with higher feed requirements and higher incidence of calving difficulty (Scholtz and Roux, 1984). Lopez de Torre et al. (1992) suggested that productive efficiency may be reduced in cows of relatively large mature weights and that the use of fast maturing animals would be a more efficient alternative.

Increasing growth rate as a breeding objective in beef cattle has been questioned. Barlow (1984) even suggested that there was no sound basis for advocating selection for growth rate in maternal breeds. While increased growth rate results in higher gross efficiency (gain/feed intake) in a growing animal, the higher maintenance requirements of heavier breeding females reduce efficiency at the herd level (Dickerson, 1982). Therefore, the benefit of increasing output by increasing body size may be largely offset by increased feed requirements. A major determinant of feed costs is cow size and milk production. Biological type primarily refers to different combinations of cow mature weight and milk production (Basarab, 1995). Cow-calf managers have become increasingly aware of the need to match the cow's biological type and management to the available feed, labour and capital resources in order to improve overall production efficiency (Kress et al., 1994; Porter, 1995).

In western Canada and USA, beef cows are usually mated during a breeding season that starts in early summer. Open cows could either be culled or re-bred in the winter. This option would result in having both a spring and a fall calving herd (Azzam et al., 1991). Spring calving can take advantage of relatively inexpensive pasture when calves are growing (Berg et al., 1991). Fall calving, on the other hand, can be advantageous if cheap feeds are available during the winter, and prices for weaned calves are usually higher in the spring (Agriculture and Agri-Food Canada, 1995).

Researchers in nutrition, genetics, physiology and management of beef cattle have identified many important factors which influence production efficiency. Fitzhugh (1978) indicated that production efficiency, whether expressed in biological or economic terms, should be evaluated for the whole integrated system, not just the individual animal. Different constraints may lead to important biological type x production environment interactions for production efficiency. Amer et al. (1994) stated that to achieve a true economic weighting system, all aspects of production must be optimized. This can be done by replacing the traditional single output production function with a complex simulation model designed to evaluate overall bioeconomic efficiency.

It is often difficult or impossible to physically evaluate the effect of alternative management strategies to best utilize a set of available resources. Some traits are either difficult to measure or it is not possible within the living system to change a particular factor in order to evaluate its particular effect. Fortunately, the computer simulation model is a powerful tool available to tackle this problem. Many biological relationships have been more precisely defined based on research in nutrition, genetics and physiology of beef cattle.

Computer simulation provides an excellent tool for the integration of quantitative knowledge from a number of disciplines which can have an impact on animal production and profitability. It allows any number of subsystems to be examined, to simulate alterations in a subsystem and to predict the expected results on the whole system (Spreen et al., 1986). The advantage of computer simulation is that it takes much less time and is much less costly than working with a true biological system. Many industries rely on simulation models to evaluate different management scenarios, finally choosing the strategy which is predicted to impact most favourably on the future viability of the enterprise.

1.2. Objectives

The objective of this study is to develop simulation models which could be used to compare the influence of different production inputs on the bioeconomic efficiency of beef production systems. Factors to be tested in the model are cow size, milk production, calving season, weaning age, and market price. Interactions of these factors are examined to simulate their combined effects on the bioeconomic efficiency of cow-calf production system.

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Chapter 2

LITERATURE REVIEW

2.1. Modelling and Simulation

2.1.1. Some Concepts

Modelling and simulation are complex activities associated with constructing models of real world systems and simulating them on a computer. There are three major elements: real system, model and computer.

Modelling deals primarily with the relationships between real systems and models. **Simulation** refers primarily to the relationships between computers and models (Zeigler, 1984).

A **model** is a representation of a system or a component of that system (McNitt, 1983). It consists of a **symbolic model** and **an abstract model**. The symbolic model includes **graphical, diagrammatical and mathematical models**. The graphical and diagrammatical models aid in visualizing a system and its performance. The **mathematical model** consist of a statistical model, an analytical model and a simulation model (Bratley et al., 1983).

A **simulation model** is a mathematical-logical abstraction and simplification of the real world system, so as to capture the principal interactions and behaviour of the system under study (Naylor, 1971).

A **system** is a collection of interdependent objects having a defined purpose and treated as a "whole" (Deo, 1983).

Systems analysis involves an analysis of the components of a system and their relationships. The purpose may be to design a new system or to improve an existing system. Systems analysis usually involves direct or indirect study of the target system using models of all or part of that system (McNitt, 1983).

2.1.2. Types of Simulation

1) Continuous vs discrete event simulation

Continuous simulation is applicable to systems whose variables are continuously changing. The output can take any value (integer or non-integer) over a given range (Roberts, 1983).

Discrete event simulation is applicable to systems whose variables change at distinct points in time. The output typically represents a number of occurrences (Pidd, 1989).

2) Static vs dynamic model

A **static model** is applicable to systems at a particular point in time (Leigh, 1983).

A **dynamic model** involves a continuous flow of changes or a series of discrete state changes. It usually represents the behaviour of the system over time (Jacoby and Kowalik, 1980).

3) Deterministic vs stochastic simulation

Deterministic simulation: In deterministic simulation, the values of all variables are known. Given a specific set of inputs to the model the outputs will always be the same. It is simple to analyse as only one replication (trial) is needed for each set of input parameters (McNitt, 1983). It is used to predict the behaviour of a system for different sets of conditions

(Spriet and Vansteenkiste, 1982).

Stochastic simulation: In stochastic simulation, one or more of the inputs is a random variable. The behaviour of such variables can be represented by a probability distribution. The outputs for any one replication is uncertain. Analysis of a stochastic model involves identifying averages and average trends. It can predict the mean and variance of the variable (Kheir, 1988; Karian and Dudewicz, 1991).

Monte Carlo simulation is restricted to those simulations in which random numbers are used to obtain solutions for problems which are inherently deterministic. On the other hand, stochastic simulation is used for those simulations that employ random numbers to solve inherently stochastic problems (Deo, 1983). "Time plays no role" is what distinguishes Monte Carlo simulation from discrete event simulation in which time plays a significant role (Zeigler, 1984).

2.1.3. The Simulation Process (Neelankavil, 1987; McHaney, 1991):

The simulation process involves the following steps:

Problem Definition and Formulation
↓
Data Collection for Parameters
↓
Model Construction
↓
Computerize the Model
↓
Verification and Validation
↓
Experimental Design
↓
Simulation Run

↓

<u>Analysis and Evaluation</u>

↓

<u>Implementation of Results</u>

2.1.4. Simulation Methods:

Continuous dynamic systems are generally represented by means of differential equations. Numerical solution of these differential equations involve some integrating procedures (Ralston and Reilly, 1983; Vandergraft, 1983; Pachner, 1984).

1) Euler's method:

Based on finite difference approximation to the derivative, "Forward difference formula" is:

$$f'(x) \approx \lim_{\Delta x \to 0} \{[f(x+\Delta x) - f(x)] / \Delta x\}$$

As $\Delta x \to 0$, the limit on the right is the definition of $f'(x)$, if Δx is small enough, the difference quotient will be close to $f'(x)$. So, Euler's formula becomes:

$$f(x+\Delta x) = f(x) + f'(x) * \Delta x$$

2) Taylor's theorem (infinite):

$$f(x+\Delta x) = f(x) + f'(x) * \Delta x + f''(x) * (\Delta x)^2 / 2! + ... + f^n(x) * (\Delta x)^n / n!$$

Euler's formula provides an approximated estimate, using only the first two terms of the Taylor' series.

3) Trapezoidal rule:

Numerical integration is to compute an approximation to the definite integral:

$$I = \int_a^b f(x)\, dx$$

To find the area between the curve for f(x) and the x-axis on the interval (a, b).

Trapezoidal rule: subdividing the interval (a, b) into N equal parts, each of length Δx, so $N * \Delta x = b - a$, let $x_0 = a$, $x_1 = a + \Delta x$, ... $x_N = b$. So the area of a trapezoid over one panel is:

$$T_i = \Delta x * (f_{(i-1)} + f_i) / 2$$

Adding the area over each panel, the total area is given by:

$$T = \Delta x * (f_0 + 2f_1 + 2f_2 + \ldots + 2f_{N-1} + f_N) / 2$$

Deo (1983) explained the difference between ordinary numerical integration and a continuous system simulation as follows:

(1) In simulation, we always keep track of the state of the system explicitly, i.e. the outcome of each step in simulation can be interpreted directly. In a numerical solution of an equation no such correspondence is preserved.

(2) There is a difference of attitude: in pure numerical calculation, we only see the given set of differential equations as a mathematical object and proceed to integrate them. But in simulation, we look upon the equations as one of the steps in the entire process. If necessary, we also prepare to modify the model based on the output data.

2.2. Simulation Models in Beef Cattle Production

Traditionally, application of animal science has been based on three general assumptions: (1) increased productivity in any single production component will result in greater net output by the system; (2) production units tend to respond similarly to inputs across geographical areas and types of production systems; (3) biological efficiency of production is closely correlated with profitability (Cartwright and Doren, 1986). This is simplistic and general, ignoring the interactions existing among genetic, environmental, and economic inputs and outputs. However, simulation technology can be used to identify and quantify these interactions.

The beef cattle production system is a complex aggregate of subsystems, each somewhat dependent on the others. Maximizing the effect of one particular sector may reduce the functional capability of the total system. Evaluation of interactions among system components leads to greater understanding of the total system. Computer modelling has the potential to integrate results from larger, more complex systems, but is limited by its ability to describe the system and its components mathematically. If the knowledge of the components can be quantified and presented in a mathematical form, simulation models can be applied for more detailed and mechanistic studies to provide more thorough understanding of the total system (France and Thornley, 1984).

Simulation modelling has received considerable attention in the last twenty years. Some of the simulation studies in beef cattle production are: Zulberti and Reid (1972); Wilton et al. (1974); Joandet and Cartwright (1975); Morris et al. (1976); Sanders and Cartwright (1979a,b); Notter et al. (1979a,b,c); Congleton and Goodwill (1980a,b,c); Loewer et al. (1981, 1983, 1986); Kahn and Spedding (1983); Clarke et al. (1984); Fox and Black (1984); Fox et al. (1988, 1992, 1995); Harris and Stewart (1986); Cartwright and Doren (1986); Oltjen et al. (1986a,b); Bourdon and Brinks (1987a,b,c); Johnson and Notter (1987); MacNeil and Harris (1988); Brinks and Miller (1990); Werth et al. (1991); Lamb et al. (1992a,b,c);

Keele et al. (1992); Williams et al. (1992a,b); Naazie (1992); Alberta Agriculture (1993); Amer et al. (1994a,b,c); Davis et al. (1994a,b); Pang et al. (1996a,b,c); and NRC (1984, 1987, 1996). The specific questions being addressed by these simulation studies varies considerably, but all can be described as involving the interface between animal performance and production system for livestock.

There are two types of simulations in animal production: 1) deterministic simulation; and 2) stochastic simulation. Models used in beef production simulation are usually dynamic and deterministic (Dougherty et al., 1985).

In deterministic simulations, the population is described in terms of the means and variances of each group of animals in the population. These values are determined according to fixed function relationships with means and variances of earlier groups of animal. Random sampling is not involved in the process. Thus the outcome for a given set of input parameters is always the same. One difficulty with deterministic simulations is that all processes must be describable in terms of algebraic functions (Kahn and Spedding, 1983).

Stochastic simulation is mainly used in animal breeding and genetics. With this model, the records for each animal are generated in the population by random sampling from pre-defined distributions which are determined by the rules of inheritance, and origins of environmental effects imposed on the model. Because random sampling is involved, the results of any two runs of the program are unlikely to be the same.

The inclusion of the random variable has the effect of introducing a degree of variability into the system that attempts to mirror the variability found in the real world. The use of stochastic simulation variables in models is increasing. Weather data are the variables most commonly treated stochastically, because of the size and comprehensiveness of that particular database (Smith et al., 1985).

In bioeconomic models the order of analysis is to first perform the biological simulation and then to compute the economic implications of the simulation. This order is chosen because management decisions which change biological performance of the animal have an impact on economic performance (Denham and Spreen, 1986; Spreen and Laughlin, 1986).

Some of the widely recognized simulation models for cattle production are:

1. **Texas A&M beef cattle simulation model** (Sanders and Cartwright, 1979a,b; Notter et al., 1979a,b,c; Sullivan et al., 1981; Doren et al., 1985; Cartwright and Doren, 1986; Bourden and Brinks, 1987a,b,c). This model is used to examine the effects of the major production traits on biological and economic efficiency under different management systems and economic conditions. The basic method involves updating each simulated animal's growth and energy status at monthly intervals, according to the availability of ME during that time period. The model has been widely used under various environmental conditions for simulating beef production systems. One of the major contributions of the model is that it allows analysis of the impact of the micro-level decision-making process for livestock producers. The system simulated by this model involves only the growth, reproduction and lactation of beef cattle. This model did not simulate the economic system which impacts beef production strategies (Cartwright and Doren, 1986). The model was used on a mainframe computer which is not user friendly.

2. **The Cornell net carbohydrate and protein system (CNCPS) for evaluating**

cattle diets (Fox and Black, 1984; Fox et al., 1988; Fox et al., 1992; Russell et al., 1992; Sniffen et al., 1992; O'Connor et al., 1993; Fox et al., 1995; Pitt et al., 1996). CNCPS is a nutritional accounting system designed to predict cattle nutrient requirements, and feed energy and protein utilization for a specific combination of cattle type, feed supply, environment and management conditions. The model contains a biologically based structure and hierarchy for evaluating all classes of cattle diets. Its purpose is to adjust nutrient requirements and feed utilization over wide variations in cattle, feed management and environmental conditions. The CNCPS was developed over a period of 15 years. It uses information and codes that can be universally obtained, understood and applied to describe cattle, and can be easily used in computer programming. However, the model did not simulate the economic system, and it was not a dynamic model.

3. **Kentucky beef-forage model** (Loewer et al., 1981; Loewer et al., 1983; Smith et al., 1985; Loewer and Smith, 1986). This is a total farm system simulation model which allows users to effectively evaluate the consequences of management decisions on plant and animal production, energy consumption, and economic returns. The model consists of: a plant growth-composition model; a physiological animal growth-feed intake model; and a plant-animal interface model which describes the logic of selective grazing as a function of the environment. The model was designed for a mainframe computer.

2.3. Cow Size

Selection for growth rate in beef cattle and the use of large size continental breeds by commercial producers, have resulted in larger cows with higher feed requirements and higher frequency of calving difficulty. In recent years, selection for growth rate as a breeding objective has been questioned (Basarab, 1995). Cow-calf managers have become increasingly aware of the need to match the cow's biological type and management to the available feed, labour and capital resources in order to increase production efficiency (Kress et al., 1994; Nickel, 1995; Porter, 1995).

Cundiff et al. (1992), based on an extensive and long term crossbreeding experiment, indicated that breeds that excel in growth rate require more total inputs. They also produce progeny with heavier birth weights which results in higher incidences of dystocia, particularly from heifers. It can, therefore, be concluded that an increase in output as a result of increase in size, is largely offset by increased feed requirements.

Long, Cartwright and Fitzhugh (1975) used the Texas model of cattle production systems to evaluate the effects of mature cow size on beef production and financial returns under two herd management regimes (drylot and pasture). Three size genotypes, represented by mature cow weights of 430, 500 and 600 kg, were compared. Economic comparisons revealed that smaller cows required slightly higher capital investment because of the accumulated effect of the fixed per head costs for health care, labour, taxes and management. Measures of economic efficiency, net income and return on investment, indicated an interaction between cow size and management regime. Larger cows were more profitable and returned more per total investment in drylot, while smaller cows were slightly more profitable on pasture.

Fitzhugh (1978) indicated that the variation in metabolic efficiency of production and maintenance activities is not related to size. Thus, when the system's inputs and outputs are proportional to size and are not constrained in different ways for different size genotypes, no general relationship between breeding female size and production efficiency would be expected. Under commercial production systems, however, differential constraints (such as feed, labor, and capital) are imposed leading to important size genotype x production environment interactions for production efficiency. Improvement of production efficiency will involve adjustment of the size and milk production of breeding female to suit a particular environment or adjustment of the environment to suit a particular biological type.

Dickerson (1978, 1982) argued that profit may be more associated with cost reduction than with increases in productivity. While increased growth results in higher gross efficiency (gain/feed intake) in growing animals, the higher maintenance costs of heavier breeding females leads to no advantage or even a disadvantage at the herd level. Barlow (1984) suggested that there was no sound basis for advocating selection for growth rate in maternal breeds.

Scholtz and Roux (1984) indicated that selection for increased body mass or growth rate may have an adverse effect on fertility and body composition. The main problems with selection for body mass or growth rate appear to be an increase in the percentage of body fat and a decrease in viability and reproductive fitness. It seems that body mass and growth rate have to be kept within certain fixed limits to maintain homeostasis. The inverse relationship between body mass and fertility may be due to a departure from an optimum body mass and the disturbance of homeostasis.

Scholtz et al. (1990) surveyed the results of selection experiments which have appeared in Animal Breeding Abstracts (ABA) since 1938. In 90% of the experiments, selection for body weight or growth rate resulted in undesirable correlated responses, such as an increase in body fat and a decrease in overall fitness. They also found that the relationship between body weight and fertility in beef cattle tended to be negative. This suggests that selection for meat production should not be based on growth rate alone.

Lopez de Torre et al. (1992) studied the relationship between growth curve parameters and cow efficiency, and reported a decrease in number of calves weaned when mature weight increased. There was a nonsignificant trend for heavier cows to have calves with heavier birth weight or weaning weight. They also found that productivity may be reduced in cows of relatively large mature weights, and that fast-maturing animals would be more efficient.

2.4. Milk Production

Profit from cow-calf production units is influenced mainly by the average calf weaning weight and percentage calf crop weaned (Wiltbank, 1970). Drewery et al. (1959) stated that milk production of the dam exerts a major influence on weaning weight of the calf. In practice, milk yields are moderately correlated with weaning weights (averaged 0.6, range between 0.12-0.8; Furr and Nelson, 1964; Lusby et al., 1976, Gleddie and Berg, 1968, Butson et al., 1980). Nevertheless, research has indicated that calves receiving less milk increase their forage intake (Baker et al., 1976; Ansotegui et al., 1991).

Clutter and Nielsen (1987) found a significant advantage in 205-d weight of calves suckling high-milking cows over those suckling low-milking cows. However, this advantage was offset by 1) the higher energy cost for milk versus other feed sources; 2) higher milk production is associated with higher requirements for maintenance (Montano-Bermudez et al., 1990); 3) reproduction, as measured by calves weaned/cow exposed, tends to favor the lower milking groups (Montano-Bermudez and Nielsen. 1990a). When level of nutrition is inadequate, the cow attempts to maintain the level of milk production according to her genetic potential, at the expense of body reserves, and subsequent reproductive performance may be affected. Thus, higher-milking cows may have lower production efficiency when feed resources are limited.

McMorris and Wilton (1986) found that an increase in milk yield of 1 kg/d was associated with an increase of 0.28 kg/d dry matter in feed intake during lactation. Higher-milking cows required more nutrients to maintain adequate body condition and regular reproduction.

Efficiency of higher milking cows may be similar or even lower than lower milking cows. Montano-Bermudez and Nielsen (1990b) found that biological efficiencies of beef production at weaning and at slaughter were maximum in the lowest milking group among cattle similar in size and growth potential. Unless feed sources for the cow herd are extremely low relative to those for calves, economic efficiencies favour cows with lower milk production potential in beef production.

Brown et al. (1976) concluded that the conversion of food energy to weaning weight was similar among breeds and breed crosses. However, Davis et al. (1983) and Jenkins et al. (1991) indicated that significant variation exists among breeds and breed crosses. Positive relationships between milk production and food energy expenditure for maintenance of cows have been reported (Jenkins et al., 1991; Montano-Bermudez et al., 1990). Jenkins et al.

(1991) concluded that heavier weight and higher milk yield potential resulted in greater food energy consumption by the dam. Moderate mature weights and milk production were found to be more biologically efficient in that study.

Freking and Marshall (1992) defined production efficiency as the amount of metabolisable energy consumed by the dam-calf pair during the year divided by the calf's weaning weight. Milk yield potential seemed to be unrelated to cow size. Their results indicated that increased milk yield was associated with improved calf production efficiency to weaning. However, the incremental improvement in efficiency per unit of increased milk yield was less for each additional unit of milk yield.

Van Oijen et al. (1993) estimated the economic and biological efficiencies of beef production in three groups of cows with different levels of milk production. They defined the economical efficiency as the ratio of income to expenses, and biological efficiency as the ratio of calf weight to total feed energy required. Income was derived from cull cows and calves at weaning or carcasses of calves fed to slaughter. Cost included feed and non-feed expenses for the cow herd and for calves to weaning or to slaughter. Their results showed that the low milk production group was always the most biologically efficient, especially when evaluation was based on calves taken to slaughter weight. Economic efficiency comparisons agreed closely with the biological efficiency comparison.

2.5. Bioeconomic Efficiency

Improving efficiency of production is an obvious goal for producers. Efficiency can be achieved by higher production per cow or reduced costs through improved reproduction, longer herd life, reduced health cost, and reduced dystocia (Freeman, 1988).

There are many different ways to evaluate biological and economic efficiency:

Hirooka (1991) used four measures of output/input efficiency: (1) biological efficiency expressed as total market weight of progeny (kg) / total feed metabolizable energy (ME, MJ); (2) biological efficiency expressed as total market weight of a dam and her progeny (kg) / total feed ME (MJ); (3) biological efficiency expressed as total market muscle weight of a dam and her progeny (kg) / total feed ME (MJ); (4) economic efficiency expressed as return from products ($) / total feed cost ($).

Green et al. (1991) used two evaluations of efficiency: 1) total cow and calf feed energy input per unit of weaned calf weight output (Mcal/kg); 2) total cow and calf feed energy input per unit of weaned calf plus 0.55 times cull cow weight (Mcal/kg).

Nunez-Dominguez et al. (1992) calculated efficiency as input cost per unit of output value. Input included costs for both cow units and purchased replacements. Output value included both weaned calves and cull cows. Cost reductions would be somewhat less for rotational crossbreeding but greater for mating smaller crossbred cows with sires of superior growth-carcass breeds.

McCall and Marshall (1991) described a model to simulate daily live weight gain of cattle from weaning to slaughter per hectare of pasture. They showed that two factors which determined biological efficiency (carcass gain (kg) /ha/yr) on pasture were: 1) pasture utilization and 2) feed conversion efficiency. Stocking rate was the major factor affecting pasture utilization rate. An increase in mature size of cows from 750 to 900 kg increased feed (kg) / carcass gain (kg) by 14%.

To estimate bioeconomic efficiency, return (R) and cost (C) should both be considered. The R and C values can be combined in several different ways: R-C, R/C, or C/R. R-C defines profit expressed in monetary units. Since the ratios are assumed to be somewhat independent of prices, they are more indicative of biological efficiency. Choosing one of the criteria: R-C, R/C or C/R is an important decision.

When determining cost, Tess et al. (1983a,b,c) stated that both variable and fixed costs must be taken into account, as economic efficiency is maximized when average total costs are minimized. Average total costs are the sum of fixed and variable costs whereas marginal costs only account for variable costs. Including fixed costs is more realistic because if production is increased, then fixed costs are spread over more products, influencing the efficiency of the total production system.

Dickerson (1970) argued that a breeder should seek to minimize cost per unit product. He suggested that biological effects on economic efficiency should be measured, which he defined as costs/return, and suggested use of the ratio C/R as the breeding objective. However, he assumed a fixed market since he used the unit of product as the basis of the calculation. In practice, this is not really accurate, since there is never really only one product, nor one price.

Harris (1970) discussed the possible use of C/R, R/C and R-C, and indicated that use of C/R is recommended only when the market for products has some limitations, so that total returns cannot be increased, and the only way to increase efficiency is to reduce costs. However, return is not constant. Using R/C as a breeding objective can increase the return as high as possible when the cost is fixed.

Brascamp et al. (1985) tried to determine the most adequate base for evaluating economic efficiencies. They were able to show that if profit is zero or is set to zero, then all criteria give the same economic weights.

James (1982) preferred R-C, arguing that for R-C the economic weights depend on prices but not means, while for C/R the weights depend on means but not prices. Therefore, there is a considerable and important difference between the two measures of efficiency. Elsen et al. (1986) also argued that R-C criterion is probably the best. Many other researchers preferred to use R-C (Armstrong et al., 1990; Kolstad, 1993; Amer et al., 1994a).

Melton and Colette (1993) indicated that output/input ratios may produce fallacious indications of economic efficiency that may, in turn, lead to erroneous conclusions regarding the true commercial applicability of breed evaluations. Specifically, these results may be both inconsistent and inefficient when viewed in terms of their ability to advance consistently the economic objectives of commercial producers.

Amer et al. (1994c) believed that the present methods used to calculate economic weights are not adequate. They stated that to have a true economic weighting system, all aspects of production must be taken into account in order to optimize production. Attempting to optimize all levels can be a very complex problem. More work is needed on combining classical economic theory with livestock economics before it will be applicable on an industry basis.

The assumed primary goal of any producer is to make a profit. Developing comprehensive animal simulation programs should enable a producer to maximize profit by choosing the most promising opportunities available.

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Chapter 3

THE SIMULATION MODEL - A BEEF PRODUCTION SIMULATION SYSTEM

3.1. Introduction

The beef cattle production system is a complex aggregate of subsystems, each somewhat dependent on the others. Maximizing the effect of one particular sector may reduce the functional capability of the total system. Fitzhugh (1978) indicated that production efficiency should be evaluated at the integrated system level, rather than at the subsystem or individual animal level. Amer et al. (1994) stated that all aspects of production must be taken into account in order to optimize production. It is necessary to replace the traditional single output production function with a complex simulation model. Biological type, which is primarily based on cow size and milk production, is a very important concept in beef production. Different sets of feed, labor, and capital inputs may lead to important biological type x environment interactions for beef production efficiency. If the system's component interactions are evaluated, it should lead to greater understanding of the total system.

Research is needed to develop the necessary methodology to evaluate and compare alternative management strategies under a set of available resources. It is often difficult or impossible to collect all the data required to develop a system for evaluating bioeconomic efficiency. Some traits are difficult to measure objectively. Furthermore, it is often too costly to change a particular factor for measuring its effect in an actual production system. Fortunately, computer simulation can assist in solving these problems. Simulation provides an excellent tool for the integration of quantitative knowledge from a variety of disciplines.

It is possible to alter a subsystem and see the effects on the whole system (Spreen et al., 1986). The advantage of computer simulation is that it takes much less time and is much less costly than working with a true biological system, but is limited by the designer's ability to describe the system and its components mathematically. If the components of a system can be quantified and presented in a mathematical form, a simulation model can provide more detailed and mechanistic studies to allow a more thorough understanding of the total system (France et al., 1984). Industries rely on simulation models to compare different management scenarios before implementing a management strategy which will affect the future of the enterprise.

Simulation modelling has received considerable attention in the last twenty years. Some of the widely recognized simulation models of cattle production are: 1). **Texas A&M beef cattle simulation model** (Sanders and Cartwright, 1979a,b; Notter et al., 1979a,b,c; Sullivan et al., 1981; Doren et al., 1985; Cartwright and Doren, 1986; Bourden and Brinks, 1987a,b,c). 2). **Kentucky beef-forage model** (Loewer et al., 1981; Loewer et al., 1983; Smith et al., 1985; Loewer and Smith, 1986). 3). **The Cornell net carbohydrate and protein system (CNCPS) for evaluating cattle diets** (Fox and Black, 1984; Fox et al., 1988; Fox et al., 1992; Russell et al., 1992; Sniffen et al., 1992; O'Connor et al., 1993; Fox et al., 1995; Pitt et al., 1996). Specific questions being addressed by these simulation studies vary considerably, but all can be described as involving the interface between animal performance and livestock production systems. The Texas A&M beef cattle simulation model and Kentucky beef-forage model were used on a mainframe computer which is not user friendly. Although the Cornell CNCPS model is user friendly, it can only predict nutrient requirements of cattle at a specific sets of physiological and environmental conditions. It is not a dynamic model.

With the rapid development of more powerful microcomputers, it has become possible to develop a complex integrated dynamic simulation model which integrates a variety of disciplines. The objective of this study was to develop a dynamic simulation model to aid researchers and producers in examining and evaluating the effects of cow size, production traits, and management strategies on the bioeconomic efficiency of beef production systems.

3.2. Materials and Methods

The project was a cooperative effort among the University of Alberta, Alberta Agriculture, Food and Rural Development (AAFRD) and Beefbooster Cattle Alberta Ltd. in Calgary. Data and some parameters were derived from appropriate published literature, and unpublished reports from AAFRD, Beefbooster and the University of Alberta ranch at Kinsella. Ten years of average market prices for culled cows, weaned calves, feed prices and other non-feed costs (Agriculture and Agri-Food Canada, 1995), and thirty years of climatic temperature, rainfall and some other climatological data (Environment Canada, 1995) were used (Table 3.1).

The model is a dynamic deterministic simulation and is programmed using STELLA II simulation software on PC/Windows or the Macintosh platforms. The STELLA II software is designed to help people build their understanding of dynamic systems and processes. It is a multi-level, hierarchical environment for constructing and interacting with models. The environment consists of two major layers: the high-level mapping and I/O (input/output) layer and the model construction layer (High Performance System, Inc., 1994). It has the ability to create interactive user interfaces for sharing modelling insights. It transforms the modelling and simulation from a back-room to a front-room activity. Users no longer have to begin by staring at a "blank screen". Instead, they can begin by looking at a high-level map of a system to get information on the context. They also can visit the lower level, which contains more detailed and correspondent structures, to get some sense for the inter-connections. On the high-level mapping and I/O layer, some main input parameters are controlled by sliders and graphical input devices which can be easily changed. The output in graphs and tables can also be collected on the high level. Users need not be distracted by the details of the model, as they run simulations and test scenarios. Therefore, STELLA II is a powerful simulation tool to examine beef production systems.

Numeric values of the various inputs can be updated as more information becomes available. Performance of individual cows and their calves is simulated in daily or weekly intervals over a number of years. The performance is determined by genetic potential, physiological status, environmental conditions, and feed availability and quality. A dynamic deterministic approach is used for the continuous portion of the model such as with animal and forage growth. Stochastic elements included are those mainly associated with weather data, such as temperature.

The major traits included in the model are: cow mature weight, milk production, body condition score, birth weight, weaning weight, pre-weaning ADG, post-weaning ADG, calving rate, weaning rate, mortality, forage yield and quality, forage growth rate, and some other environmental and economic factors. Body condition score (CS) was assessed on a scale ranging from 1 (emaciated) to 9 (extremely fat) based on the American evaluation system (Richards et al., 1986).

The model, named **"Beef Production Simulation System" (BPSS)**, is the result of an interdisciplinary effort that incorporates the interactions of beef cattle energy and protein requirements, herd dynamics, forage production and economics for range production systems. The model is composed of four major submodels: **Herd Inventory, Nutrient Requirements, Forage Production, and Economic submodels.**

3.2.1. Herd Inventory submodel

Herd inventory and composition is an initial condition of the livestock component. Cows in the herd are divided into categories according to their age and physiological status. The Herd Inventory submodel is used to:

1. Simulate dynamics of age groups in a cow herd. Nine age groups of cows are classified (from 1 to 9 plus years old). At the end of each year, cows in each age group are automatically moved to the next age group. The initial ratio for each age group is shown in Table 3.2, which is based on data from University of Alberta Beef Research Ranch at Kinsella (Arthur et al., 1992).

2. Predict the number of replacements and culled cows based on expansion or reduction of the herd. Older and open cows are culled at the end of each year to maintain the desired herd size. If needed, first year heifers can be bought from outside the herd to adjust the herd size. The culling and mortality rates (ratio of culled or dead cows to sub-total cows) in each age group are shown in Table 3.2.

3. Calving pattern: The calving season is divided into six periods of 21 days each.

The default calves born (%) in each period is shown in Table 3.3 (Mathison, 1993), which can be changed by the users. The calving rate and the first date of calving are also input parameters.

4. Simulate how many culled cows and weaned calves are available in each age group and in the whole herd;

5. Estimate energy (ME) and protein (MP) requirements, and dry matter intakes (DMI) in the herd and for each cow age group, based on the outputs of the Nutrient Requirements submodel.

3.2.2. Nutrient Requirements submodel

The Nutrient Requirements submodel is mainly based on the Cornell Net Carbohydrate and Protein System for Evaluating Cattle Diets (CNCPS, Fox et al., 1984, 1988, 1992, 1995). It is used to evaluate nutrient and feed requirements of calves and cows depending on their physiological status (maintenance, growth, lactation and gestation) and climatic conditions (temperature, relative humidity and wind speed). The model can also be used as a daily management aid for adjusting nutrient requirement and utilization over wide variations in cattle, feed, management and environmental conditions. The effects of cold stress and lower critical temperature (LCT) on maintenance requirements are also considered.

All the equations and validations for predicting cattle energy and protein requirements in the CNCPS were published by Fox et al. (1988, 1992). Computation of cattle requirements is based on the following:

1. Maintenance requirements were determined from body weight, previous

nutritional status and level of production, and tissue and external insulation relative to effective ambient temperature, wind, and other environmental conditions (NRC, 1984).

2. Growth requirements were based on empty body tissue composition of the expected gain. Factors that influenced requirements for growth were assumed to be weight, stage of growth, growth rate, and use of anabolic implants.

3. Pregnancy requirements were predicted from uterine and conceptus demand. Gestation requirements vary with conceptus size and day of gestation.

4. Lactation requirements were computed from the amount and composition of milk. They are determined by genetic potential for milk production, milk fat and protein contents. Peak milk yield can be an input parameter (if it is known) or predicted based on observed calf weaning weights for various mature cow sizes (Fox et al., 1988). Milk production was predicted from lactation curves (Woods, 1967).

5. Energy and protein reserves were estimated from NRC (1996). From the energy balance, the change of cow body condition score (CS) could be estimated. The formulae are as follows:

1) Body composition was computed for the current CS:

Proportion of empty body fat:	AF = 0.037683 * CS
Proportion of empty body protein:	AP = 0.200886 - 0.0066762 * CS
Proportion of empty body ash:	AA = 0.078982 - 0.00438 * CS
Shrunk body weight, kg:	SBW = 0.96 * BW
Empty body weight, kg:	EBW = 0.891 * SBW
Total ash, kg:	TA = AA* EBW

2) EBW and component body mass at CS=i (from score 1 to 9, and assuming that ash mass does not vary with CS):

Empty body weight at CS=i, kg: $EBWi = TA / AAi$

Total body fat, kg: $TFi = AF * EBWi$

Total body protein, kg: $TPi = AP * EBWi$

3) Calculate the body composition at next CS (TF_{i-1}, TP_{i-1}), the same method as above.

4) Mobilizable energy and protein were calculated:

Mobilizable fat, kg: $FM = TFi - TF_{i-1}$

Mobilizable protein, kg: $PM = TPi - TP_{i-1}$

Energy reserve, Mcal/score: $ER = 9.4 * FM + 5.7 * PM$

5) Convert Rate: During mobilization, 1 Mcal of ER will substitute for 0.80 Mcal of diet NEm; during repletion, 1 Mcal diet NEm will provide 1 Mcal of ER.

6) Based on the diet balance, get the deficient or excess net energy (NE_{change}):

$NE_{change} = (DMI_{graze}-DMI_{req}) * NEm(diet)$

7) Days to change 1 CS = ER * Convert Rate / NE_{change}

8) CS change rate per day = 1 / Days to change 1 CS

9) New CS = Old CS + CS change rate

The ability of an animal to meet its nutritional requirements depends on the amount of dietary energy and protein. Routine evaluation of diets including costs, animal performance, and environmental conditions unique to a particular farm are essential to the process of making appropriate management decisions with regards to daily feed, herd and managements of the operation.

3.2.3. Forage Production submodel

The Forage Production submodel is used to predict soil moisture, forage growth rate, cattle grazing rate, forage yield and quality, stocking rate and total hectares required for a herd, based on common forage species in different soil climatic zones in Alberta (Alberta Agriculture, 1995).

Six soil climatic zones in Alberta (Alberta Agriculture, 1995) are shown in Table 3.4. The commonly used forage species and their average yields (DM kg/ha) are shown in Table 3.5.

Seasonal growth of forage was simulated using first order differential equations, which are continuously integrated over time. Forage growth is based on the genetic potential of the forage species, air temperature, rainfall, soil moisture, cattle grazing rate, and management. Soil moisture is estimated from rainfall and pan evaporation data.

Forage growth is a dynamic phenomenon which functions as a self-sustaining process responding to its environment. Leaves of the growing forage receive solar energy and photosynthetically manufacture carbohydrates, which along with nutrients and water from the soil and air produces dry matter.

Logistic functions (Richards, 1959) were found to best describe the relationship of forage yield to days of growth. The form of the logistic equation is

$$Y = K / (1 + b * e^{-rt})$$

where, Y is the forage yield or biomass (DM kg/ha); K is an estimate of maximum yield of the forage (kg/ha); r is the maximum instantaneous rate of growth (kg/d/ha); b is a constant;

t is the period of growth in days. Based on this equation, the forage growth rate (kg/d/ha) can be estimated as:

$$dY/dt = r * Y (1- Y/K)$$

If the soil moisture and temperature factors were considered, the adjusted forage growth rate would be

$$dY/dt = r * Y (1- Y/K) * \text{soil moisture factor} * \text{temperature factor}$$

Soil moisture (SM) = Rainfall - Evapotranspiration - Run Percolation - Runoff. Soil moisture factor = 1- exp (-a * (SM-b)) (Smith and Williams, 1973), where a and b are constants. Temperature factor is included because pasture only grows within a critical temperature range. If the temperature is too low or too high, pasture growth will stop or slow down.

Forage biomass (yield) is also affected by the cattle grazing rate. Cow grazing rate increases at low forage biomass and reaches a plateau at high forage biomass. However, as forage biomass declines, the amount of forage eaten by each cow also declines because of low forage availability. The minimum forage biomass which allows any grazing was set at 800 kg DM/ha with a height of grass between 10 and 15 cm (Alberta Agriculture, 1987). A saturation of dry matter intake (DMI) for a cow is reached only when forage biomass is very abundant so that cows can eat all they want. This effect is called "functional response". This is described by the Michaelis-Menton equation ($Y/(Y+Y_{50})$) which approximately estimates the effect of this saturation (Shipley and Spalinger, 1992). So the cow grazing rate (GR) is:

$$GR = DMI_{max} * (Y / (Y + Y_{50})$$

where, DMI_{max} is the maximum dry matter intake of cows from one hectare based on nutrient requirements (kg/ha); Y is the forage biomass or yield (kg/ha); Y_{50} is the forage biomass at half of the maximum grazing rate (kg/ha). Here Y_{50} = 350 DM kg/ha (NRC, 1987).

Climatic conditions were characterized as stochastic variables to allow for random influences on the herd's performance. The influence of climatic variables could be filtered through soil moisture and temperature response functions in a forage submodel.

Daily temperature and rainfall were stochastically estimated from a normal distribution of monthly means and variances based on thirty years of meteorological data in Edmonton, Alberta (Environment Canada, 1995). The climatic data are input variables, which can be changed to accommodate specific conditions.

Stocking rate was based on forage yield and cow mature weight. Animal Unit (AU) is defined as a 450 kg cow with or without a calf, requiring a feed DM consumption of 12 kg/d (Alberta Agriculture, 1987). For example, the total forage required for a 550 kg cow during the grazing season (180 days) is:

550 kg / 450 kg * 12 (kg/d/AU) * 180 days = 2640 kg/AU

Generally, only half of the forage is utilized, so the requirement is 2640 kg * 2 = 5280 kg/AU. If Timothy yields: K=4225 kg/ha, then Stocking Rate (SR) = 4225 (kg/ha) / 5280 (kg/AU)=0.8 (AU/ha).

Total hectares required for grazing was based on the stocking rate (SR). Assuming SR=0.8: (1) given the number of cows, the number of hectares required can be estimated (e.g. if there are 100 cows in a herd, the total hectares required = 100/0.8 = 125 hectares); (2) given the available hectares, the number of cows that be grazed during the grazing season can also be estimated (e.g. on a 1000 hectares ranch, the total number of cows that could be pastured during the grazing season = 1000 * 0.8 = 800 cows).

3.2.4. Economic submodel

Bioeconomic efficiency, measured as net return per cow, is obtained by subtracting total cost from total return.

Net return = Total return - Total cost

Total return was estimated from the sale of culled cows and calves at different market endpoints: 1) weaned calves; 2) backgrounded calves; 3) finished calves. The average sale prices were based on 10 years data as shown in Table 3.6 (Agriculture and Agri-Food Canada, 1995). Cattle sale price is discounted by two factors: body weight and carcass grade. Weaned calf price was discounted $4 per 45 kg body weight as calf weight increased, starting from 140 kg of calf weaning weight (Alberta Agriculture, 1987).

Total cow cost was the sum of fixed and variable costs. Fixed costs included interest on intermediate and long term debt, depreciation, property taxes, repair and insurance. Variable costs included cow or replacement purchase cost, feed and non-feed expenses for the cow herd and for calves to weaning or to slaughter. Cow replacement purchase cost was considered only if herd size was increasing and some replacements need to be purchased from outside the farm. Non-feed costs included death loss, interest on operating loan, labour, manure and feed handling, fuel, veterinary service, housing and feed storage, marketing, breeding and miscellaneous costs. The default values in the model for cow fixed costs and non-feed costs were $65.54 and $68.39 /cow/yr, respectively, based on Beefbooster data (MacNeil et al., 1994). Feed costs included pasture and winter feed. The prices for pasture and winter feed were assumed to be 0.03 and 0.06 $/kg (Alberta Agriculture, 1987).

Three price levels for cows and calves were used to evaluate the market price effect on the bioeconomic efficiency. The maximum prices for cows and weaned calves respectively, at low, medium and high price levels, were 0.9 and 2.0, 1.0 and 2.2, 1.1 and 2.4 $/kg.

3.3. Results and Discussion

3.3.1. Herd Inventory submodel

The simulated dynamics of herd size and numbers of cows in each age group in a 100 cow herd for 6 years is shown in Figure 3.1 (only 1 year old to 4 year old age groups are shown in this example). The number of cows in each age group is changed in different years. Table 3.7 shows the predicted numbers of replacements and culled cows for each age group for the 100 cow herd.

The Herd Inventory submodel can also estimate the metabolizable energy and metabolizable protein requirements for the whole herd and for each age group (Figure 3.2), based on the outputs of the Nutrient Requirements submodel. Figure 3.3 shows the dry matter intake (kg/d/herd) based on the requirement for a herd of 100 cows.

3.3.2. Nutrient Requirements submodel

1. Maintenance and cow body condition score

The main effect of cow body condition score (CS) on efficiency is through its effect on the Lower Critical Temperature (LCT) and net energy for maintenance (NEm). If the thermal environment (temperature) drops below the animal's LCT, the possibility of cold stress and extra energy requirement will occur. Generally, a decrease in CS leads to an increase of the cow's LCT, making it easier for the environmental temperature to fall below the cow's LCT, resulting the cold stress.

Average temperatures, daily temperatures, lower critical temperatures (LCT), and net energy for maintenance for a cow in body condition score 2, 5 and 8 are shown in Figures 3.4, 3.5. and 3.6., respectively. Daily temperature is stochastically estimated from a normal distribution of monthly means and variances based on thirty years of meteorological data in Edmonton, Alberta (Environment Canada, 1995). NE for maintenance (NEm) increased during the grazing season (May - October) because of the grazing activity. The extra NEm required for cold stress during winter is influenced by the cow's CS. When a cow's CS=2 (thin), her LCT is higher than the environmental temperature, and she requires extra NEm for the cold stress (Figure 3.4). However, when a cow's CS=8 (very fleshy), her LCT is lower than the environmental temperature, and no extra NEm is required (Figure 3.6).

2. Heifer growth

Figure 3.7 shows a heifer's body weight, growth rate, metabolizable energy for gain (MEgain), metabolizable protein for gain (MPgain), and the dynamic changes in these factors for one year. Both MEgain and MPgain decreased with the reduced growth rate.

3. Pregnancy

Figure 3.8 shows a cow's metabolizable energy (MEpreg) and metabolizable protein (MPpreg) requirements for a pregnancy over the course of one year.

4. Lactation

Figure 3.9 shows a cow's milk yield, metabolizable energy (MElact) and metabolizable protein (MPlact) requirements for lactation over the course of one year.

5. Total nutrient requirements

Predicted metabolizable energy (ME, Mcal/d) and metabolizable protein (MP, g/d) requirements for maintenance, gain, lactation, pregnancy, and total for a heifer over one year on a daily basis are shown in Figure 3.10 and Figure 3.11.

The model can also predict the nutrient requirements of a cow for several consecutive years. Figures 3.12 and 3.13 shows the predicted metabolizable energy (ME, Mcal/d) and metabolizable protein (MP, g/d) requirements for maintenance including environmental factors, gain, lactation, pregnancy, and total ME and MP of a cow for six consecutive years. Some fluctuation is seen in the maintenance curve when the effect of cold stress was considered.

Figures 3.14 and 3.15 show the predicted total metabolizable energy (ME, Mcal/d) and metabolizable protein (MP, g/d) requirements for a cow, a calf and a cow-calf pair for six consecutive years.

6. Body reserve and body condition score change based on energy balance

Available body reserve, monitored by body condition score, is used when energy intake is below requirement and replenished when requirement is lower or feed supply is more plentiful. Current body condition score of an animal can be used to predict the number of days required for one unit change (±) in condition score based on the energy intake relative to the energy requirement of the animal.

Table 3.8 presents the estimated number of days it takes for one unit change in condition score, when net energy intake is ±3 Mcal/day higher or lower than the energy requirement for cows of three different mature weights. It also gives the rate of change in condition score and the new condition score after a diet change of 10 days for the three cow sizes. Energy reserves for cow size of 450, 550 and 650 kg were 127, 155 and 183 Mcal/score, respectively. As an example, if a ration is deficient by 3 Mcal of NE/d, then a cow in a CS 5 would reach CS 4 in 34, 41 and 49 days for cow size of 450, 550 and 650 kg, respectively. If a cow at CS 5 consumes 3 Mcal of NE/d in excess of requirements, she will move to a CS of 6 in 42, 52 and 61 days for cow size of 450, 550 and 650 kg, respectively.

The model can also predict cow condition score changes year round based on the diet and animal energy balance (Figure 3.23). Table 3.9 gives an example of the ME and DMI requirements, actual DMI of a cow, the rate of change in her condition score (ΔCS) and new CS in each month year round. It showed that cow condition score increases during the grazing season (May to October), and decreases during the winter (November to April).

3.3.3. Forage Production submodel

Figure 3.16 shows the forage growth rate (kg/ha/d), green forage yield (kg/ha), dry forage yield (kg/ha), and cow's grazing rate (kg/ha/d) for Smooth Brome grass in southern Alberta. The total forage biomass (yield, kg/ha) and available forage biomass based on the forage quality are shown in Figure 3.17.

3.4. Model Validation

The validation involved testing and an assessment of the created model. The model should mimic the real system satisfactorily to fulfil the purposes for which it was developed. When one is confident that the behaviour of the model is satisfied, the formal validation process is finished (Dent and Blackie, 1979). The process of gaining confidence in the model is generally a slow process and occurs through model-construction, validation and application.

Most of the equations used in this model have been independently validated for the nutrient requirements submodel (NRC, 1984, 1987, 1996; Fox et al.1984, 1988, 1992, 1995) and forage submodel (Smith and Williams, 1973).

Comparisons of predicted metabolizable energy (ME) requirements for a cow's lactation, pregnancy, maintenance and the total by the Fox model (Fox et al., 1988, 1992) and Beef Production Simulation System (BPSS) are presented in Figure 3.24, 3.25 and 3.26. The results predicted by the Fox model and BPSS were similar as expected, ME requirements predicted from BPSS are slightly higher than those from the Fox model, but these differences are not significant. Figure 3.27 illustrates that the predicted ME requirements for calf and cow-calf pair from the Fox model and BPSS were similar as well.

For validation, the nutrient requirements predicted by BPSS were compared to those recommended by the National Research Council (NRC, 1984) and Alberta Agriculture (AA, 1987). Table 3.10 shows a comparison of the nutrient requirements (ME, CP and DMI) of a mature cow (first 3-4 months postpartum, 5 kg milk yield /day) recommended by Alberta Agriculture (AA), NRC and BPSS. Nutrient allowance values recommended by AA were usually above BPSS and NRC values. Predicted nutrient requirements based on BPSS were generally equal to or slightly higher than those based on NRC.

There are no practical data available for validating the forage growth curves and soil moisture in the forage submodel. The validation work for the Forage Production submodel should be done in future studies. Herd Inventory and Economic submodels are mainly based on logic rather than quantitative relationships. It is difficult to validate a logic model (Dent and Blackie, 1979). However, the Herd Inventory and Economic submodels were checked and verified to ensure that they were not generating unreasonable results and were evaluated for robustness.

3.5. Sensitivity Analyses

Sensitivity analysis is a procedure carried out on the validated model which involves exploring the operation and performance of the model (Dent and Blackie, 1979). It is used to identify the parameters to which the system is more sensitive. In successive "runs" of the model under identical environmental conditions, the value of a parameter may be changed. Outputs of the model were analysed to determine whether or not the changed parameter values are of material consequence. A sensitive parameter is one which causes a major change in model-output, and the model is said to be sensitive to such a parameter. We do not need to pay close attention to the parameter to which the model is not relatively sensitive.

Sensitivity analyses were conducted by varying some of the important input parameters by ±10% of their default values (Table 3.11). When the value of one parameter was changed, all other parameters were held constant. The important input parameters analysed for sensitivity in this study included cow mature weight, calf weaning weight (which also reflects the level of cow milk production), calf birth weight, pasture price and winter feed price.

The effect of increasing or reducing the cow mature weight (MWt) by 10% on the total required metabolizable energy (ME) of a cow while holding the other parameters constant is shown in Figure 3.18. An increase or decrease in cow mature weight resulted in a large change in cow total ME requirement during winter (November - March), had a very small effect during the spring and summer (April - August), and a small effect during the autumn (September - October). The model was sensitive to changes in MWt during winter, and was not sensitive to MWt during the summer. It is concluded that cow mature weight plays an important role in cow nutrient and feed requirements during the winter.

The effect of varying calf weaning weight (which reflects cow milk production level) by ±10% on the total required metabolizable energy for a cow, while holding the other parameters constant is shown in Figure 3.19. The model is very sensitive to the changes in calf weaning weight from calving to weaning (April - October), but is not sensitive to weaning weight during the winter for a cow-calf production system. Since calf weaning weight is mainly affected by its dam's milk production (Drewery et al., 1959), therefore, calf weaning weight and cow milk production are very important traits for calf production.

The effect of varying calf birth weight by ±10% on the total required metabolizable energy of a cow is very small, having only a small effect during the late stage (February - March) of pregnancy (Figure 3.20). The model is not sensitive to changes in birth weight, and accuracy in the estimation of birth weight is not critical for the total nutrient requirement.

The effect of increasing or reducing the pasture price by 10% on total cow cost for a herd, given that the other parameters are held constant, is shown by Figure 3.21. During the grazing season (May - October), the model is very sensitive to changes in pasture price, but during the winter season (November - April), the model is very sensitive to the winter feed price (Figure 3.22). Therefore, accuracy in the estimation of pasture price and winter feed price are critical in the model.

3.6. Summary and Conclusions

The agricultural system is a complex aggregate of subsystems, each somewhat dependent on the others. Maximizing the effect of one particular sector may reduce the functional capability of the total system. If the system component interactions are evaluated, it leads to greater understanding of the total system by the producer. Simulation models provide more detailed and mechanistic studies to facilitate a more thorough understanding of the total system.

The **Beef Production Simulation System (BPSS)** is a dynamic deterministic model, which is the result of an multidisciplinary effort that incorporates the interactions of growing crops, grazing beef cattle, energy utilization, and economics in a beef cattle production system. The model is composed of four major submodels: Herd Inventory, Nutrient Requirement, Forage Production, and Economic submodels. The Herd Inventory submodel simulates dynamic changes in nine age groups of a cow herd, and predicts how many culled cows and weaned calves are available in each age group and in the whole herd. The Nutrient Requirement submodel can predict nutrient requirements (ME, MP) for maintenance, growth, lactation, and pregnancy of a cow, a calf, a cow-calf pair, and a whole herd. The model also considers the effects of cold stress and lower critical temperature (LCT) on maintenance requirement. The model can predict cow condition score changes on a year round basis based on the diet and animal energy balance. The Forage Production submodel can predict soil moisture, forage growth rate, cattle grazing rate, forage yield and quality, stocking rate and total hectares required for a herd, based on climatic conditions and common forage species in different soil climatic zones in Alberta. The Economic submodel can estimate feed cost, total cow cost, return, and net return, or bioeconomic efficiency of the herd.

The nutrient requirements predicted by BPSS were compared to those recommended by the National Research Council (NRC) and Alberta Agriculture (AA) for validation. Nutrient allowance values recommended by AA were usually above BPSS and NRC values. Predicted nutrient requirements based on BPSS were generally equal to or slightly higher than those based on NRC. Sensitivity analyses show that: 1) cow mature weight plays an important role in cow nutrient and feed requirements during the winter; 2) calf weaning weight and cow milk production are very important traits for calf production; 3) the model is not sensitive to changes in calf birth weight; 4) accuracy in the estimation of pasture price and winter feed price are critical in the model.

Although the model considers the effect of the diet and energy balance on condition score, other production traits are not responded to the limitation of feed resource. The model assumed that animals could meet their nutrient requirements. Further research is needed to examine the effects of feed limitation on the growth and milking performance in beef cattle.

It can be concluded that BPSS provides a useful method for simultaneous consideration of many factors in an integrated system, which could be helpful to beef cattle extension specialists and cow-calf production managers, for predicting the effects of different management and selection strategies on bioeconomic efficiency. Proper use of the model, when the factors which influence bioeconomic efficiency are well defined, will hopefully lead to a strategy which has a higher probability of success under a defined environment.

Table 3.1. Monthly average temperatures and precipitation in Edmonton, Alberta*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Daily temperature (^0C)													
Maximum	-10.9	-5.6	-0.9	9.3	17.2	20.8	22.4	21.5	16.5	11.4	-0.1	-7.5	7.8
Minimum	-22.0	-17.1	-12.4	-2.9	3.0	7.3	9.2	8.1	3.1	-2.1	-10.9	-18.5	-4.6
Average	-16.5	-11.4	-6.7	3.2	10.1	14.1	15.8	14.8	9.8	4.7	-5.5	-13.1	1.6
Standard deviation	4.7	4.6	3.8	2.5	1.1	1.5	1.1	1.9	2.2	1.8	3.6	4.3	1.0
Precipitation (mm)													
Rainfall	2.0	0.6	1.5	8.4	39.3	76.7	91.6	78.2	42.9	8.9	2.1	0.7	352.9
Snowfall	28.7	21.4	18.6	12.9	2.9	0.0	0.0	0.0	2.7	6.7	18.0	26.0	137.9
Total precipitation	24.4	17.6	16.0	20.2	42.2	76.7	91.6	78.2	45.7	15.4	16.7	21.9	466.6
Standard deviation	14.1	9.5	9.7	11.1	26.1	41.6	26.3	44.5	31.0	11.8	11.1	8.9	79.6

* Based on 30 years climatic data in Edmonton, Alberta, Canada (Environment Canada, 1995).

Table 3.2. Age distribution, culling rates and mortalities of cows in different age groups*

Age (year)	1	2	3	4	5	6	7	8	9+
Ratio	0.25	0.20	0.14	0.10	0.08	0.06	0.05	0.04	0.08
Culling rate	0.18	0.18	0.16	0.15	0.16	0.15	0.17	0.17	0.50
Mortality	0.031	0.021	0.017	0.012	0.01	0.01	0.01	0.016	0.052

* Based on Arthur et al., 1992.

Table 3.3. Calving distribution of beef cattle during the calving season*

	Days from the first calving					
Calving period	1-21	22-42	43-63	64-84	85-105	106-126
Calves born (%)	42.5	33.4	16.2	7.9	0	0

* Based on Mathison, 1993.

Table 3.4. Soil climatic zones and soil types in Alberta*

Zone	Soil Type	Annu. Precip. (mm)	Cities
1	Brown	250-350	Brooks, Bow Island
2	Dark Brown	350-450	Lethbridge, Calgary
3	Black	350-450	Red Deer, Edmonton
4	Gray Luvisol	450-550	Westlock, Fort Kent
5	Gray Luvisol	350-550	Peace River, Falher
6	Irrigation		Brooks, Lethbridge

* Based on Agriculture Alberta. 1995. Agri-fax.

Table 3.5. Average yields of commonly used forages in different zones of Alberta*

Zone	Forage	Ave. Yield (kg/ha)
1 & 2		
	1). Alfalfa-Grass Mixture	8675
	2). Smooth Brome	8130
	3). Crested Wheat Grass	4485
	4). Intermediate & Pubescent Wheatgrass	6300
	5). Russian Wildrye	4330
	6). Native Grass (Needle-thread/blue grama)	3150
3		
	1). Alfalfa-Grass Mixture	7400
	2). Meadow Brome (MB)	6560
	3). Smooth Brome (SB)	8575
	4). MB x SB	7500
	5). Orchard Grass	6370
	6). Foxtail	4750
	7). Timothy	5700
	8). Native Grass (Parkland)	3000
4 & 5		
	1). Alfalfa-Grass Mixture	4500
	2). Meadow Brome	3250
	3). Smooth Brome	3410
	4). Timothy	3990
	5). Creeping Red Fescue	3380
	6). Native Grass (Bush Pasture)	2600
Irrigation		
	1). Alfalfa-Grass Mixture	12200
	2). Meadow Brome	12410
	3). Smooth Brome	10160
	4). Orchard Grass	10400
	5). Timothy	10365
	6). Intermediate & Pubescent Wheat Grass	11020

* Based on Agriculture Alberta. 1995. Agri-fax.

Table 3.6. Average sale prices of culled cows, weaned, backgrounded and finished calves in Alberta*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Culled Cows ($/kg)	1.25	1.30	1.36	1.35	1.34	1.33	1.40	1.35	1.31	1.23	1.17	1.21	1.28
Calves ($/kg)													
Weaned	2.42	2.47	2.50	2.54	2.31	2.09	2.26	2.37	2.42	2.37	2.31	2.11	2.38
Backgrounded	2.11	2.14	2.13	2.12	2.13	2.12	2.23	2.21	2.20	2.18	2.15	2.13	2.16
Finished	1.89	1.92	1.96	1.94	1.88	1.80	1.82	1.82	1.80	1.83	1.84	1.84	1.85

* Based on 10 years reports in Calgary, Alberta (Agriculture, Agri-Food Canada, 1995. Livestock Market Review).

Table 3.7. Numbers of replacements and culled cows of different age groups for a stable herd of 100 cows for 6 years predicted by BPSS

		Number of culled cows by age group (yr)								
Year	replacement	1	2	3	4	5	6	7	8	9+
1	21	4	4	2	1	1	1	1	1	4
2	21	4	4	2	2	1	1	1	1	3
3	21	4	3	2	2	2	1	1	1	3
4	21	4	3	2	2	2	1	1	1	3
5	21	4	3	2	2	2	1	1	1	3
6	20	4	3	2	2	1	1	1	1	3

Table 3.8. Effects of energy reserve and energy balance on body condition scores (CS) of cows differing in mature weight*

Mature weight (kg)	Energy reserve (Mcal/score)	ΔNE (Mcal/d)	Days changing to next CS	ΔCS change rate (score/d)	New CS (After 10 days)
450	127	-3	-34	-0.03	5 → 4.73
550	155	-3	-41	-0.02	5 → 4.78
650	183	-3	-49	-0.02	5 → 4.82
450	127	+3	42	+0.02	5 → 5.21
550	155	+3	52	+0.02	5 → 5.17
650	183	+3	61	+0.02	5 → 5.15

* Initial condition score was assumed CS=5.

Table 3.9. Monthly changes in cow condition score based on the energy balance

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ME_{req}, Mcal/d	22.11	22.81	22.58	23.5	24.11	24.95	24.25	24.25	24.0	20.41	19.33	20.99
DMI_{req}, kg/d	10.05	10.37	10.27	10.68	9.65	9.98	10.78	10.78	10.67	9.07	9.66	10.49
DMI_{act}, kg/d	9.77	9.9	10	10	10	10.05	10.94	11.67	11.57	9.72	9.6	9.6
ΔCS, score/d	-0.02	-0.03	-0.02	-0.06	0.02	0.02	0.02	0.06	0.06	0.04	-0.01	-0.07
CS_{new}, score*	4.96	4.84	4.75	4.60	4.71	4.68	4.72	4.78	4.90	5.22	5.28	5.14

* Initial condition score on January 1 was assumed CS=5.

Table 3.10.Comparisons of nutrient requirements of a mature cow (first 3-4 months postpartum, 5 kg milk /day) as recommended by Alberta Agriculture (AA), NRC and Beef Production Simulation System (BPSS)

Mature Wt	ME (Mcal/d)			CP (g/d)			DMI (kg/d)		
(kg)	AA	NRC	BPSS	AA	NRC	BPSS	AA	NRC	BPSS
450	19.7	19.1	19.4	1000	911	945	10.4	9.2	9.6
550	23.0	21.5	21.7	1044	1001	1012	12.3	10.6	10.8
650	25.0	23.9	23.9	1135	1086	1089	14.5	11.9	11.9

Table 3.11. The parameters used for sensitivity analyses

Parameter	-10%	unchanged	+10%
Cow mature weight, kg	495	550	605
Calf weaning weight, kg	225	250	275
Calf birth weight, kg	36	40	44
Pasture price, $/kg	0.027	0.03	0.033
Winter feed price, $/kg	0.054	0.06	0.066

Figure 3.1. The simulated dynamics of age groups in a 100 cow herd for 6 years. Number of cows at 1 year old (1:Cow1yr), 2 years old (2:Cow2yr), 3 years old (3:Cow3yr), 4 year old age groups (4:Cow4yr), and the herd size (5:HerdSize).

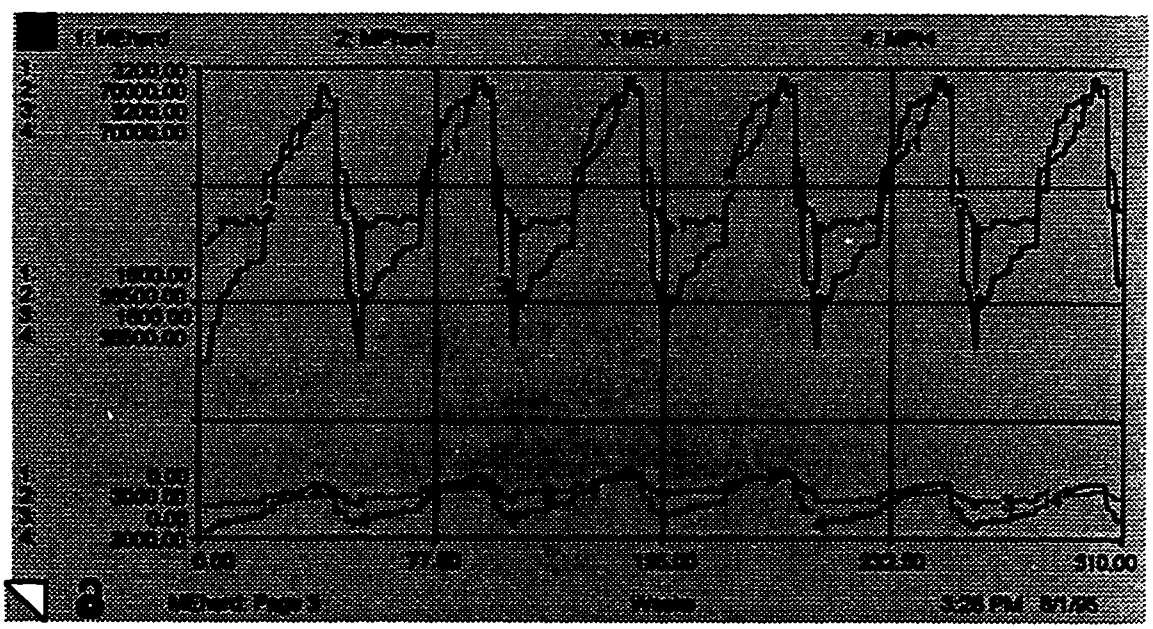

Figure 3.2. Metabolizable energy (ME, Mcal/d) and metabolizable protein (MP, g/d) requirements for a herd of 100 cows (1:MEherd and 2:MPherd) and different age groups. Here takes age group 4 as an example (3:MEt4 and 4:MPt4).

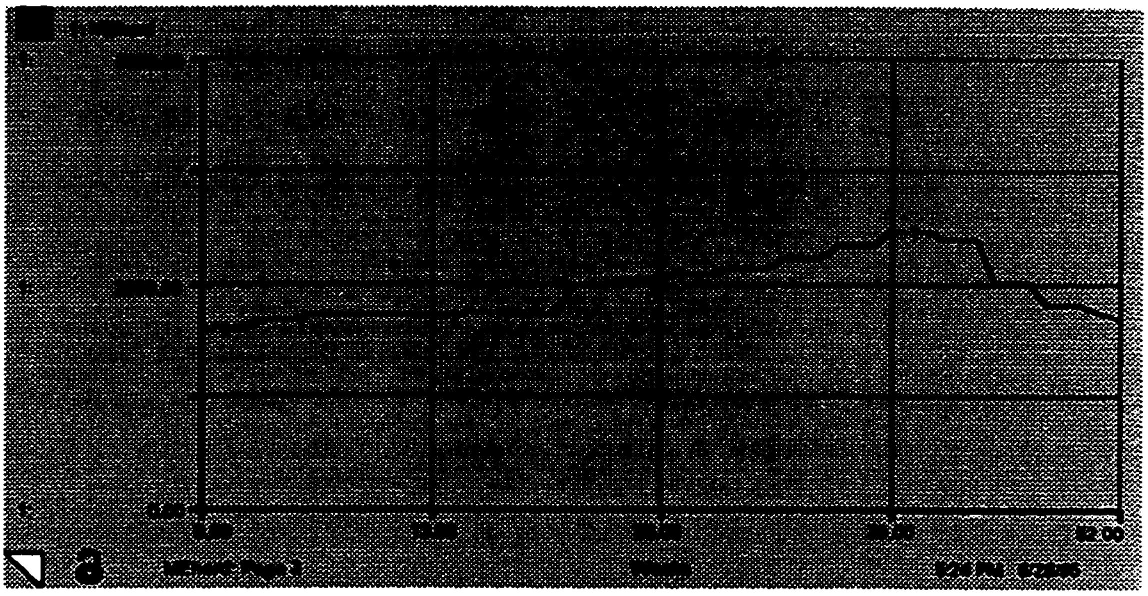

Figure 3.3. Dry matter intake (DMI, kg/d/herd) based on the requirement for a 100 cow herd in one year.

Figure 3.4. Average temperature (1:Temp, °C), daily temperature (3:TempV, °C), low critical temperature (2:LCT, °C), and net energy for maintenance (4:NEm & 5:NEmenv, Mcal/d) for a cow with body condition score CS=2 (mature weight=550 kg, peak milk yield=8.2).

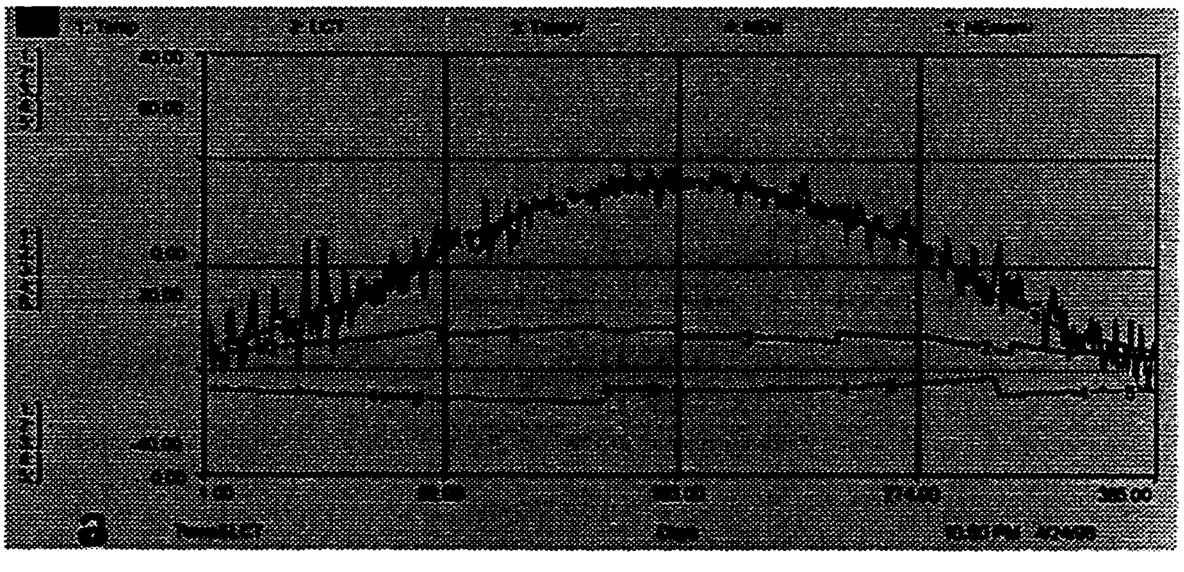

Figure 3.5. Average temperature (1:Temp, °C), daily temperature (3:TempV, °C), low critical temperature (2:LCT, °C), and net energy for maintenance (5:NEm & 5:NEmenv, Mcal/d) for a cow with body condition score CS=5 (mature weight=550 kg, peak milk yield=8.2).

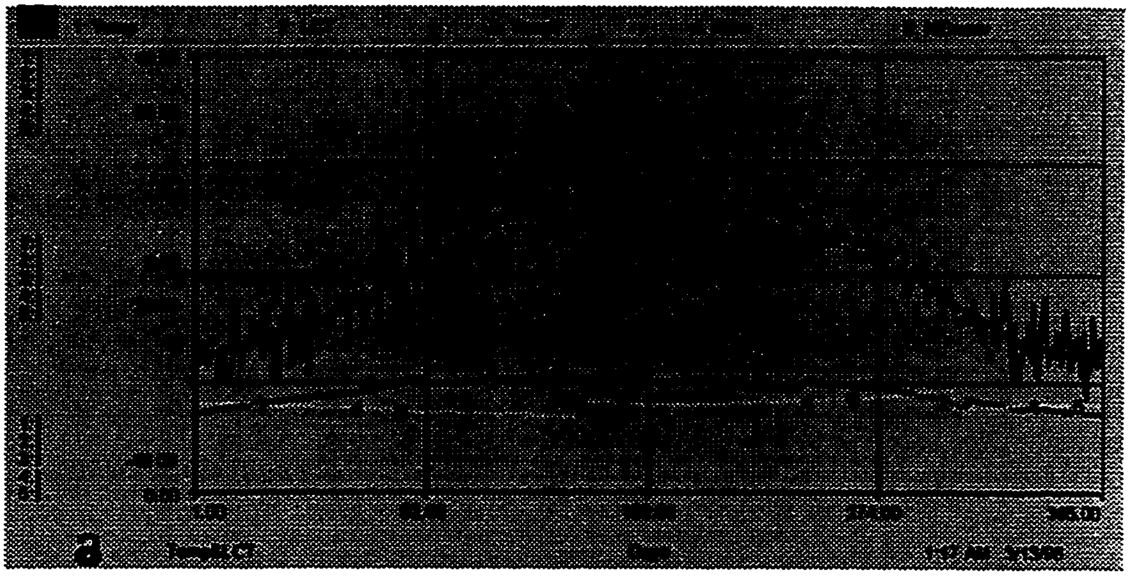

Figure 3.6. Average temperature (1:Temp, °C), daily temperature (3:TempV, °C), low critical temperature (2:LCT, °C), and net energy for maintenance (5:NEm & 5:NEmenv, Mcal/d) for a cow with body condition score CS=8 (mature weight=550 kg, peak milk yield=8.2).

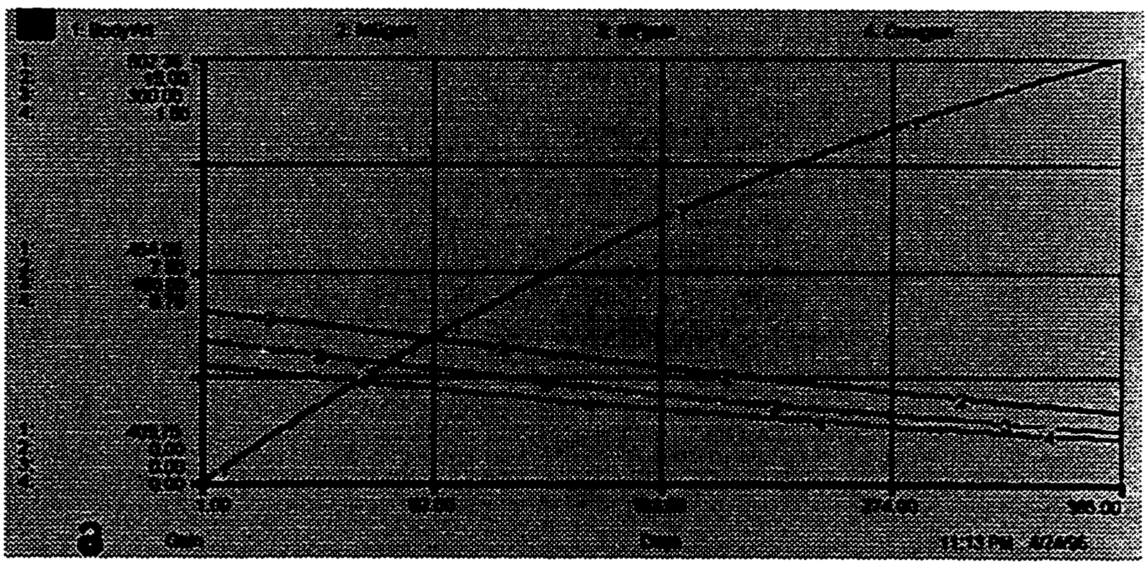

Figure 3.7. Body weight (1:BodyWt, kg), growth rate (4:Cowgain, kg/d), metabolizable energy (2:MEgain, Mcal/d) and metabolizable protein (3:MPgain, g/d) requirements for gain of a heifer (mature weight=550 kg, peak milk yield=8.2 kg/d, body condition score CS=5).

Figure 3.8. Metabolizable energy (1:MEpreg, Mcal/d) and metabolizable protein (2:MPgain, g/d) requirements for pregnancy of a cow (mature weight=550 kg, calf birth weight=35 kg, cow body condition score CS=5).

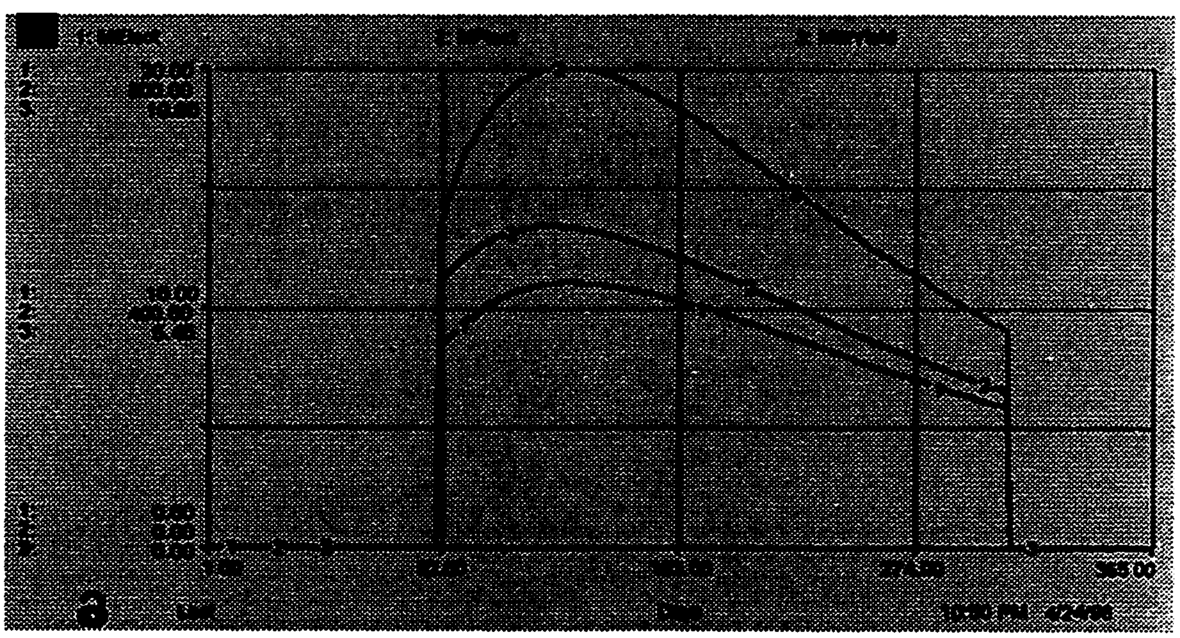

Figure 3.9. Metabolizable energy (1:MElact, Mcal/d) and metabolizable protein (2:MPlact, g/d) requirements for lactation, and milk yield (kg/d) of a cow (mature weight=550 kg, peak milk yield=10.9 kg/d, cow body condition score CS=5).

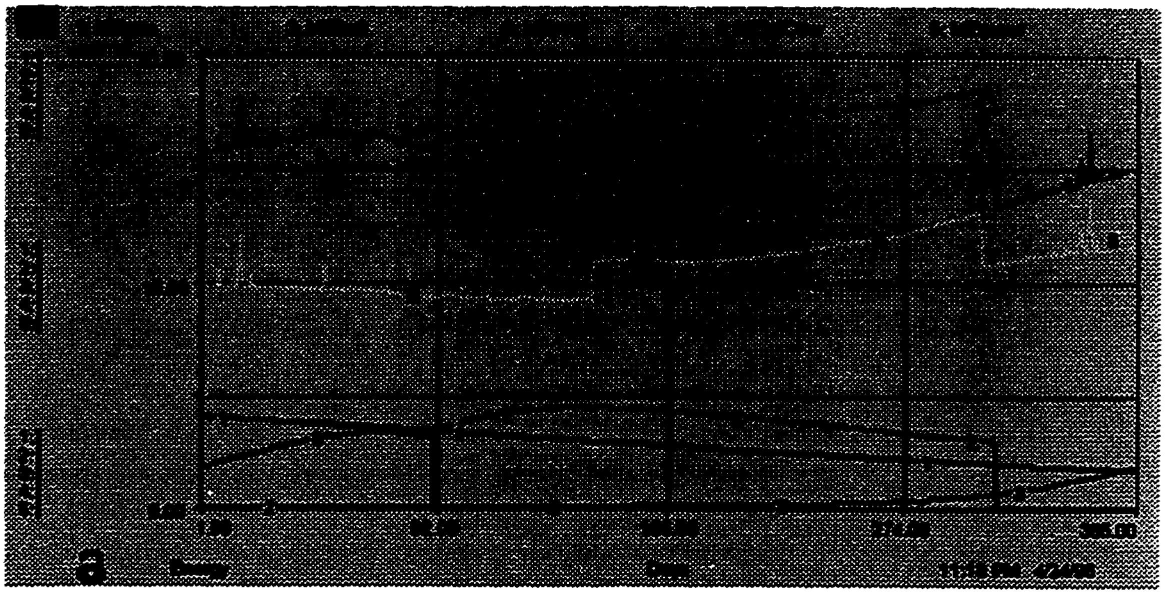

Figure 3.10. Metabolizable energy requirements (Mcal/d) for maintenance (5:MEmenv), gain (1:MEgain), lactation (2:MElact), pregnancy (3:MEpreg), and total (4:MEtotCow) of a heifer in one year (mature weight=550 kg, peak milk yield=8.2 kg/d, birth weight=35 kg, CS=5, two years old).

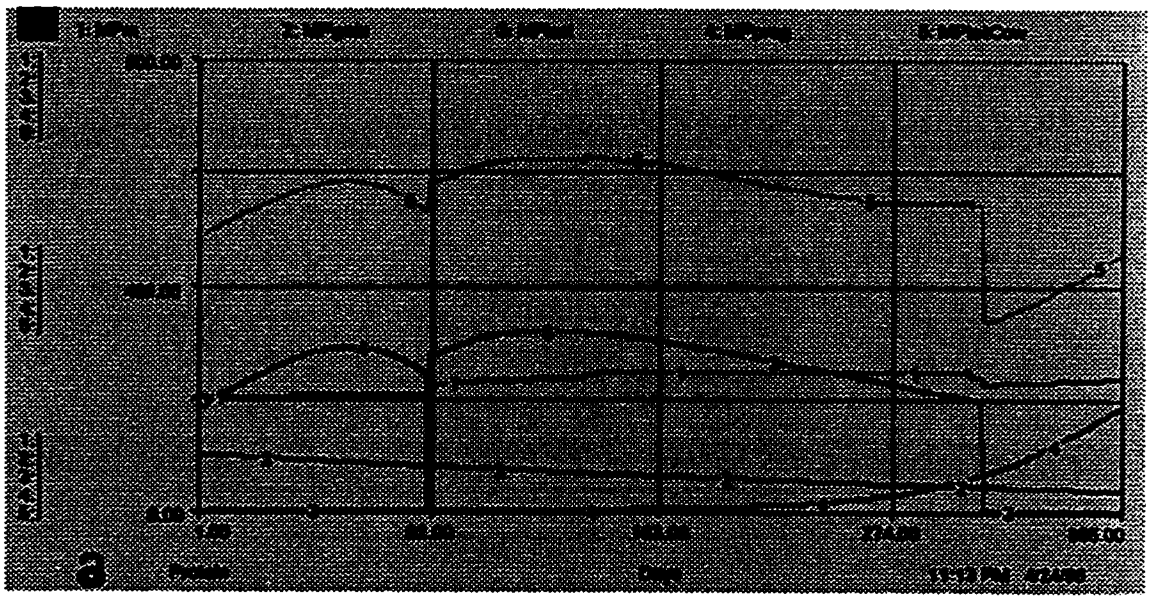

Figure 3.11. Metabolizable protein requirements (g/d) for maintenance (1:MPm), gain (2:MPgain), lactation (3:MPlact), pregnancy (4:MPpreg), and total (5:MPtotCow) of a heifer in one year (mature weight=550 kg, peak milk yield=8.2 kg/d, birth weight=35 kg, CS=5, two years old).

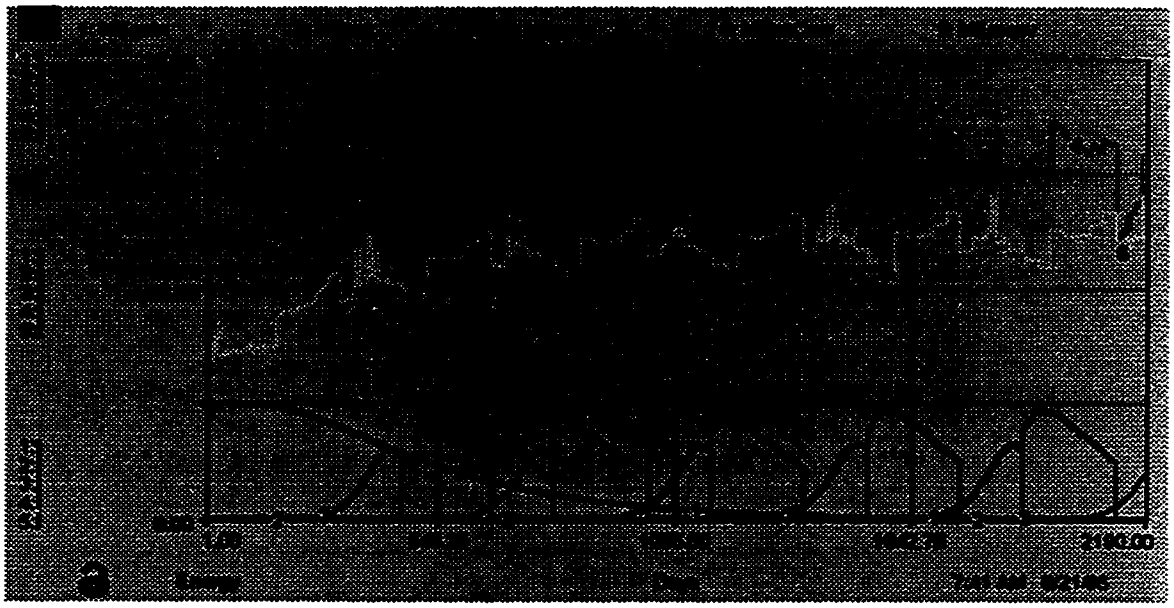

Figure 3.12. Metabolizable energy requirements (Mcal/d) for maintenance including environmental factors (5:MEmenv), gain (1:MEgain), lactation (2:MElact), pregnancy (3:MEpreg), and total ME (4:MEtotcow) of a cow (mature weight=550 kg, peak milk yield=5.4 kg/d, birth weight=35 kg, body condition score CS=5) for 6 years.

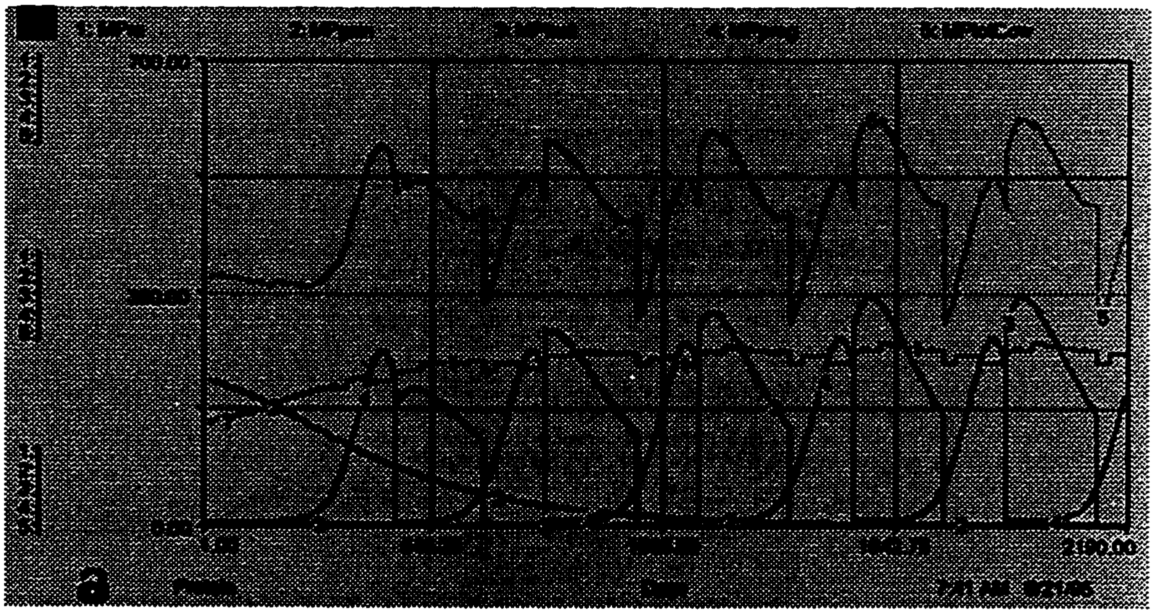

Figure 3.13. Metabolizable protein requirements (g/d) for maintenance including environmental factors (1:MPm), gain (2:MPgain), lactation (3:MPlact), pregnancy (4:MPpreg), and total MP (5:MPtotcow) of a cow (mature weight=550 kg, peak milk yield= 5.4 kg/d, birth weight=35 kg, body condition score CS=5) for 6 years.

Figure 3.14. Total metabolizable energy (ME, Mcal/d) requirements for a cow (1:MEtotCow), a calf (2:MEg&mc), and a cow-calf pair (3:MECow&Calf) for 6 years.

Figure 3.15. Total metabolizable protein requirements (MP, g/d) for a cow (1:MPtotCow), a calf (2:MPtotCalf), and a cow-calf pair (3:MPCow&Calf) for 6 years.

Figure 3.16. Forage growth rate (3:GrowthRate, kg/ha/d), green forage yield (1:GreenYield, kg/ha), dry forage yield (2:DryYield, kg/ha), green grazing rate (4:GrazGreen, kg/ha/d), and dry grazing rate (5:GrazDry, kg/ha/d) of Smooth Brome in southern Alberta.

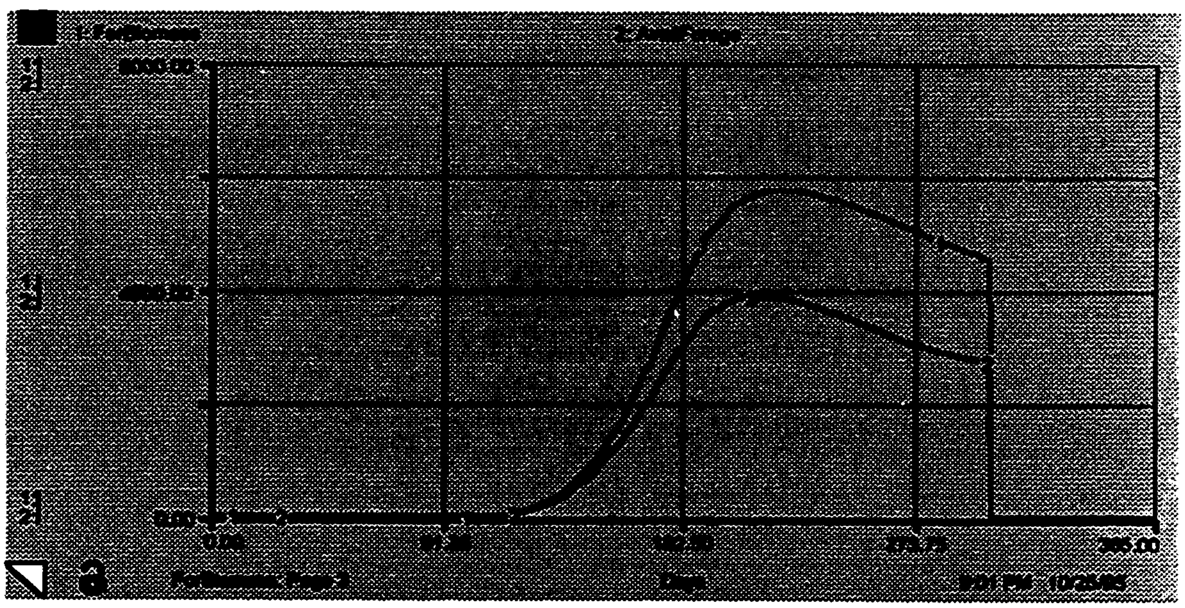

Figure 3.17. Total forage (include green and dry) yield (1:ForBiomass, kg/ha) and available forage yield (2:AvailForage, kg/ha) based on the forage quality of Smooth Brome in southern Alberta.

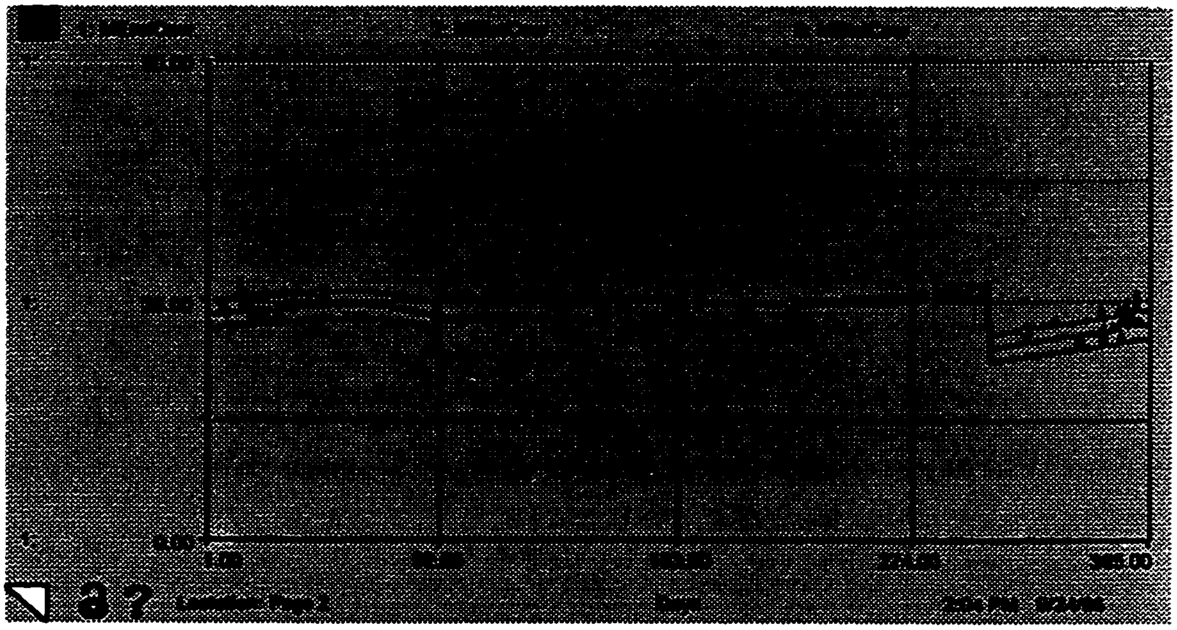

Figure 3.18. Effect of increasing or reducing the mature weight (MWt) by 10% on the ME requirement (MEtotCow, Mcal/d) of a cow. 1- MWt reduced 10% (495 kg); 2- MWt unchanged (550 kg); 3- MWt increased 10% (605 kg).

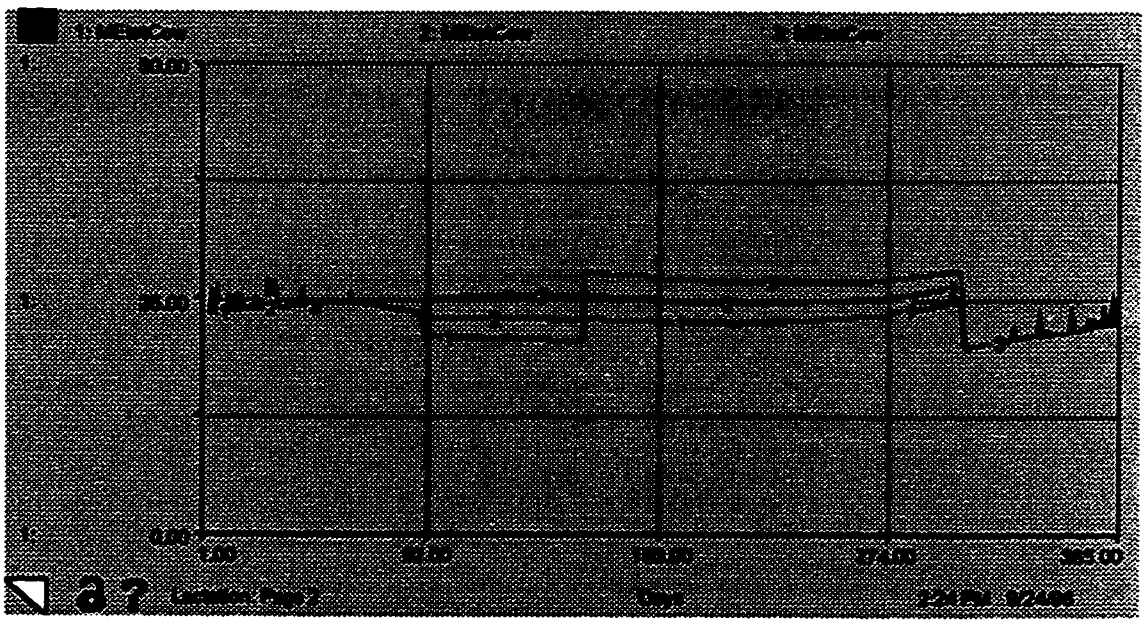

Figure 3.19. Effect of increasing or reducing the weaning weight (WWt) by 10% on the ME requirement (MEtotCow, Mcal/d) of a cow. 1- WWt reduced 10% (225 kg); 2- WWt unchanged (250 kg); 3- WWt increased 10% (275 kg).

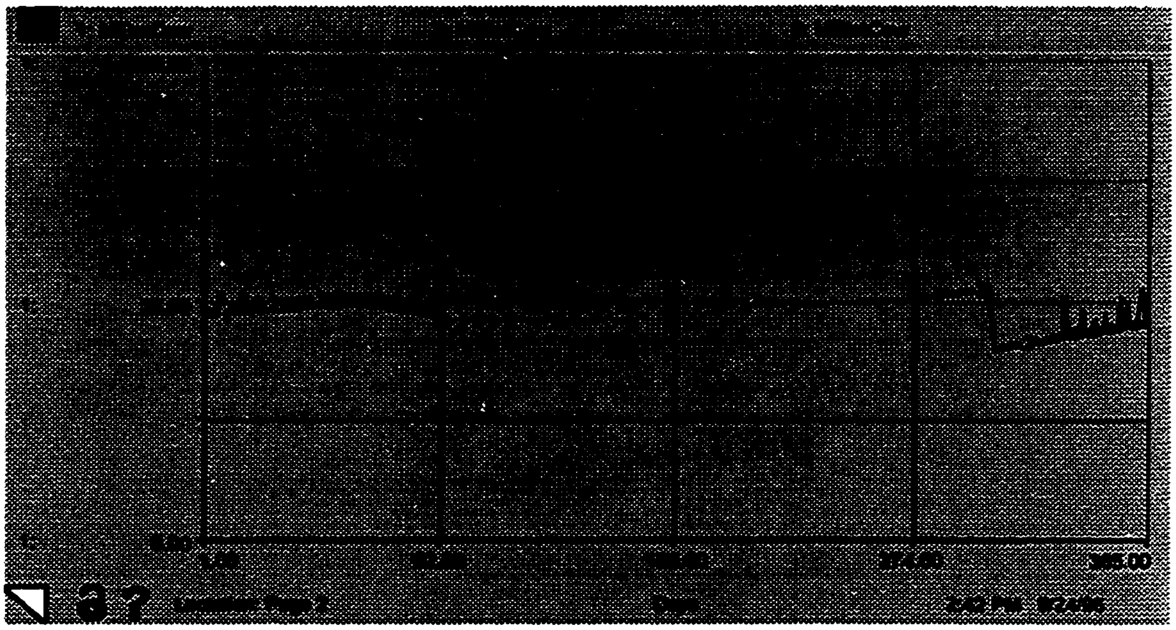

Figure 3.20. Effect of increasing or reducing the calf birth weight (BWt) by 10% on the ME requirement (MEtotCow, Mcal/d) of a cow. 1- BWt reduced 10% (36 kg); 2- BWt unchanged (40 kg); 3- BWt increased 10% (44 kg).

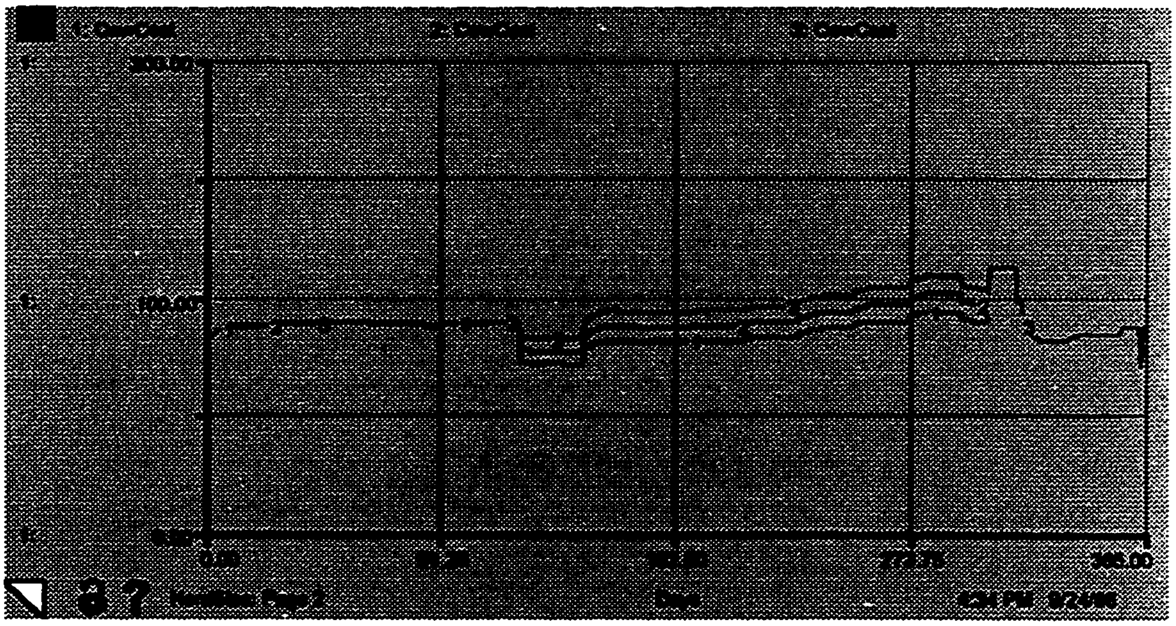

Figure 3.21. Effect of increasing or reducing the pasture price by 10% on the total cow cost (CowCost, $/d/herd) of a 100 cow herd. 1- pasture price reduced 10% (0.027 $/kg); 2- pasture price unchanged (0.03 $/kg); 3- pasture price increased 10% (0.033 $/kg).

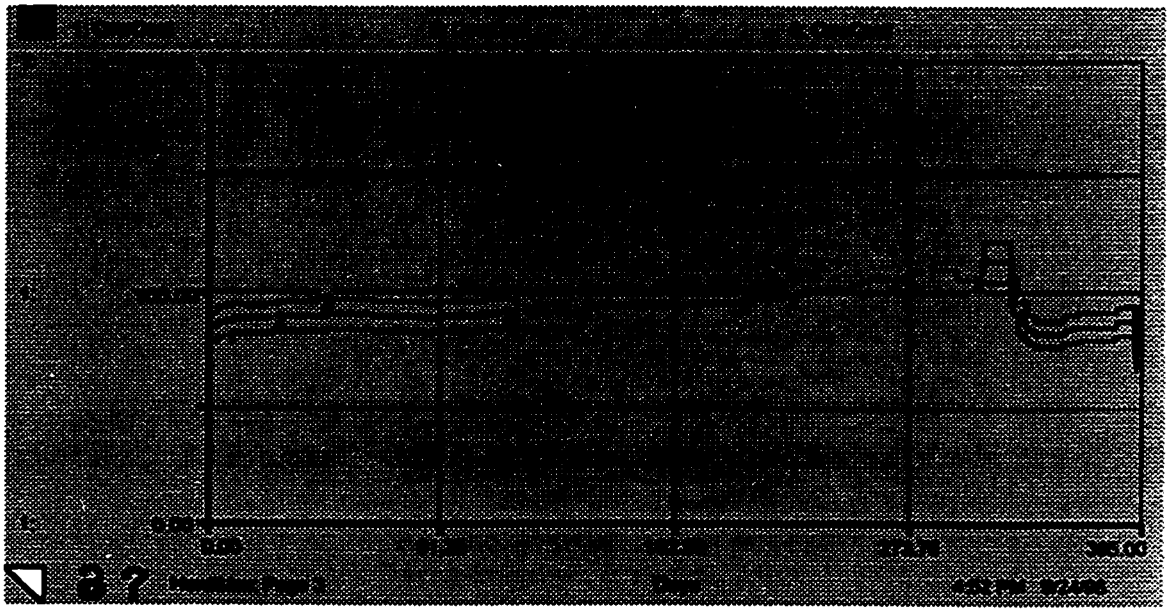

Figure 3.22. Effect of increasing or reducing the winter feed price by 10% on the total cow cost (CowCost, $/d/herd)of a 100 cow herd. 1- winter feed price reduced 10% (0.054 $/kg); 2- winter feed price unchanged (0.06 $/kg); 3- winter feed price increased 10% (0.066 $/kg).

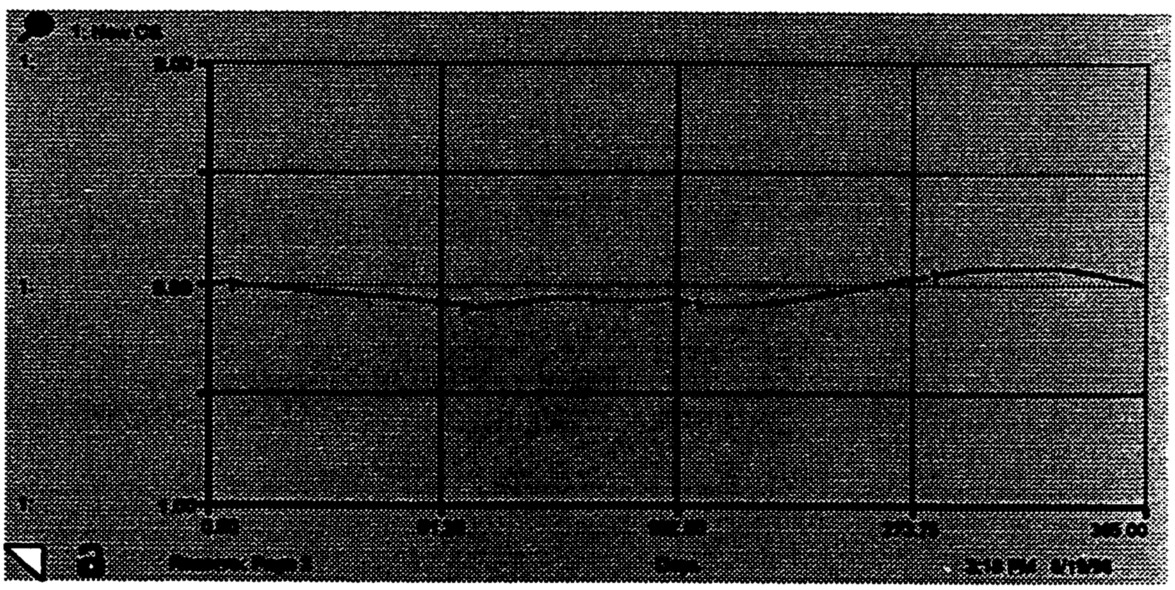

Figure 3.23. Year round changes in cow condition score based on the animal energy balance (initial CS=5).

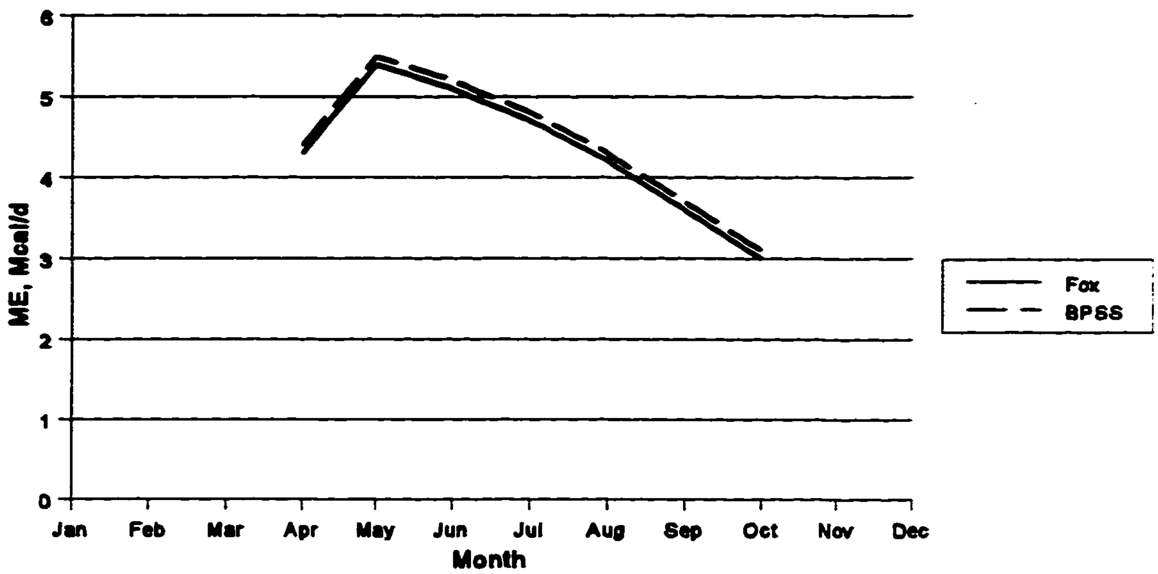

Figure 3.24. Comparison of metabolizable energy (ME) requirements for lactation of a cow (5 years old, 567 kg, peak milk yield=5.4 kg/d, CS=5) by Fox model and BPSS.

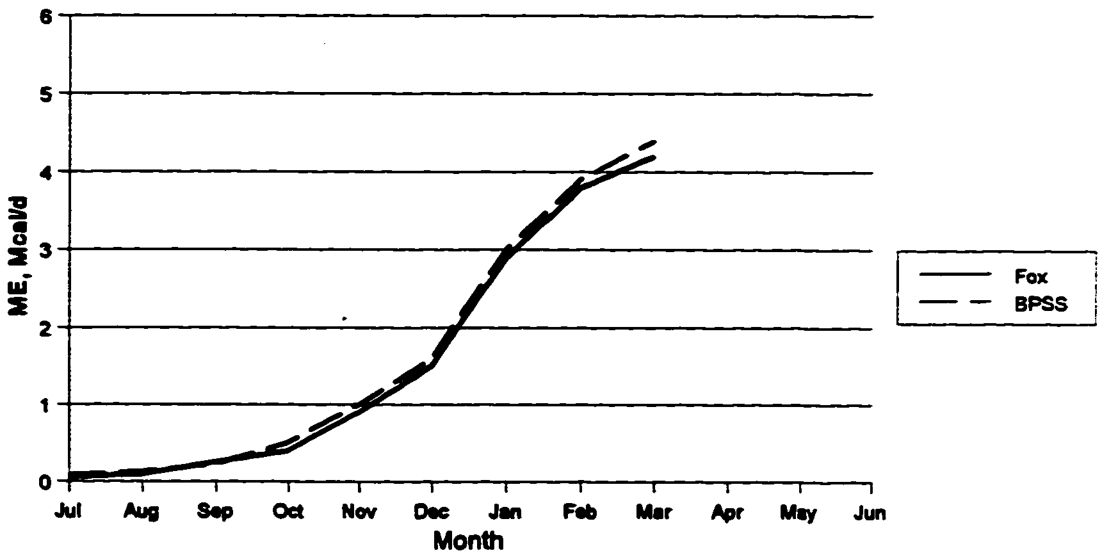

Figure 3.25. Comparison of metabolizable energy (ME) requirements for pregnacy of a cow (5 years old, 567 kg, peak milk yield=5.4 kg/d, CS=5) by Fox model and BPSS.

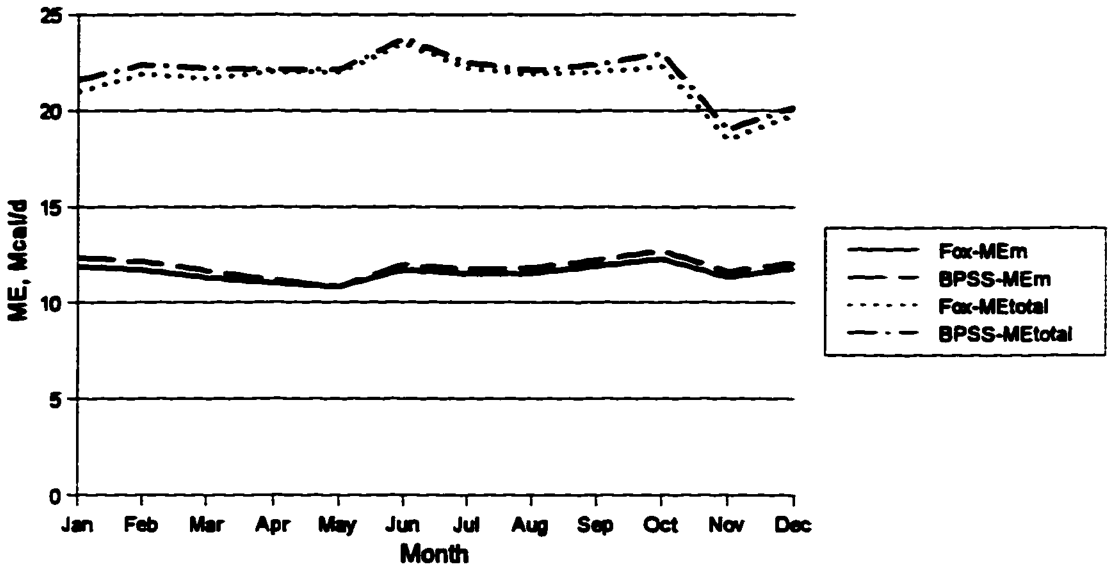

Figure 3.26. Comparisons of metabolizable energy requirements for maintenance (MEm) and total (MEtotal) of a cow (5 years old, 567 kg, peak milk yield=5.4 kg/d, CS=5) by Fox model and BPSS.

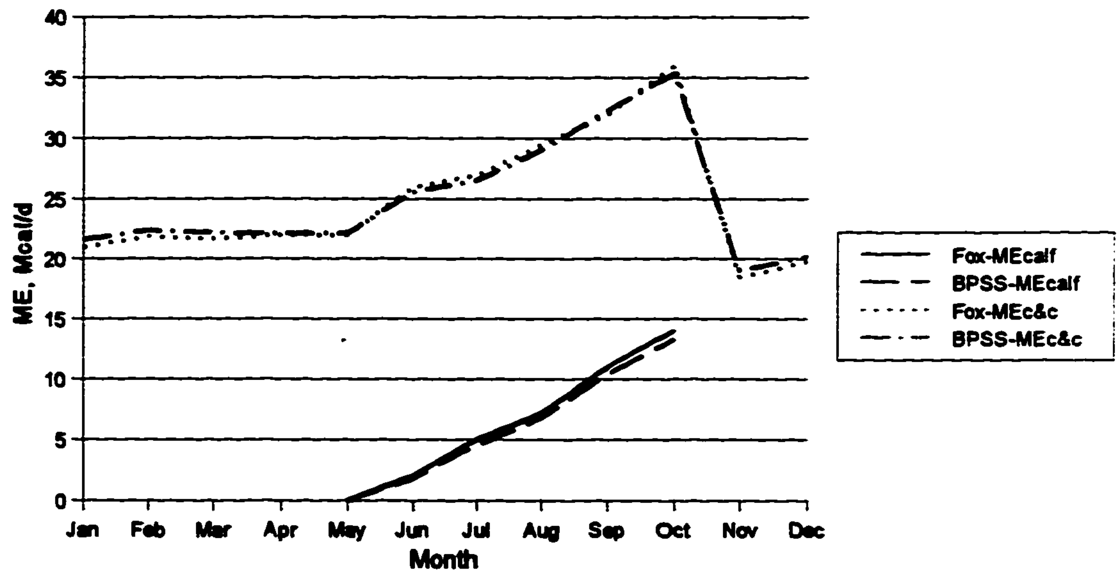

Figure 3.27. Comparisons of total metabolizable energy requirements for a calf (MEcalf) and a cow-calf pair (MEc&c) (with a cow of 5 years old, 567 kg, peak milk yield=5.4 kg/d, CS=5) by Fox model and BPSS.

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Chapter 4

Simulated Effects of Cow Size and Milk Production on Bioeconomic Efficiency in Cow-calf Production Systems

4.1. Introduction

Selection for growth rate and the use of large size continental breeds by commercial producers have resulted in larger cows with higher feed requirements and higher incidences of calving difficulty. Lopez de Torre et al. (1992) suggested that production efficiency may be reduced with cows of relatively large mature weights and that the use of earlier maturing animals would be a somewhat more efficient alternative.

In recent years, increasing growth rate as a breeding objective in beef cattle has been questioned. Barlow (1984) even suggested that there was no sound basis for advocating selection for growth rate in maternal breeds. While increased growth rate results in higher gross efficiency (gain/feed intake) in growing animals, the higher maintenance requirements of heavier breeding females reduce the efficiency at the herd level (Dickerson, 1982). Therefore, advantages of increasing output by increasing body size may be largely offset by increased feed requirements.

Cow-calf managers have become increasingly aware of the need to match cow size and management to the available feed, labour and capital resources in order to increase overall production efficiency (Nickel, 1995; Porter, 1995). Kress et al. (1994) indicated that it is important to match a cow's biological type to the feed resources. Large cows may be matched with average or better feed resource, but intermediate or small cows are a better match for limited feed resources.

Basarab (1995) showed that reducing the cost of production is essential for a profitable operation, and a cow's biological efficiency index decreased as her weight increased. Feed costs account for as much as 60-70 % of total production cost in a beef herd. A major determinant of feed cost is cow size and milk production.

Long, Cartwright and Fitzhugh (1975) used the Texas model of cattle production systems to evaluate the effects of mature cow size and mating plan on beef production and financial returns for two herd management regimes: drylot and pasture. Three size genotypes, represented by mature cow weights of 430, 500 and 600 kg, were compared. Measures of economic efficiency, net income and return on investment, identified an interaction between cow size and management regime. Larger cows were more profitable and returned more per total investment in drylot, while smaller cows were slightly more profitable on pasture.

Calf weaning weight is an important production trait in a cow-calf production enterprises (Wiltbank, 1970). The cow's milk production exerts a major influence on the weaning weight of the calf (Drewery et al., 1959). Milk yield has been shown to be moderately correlated with weaning weight, averaging 0.6, and ranging between 0.12 and 0.8 (Furr and Nelson, 1964; Lusby et al., 1976, Gleddie and Berg, 1968, Butson et al., 1980). Freking et al. (1992) indicated that increased milk yield was associated with improved calf production to weaning. Clutter and Nielsen (1987) also found a significant advantage in 205-d weight of calves suckling high-milking cows over those suckling low-milking cows. These results suggest that high-milking cows would be more efficient than low-milking cows due to higher output. However, this advantage may be offset by: 1) the higher energy cost for milk versus other feed sources available to the calf (Baker et al., 1976; Ansotegui et al., 1991); 2) high milk production is associated with high requirement for maintenance (Montano-Bermudez et al., 1990); and 3) reproduction, as measured by calves weaned/cow exposed, tends to favor the lower milking group (Montano-Bermudez and Nielsen. 1990a). When the level of nutrition is inadequate, the cow attempts to maintain a level of milk production based on her genetic potential at the expense of body reserves, which could have a negative effect on her subsequent reproductive performance. Therefore, overall production efficiency may be similar or even lower for high-milking cows, compared to low milking cows. It is therefore necessary to examine the cost effectiveness of high milk yield in increasing the weaning weight.

Montano-Bermudez and Nielsen (1990b) classified cows into three groups according to their milk production, and found that biological efficiencies of beef production at weaning and at slaughter of calves were maximum in the lowest milking group among cattle similar in size and growth potential. Unless feed resources for the cow herd are very cheap relative to the price of growing calves, economic efficiency would also favour cows with low milk production potential in beef cattle. Van Oijen et al. (1993) estimated the economic and biological efficiencies of beef production in three groups of beef cattle with different levels of milk production. They found that the low milk production group was biologically the most efficient, especially when it was evaluated based on finished slaughter calves. The economic efficiency comparisons agreed closely with the biological efficiency comparison. Jenkins et al. (1991) concluded that heavier weight and higher milk yield potential resulted in greater food energy consumption of the dam, and that moderate mature weight and milk production were biologically more efficient.

Fitzhugh (1978) indicated that production efficiency should be evaluated for the integrated system, not just the individual animal. Different sets of feed, labor, and capital inputs may lead to important biological type x environment interactions for beef production efficiency. Simulation modelling can be used to assist managers in understanding how various inputs may impact the profitability of the enterprise.

A dynamic simulation model, named "**Beef Production Simulation System**" (BPSS), was developed to evaluate the effects of different management strategies on the bioeconomic efficiency of beef production systems (Chapter 3). The model is the result of a multidisciplinary effort that incorporates the interactions of beef cattle energy and protein requirements, herd dynamics, forage production and economics for range production systems.

The objective of the present study was to evaluate the influence of cow size, milk production, interaction effect of cow size with milk production and market price on bioeconomic efficiency in cow-calf production systems, using the Beef Production Simulation System.

4.2. Materials and Methods

The **Beef Production Simulation System** (BPSS) model was used to examine the effects of cow size and milk production on bioeconomic efficiency of beef production systems. The model is a dynamic deterministic simulation and was programmed using STELLA II simulation software on PC/Windows or the Macintosh platforms. The model was composed of four major submodels: **Herd Inventory, Nutrient Requirements, Forage**

Production, and Economic submodels. Detailed information about the model was presented in Chapter 3.

Data and some parameters in the model were derived from appropriate published literature, and unpublished reports from the University of Alberta Beef Research Ranch at Kinsella, Alberta Agriculture, Food and Rural Development (AAFRD), and Beefbooster Cattle Alberta Ltd. Daily temperature and precipitation were stochastically estimated from a normal distribution of monthly means and standard deviations (Table 3.1) based on thirty years of meteorological data in Edmonton, Alberta (Environment Canada, 1995). The climatic data were input variables, which could be easily modified by users of the model.

A herd size of 100 cows with all replacements being produced within the herd was assumed. It was also assumed that cattle were grazed on pastures from May to October; that they received grass hay, straw and supplements during the winter months. Dry matter intake (DMI) was estimated based on actual requirements for the cows and calves. The first day of calving was set at the end of March, and the calving period lasted 84 days. Calves were assumed to be weaned at the end of October each year.

Herds of small, medium and large size cow (mature cow weights of 450, 550 and 650 kg), three levels of milk production (peak milk yields of 5.4, 8.2 and 10.9 kg/d) and three market price levels (low, medium and high price), and their interactions were compared for bioeconomic efficiency. The maximum prices for cows and weaned calves at low, medium and high price levels were 0.9 and 2.0, 1.0 and 2.2, 1.1 and 2.4 $/kg, respectively.

Comparisons were carried out using two alternative methods: 1) a constant calf weaning age (200 d) resulting in different weaning weights for cow size or milk production groups; 2) similar calf weaning weights with different weaning ages for cow size or milk production groups.

Bioeconomic efficiency, measured as the net return per cow, was obtained by subtracting total cost from total return. Total return was estimated from the sale of culled cows and weaned calves. The average cow and weaned calf sale prices were based on 10 years data as shown in Table 3.6 (Agriculture and Agri-Food Canada, 1995). Weaned calf price was discounted $4 per 45 kg body weight as calf weight increased, starting at 140 kg weight (Alberta Agriculture, 1987).

Total cow cost was the sum of fixed and variable costs. Fixed costs included interest on intermediate and long term debt, depreciation, property taxes, repairs and insurance. Variable costs included cow or replacement purchase cost, feed costs and non-feed costs for the cow herd and for calves to weaning. Cow replacement purchase cost was considered only if herd size was increasing and some replacements need to be purchased from outside the farm. Non-feed costs included death loss, interest on operating loans, labour, manure and feed handling, fuel, veterinary, housing and feed storage, marketing, breeding and miscellaneous costs. The default values in the model for cow fixed costs and non-feed costs were $65.54 and $68.39 /cow/yr, respectively, based on the Beefbooster's data (MacNeil et al., 1994). Feed costs included pasture and winter feed cost. The prices for pasture and winter feed were assumed to be 0.03 and 0.06 $/kg, respectively (Alberta Agriculture, 1987).

4.3. Results and Discussion

4.3.1. Cow size

4.3.1.1. Nutrient requirements for different cow sizes

Keeping other parameters constant (mature cow, peak milk yield = 8.2 kg/d, initial condition score CS = 5, birth weight = 35 kg, calving in April and weaning in October), the nutrient requirements (ME and MP) and predicted dry matter intakes (DMI) were compared for small, medium and large cow sizes (mature cow weights of 450, 550 and 650 kg).

The requirements of metabolizable energy (ME_m, Mcal/d) and metabolizable protein (MP_m, g/d) for maintenance for individual cows differing in size over one year are shown in Figures 4.1 and 4.2. The total ME and MP requirements for a cow during one year were compared for different cow sizes (Figures 4.3 and 4.4). It can be seen that the difference in nutrient requirements (ME and MP) of individual cows differing in size was mainly due to difference in maintenance requirement, larger cows requiring more ME_m and MP_m than smaller cows.

The ME and MP requirements for calves from the start of grazing to weaning were compared for small, medium and large cow size groups (Figures 4.5 and 4.6). There was no difference for ME requirement for calves in different cow size groups during the early pasture stage (May - June). Differences of ME and MP requirements for calves in the different cow size groups increased over time.

Comparisons of ME and MP requirements for cow-calf pairs in different cow size groups are shown in Figures 4.7 and 4.8. The requirements differed greatly among the cow size groups during the period from calving to weaning, especially for MP. The predicted DMI for cows and cow-calf pairs are presented in Figure 4.9 and 4.10, respectively. There were obvious difference in the DMI among the cow size groups, larger cow size resulting in higher requirement for DMI.

4.3.1.2. Comparison of cow size at constant calf weaning age

The results of comparing small, medium and large cow sizes (mature cow weights of 450, 550 and 659 kg) at a constant calf weaning age (200 days) for each of the milk production levels are presented in Table 4.1. At a constant weaning age (200 days), calf weaning weight (kg), calf forage DMI (kg/yr), metabolizable energy requirement (ME, Mcal/d/cow-calf pair) and dry matter intake for a cow-calf pair (DMI, kg/d/cow-calf pair) increased with cow size within each milk production level. For a herd, the average feed cost and total cost per cow ($/cow/yr) also increased with cow size within each milk production level.

Returns and net returns ($/cow/yr) for different cow sizes were compared at low, medium, and high price levels and at each milk production level (Table 4.1). Although returns were generally higher for the larger cow size group, because their total production was higher, net returns (or bioeconomic efficiencies) changed with different price levels. At the low price level (Figure 4.11), the medium cow size (550 kg) had the highest net return, and the small cow size (450 kg) had the lowest net return when milk production was at medium (8.2 kg/d) and high (10.9 kg/d) levels. However, at the low level of milk production (5.4 kg/d), medium and large cow sizes had almost the same net return, and small cow size had the lowest net return.

At the medium price level (Figure 4.12), the small cow size always had the lowest net return for each milk production group. The medium and large cow sizes had similar net returns for milk production at the high level. However, the large cow size had a higher net return than medium cow size when milk production was at the low and medium levels.

At the high price level (Figure 4.13), the net returns increased with cow size for all milk production levels, with the large cow size having the highest net return.

4.3.1.3. Comparison of cow size at similar calf weaning weights

The results of comparing cow sizes at similar calf weaning weights for each milk production level are shown in Table 4.2. Within each milk production group, the weaning age for small, medium and large cow sizes were set at 220, 200 and 180 days, respectively, to achieve similar calf weaning weights for different cow sizes.

Metabolizable energy requirement (ME, Mcal/d/cow-calf pair) and dry matter intake (DMI, kg/d/cow-calf pair) increased with increasing cow size at each milk production level. For the herd, the average feed cost and total cost per cow ($/cow/yr) also increased with increasing cow size at each milk production level.

Returns and net returns ($/cow/yr) for different cow sizes were compared at low, medium, and high price levels and at each milk production level (Table 4.2). Returns increased with larger cow size as expected. However, net returns changed with different price levels. At the low price level, net returns decreased with cow size when milk production was at low or medium levels. The small size cow had the highest net return. However, at the high level of milk production (10.9 kg/d), the medium cow size had the highest net return, while the large cow size had the lowest net return (Figure 4.14).

At the medium price level, the large cow size always had the lowest net return in each milk production group. The small and medium cow sizes had similar net returns when milk production was at low and medium levels. However, the medium cow size had a higher net return than low cow size when milk production was at the high level (Figure 4.15).

At the high price level, the medium cow size always had the highest net returns and the large cow size always had the lowest net return for all milk production levels (Figure 4.16).

4.3.2. Milk production

4.3.2.1. Nutrient requirements for different levels of milk production

Keeping other parameters constant (5 years old cow, mature weight = 550 kg, cow condition score CS = 5, calf birth weight = 35 kg, calving in April and weaning in October), the nutrient requirements (ME and MP) and predicted dry matter intakes (DMI) were compared for low, medium and high milk production levels (peak milk yield of 5.4, 8.2, and 10.9 kg/d).

The requirements of metabolizable energy (ME_{lact}, Mcal/d) and metabolizable protein (MP_{lact}, g/d) for lactation for individual cows differing in milk production over one year are presented in Figures 4.17 and 4.18. The total ME and MP requirements for a cow over one year were compared for different milk production levels (Figures 4.19 and 4.20). The results indicate that the differences in nutrient requirements (ME and MP) for individual cows differing in milk production was mainly related to the lactation requirement during the period from calving to weaning, where other parameters were constant. Cows with high milk production required more ME_{lact} and MP_{lact} than cows with low milk production.

The ME and MP requirements for a calf from the start of grazing to weaning were compared for low, medium and high milk production levels (Figures 4.21 and 4.22). When cow size was the same, there was no obvious difference for ME and MP requirements of calves from different milk production levels, especially between the medium and high milk levels. The differences in MP requirement for calves during the early stage (May - June) among the different milk production levels was higher than those during the later stage.

Comparisons of ME and MP requirements for cow-calf pairs at different milk production levels are shown in Figures 4.23 and Figure 4.24. The differences for the nutrient requirements among the milk production levels occurred only during the period from calving to weaning, since other parameters were assumed to be constant following weaning (November - February). The predicted DMIs for a cow and a cow-calf pair are presented in Figure 4.25 and 4.26, respectively. As expected, there were significant differences in the DMI among the milk production levels during the lactation period, with higher milk production requiring higher DMI.

4.3.2.2. Comparison of milk production at constant calf weaning age

The results of comparisons among low, medium and high milk production levels (peak milk yield of 5.4, 8.2, and 10.9 kg/d) at a constant calf weaning age (200 days) are shown in Table 4.1. At a constant weaning age (200 days), calf forage DMI (kg/calf/yr) decreased with higher milk production. However, calf weaning weight (kg), calf milk DMI (kg/calf/yr), metabolizable energy requirement (ME, Mcal/d/cow-calf pair) and dry matter intake (DMI, kg/d/cow-calf pair) increased with increasing milk production at each cow size level. These results agree with other research which indicates that calves receiving less milk increased their forage intake (Baker et al., 1976; Ansotegui et al., 1991). At the herd level, the average feed cost and yearly total cost per cow ($/cow/yr) also increased with the increase in milk production within each cow size level.

The returns and net returns ($/cow/yr) for different milk production levels were compared at low, medium, and high price levels and in each cow size class (Table 4.1). The returns were generally higher with higher milk production because of heavier calf weights. The net returns, or bioeconomic efficiencies, at low, medium and high price levels are shown in Figure 4.27, 4.28 and 4.29, respectively. The net returns increased with increasing milk production for all cow size levels and all price levels. The high milk production level (10.9 kg/d) gave the highest net return within each cow size class when the comparisons were made at the same weaning age.

4.3.2.3. Comparison of milk production at similar calf weaning weights

The results of comparing of milk production at similar calf weaning weights by cow size classes are shown in Table 4.3. For each cow size class, the weaning age for low, medium and high cow sizes were set at 220, 200 and 180 days, respectively, so that the calf weaning weights were similar for different milk production levels.

At similar calf weaning weights, calf milk DMI (kg/calf/yr) increased with the increase in milk production within each cow size class. In contrast, calf forage DMI (kg/calf/yr) was reduced with higher milk production. The metabolizable energy requirements (ME, Mcal/d/cow-calf pair) and dry matter intakes (DMI, kg/d/cow-calf pair) were almost the same for different milk production levels within each cow size class. On a herd basis, the average feed cost and total cost per cow (\$/cow/yr) increased slightly with the increase in milk production within each cow size class.

The returns and net returns (\$/cow/yr) for different milk production levels were compared at low, medium, and high price levels and within each cow size class (Table 4.3). The returns were the same for different milk production levels since cow size and calf weaning weight were the same. The net returns at low, medium and high price levels are shown in Figure 4.30, 4.31 and 4.32, respectively. Net return, or bioeconomic efficiency, decreased with increasing milk production for all cow size classes and all price levels. Cows with low milk production (5.4 kg/d) had the highest net return within each cow size class when the comparisons were made at a similar weaning weight.

4.4. Summary and Conclusions

For the effects of cow size, simulated results lead to the conclusion that the differences in nutrient requirements (ME and MP) for cows differing in size was mainly due to differences in maintenance requirement. Larger cows required more ME_m and MP_m than smaller cows. Calf forage DMI, ME and DMI for a cow-calf pair, feed cost and total cost per cow, and return increased with size of cow.

When comparisons of cow size were made at a constant calf weaning age (220 d), the small cow size group always had the lowest bioeconomic efficiency for each milk production group and at each market price level. The medium cow size group had the highest bioeconomic efficiency for each milk production group at the low price level, however, the large cow size group had the highest bioeconomic efficiency for each milk production group at the medium and high price levels.

When comparisons of cow size were made at similar calf weaning weights, the large cow size group always had the lowest bioeconomic efficiency for each milk production group and at each market price level. The medium cow size group had the highest bioeconomic efficiency among the high milk production groups at all price levels, and for each milk production group at the high price level. The small size group had the highest bioeconomic efficiency only at low or medium milk production levels and at low market price level, this illustrates the interactions between cow size and market price level, and between cow size and milk production.

For the effects of milk production, differences in nutrient requirements (ME and MP) of cows differing in milk production was mainly caused by the lactation requirement during the period from calving to weaning, since other parameters were constant. Cows with a high milk production required more ME and MP for lactation than cows with low milk production. When comparisons of milk production were made at a constant weaning age (200 d), calf forage DMI decreased with higher milk production, but the calf milk DMI, ME and DMI for a cow-calf pair, feed cost and total cost per cow, and return increased with higher milk production. The high milk production level, with a higher weaning weight, had the highest bioeconomic efficiency regardless of market price level or cow size.

When comparisons of milk production were made at similar weaning weights, DMI and total cost per cow for the low milk production level were slightly lower than for the other levels. So the low milk production level had the highest bioeconomic efficiency regardless of the market price level or the cow size group. These results lead to the conclusion that, although the weaning age required to reach a predetermined weaning weight for higher milking levels would be shorter, the saving in feed cost due to a shorter period is offset by the increased cost of the higher milk production. On the basis of the costs and returns specific to this study, to reach a certain weaning weight, increased milk production was not cost effective for a cow-calf beef production system.

The study demonstrates that the BPSS model may provide a useful method for simultaneous consideration of many factors in an integrated system to estimate optimum cow size and milk production for specific resource availabilities and market prices.

Table 4.1. Effects of cow size on DMI, cow cost, return, and net return at different milk production and price levels assuming constant weaning age (200 d)[1]

Peak milk yield (kg/d)	5.4			8.2			10.9		
Cow mature wt (kg)	450	550	650	450	550	650	450	550	650
Weaning age (day)	200	200	200	200	200	200	200	200	200
Weaning wt (kg)	185	215	245	210	245	280	235	270	305
Milk DMI (kg/calf/yr)[2]	106	106	106	157	157	157	201	201	201
Forage DMI (kg/calf/yr)	406	490	574	343	425	508	270	339	412
ME (Mcal/d/cow-calf)[3]	20.6	23.5	25.9	21.7	24.6	27.6	22.6	25.6	28.6
DMI (kg/d/cow-calf)	9.14	10.43	11.53	9.63	10.93	12.27	10.05	11.36	12.7
Feed cost ($/cow/yr)	200	228	252	210	238	267	218	247	276
Cow total cost ($/cow/yr)	283	316	358	293	326	373	302	335	382
Low price level									
Return ($/cow/yr)	296	340	382	318	364	407	339	382	422
Net return ($/cow/yr)[4]	12.7	24.4	23.9	24.8	37.9	33.6	36.6	47.1	40.1
Medium price level									
Return ($/cow/yr)	328	378	425	353	405	454	339	426	473
Net return ($/cow/yr)	44.4	61.9	67.0	59.7	79.0	81.0	74.5	91.3	90.7
High price level									
Return ($/cow/yr)	360	415	468	388	446	501	415	471	523
Net return ($/cow/yr)	76.1	99.2	110	94.5	120.1	128.4	112.5	135.5	141

[1] The prices for cows and weaned calves at low, medium and high price levels were 0.9 and 2.0, 1.0 and 2.2, 1.1 and 2.4 $/kg, respectively. The prices for pasture and winter feed were the same for three price levels as 0.03 and 0.06 $/kg.

[2] Milk DMI and Forage DMI were the average DMI of a calf per day for one year.

[3] Consumed ME and DMI were the average values per day for one year on a cow-calf pair basis.

[4] Net return = Return - Cow total cost

Table 4.2. Effects of cow size on DMI, cow cost, return and net return at different milk production and price levels assuming similar weaning weights[1]

Peak milk yield (kg/d)	5.4			8.2			10.9		
Cow mature wt (kg)	450	550	650	450	550	650	450	550	650
Weaning age (day)	220	200	180	220	200	180	220	200	180
Weaning wt (kg)	210	215	210	240	245	245	260	270	270
ME (Mcal/d/cow-calf)[2]	21.3	23.5	25.2	22.5	24.6	26.6	23.5	25.6	27.5
DMI (kg/d/cow-calf)	9.46	10.43	11.19	9.99	10.93	11.84	10.45	11.36	12.2
Feed cost ($/cow/yr)	207	228	246	218	238	259	228	247	267
Cow total cost ($/cow/yr)	291	316	351	302	326	365	311	335	373
Low price level									
Return ($/cow/yr)	318	340	354	343	364	382	357	382	400
Net return ($/cow/yr)[3]	27.6	24.4	2.51	40.7	37.9	17.4	46.1	47.1	27.2
Medium price level									
Return ($/cow/yr)	353	378	392	381	405	425	398	426	446
Net return ($/cow/yr)	62.4	61.9	41.3	79.3	79.0	60.5	87.1	91.3	73.4
High price level									
Return ($/cow/yr)	388	415	431	420	446	468	439	471	492
Net return ($/cow/yr)	97.2	99.2	80.0	117.8	120.1	103.6	128.1	135.5	120

[1] The prices for cows and weaned calves at low, medium and high price levels were 0.9 and 2.0, 1.0 and 2.2, 1.1 and 2.4 $/kg, respectively. The prices for pasture and winter feed were the same for three price levels as 0.03 and 0.06 $/kg.

[2] Consumed ME and DMI were the average values per day for one year on a cow-calf pair basis.

[3] Net return = Return - Cow total cost

Table 4.3. Effects of milk production on DMI, cow cost, return and net return at different cow size and price levels assuming similar weaning weights[1]

Cow mature wt (kg)	450			550			650		
Peak milk yield (kg/d)	5.4	8.2	10.9	5.4	8.2	10.9	5.4	8.2	10.9
Weaning age (day)	220	200	180	220	200	180	220	200	180
Weaning wt (kg)	210	210	210	245	245	240	280	280	270
Milk DMI (kg/calf/yr)[2]	108	157	196	108	157	196	108	157	196
Forage DMI (kg/calf/yr)	446	343	233	538	425	294	597	508	359
ME (Mcal/d/cow-calf)[3]	21.3	21.7	21.8	24.3	24.6	24.6	26.9	27.6	27.5
DMI (kg/d/cow-calf)	9.46	9.63	9.68	10.8	10.93	10.94	11.93	12.27	12.24
Feed cost ($/cow/yr)	207	210	211	236	238	239	261	267	267
Cow total cost ($/cow/yr)	291	293	295	324	326	327	367	373	373
Low price level									
Return ($/cow/yr)[4]	318	318	318	364	364	360	407	407	400
Net return ($/cow/yr)	27.6	24.8	23.4	39.8	37.9	33.6	39.6	33.6	27.2
Medium price level									
Return ($/cow/yr)	353	353	353	405	405	401	454	454	446
Net return ($/cow/yr)	62.4	59.7	58.3	80.9	79.0	74.1	87.0	81.0	73.4
High price level									
Return ($/cow/yr)	388	388	388	446	446	441	501	501	492
Net return ($/cow/yr)	97.2	94.5	93.1	122.1	120.1	114.6	134.4	128.4	120

[1] The prices for cows and weaned calves at low, medium and high price levels were 0.9 and 2.0, 1.0 and 2.2, 1.1 and 2.4 $/kg, respectively. The prices for pasture and winter feed were the same for three price levels as 0.03 and 0.06 $/kg.
[2] Milk DMI and Forage DMI were the average DMI of a calf per day for one year.
[3] Consumed ME and DMI were the average values per day for one year on a cow-calf pair basis.
[4] Net return = Return - Cow total cost

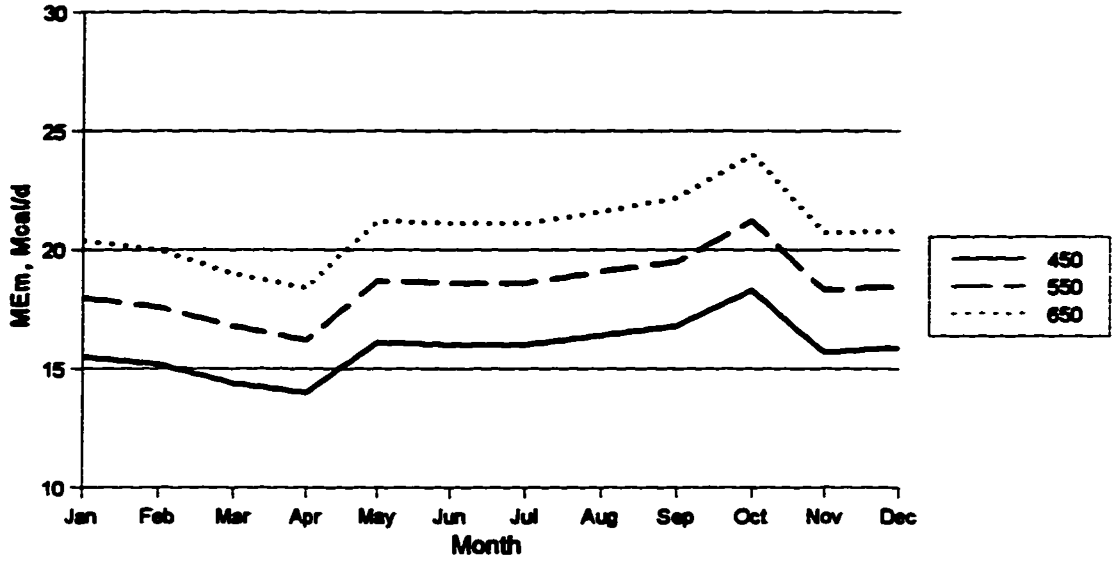

Figure 4.1. Metabolizable energy requirement for maintenance (MEm, Mcal/d) of mature cows differing in size (450, 550, and 650 kg) and assuming other parameters are constant (5 years old, peak milk yield=8.2 kg/d, CS=5).

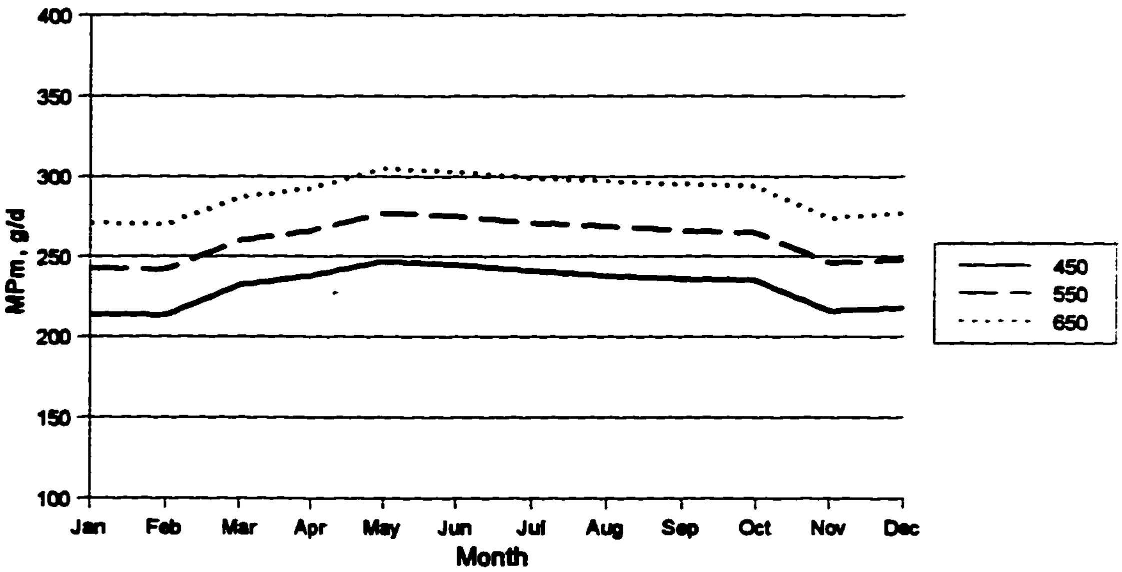

Figure 4.2. Metabolizable protein requirement for maintenance (MPm, g/d) of mature cows differing in size (450, 550, and 650 kg) and assuming other parameters are constant (5 years old, peak milk yield=8.2 kg/d, CS=5).

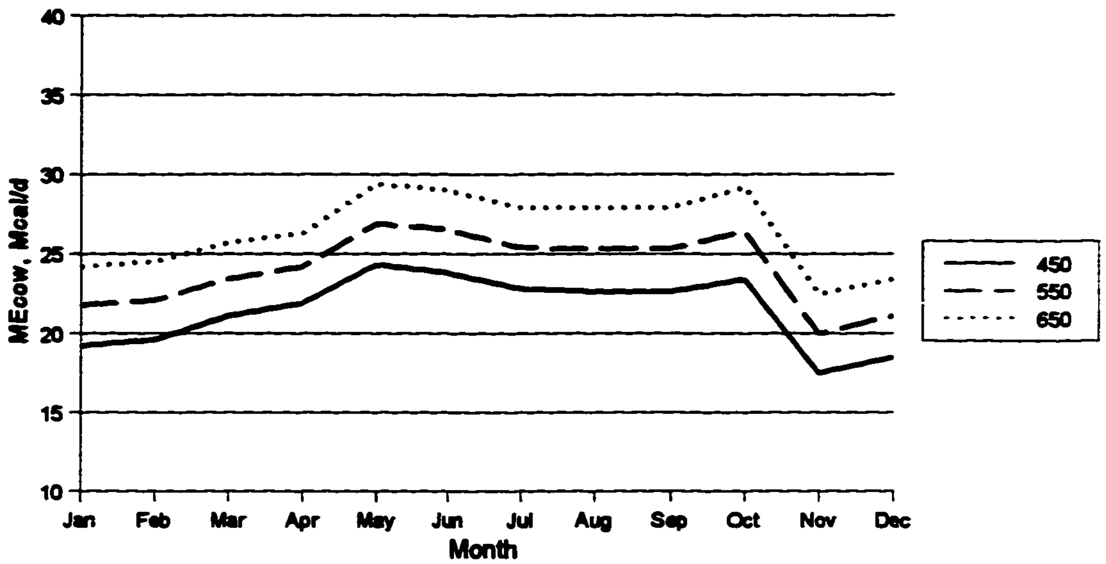

Figure 4.3. Total metabolizable energy requirement (MEcow, Mcal/d) of mature cows differing in size (450, 550, and 650 kg) and assuming other parameters are constant (5 years old, peak milk yield=8.2 kg/d, CS=5).

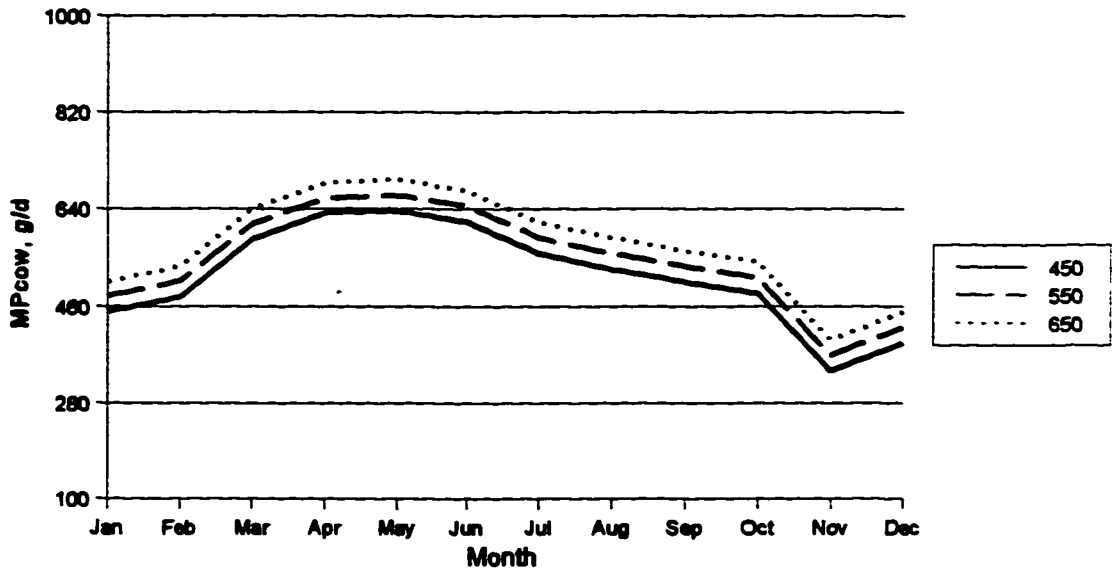

Figure 4.4. Total metabolizable protein requirement (MPcow, g/d) of mature cows differing in size (450, 550, and 650 kg) and assuming other parameters are constant (5 years old, peak milk yield=8.2 kg/d, CS=5).

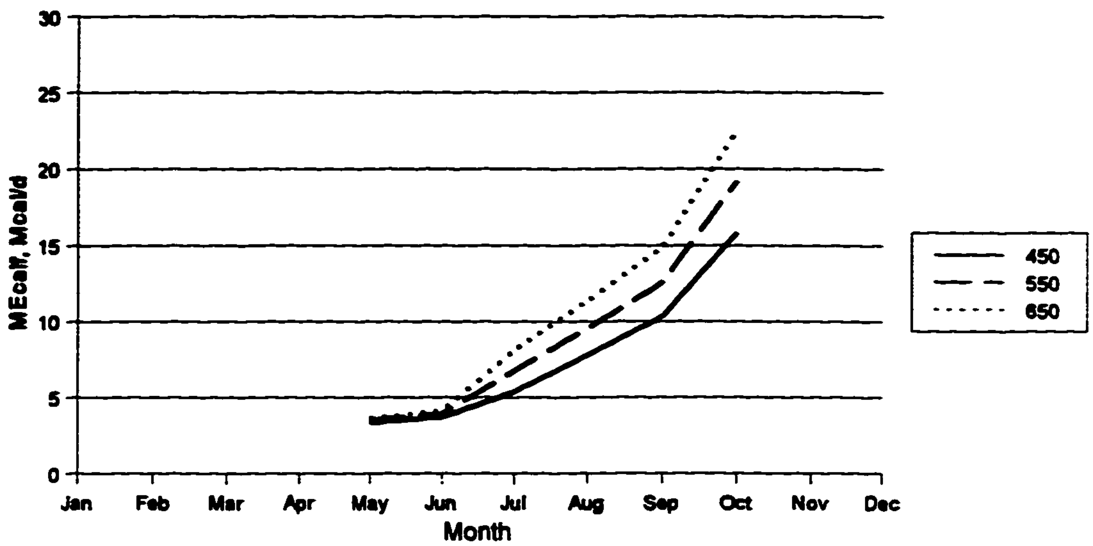

Figure 4.5. Metabolizable energy requirements (MEcalf, Mcal/d) of calves based on mature sizes of the dams (450, 550, and 650 kg) and assuming other parameters are constant (5 years old, peak milk yield=8.2 kg/d, CS=5).

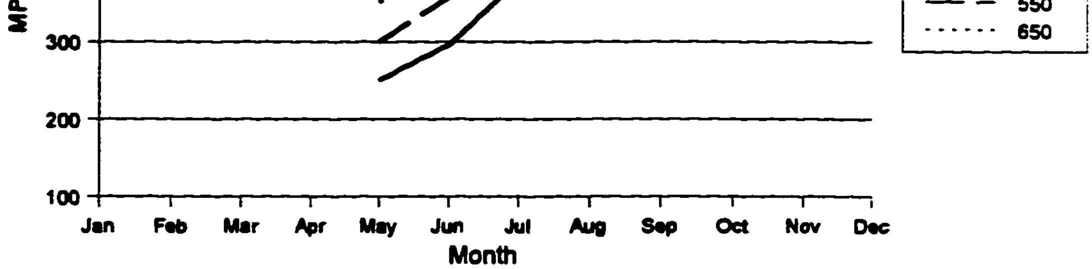

Figure 4.6. Metabolizable protein requirements (MPcalf, g/d) of calves based on mature sizes of the dams (450, 550, and 650 kg) and assuming other parameters are constant (5 years old, peak milk yield=8.2 kg/d, CS=5).

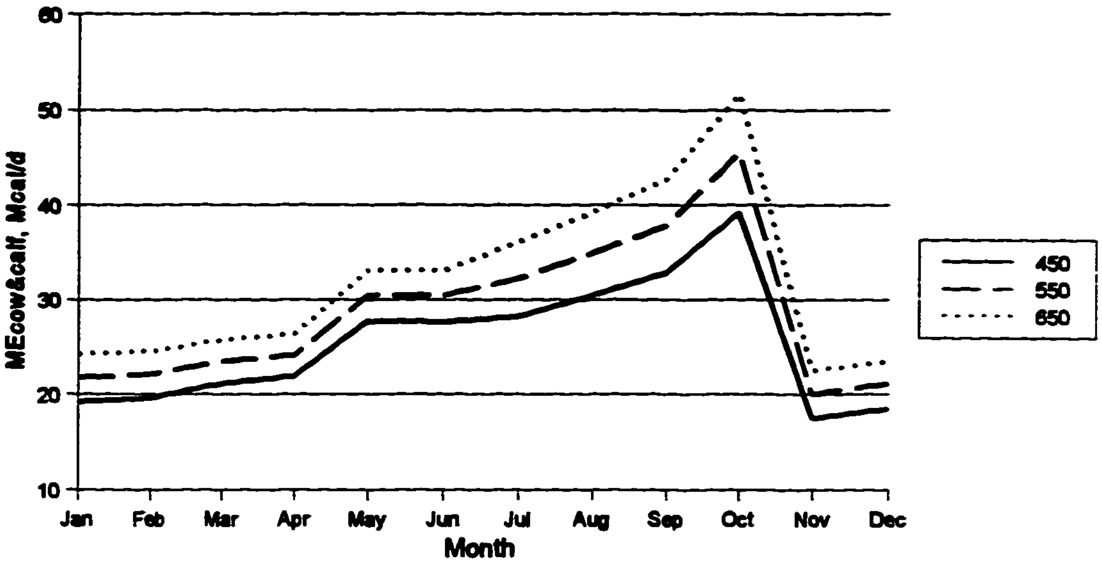

Figure 4.7. Metabolizable energy requirements (MEcow&calf, Mcal/d) of cow-calf pairs based on the mature sizes of the cows (450, 550, and 650 kg) and assuming other parameters are constant (5 years old, peak milk yield=8.2 kg/d, CS=5).

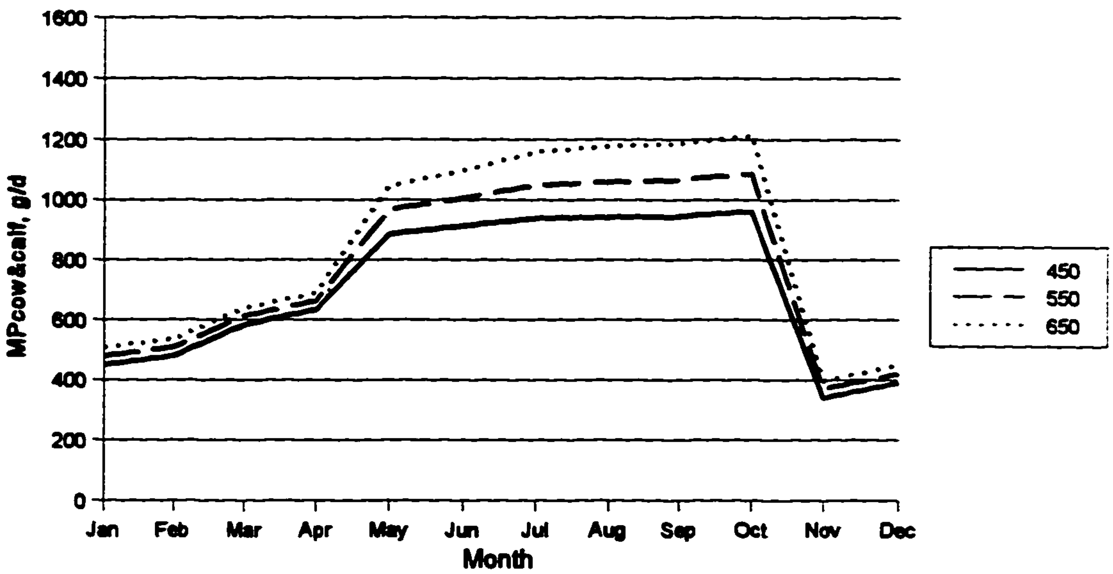

Figure 4.8. Metabolizable protein requirements (MPcow&calf, g/d) of cow-calf pairs based on the mature sizes of the cows (450, 550, and 650 kg) and assuming other parameters are constant (5 years old, peak milk yield=8.2 kg/d, CS=5).

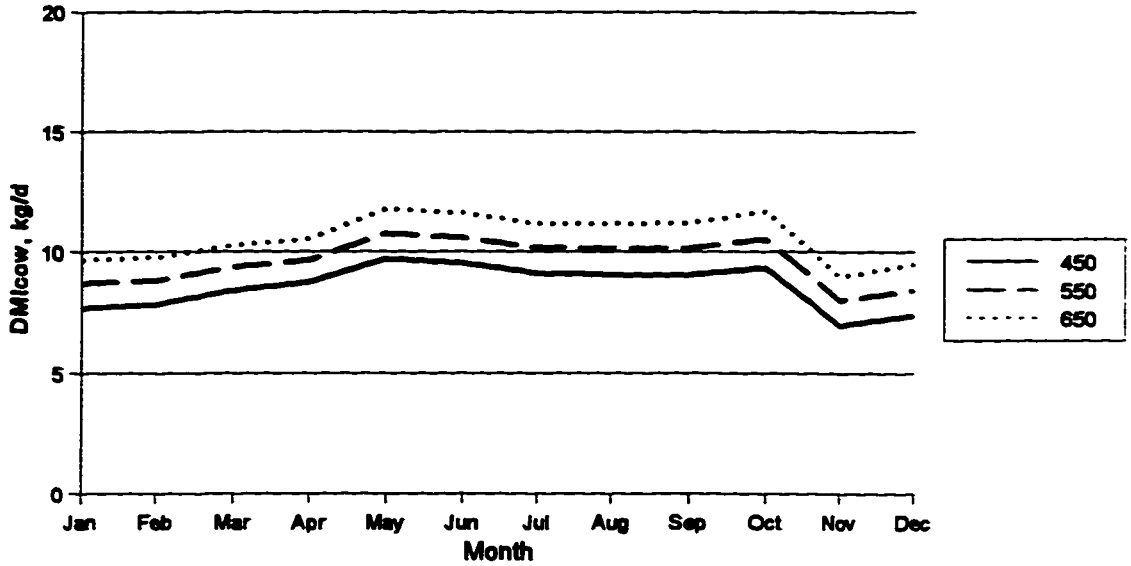

Figure 4.9. Predicted dry matter intakes (DMIcow, kg/d) of mature cows differing in size (450, 550, and 650 kg) and assuming other parameters are constant (5 years old, peak milk yield=8.2 kg/d, CS=5).

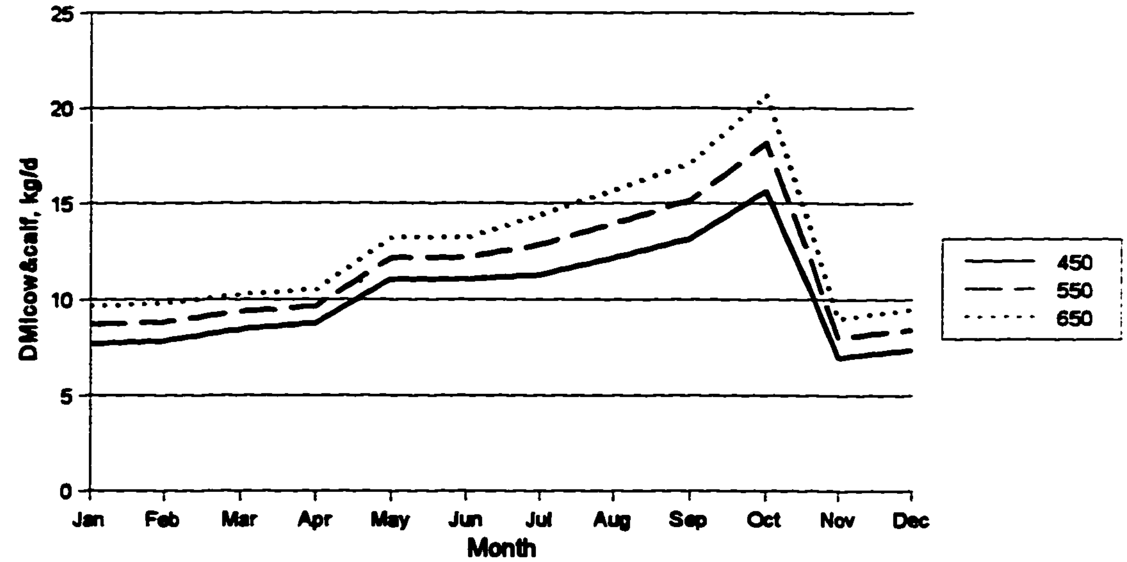

Figure 4.10. Predicted dry matter intakes (DMIcow&calf, kg/d) of cow-calf pairs based on the mature sizes of the cows (450, 550, and 650 kg) and assuming other parameters are constant (5 years old, peak milk yield=8.2 kg/d, CS=5).

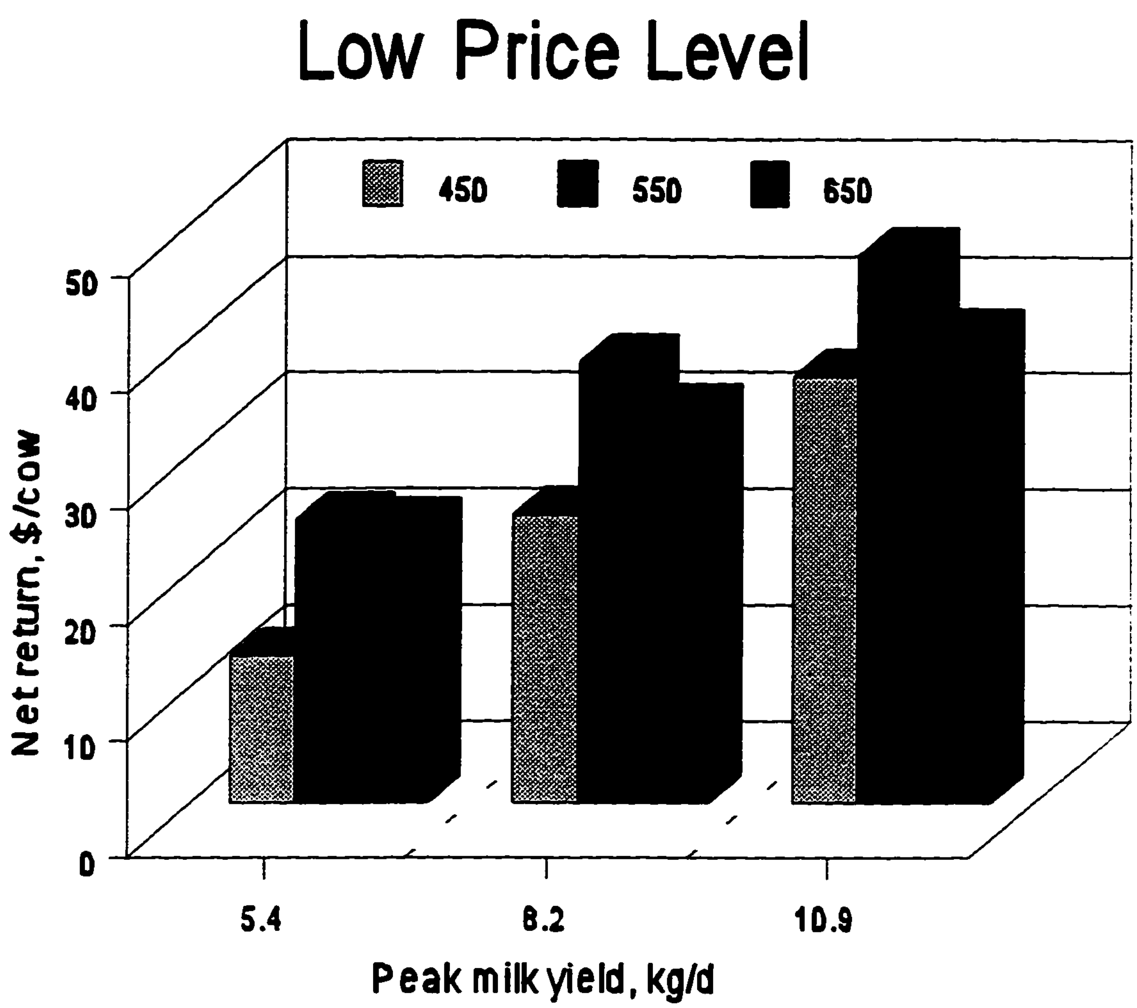

Figure 4.11. Net returns from different cow sizes (450, 550 and 650 kg) in each milk production class at **low price level** when comparisons were at **constant weaning age** (200 d).

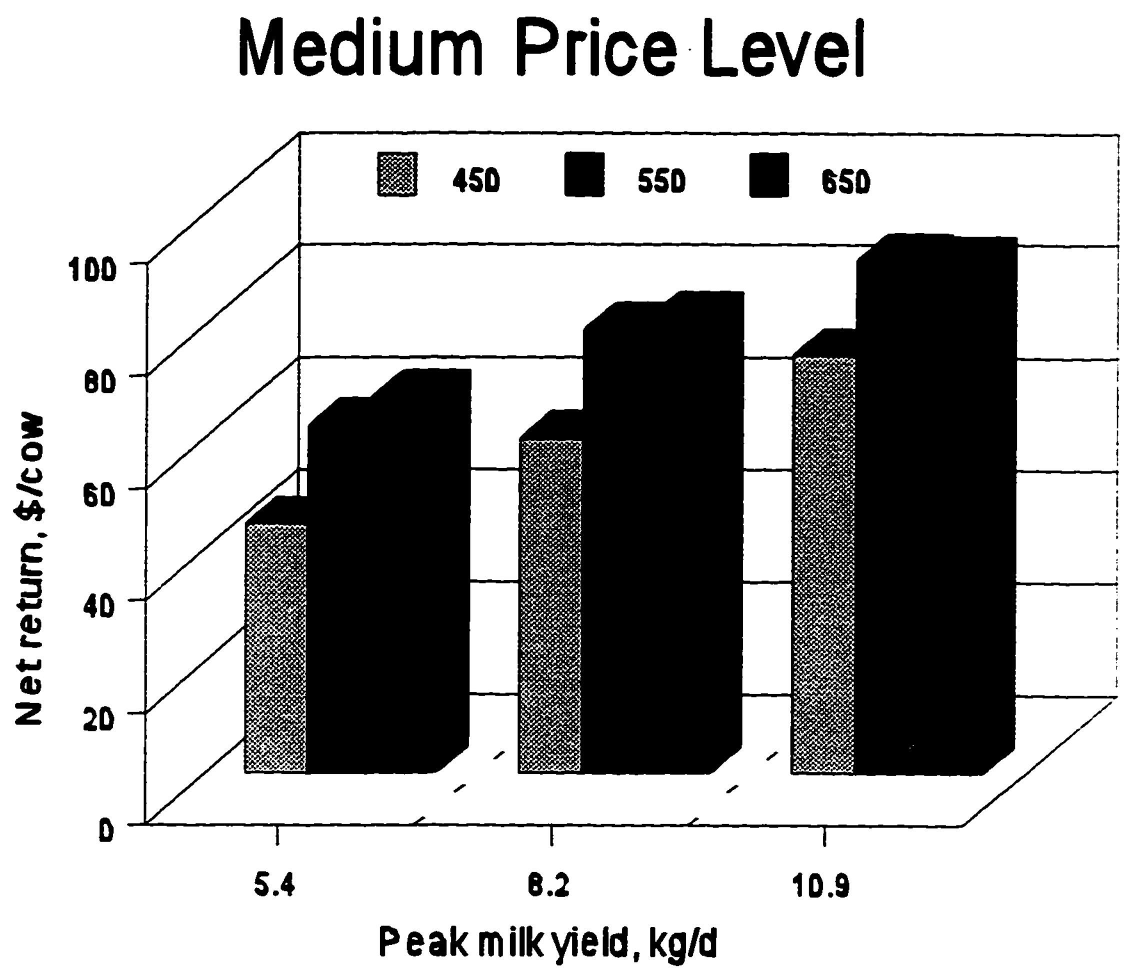

Figure 4.12. Net returns from different cow sizes (450, 550 and 650 kg) in each milk production class at **medium price level** when comparisons were at **constant weaning age** (200 d).

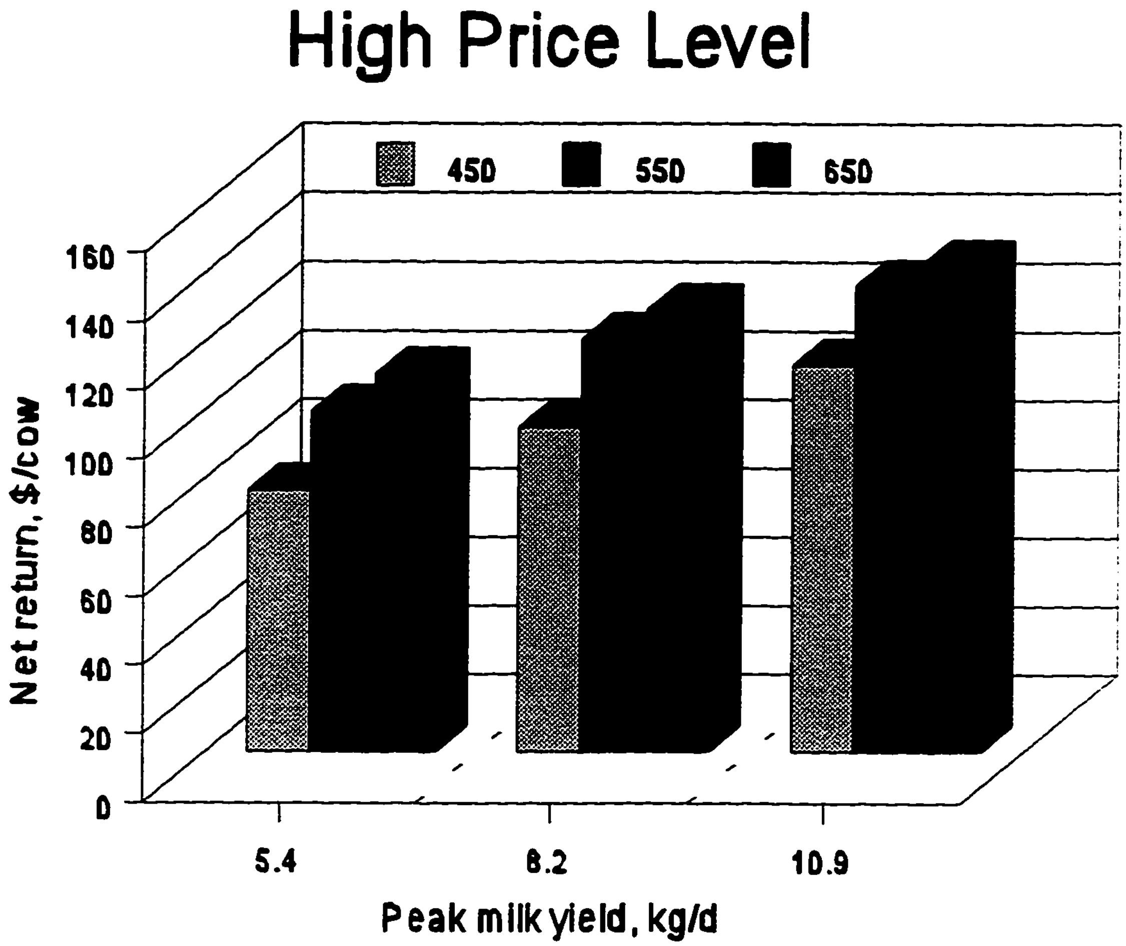

Figure 4.13. Net returns from different cow sizes (450, 550 and 650 kg) in each milk production class at **high price level** when comparisons were at **constant weaning age** (200 d).

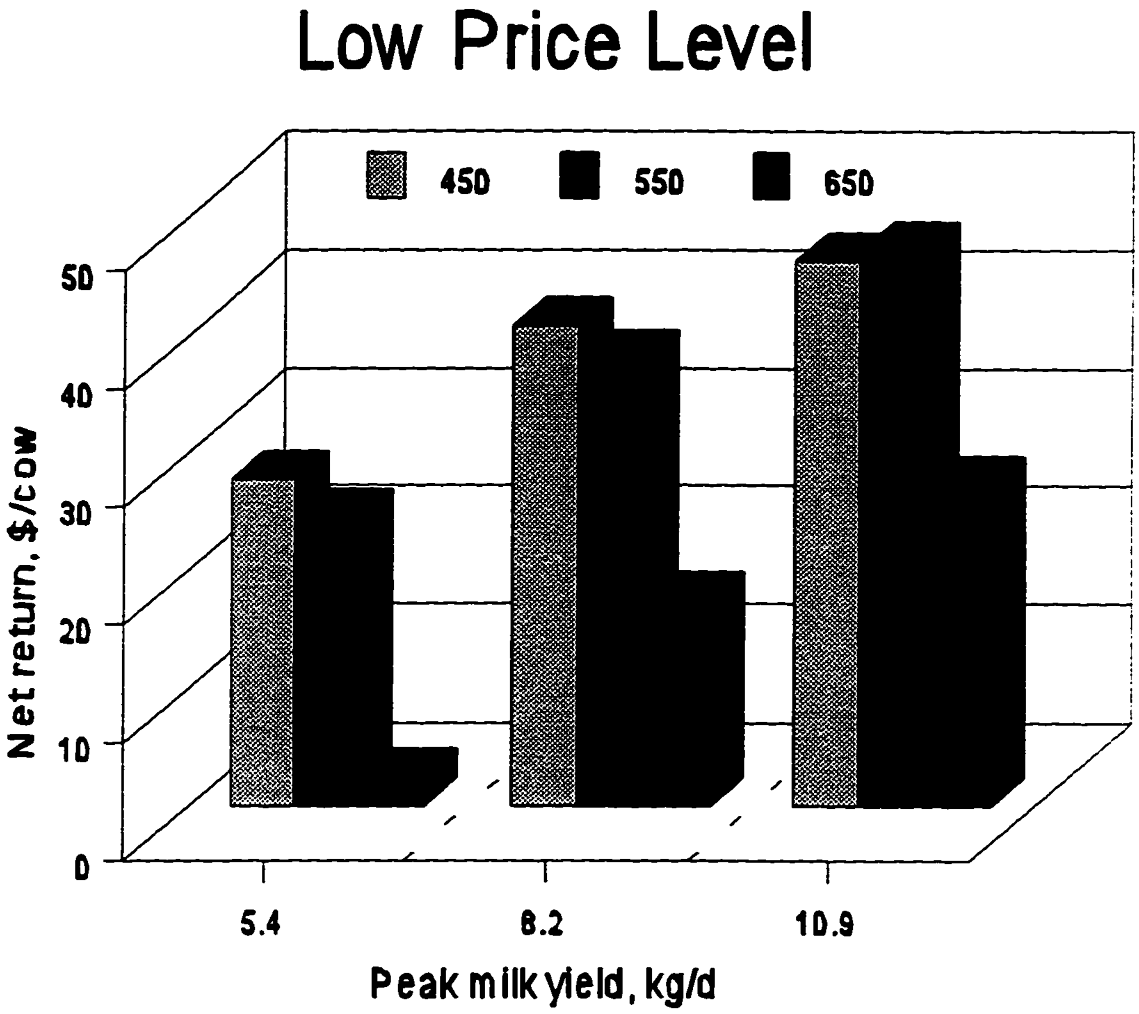

Figure 4.14. Net returns from different cow sizes (450, 550 and 650 kg) in each milk production class at **low price level** when comparisons were at **similar weaning weights**.

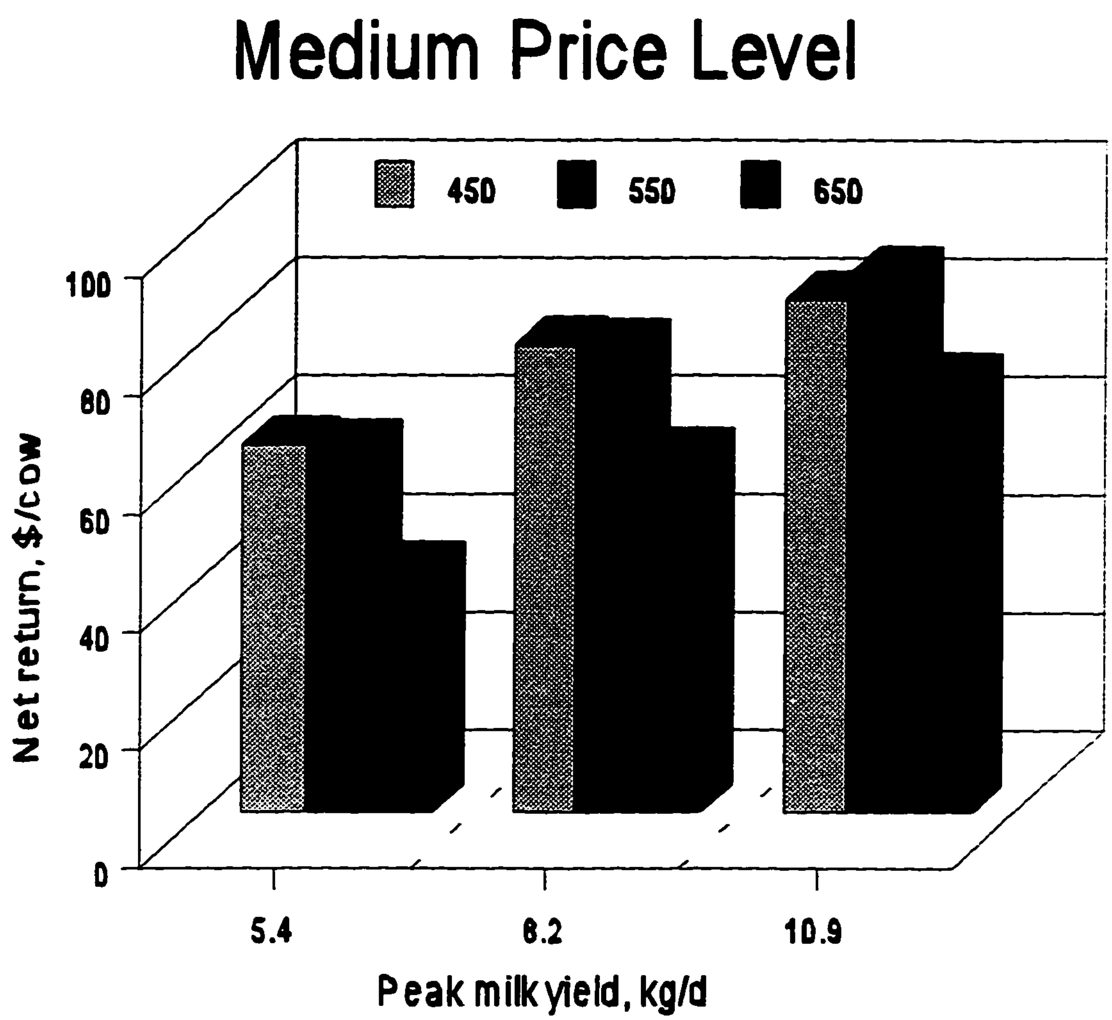

Figure 4.15. Net returns from different cow sizes (450, 550 and 650 kg) in each milk production class at **medium price level** when comparisons were at **similar weaning weights**.

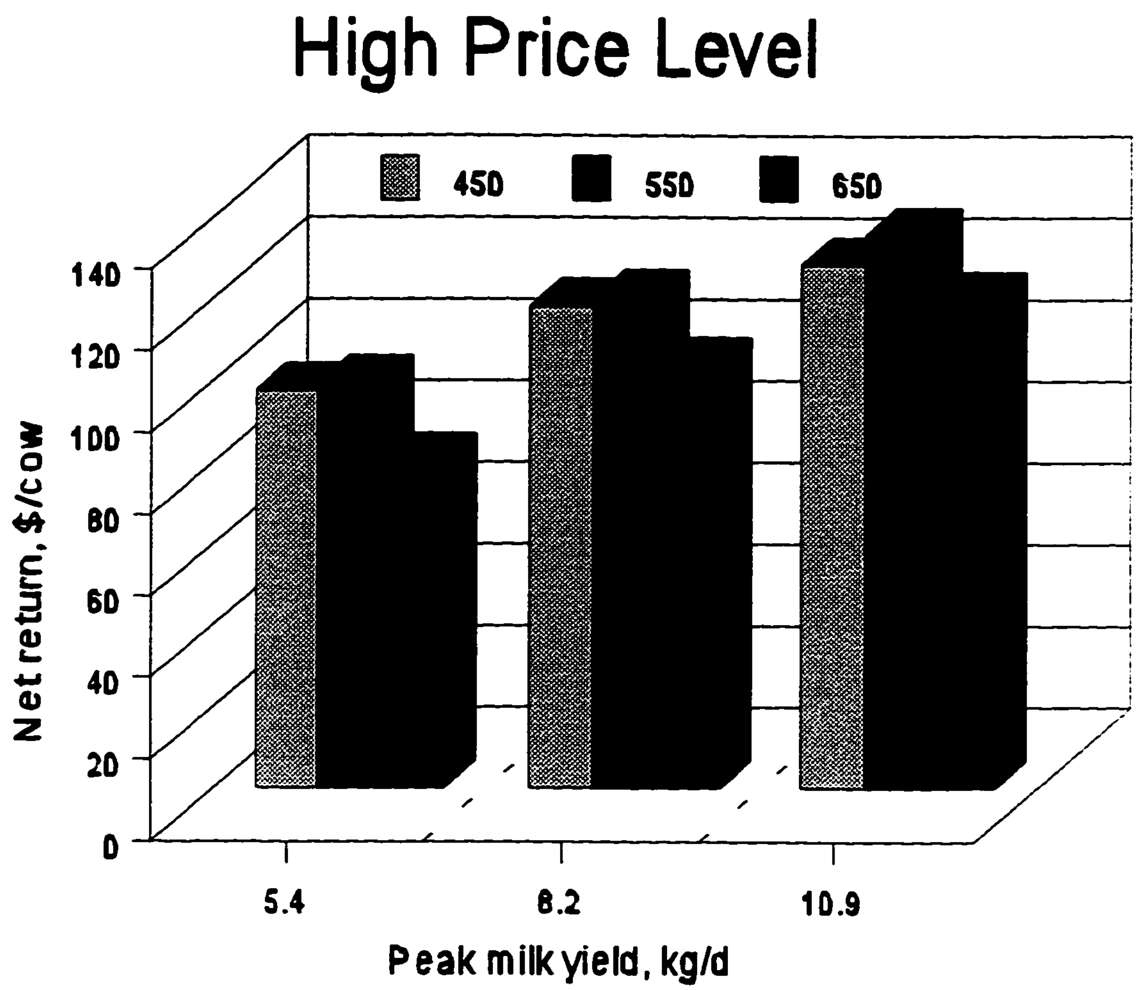

Figure 4.16. Net returns from different cow sizes (450, 550 and 650 kg) in each milk production class at **high price level** when comparisons were at **similar weaning weights**.

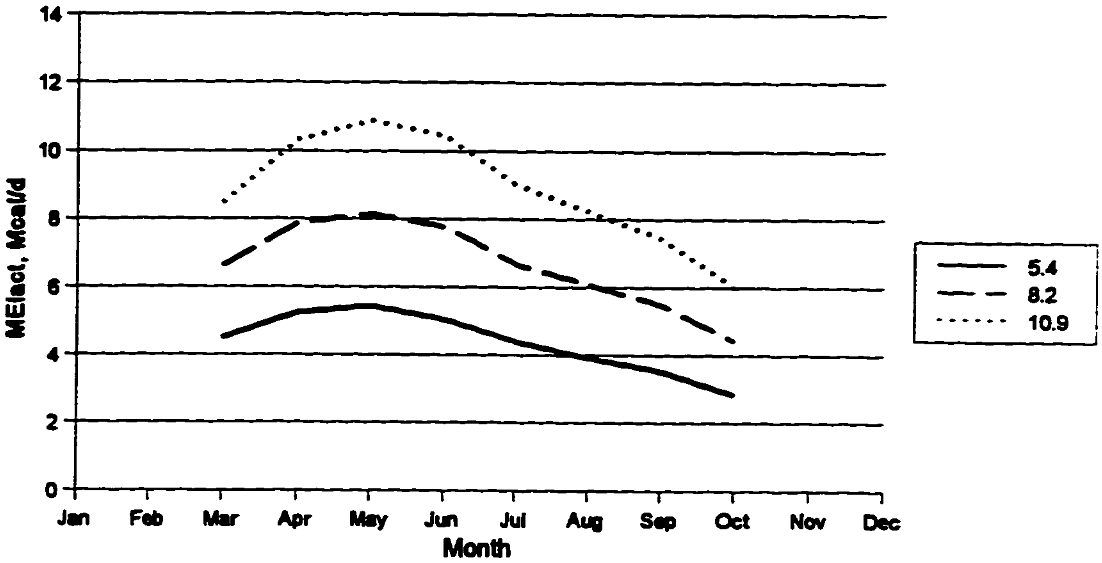

Figure 4.17. Metabolizable energy requirements for lactation (MElact, Mcal/d) of mature cows differing in peak milk yield (5.4, 8.2, and 10.9 kg/d) and assuming other parameters are constant (5 years old, cow mature weight = 550 kg/d, CS = 5).

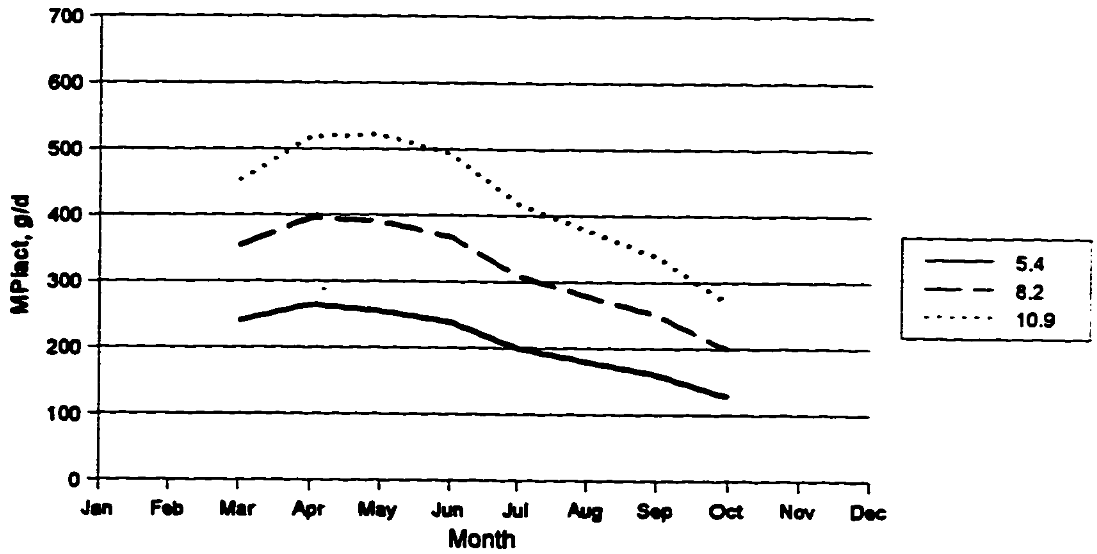

Figure 4.18. Metabolizable protein requirements for lactation (MPlact, g/d) of mature cows differing in peak milk yield (5.4, 8.2, and 10.9 kg/d) and assuming other parameters are constant (5 years old, cow mature weight = 550 kg/d, CS = 5).

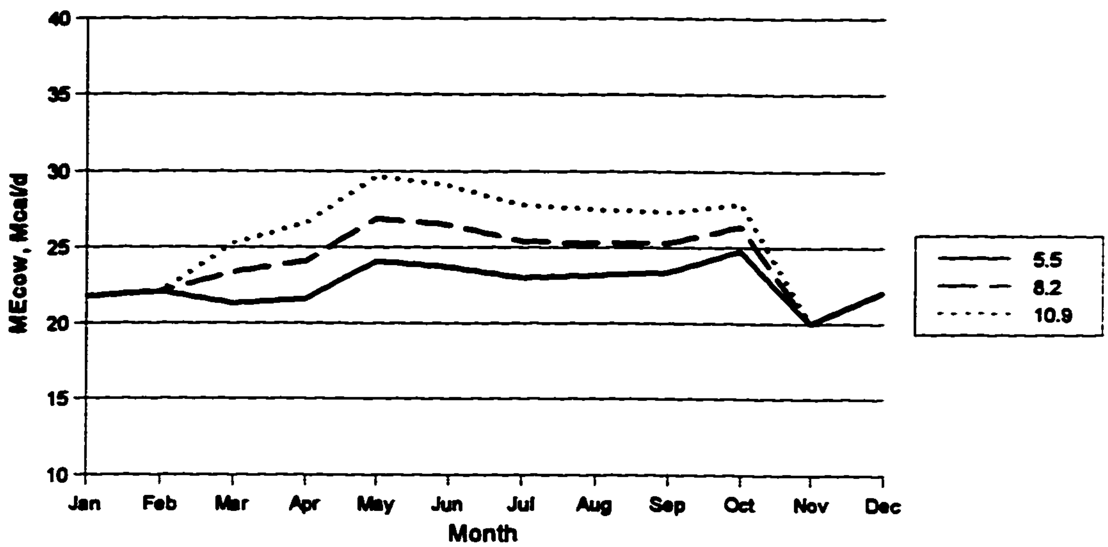

Figure 4.19. Total metabolizable energy requirements (MEcow, Mcal/d) of mature cows differing in peak milk yield (5.4, 8.2, and 10.9 kg/d) and assuming other parameters are constant (5 years old, cow mature weight = 550 kg/d, CS = 5).

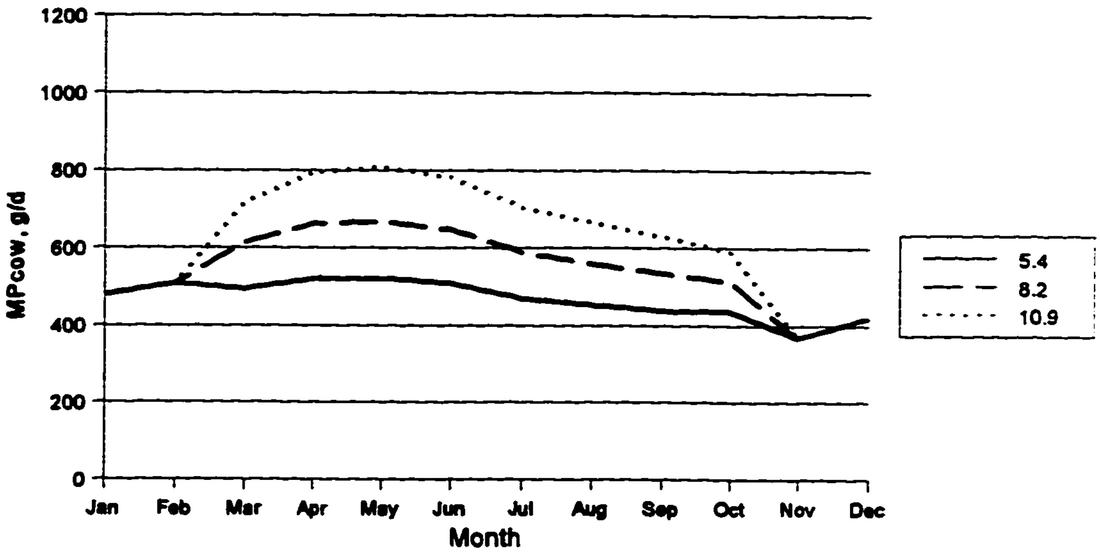

Figure 4.20. Total metabolizable protein requirements (MPcow, g/d) of mature cows differing in peak milk yield (5.4, 8.2, and 10.9 kg/d) and assuming other parameters are constant (5 years old, cow mature weight = 550 kg/d, CS = 5).

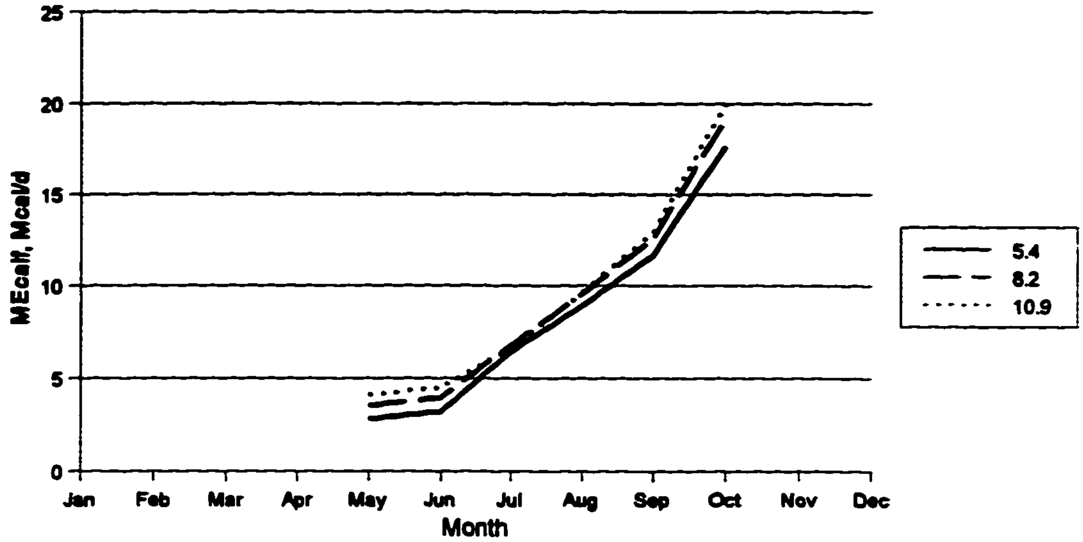

Figure 4.21. Metabolizable energy requirements (MEcalf, Mcal/d) of calves based on peak milk yields of the dams (5.4, 8.2, and 10.9 kg/d) and assuming other parameters are constant (5 years old, cow mature weight = 550 kg/d, CS = 5).

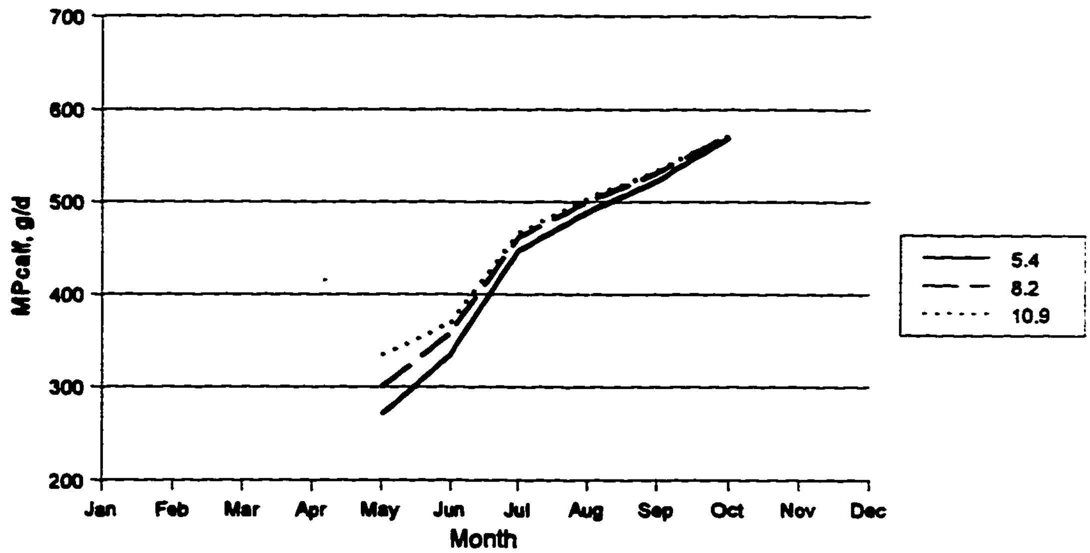

Figure 4.22. Metabolizable protein requirements (MPcalf, g/d) of calves based on peak milk yields of the dams (5.4, 8.2, and 10.9 kg/d) and assuming other parameters are constant (5 years old, cow mature weight = 550 kg/d, CS = 5).

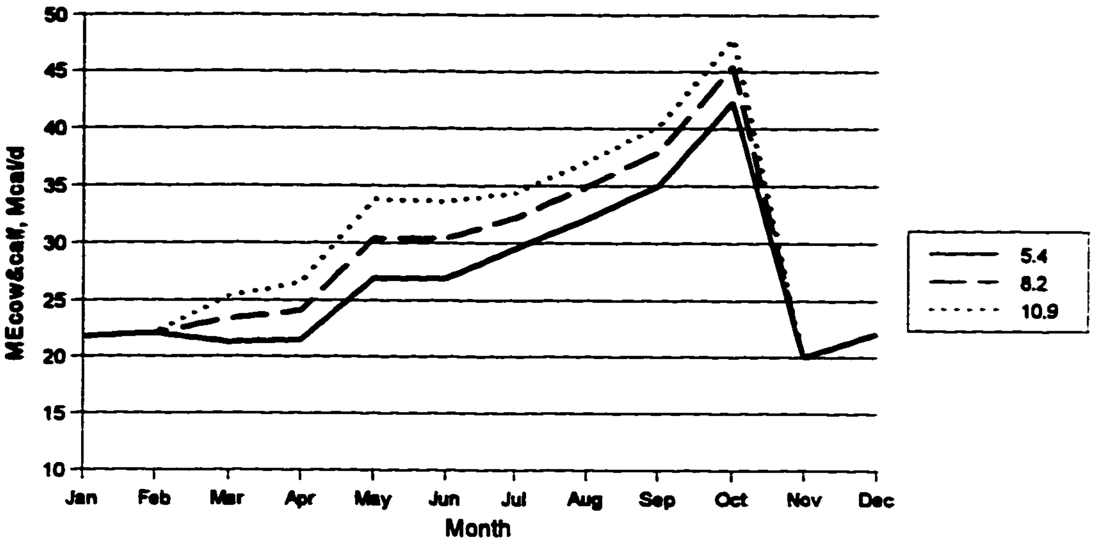

Figure 4.23. Metabolizable energy requirements (MEcow&calf, Mcal/d) of cow-calf pairs based on peak milk yields of the dams (5.4, 8.2, and 10.9 kg/d) and assuming other parameters are constant (5 years old, cow mature weight = 550 kg/d, CS = 5).

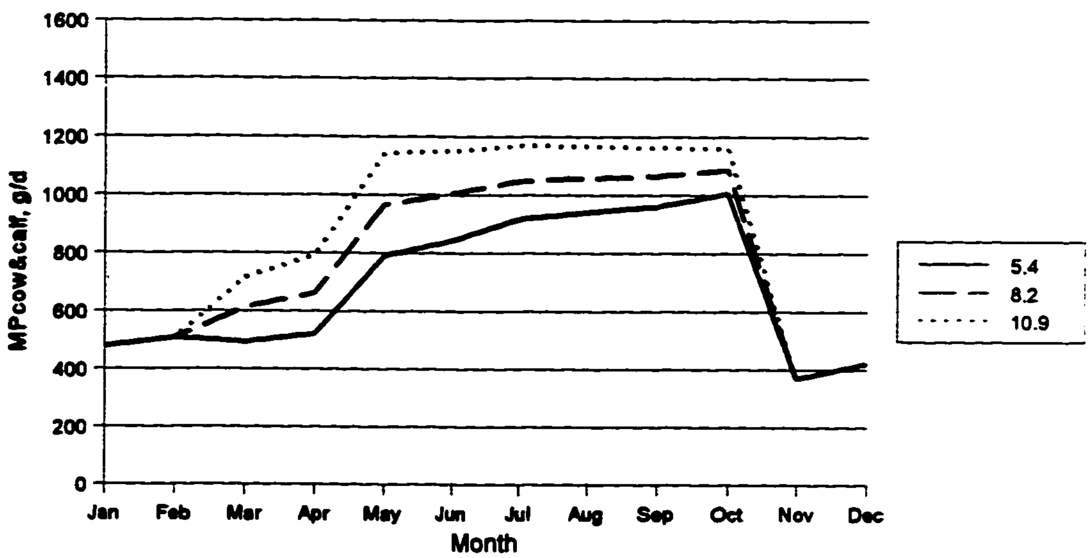

Figure 4.24. Metabolizable protein requirements (MPcow&calf, g/d) of cow-calf pairs based on peak milk yields of the dams (5.4, 8.2, and 10.9 kg/d) and assuming other parameters are constant (5 years old, cow mature weight = 550 kg/d, CS = 5).

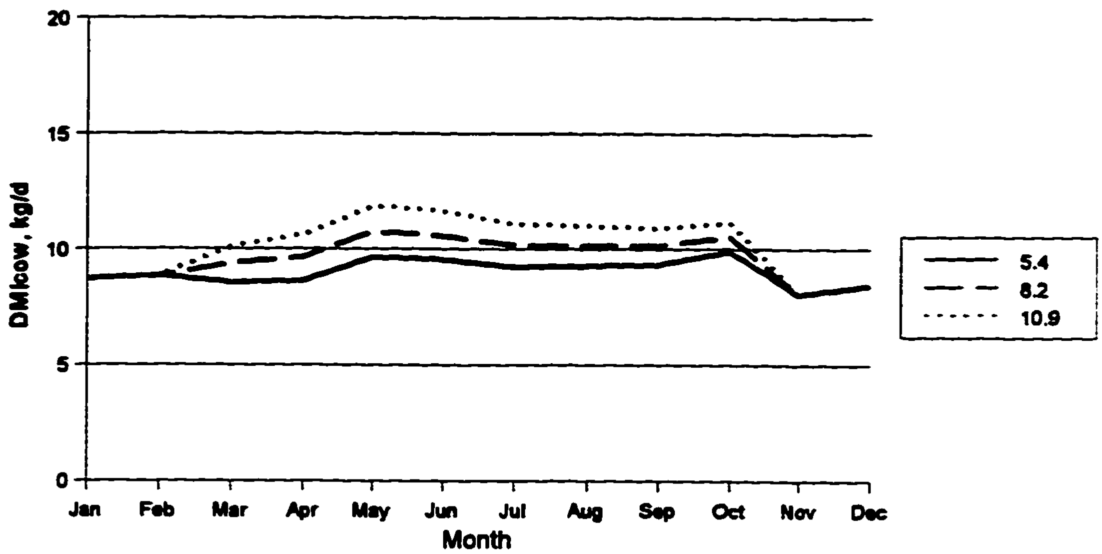

Figure 4.25. Predicted dry matter intakes (DMIcow, kg/d) of mature cows differing in peak milk yield (5.4, 8.2, and 10.9 kg/d) and assuming other parameters are constant (5 years old, cow mature weight = 550 kg/d, CS = 5).

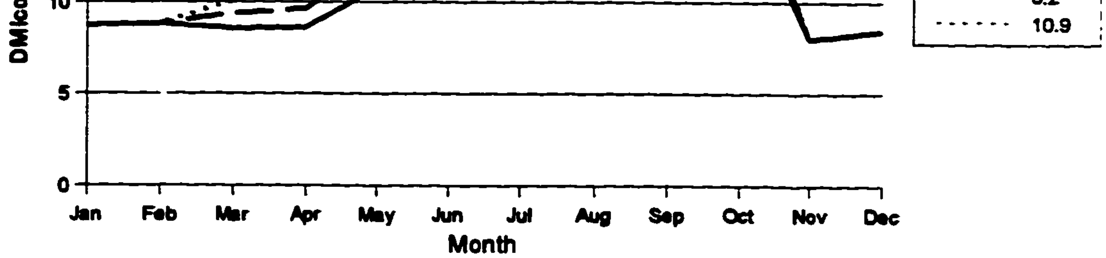

Figure 4.26. Predicted dry matter intake (DMIcow&calf, kg/d) of cow-calf pairs based on peak milk yields of the dams (5.4, 8.2, and 10.9 kg/d) and assuming other parameters are constant (5 years old, cow mature weight = 550 kg/d, CS = 5).

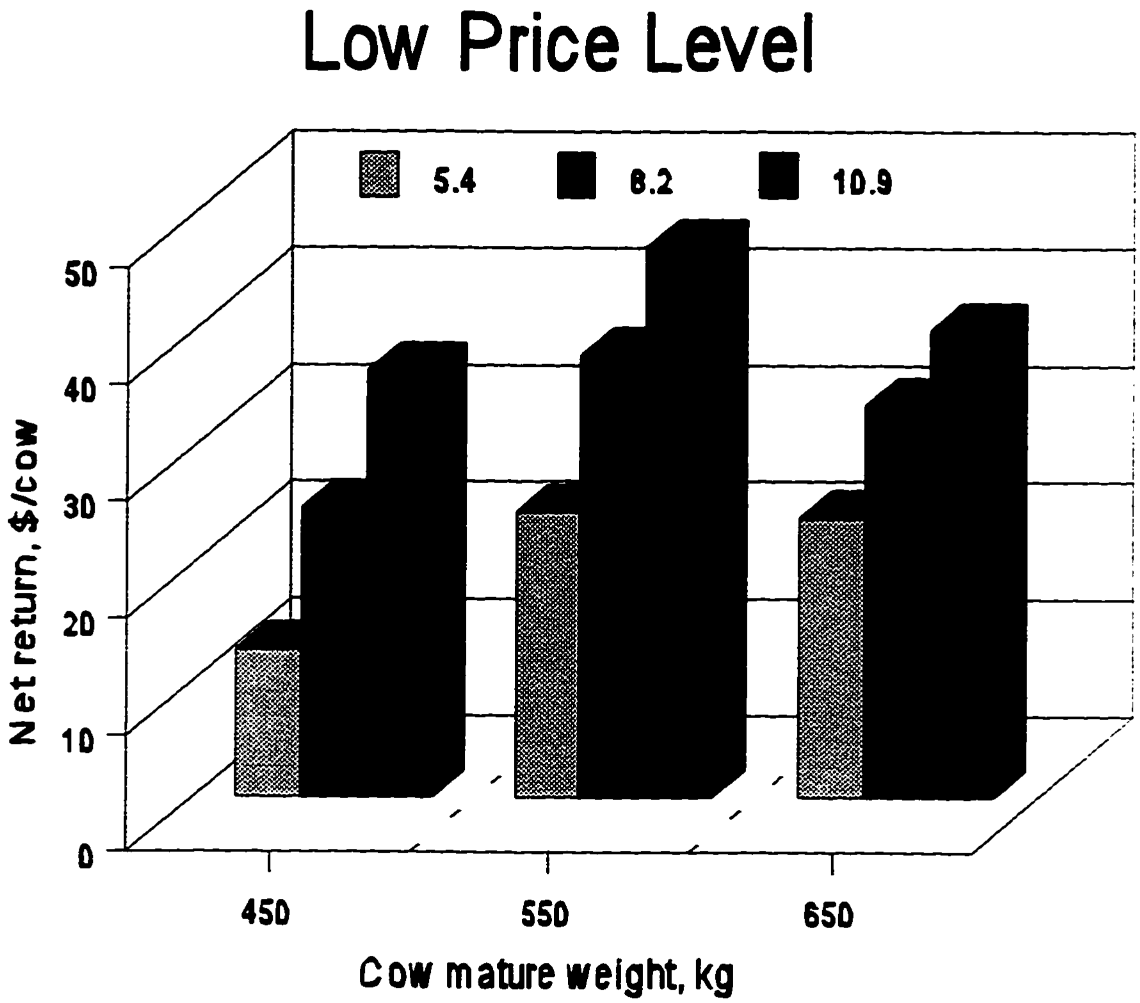

Figure 4.27. Net returns at **low price level** from different milk production levels (5.4, 8.2 and 10.9 kg/d) in each cow size group when comparisons were at **constant weaning age** (200 d).

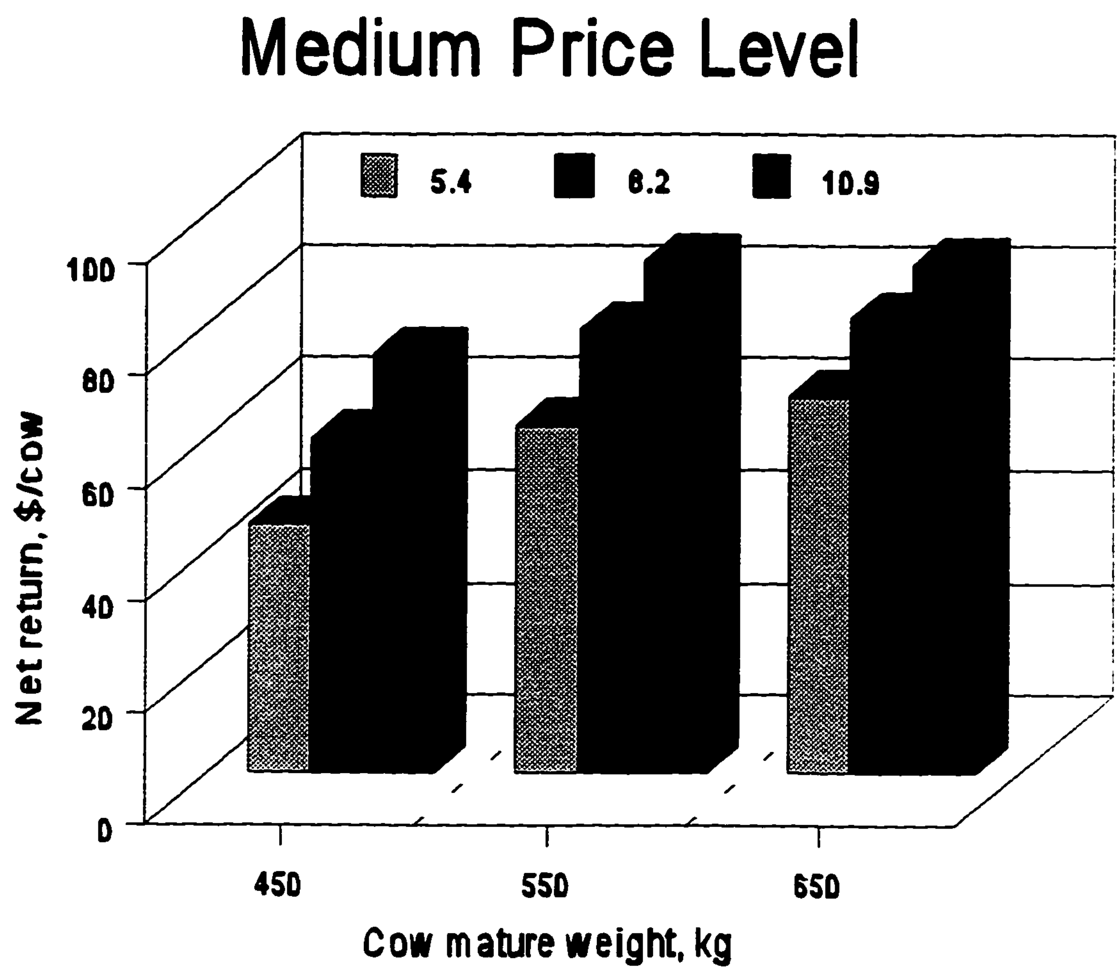

Figure 4.28. Net returns at **medium price level** from different milk production levels (5.4, 8.2 and 10.9 kg/d) in each cow size group when comparisons were at **constant weaning age** (200 d).

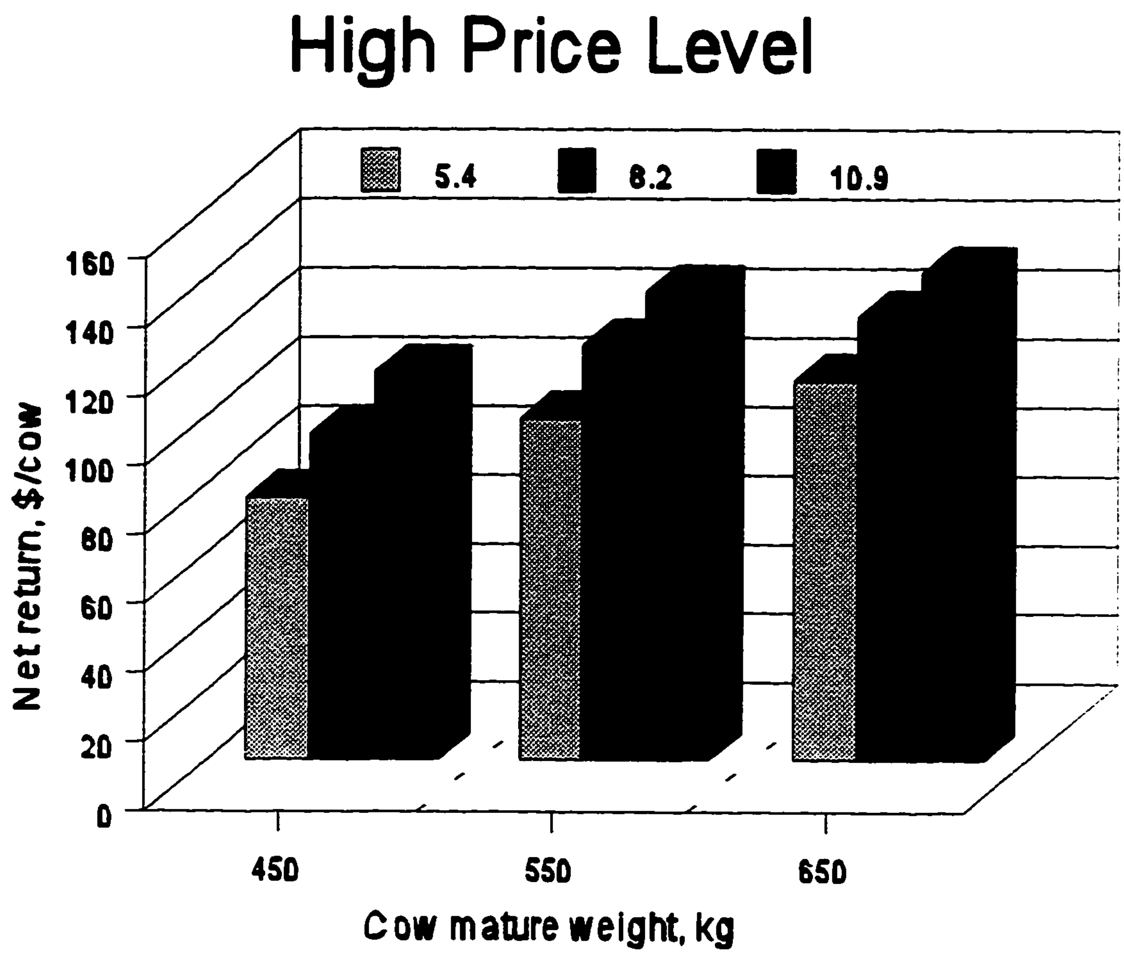

Figure 4.29. Net returns at **high price level** from different milk production levels (5.4, 8.2 and 10.9 kg/d) in each cow size group when comparisons were at **constant weaning age** (200 d).

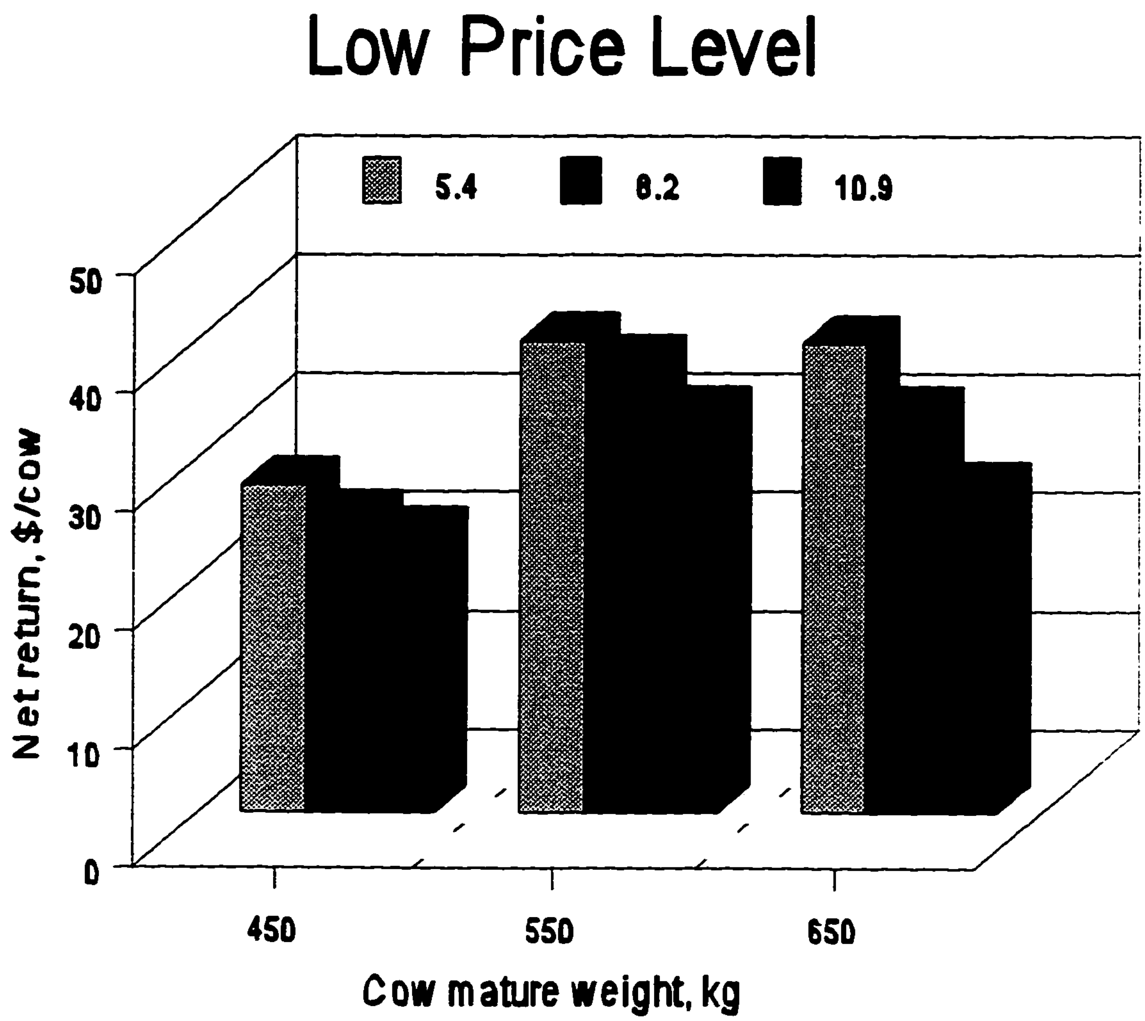

Figure 4.30. Net returns at **low price level** from different milk production levels (5.4, 8.2 and 10.9 kg/d) in each cow size group at **low price level** when comparisons were at **similar weaning weights**.

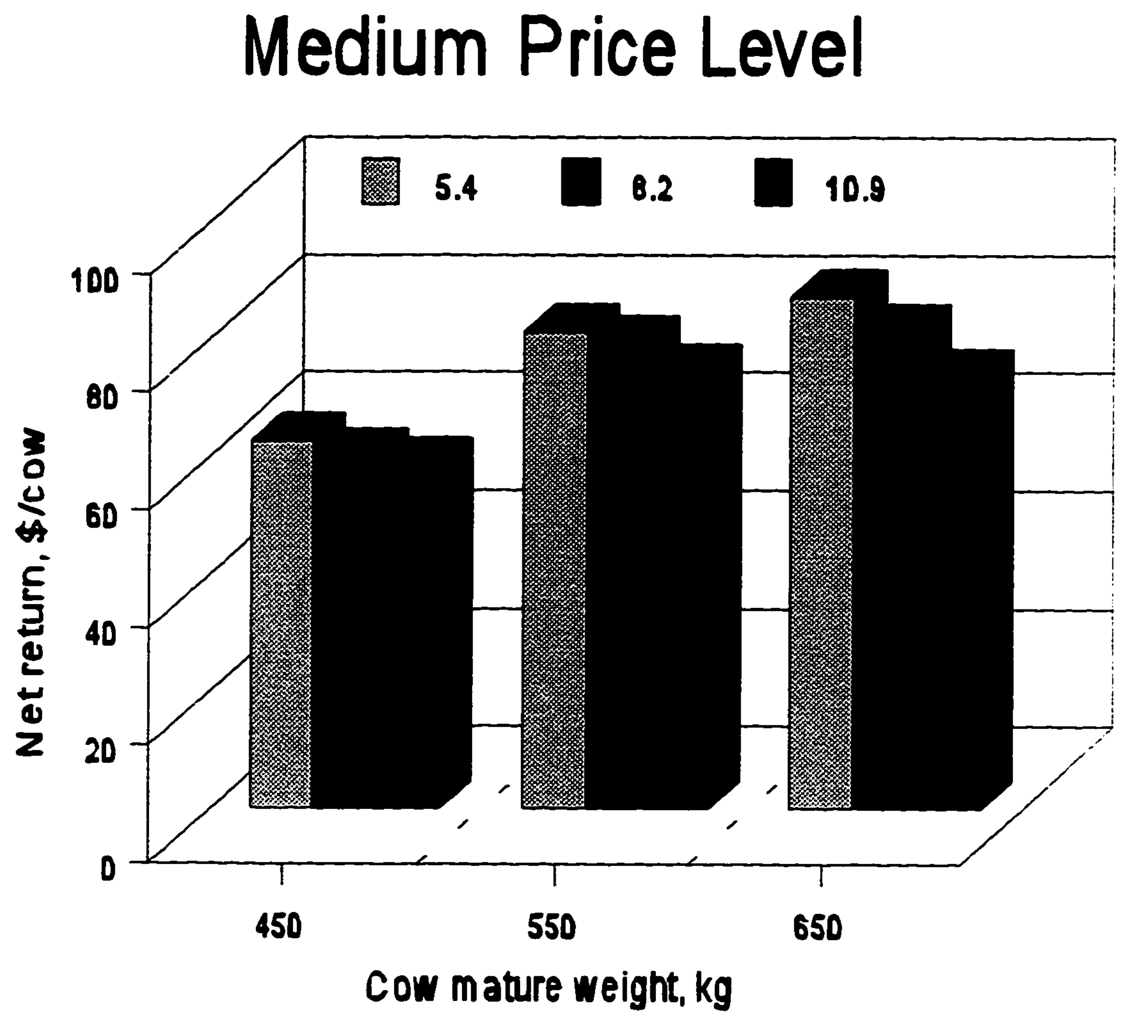

Figure 4.31. Net returns at **medium price level** from different milk production levels (5.4, 8.2 and 10.9 kg/d) in each cow size group when comparisons were at **similar weaning weights**.

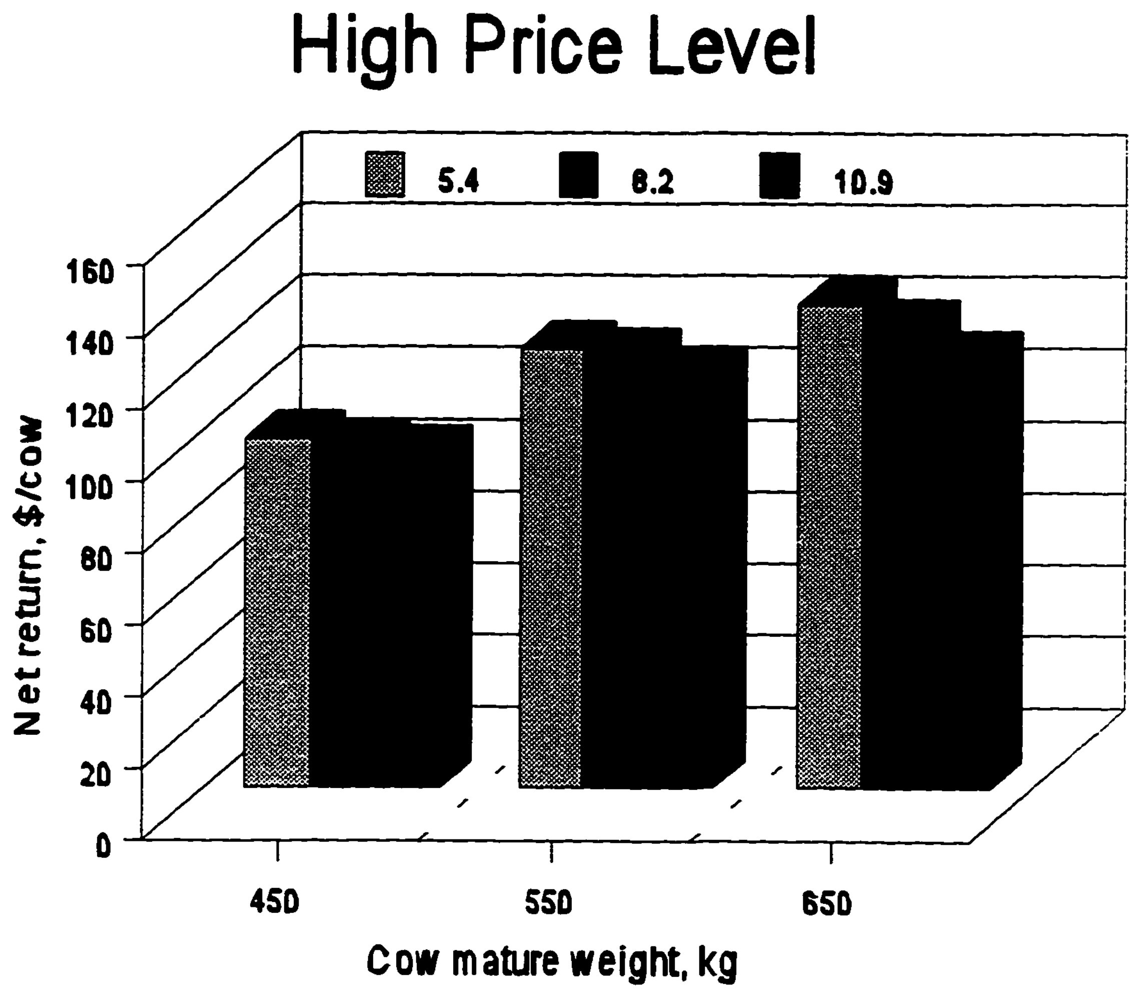

Figure 4.32. Net returns at high price level from different milk production levels (5.4, 8.2 and 10.9 kg/d) in each cow size group when comparisons were at similar weaning weights.

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Chapter 5

Simulated Effects of Calving Season and Weaning Age on Bioeconomic Efficiency in Cow-calf Production Systems

5.1. Introduction

In western Canada and USA, beef cows are usually mated during a breeding season that starts in early summer. Open cows could either be culled or re-bred in the winter. This option would result in having both a spring and a fall calving herd (Azzam et al., 1991). Spring calving can take advantage of relatively inexpensive pasture when calves are growing (Berg et al., 1991). Fall calving, on the other hand, can be advantageous if cheap feeds are available during the winter, and prices for weaned calves are usually higher in the spring (Pritchard, 1987; Agriculture and Agri-Food Canada, 1995).

Sellers et al. (1970) and Bellido et al. (1981) reported significant calving season x breed interactions for calf preweaning growth and cow efficiency. McCarter et al. (1991a) and Roberson et al. (1986) showed that birth weights of spring-born calves were significantly heavier than those of fall-born calves. Spring-born calves also had a higher preweaning growth rate than fall-born calves (Rege and Famula, 1993). McCarter et al. (1991b) and Bailey et al. (1988) indicated that season of calving significantly affected age at first calf, lifetime calving percentage, and weight weaned per year. Spring calving herds had higher overall fertility levels than fall calving herds (Lesmeister et al., 1973; Nelsen et al., 1982; and Deutscher et al. 1991). Azzam et al. (1989, 1990), on the other hand, reported that fall-calving season resulted in higher conception rate than spring-calving season. But others reported that conception rate was not affected by season of calving or stocking rate (Bellido et al. 1981; Bagley et al. 1987).

Seasonal forage availability and quality, and market prices should influence the calving season in cow-calf production systems (Gaertner et al. 1992). Feed costs could differ between spring- and fall-calving because of seasonal differences on nutrient requirement, feed availability, and feed prices. Prices received for culled cows and weaned calves also vary with the season of sale. Therefore the bioeconomic efficiency of the herd could be influenced by calving season.

Weaning age is also an important factor influencing calf's weaning weight. Calves born early in the calving season weigh more at weaning because they are older than those born later (Lesmeister et al., 1973; Keller and Brinks, 1978; Deutscher et al., 1991). Cows calving early have a greater chance of becoming pregnant subsequently (Burris and Priode, 1958; Warnick et al., 1967; Garcia Paloma et al., 1992). Older calves are generally heavier at weaning, however, feed consumption also increases with increase in weaning age. It is important to examine the cost effectiveness of extending the weaning age.

A dynamic simulation model, named **"Beef Production Simulation System"** (BPSS), was developed to evaluate the effects of different management strategies on the bioeconomic efficiency of beef production systems (Chapter 3). The model is the result of an interdisciplinary effort that incorporates the interactions of beef cattle energy and protein requirements, herd dynamics, forage production and economics for range production systems.

Little information is available on the effects of calving season on nutrient requirements of a cow-calf pair over a year. The objective of this study was to examine the nutrient requirements for cows and calves under spring- and fall-calving management systems, and evaluate the effects of calving season and weaning age on the bioeconomic efficiency in cow-calf production systems, using the Beef Production Simulation System.

5.2. Materials and Methods

The **Beef Production Simulation System** model was used to examine the effects of calving season and weaning age on bioeconomic efficiency of beef production systems. The model was a dynamic, deterministic simulation and was programmed using STELLA II simulation software on either PC/Windows or the Macintosh platforms. The model was composed of four major submodels: **Herd Inventory, Nutrient Requirements, Forage Production, and Economic submodels**. More detailed information about the model was presented in Chapter 3.

Data and some parameters in the model were derived from appropriate published literature, and unpublished reports from the University of Alberta Beef Research Ranch at Kinsella, Alberta Agriculture, Food and Rural Development (AAFRD), and Beefbooster Cattle Alberta Ltd. Daily temperature and precipitation were stochastically estimated from a normal distribution of monthly means and standard deviations (Table 3.1) based on thirty years of meteorological data in Edmonton, Alberta (Environment Canada, 1995). The climatic data were input variables, which could be easily modified by users.

Nutrient requirements for spring- and fall-calving season on a year round basis were examined. Bioeconomic efficiencies for herds of spring- and fall-calving seasons, and different weaning ages (220, 200, 180, 160, and 140 days) were compared at the same cow size (mature weight 550 kg), and the same milk production (peak milk yield 8.2 kg/d).

A herd size of 100 cows was assumed, and all replacement were produced within the herd. Many reports indicated that spring calving herds had higher overall fertility than fall calving herds (Lesmeister et al., 1973; Nelsen et al., 1982; and Deutscher et al. 1991), so weaning rate for spring- and fall-calving season in this study was assumed to be 0.85 and 0.80, respectively. It was assumed that cattle were grazed on pasture from May to October. They received hay, straw and mineral supplements during the winter months. Dry matter intake (DMI) was estimated based on actual requirements for the cows and calves.

The first day of calving for spring- and fall-calving cows was assumed to be March 28 and on September 8, respectively. The calving period lasted about 84 days. Calves were weaned in early November and April for spring- and fall-calving cows respectively, when the average calf weaning age was assumed to be 220 days (Table 5.1). For a comparison of the effect of weaning age, 5 classes of weaning age were assumed: 220, 200, 180, 160, and 140 days.

Bioeconomic efficiency, measured as the net return per cow, was obtained by subtracting total cost from total return. Total return was estimated from the sale of culled cows and weaned calves. Weaned calf sale price was influenced by two factors: seasonal change and discount by body weight. The monthly average product sale prices were based on 10 years data as shown in Table 3.6 (Agriculture and Agri-Food Canada, 1995), the highest sale price for weaned calves was in April, which favored fall-calving group. The weaning dates and maximum calf prices for different weaning age groups in spring- and fall-calving herds are shown in Table 5.2. Weaned calf price was discounted $4 per 45 kg body weight as calf weight increased, starting at 140 kg weight (Alberta Agriculture, 1987). The sale price for culled cows was assumed to be the same for both calving seasons, at 1.17 $/kg live weight.

Total cow cost was the sum of fixed and variable costs. Fixed costs included interest on intermediate and long term debt, depreciation, property taxes, repairs and insurance. Variable costs included cow or replacement purchase cost, feed costs and non-feed costs for the cow herd and for calves to weaning or to slaughter. Cow or replacement purchase cost was considered only if the herd size was increasing and some cows and replacements need to be purchased from outside. Non-feed costs consisted of death loss, interest on operating loan, labour, manure and feed handling, fuel, veterinary, housing and feed storage, marketing, breeding and miscellaneous costs. The default values in the model for cow fixed costs and non-feed costs were $65.54 and $68.39 /cow/yr, respectively, based on the Beefbooster's data (MacNeil et al., 1994). Feed costs included pasture and winter feed costs. The prices for pasture and winter feed were assumed as 0.03 and 0.06 $/kg, respectively (Alberta Agriculture, 1987).

5.3. Results and Discussion

5.3.1. Nutrient requirements for spring and fall calving seasons

Keeping the other parameters constant (mature weight = 550 kg, peak milk yield = 8.2 kg/d, calf birth weight = 35 kg, initial cow condition score CS = 5, at 5 years of age), the nutrient requirements (ME and MP) and predicted dry matter intake (DMI) were compared for spring- and fall-calving seasons.

The metabolizable energy requirements (Mcal/d) for maintenance (ME_m), gain (ME_{gain}), lactation (ME_{lact}), pregnancy (ME_{preg}), and total (ME_{totcow}) of a cow over a year in fall- and spring-calving season groups are shown in Figure 5.1 and 5.2, respectively. The metabolizable protein requirements (g/d) for maintenance (MP_m), gain (MP_{gain}), lactation (MP_{lact}), pregnancy (MP_{preg}), and total (MP_{totcow}) of a cow for one year in fall- and spring-calving season group are shown in Figure 5.3 and 5.4, respectively. Because the mature weight, milk production, condition score, and calf birth weight were assumed to be the same for the two calving seasons, the nutrient requirements for maintenance, lactation, and pregnancy were quite similar. The only differences were that the curve peaks were reached in different months. The total nutrient requirement of a cow reached its maximum value after calving (in April and May for the spring-calving season, and in September and October for the fall-calving season). It reached the lowest value after weaning, in November for the spring-calving season and in April for the fall-calving season.

The metabolizable energy requirements (ME, Mcal/d) for a cow, a calf, and a cow-calf pair in one year for fall- and spring-calving seasons are shown in Figure 5.5 and Figure 5.6, respectively. The ME requirement for a cow-calf pair reached the maximum value at weaning (in October for spring-calving season and in April for fall-calving season).

The model also predicted the nutrient requirements of a cow for several consecutive years. The ME_m, ME_{gain}, ME_{lact}, ME_{preg}, ME_{totcow} requirements (Mcal/d) of a cow for 6 years in the fall- and spring-calving season groups are shown in Figure 5.7 and Figure 5.8, respectively. The MP_m, MP_{gain}, MP_{lact}, MP_{preg}, and MP_{totcow} requirements (g/d) of a cow for 6 years in the fall- and spring-calving season groups are shown in Figure 5.9 and Figure 5.10, respectively.

Based on the requirements, dry matter intake for a herd (DMIherd, kg/d) of 100 cows in one year for the fall- and spring calving seasons are shown in Figure 5.11 and Figure 5.12, respectively. The feed requirement for the whole herd reached its maximum point in October for the spring-calving season and in March for the fall-calving season.

Comparison of total ME, MP, and DMI requirements of a cow in each month of the year for spring- and fall-calving seasons are shown in Figures 5.13, 5.14, and 5.17. Compared to the spring-calving season group, nutrient requirement in the fall-calving herd was higher during the fall and winter (from September to February), and was lower during spring and summer (from March to August). However, the averages of daily ME requirement of a cow over one year for the two calving seasons were very close, 23.57 and 23.71 Mcal/d for the spring- and fall-calving season, respectively (Figure 5.19).

Comparison of total ME, MP, and DMI requirements of a cow-calf pair in each month of the year for the spring- and fall-calving seasons are shown in Figures 5.15, 5.16, and 5.18. Between November and March, the nutrient requirements in the fall-calving season group were higher than those of the spring-calving season. However, the opposite results were observed between April and October.

5.3.2. Effects of calving season and weaning age on bioeconomic efficiency

The effects of calving season and weaning age on weaning weight, DMI, feed and total cost, return, and net return are shown in Table 5.2.

Weaning weight. Calf weaning weight increased with weaning age in both calving seasons (Figure 5.20). Generally, spring born calves were heavier than fall born calves at each weaning age. This indicated that the pre-weaning growth rate was lower for the fall born calves, because birth weight were assumed to be the same for both calving seasons. Similar results were reported by McCarter et al. (1991a) and Roberson et al. (1986).

Dry matter intake (DMI). Metabolizable energy requirement (ME, Mcal/d) and predicted DMI (kg/d) for a cow-calf pair increased with weaning age in both calving seasons, and requirements for ME and DMI were both higher in the fall-calving season than those of spring-calving season at each weaning age (Table 5.2 and Figure 5.21). This reflects the fact that calves of fall-calving herd had greater exposure to cold weather than those in the spring-calving herd. Therefore the fall-calving season herd required somewhat more feed than the spring-calving herd.

Total cost. Feed cost and total cost ($/yr) per cow-calf pair increased with weaning age in both calving seasons as expected, and the costs were higher in the fall-calving season group than those of spring-calving season group (Table 5.2 and Figure 5.22), as calves in the fall-calving season group consumed more feed than those in the spring-calving season group.

Net return. Returns and net returns ($/cow/tr) for the two calving seasons were compared at each weaning age (from 140 to 220 days) (Table 5.2). The returns and net return increased with weaning age within each calving season (Figure 5.23 and Figure 5.24). Returns in the spring-calving herd were higher than those in the fall-calving herd when weaning age was less than 180 days. Although the spring born calves were heavier at each weaning age compared to the fall born calves, return in the fall calving herd was equal to or higher than those in the spring-calving herd at weaning age of 200 and 220 days (Figure 5.23), because of the higher market price for the fall born calves. Comparison of net returns for different calving seasons are shown in Figure 5.24. Net returns in the spring-calving season were higher than those of the fall-calving season when weaning age was less than 200 days. However, the net return at weaning age of 220 days in the fall-calving season group was higher than that of the spring-calving herd. This indicates that there was an interaction between calving season and weaning age.

5.4. Summary and Conclusions

Nutrient requirements for cows and calves in each month of the year were different for the spring- and fall- calving seasons. The nutrient requirements of a cow-calf pair was higher in a fall-calving herd than in a spring-calving herd between November and March, and was lower than a spring-calving herd between April and October.

Fall-calving in Alberta generally results in longer exposure of calves to extreme cold weather after calving, and therefore DMI and feed cost were higher in the fall-calving season group than in the spring-calving season group. The estimated weaning weights of the spring born calves were greater at all weaning ages (140-220 days) than fall born calves. The returns and net returns increased with increases in weaning age within each calving season. Bioeconomic efficiencies in the spring-calving herd were higher than those of the fall-calving herd when weaning age was less than 200 days. However, the bioeconomic efficiency at weaning age of 220 days was higher in the fall-calving herd than in the spring-calving herd due to the higher market price of the fall born calves. This indicates interaction between calving season and weaning age.

In the spring calving season, there is also the problem of labor supply, as there is labor demand for crop production in addition to the cow herd management. Fall calving may have a benefit from spreading labor over the year, resulting in lower variable costs (Berg et al., 1991). This factor is worthy of further study.

In this study, the maximum weaning age was assumed at 220 days. Under this condition, the bioeconomic efficiency generally increased with increasing weaning age. This study assumed that animals could meet their nutrient requirements. Further research is needed to examine the effect of limited feed supply on bioeconomic efficiency in fall- and spring-calving herds.

Table 5.1. Breeding, calving and weaning dates for spring- and fall-calving herds

	Spring	Fall
Breeding date[1]	170 (June 19)	334 (Nov. 30)
Calving date[2]	87 (March 28)	251 (Sept. 8)
Weaning date (220d)[3]	307 (Nov. 3)	106 (April 16)

[1] Day 1 = January 1.
[2] Gestation period for beef cattle is 282 days (Alberta Agriculture, 1987).
[3] The maximum weaning age was assumed to be 220 days.

Table 5.2. Effects of calving season and weaning age on DMI, cow cost, return, and bioeconomic efficiency in a cow-calf production system

Calving season	Spring					Fall				
Weaning age (day)	140	160	180	200	220	140	160	180	200	220
Weaning wt (kg)	165	190	215	245	275	155	180	210	240	270
Weaning date	Aug14	Sep04	Sep24	Oct14	Nov03	Jan27	Feb17	Mar07	Mar27	Apr16
Max calf price ($/kg)[1]	2.37	2.42	2.42	2.37	2.31	2.42	2.47	2.50	2.50	2.54
ME (Mcal/d/cow-calf)[2]	22.42	23.07	23.82	24.60	25.63	22.89	23.52	24.25	25.08	26.02
DMI (kg/d/cow-calf)	9.97	10.25	10.59	10.93	11.39	10.17	10.45	10.78	11.15	11.56
Feed cost ($/yr/cow-calf)	218.4	224.1	230.7	238.1	247.7	224.2	230.9	238.8	247.7	257.9
Total cost ($/yr/cow-calf)	306.4	312.1	318.7	326.2	335.8	312.2	319.0	326.9	335.8	346.0
Return ($/yr/cow-calf)	361.8	396.9	425.2	449.3	467.4	344.7	379.4	417.1	449.2	485.4
Net return ($/yr/cow-calf)[3]	55.4	84.8	106.5	123.1	131.6	32.5	60.4	90.2	113.4	139.4

[1] Maximum calf prices were changed by month based on Table 3.6. Calf price was discounted $4 per 45 kg body weight as calf weight increased, starting at 140 kg weight. Culled cow sale price was assumed to be 1.17 $/kg for both calving seasons. The prices for pasture and winter feed were 0.03 and 0.06 $/kg, respectively.
[2] Consumed ME and DMI were the average values per day for one year on a cow-calf pair basis.
[3] Bioeconomic efficiency was expressed as: Net return = Return - Total cost.

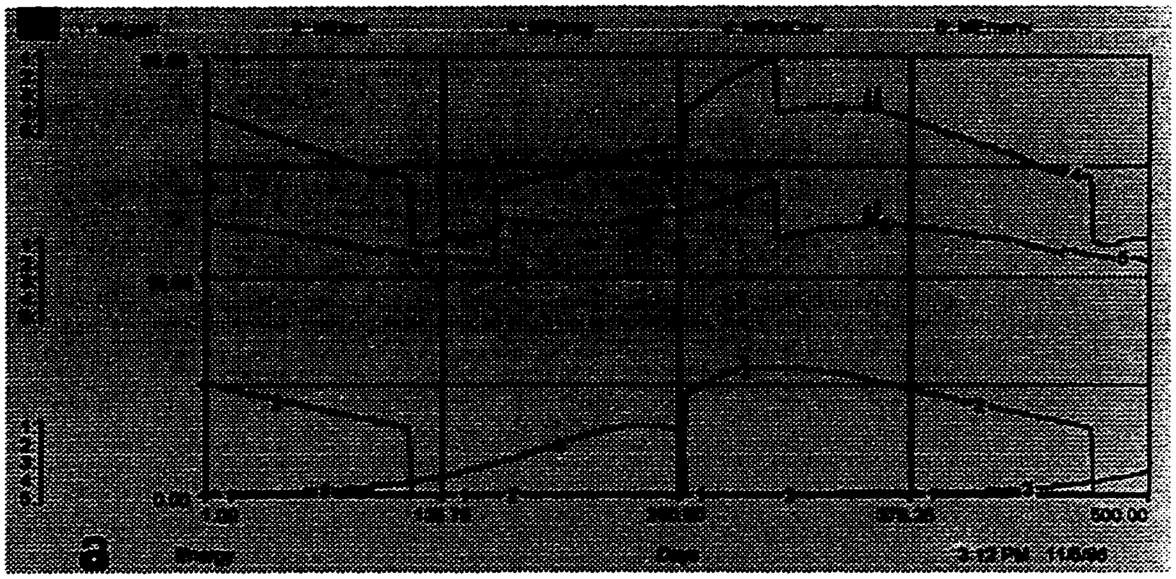

Figure 5.1. Metabolizable energy requirements (Mcal/d) for maintenance (5:MEm), gain (1:MEgain), lactation (2:MElact), pregnancy (3:MEpreg), and total (4:MEtotCow) of a cow for 500 days in a fall-calving herd (mature weight=550 kg, peak milk yield=8.2 kg/d, birth weight=35 kg, initial CS=5, 5 years old, day 1 or day 366=January 1).

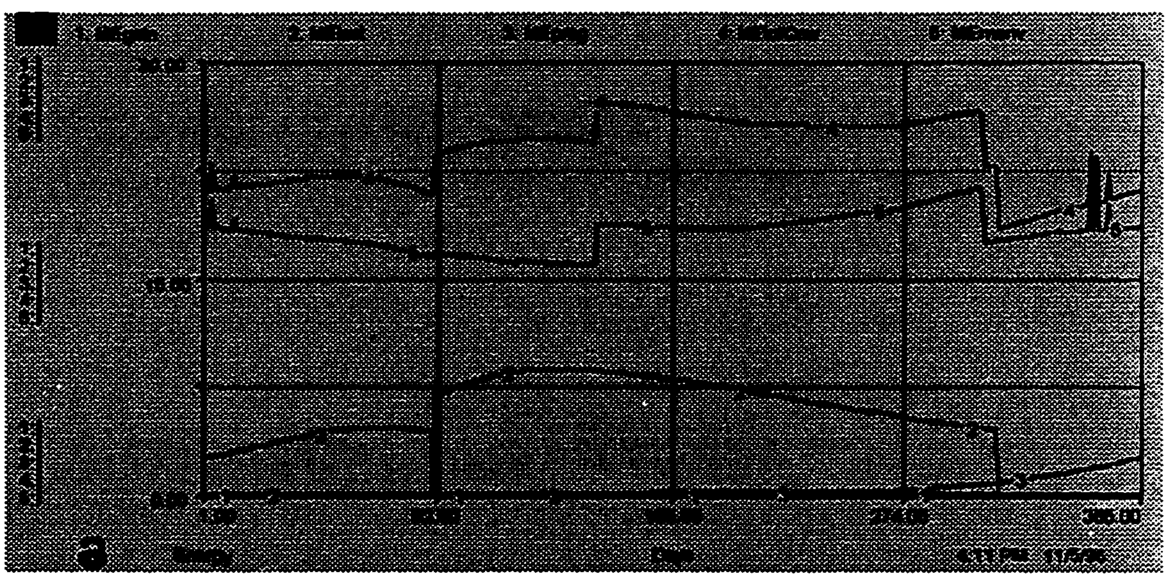

Figure 5.2. Metabolizable energy requirements (Mcal/d) for maintenance (5:MEm), gain (1:MEgain), lactation (2:MElact), pregnancy (3:MEpreg), and total (4:MEtotCow) of a cow in one year in a spring-calving herd (mature weight=550 kg, peak milk yield=8.2 kg/d, birth weight=35 kg, initial CS=5, 5 years old, day 1=January 1).

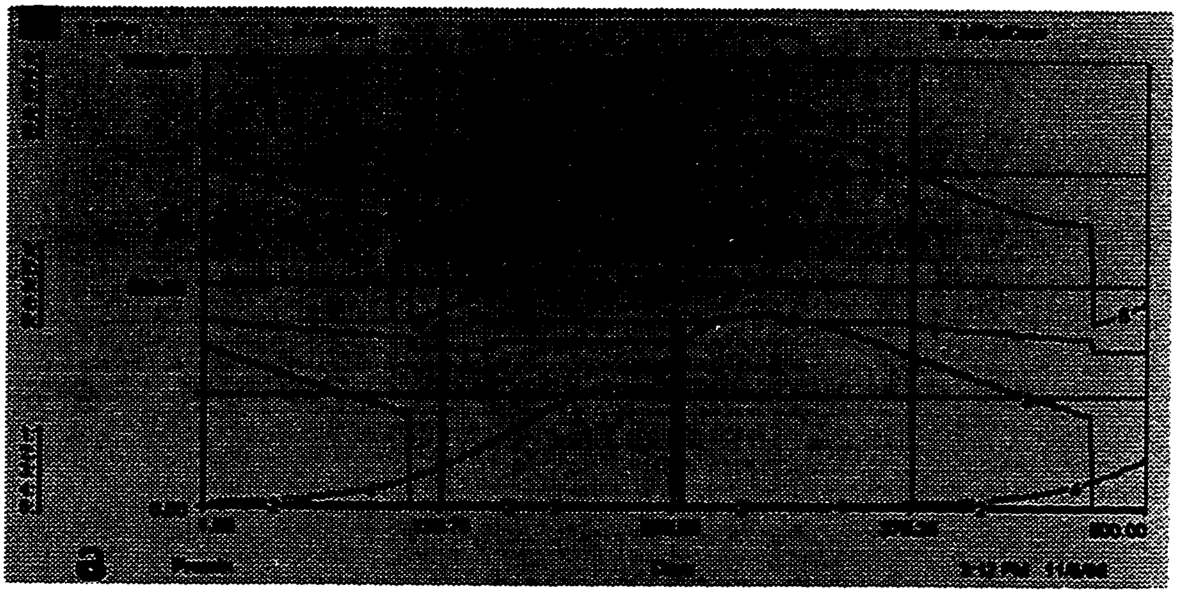

Figure 5.3. Metabolizable protein requirements (g/d) for maintenance (1:MPm), gain (2:MPgain), lactation (3:MPlact), pregnancy (4:MPpreg), and total (5:MPtotCow) of a cow for 500 days in a fall-calving herd (mature weight=550 kg, peak milk yield=8.2 kg/d, birth weight=35 kg, initial CS=5, 5 years old, day 1 or day 366=January 1).

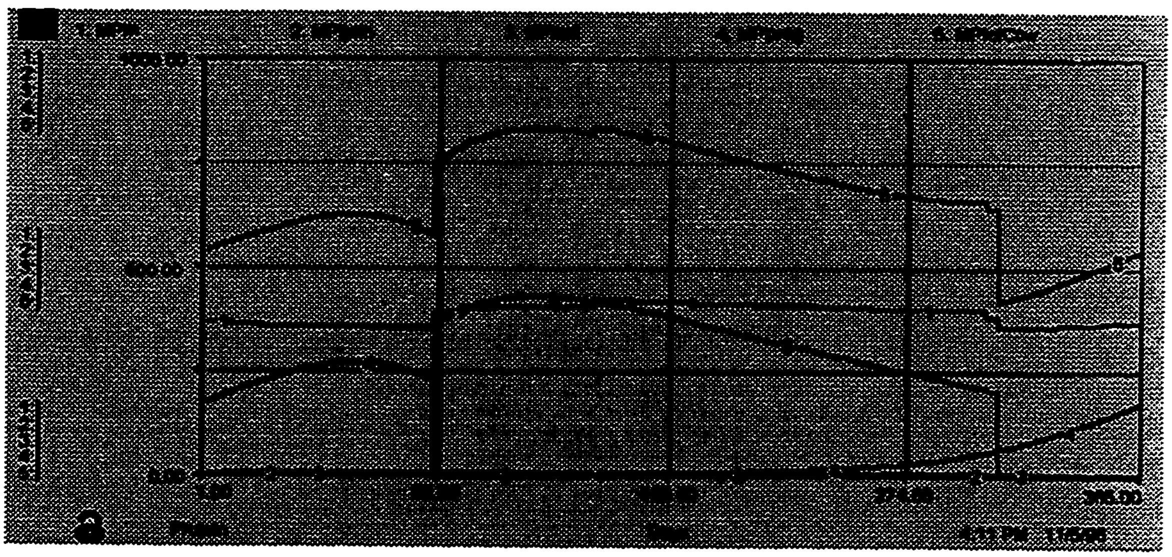

Figure 5.4. Metabolizable protein requirements (g/d) for maintenance (1:MPm), gain (2:MPgain), lactation (3:MPlact), pregnancy (4:MPpreg), and total (5:MPtotCow) of a cow in one year in a spring-calving herd (mature weight=550 kg, peak milk yield=8.2 kg/d, birth weight=35 kg, initial CS=5, 5 years old, day 1=January 1).

Figure 5.5. Total metabolizable energy requirements (Mcal/d) for a cow (1:MEtotCow), a calf (2:MEg&mc), and a cow-calf pair (3:MEC&c) for 500 days in a fall-calving herd (mature weight=550 kg, peak milk yield=8.2 kg/d, birth weight=35 kg, initial CS=5, 5 years old, day 1 or day 366=January 1).

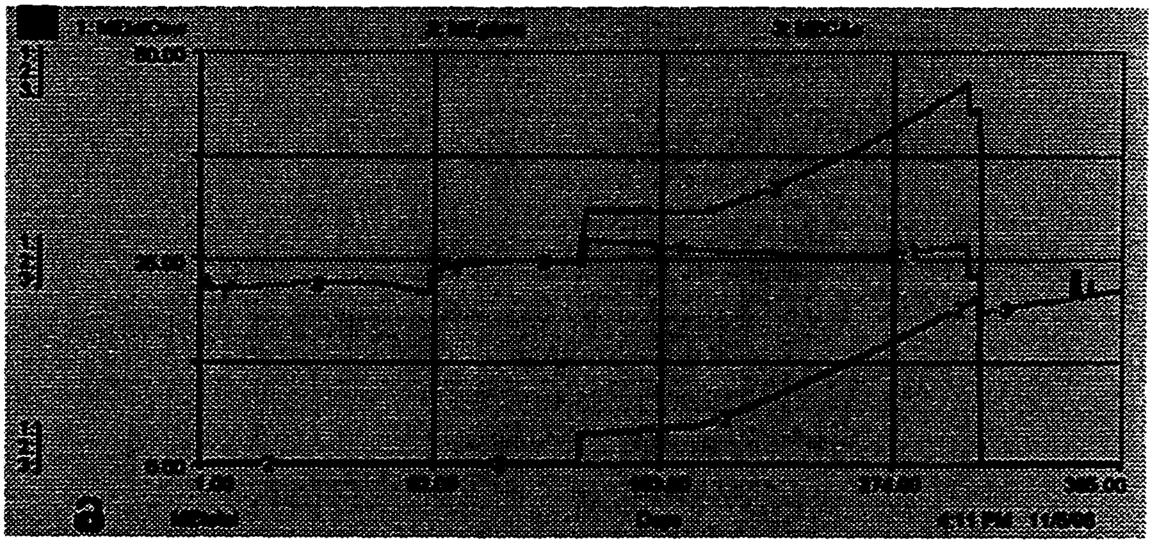

Figure 5.6. Total metabolizable energy requirements (Mcal/d) for a cow (1:MEtotCow), a calf (2:MEg&mc), and a cow-calf pair (3:MEC&c) in one year in a sprin g-calving herd (mature weight=550 kg, peak milk yield=8.2 kg/d, birth weight=35 kg, initial CS=5, 5 years old, day 1=January 1).

Figure 5.7. Metabolizable energy requirements (Mcal/d) for maintenance (5:MEm), gain (1:MEgain), lactation (2:MElact), pregnancy (3:MEpreg), and total (4:MEtotCow) of a cow for 6 years in a fall-calving herd (mature weight=550 kg, peak milk yield=8.2 kg/d, birth weight=35 kg, initial CS=5, day 1=January 1).

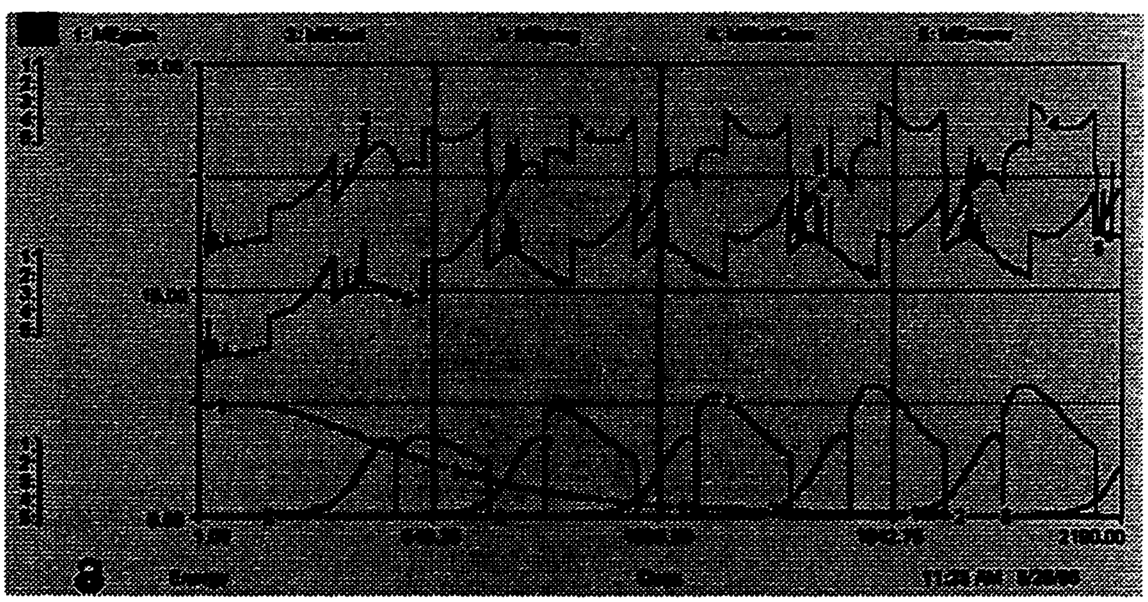

Figure 5.8. Metabolizable energy requirements (Mcal/d) for maintenance (5:MEm), gain (1:MEgain), lactation (2:MElact), pregnancy (3:MEpreg), and total (4:MEtotCow) of a cow for 6 years in a spring-calving herd (mature weight=550 kg, peak milk yield=8.2 kg/d, birth weight=35 kg, initial CS=5, day 1=January 1).

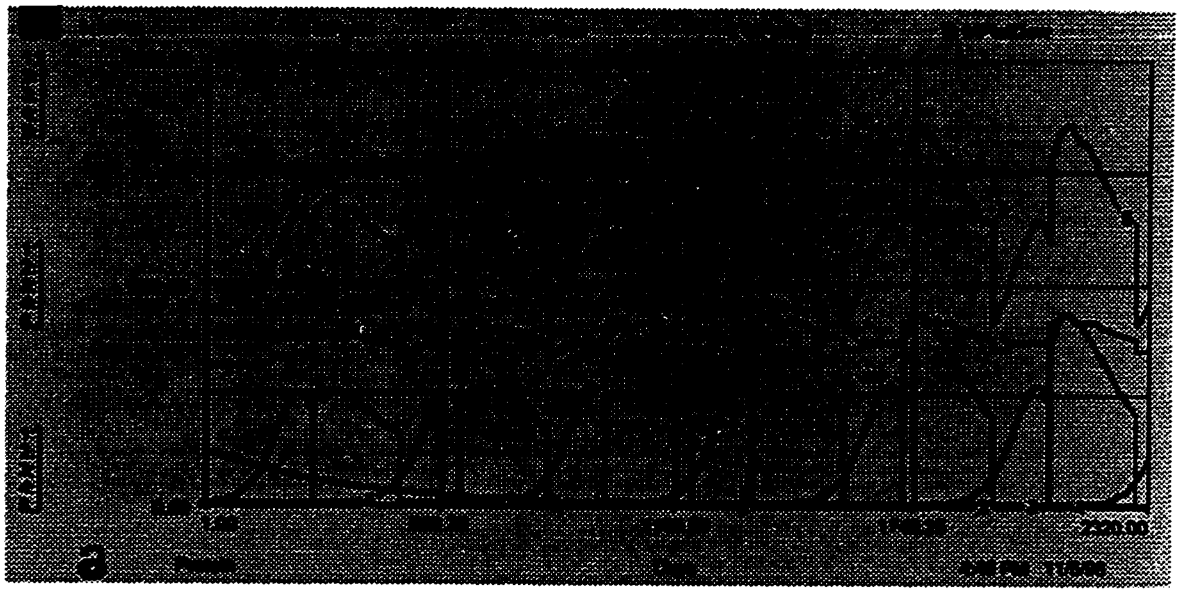

Figure 5.9. Metabolizable protein requirements (g/d) for maintenance (1:MPm), gain (2:MPgain), lactation (3:MPlact), pregnancy (4:MPpreg), and total (5:MPtotCow) of a cow for 6 years in a fall-calving herd (mature weight=550 kg, peak milk yield=8.2 kg/d, birth weight=35 kg, initial CS=5, day=January 1).

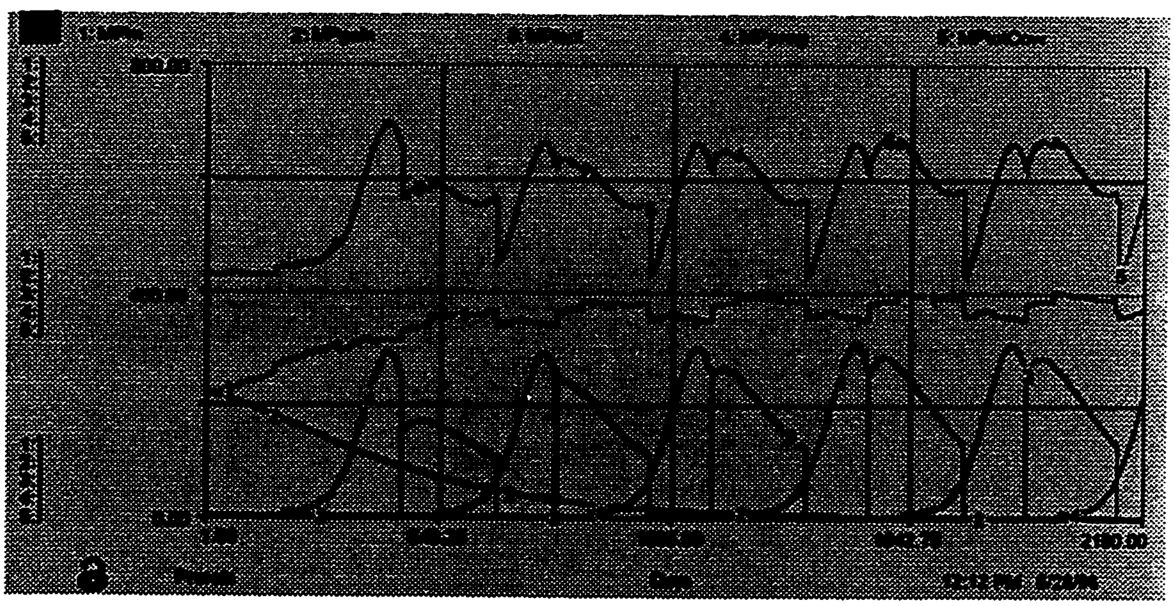

Figure 5.10. Metabolizable protein requirements (g/d) for maintenance (1:MPm), gain (2:MPgain), lactation (3:MPlact), pregnancy (4:MPpreg), and total (5:MPtotCow) of a cow for 6 years in a spring-calving herd (mature weight=550 kg, peak milk yield=5.4 kg/d, birth weight=35 kg, initial CS=5, day=January 1).

Figure 5.11. Dry matter intake (DMI, kg/d/herd) based on the requirement for a 100 cow herd in one year in the fall-calving season group (average mature weight=550 kg, average peak milk yield=8.2 kg/d).

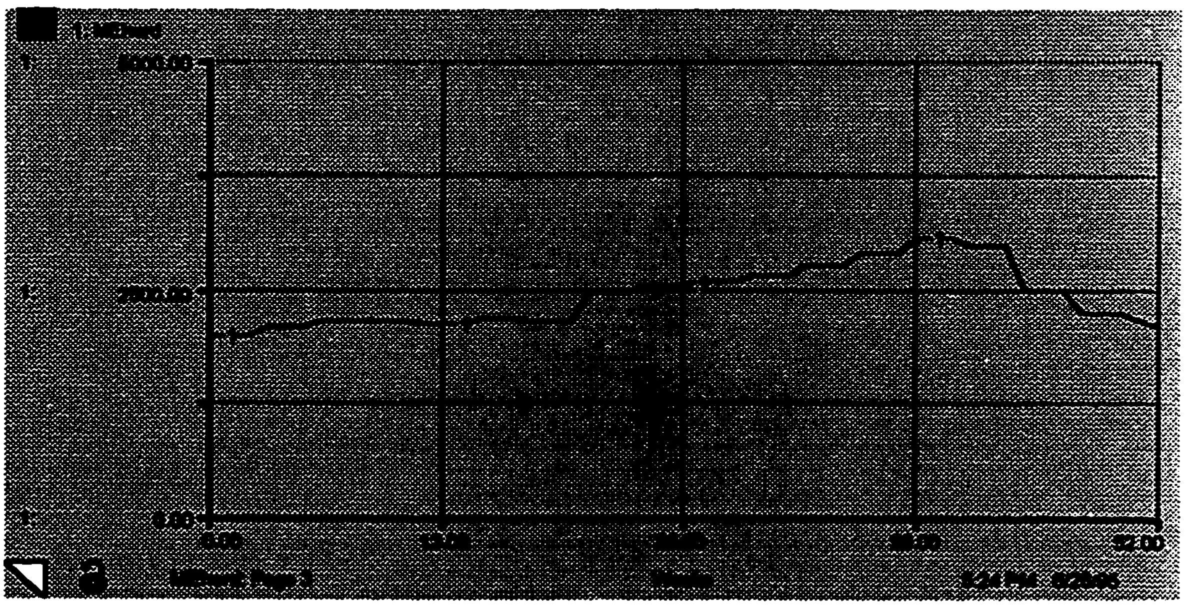

Figure 5.12. Dry matter intake (DMI, kg/d/herd) based on the requirement for a 100 cow herd in one year in the spring-calving season group (average mature weight=550 kg, average peak milk yield=8.2 kg/d).

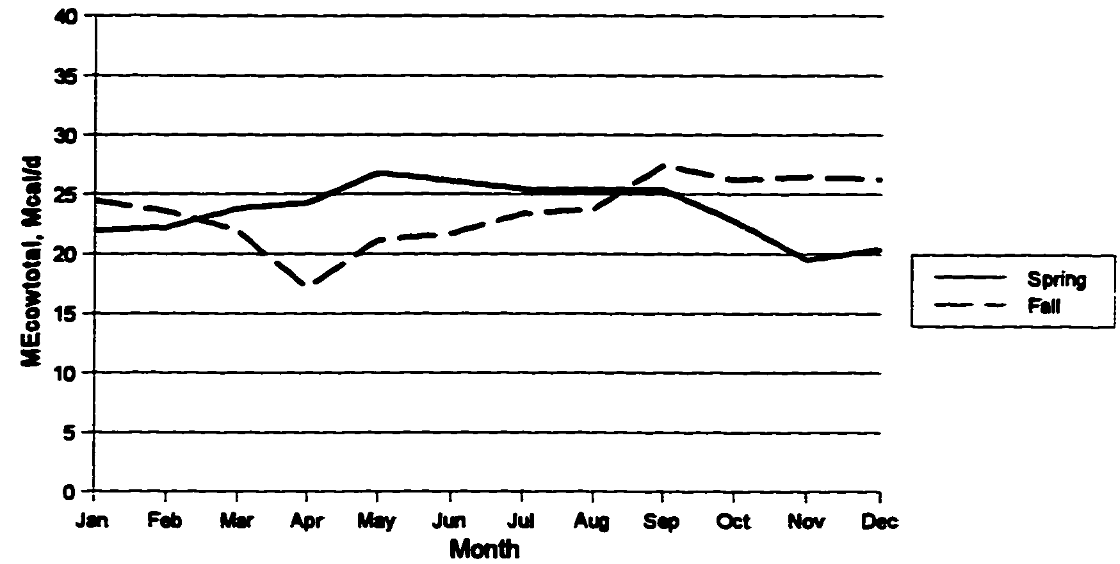

Figure 5.13. Total metabolizable energy requirements (MEcowtotal, Mcal/d) of mature cows calving in the spring and fall, and assuming other parameters are constant (5 years old, mature weight=550 kg, peak milk yield=8.2 kg/d, CS=5).

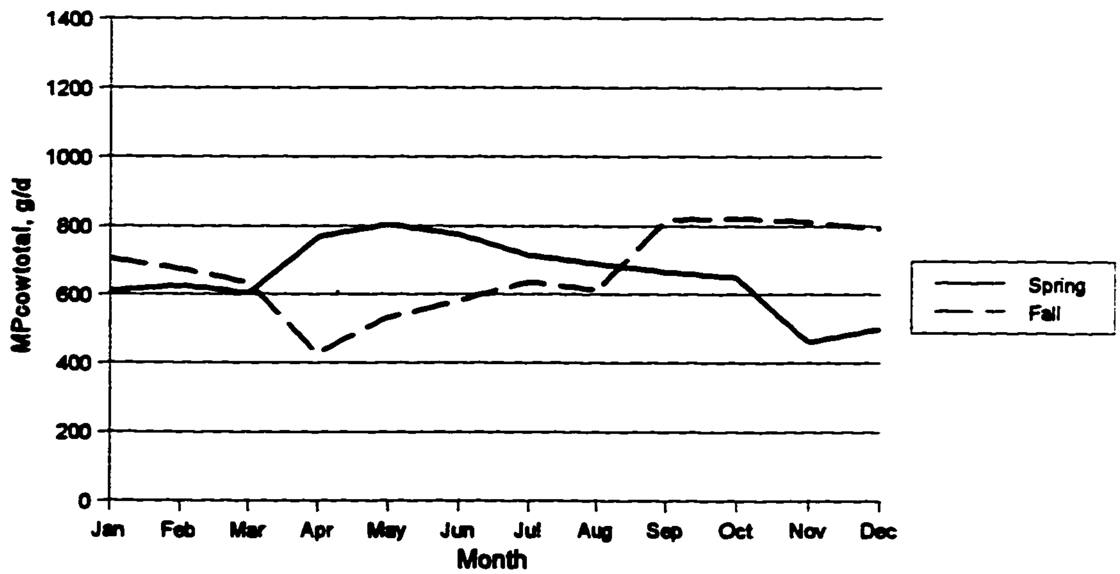

Figure 5.14. Total metabolizable protein requirements (MPcowtotal, g/d) of mature cows calving in the spring and fall, and assuming other parameters are constant (5 years old, mature weight=550 kg, peak milk yield=8.2 kg/d, CS=5).

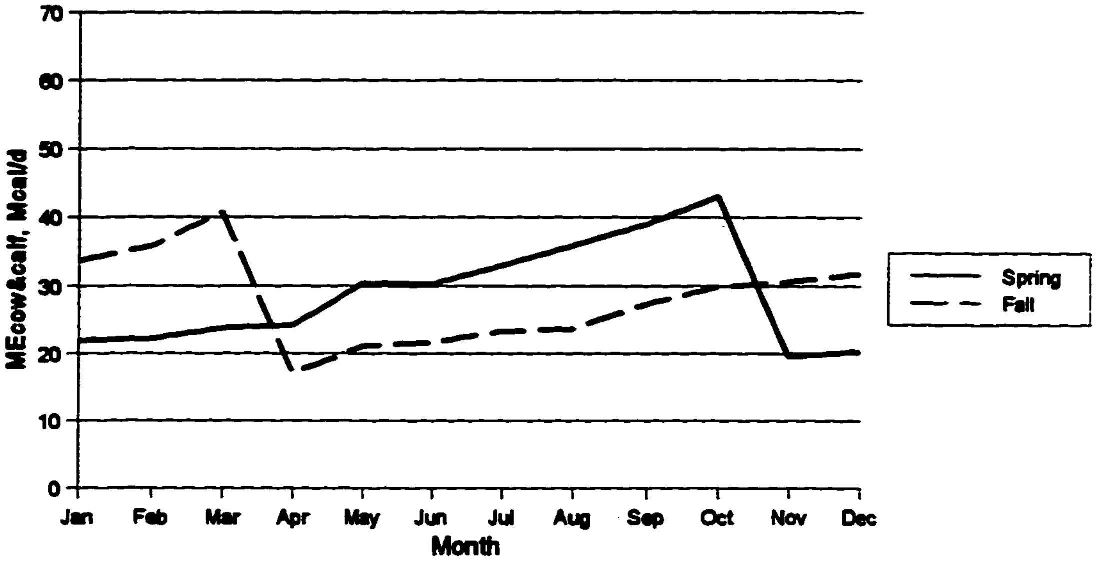

Figure 5.15. Total metabolizable energy requirements (MEcow&calf, Mcal/d) for a cow-calf pair based on calving in the spring and fall, and assuming other parameters are constant (5 years old, mature weight=550 kg, peak milk yield=8.2 kg/d, CS=5).

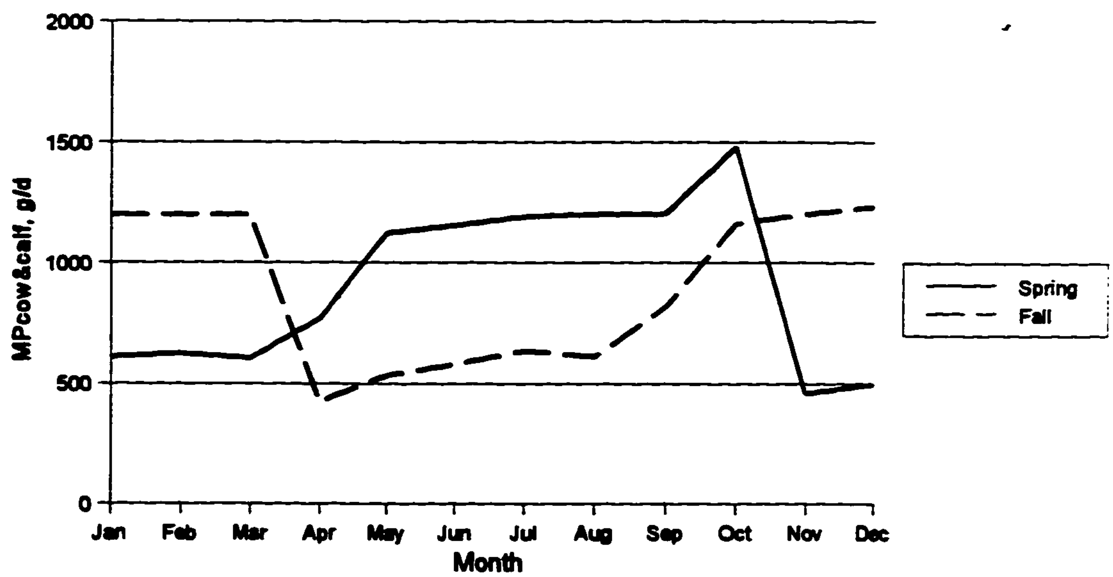

Figure 5.16. Total metabolizable protein requirements (MPcow&calf, g/d) for a cow-calf pair based on calving in the spring and fall, and assuming other parameters are constant (5 years old, mature weight=550 kg, peak milk yield=8.2 kg/d, CS=5).

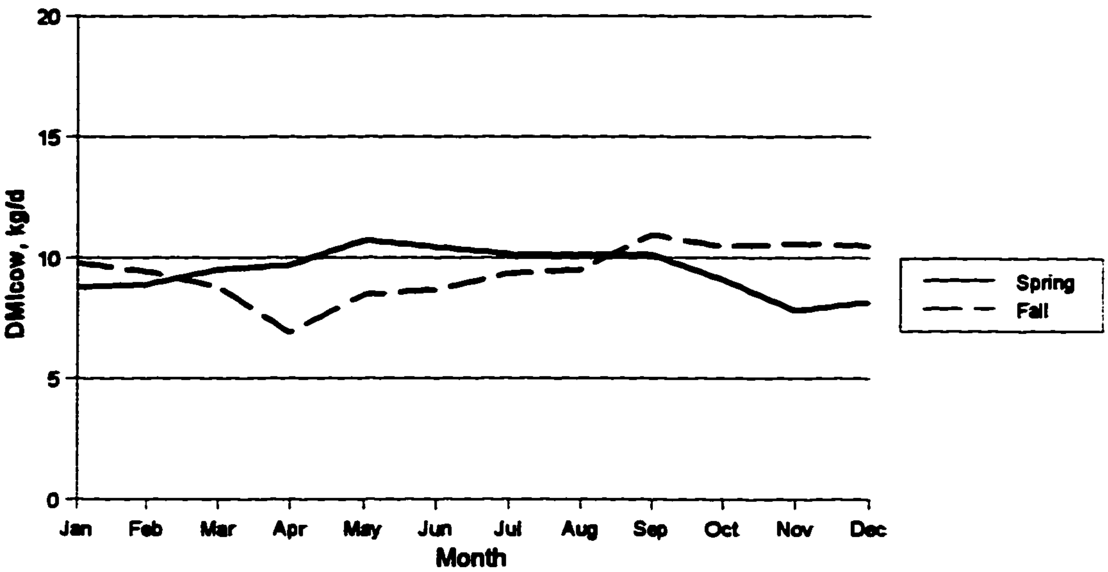

Figure 5.17. Predicted dry matter intakes (DMIcow, kg/d) of mature cows calving in the spring and fall, and assuming other parameters are constant (5 years old, mature weight=550 kg, peak milk yield=8.2 kg/d, CS=5).

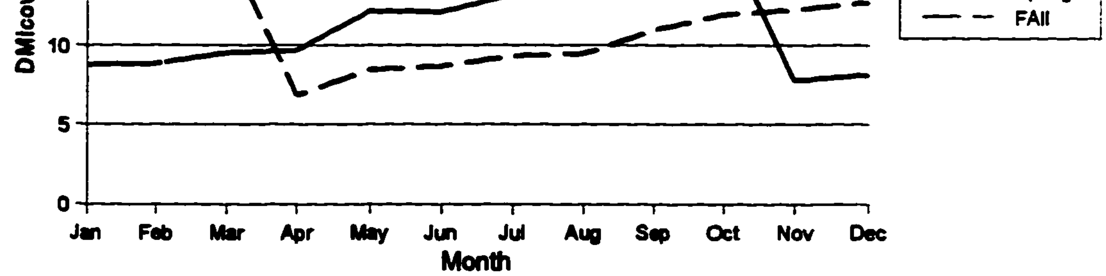

Figure 5.18. Predicted dry matter intakes (DMIcow&calf, kg/d) for cow-calf pairs based on calving in the spring and fall, and assuming other parameters are constant (5 years old, mature weight=550 kg, peak milk yield=8.2 kg/d, CS=5).

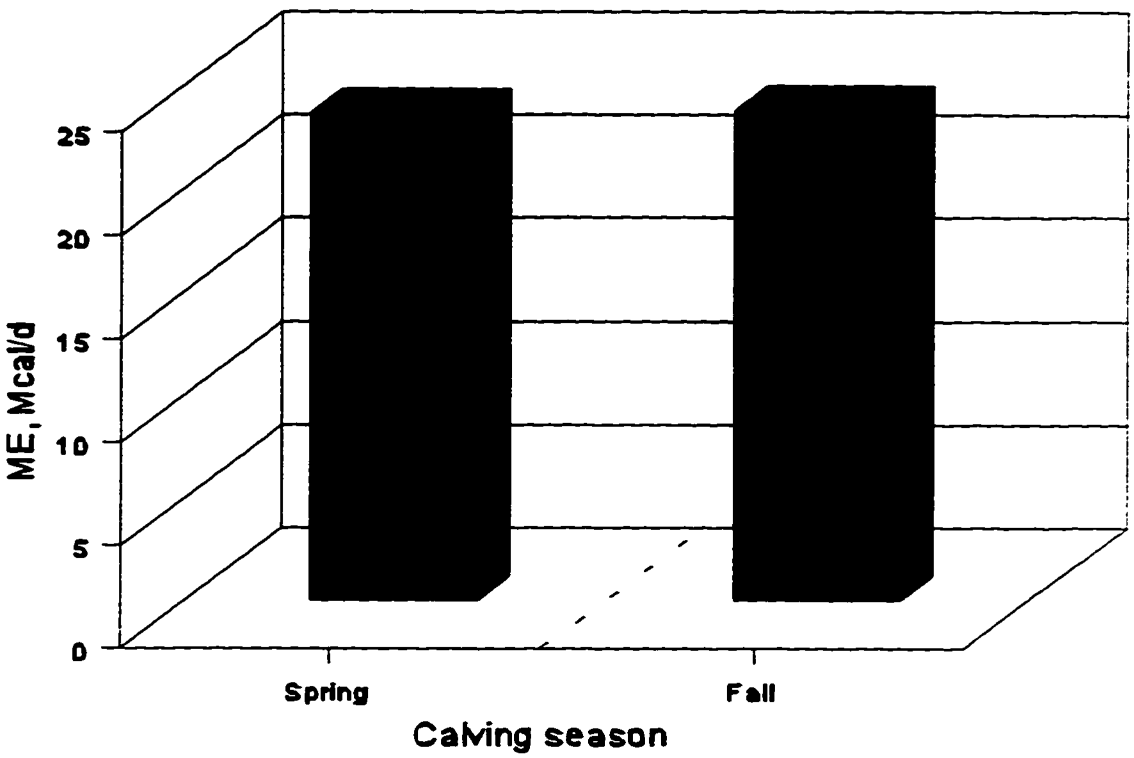

Figure 5.19. Average daily metabolizable energy (ME, Mcal/d) of a cow over one year for spring- and fall-calving herds, and assuming other parameters are constant (5 years old, mature weight=550 kg, peak milk yield=8.2 kg/d, CS=5).

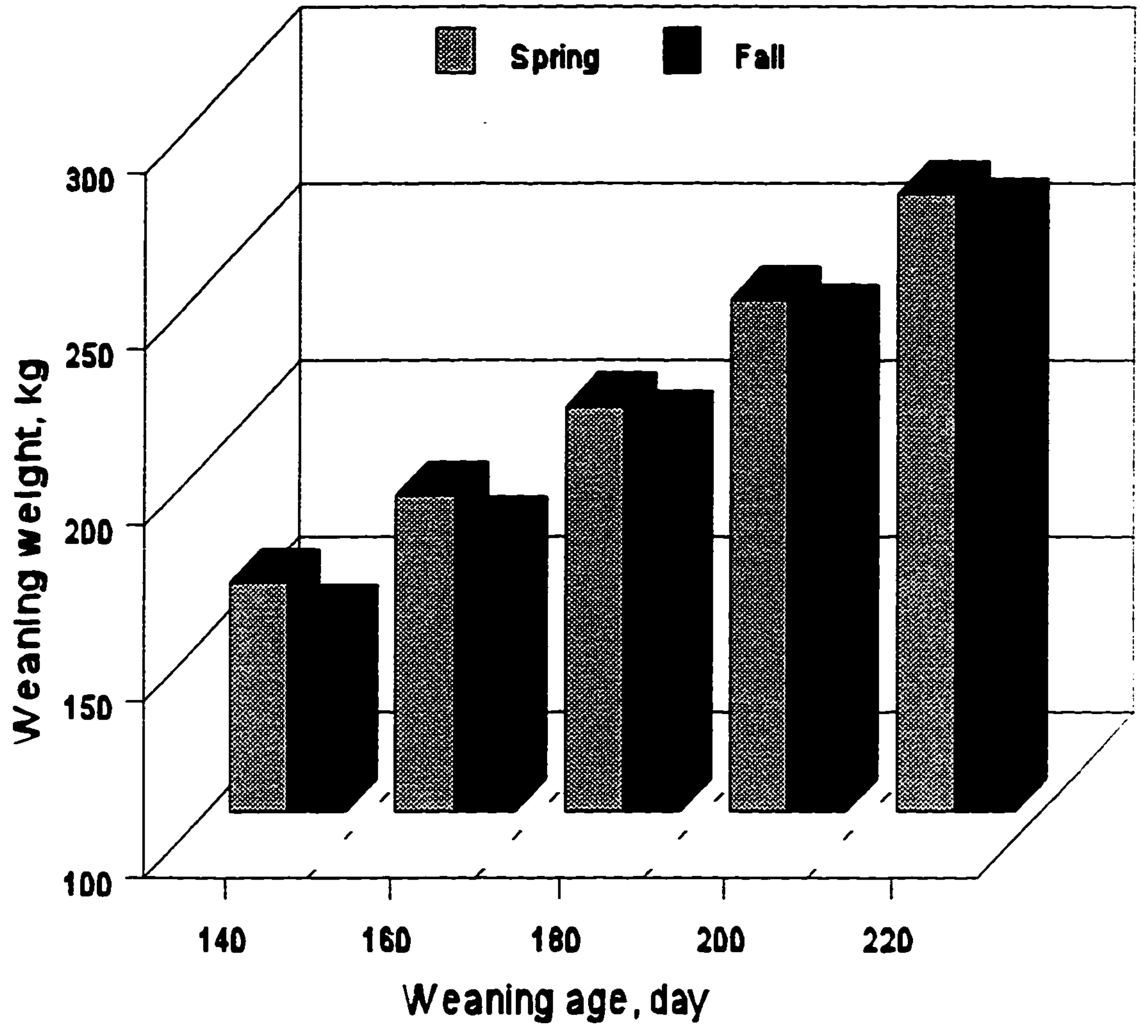

Figure 5.20. Calf weaning weights for spring- and fall-calving herds when calves were weaned at different ages and assuming other parameters are constant (5 years old, mature weight=550 kg, peak milk yield=8.2 kg/d, CS=5).

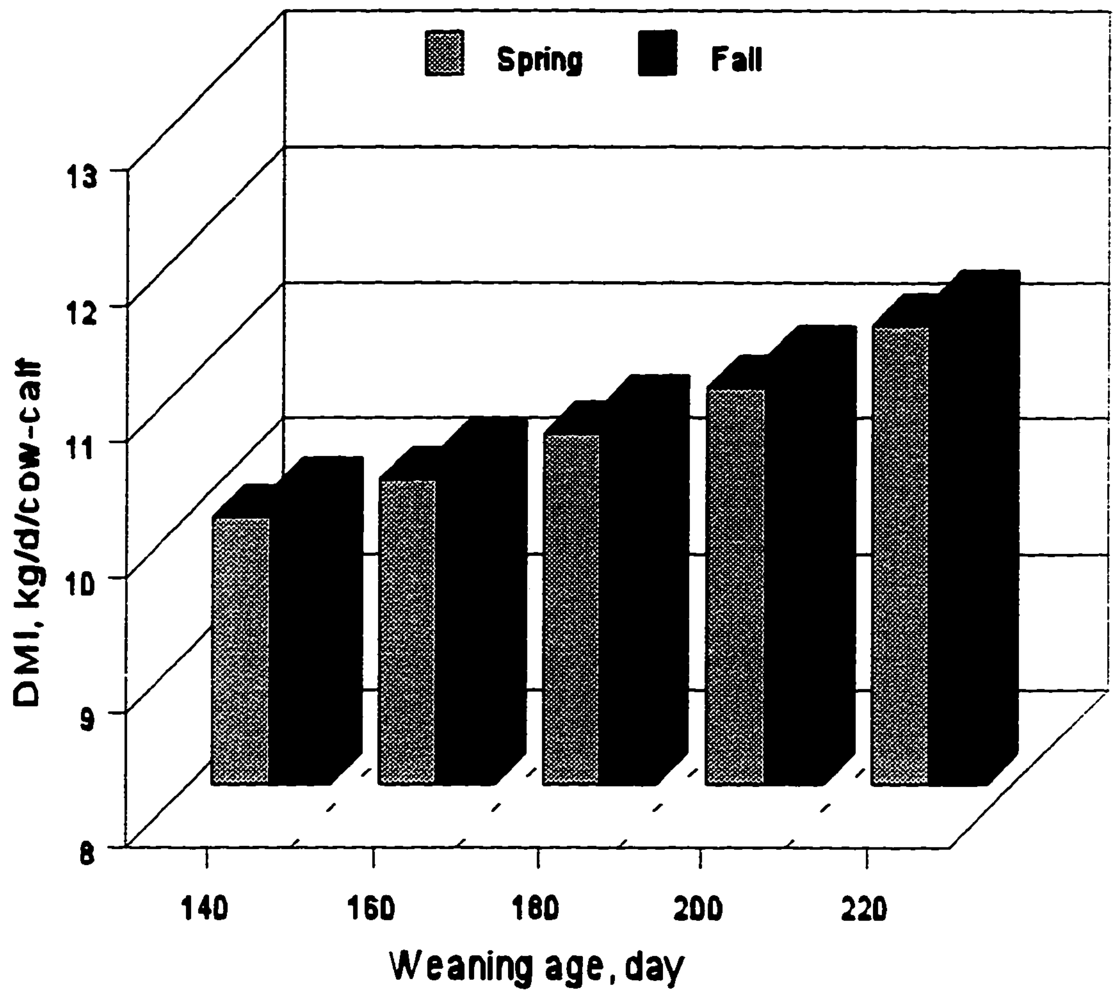

Figure 5.21. DMI for cow-calf pairs for spring- and fall-calving herds when calves were weaned at different ages and assuming other parameters are constant (5 years old, mature weight=550 kg, peak milk yield=8.2 kg/d, CS=5).

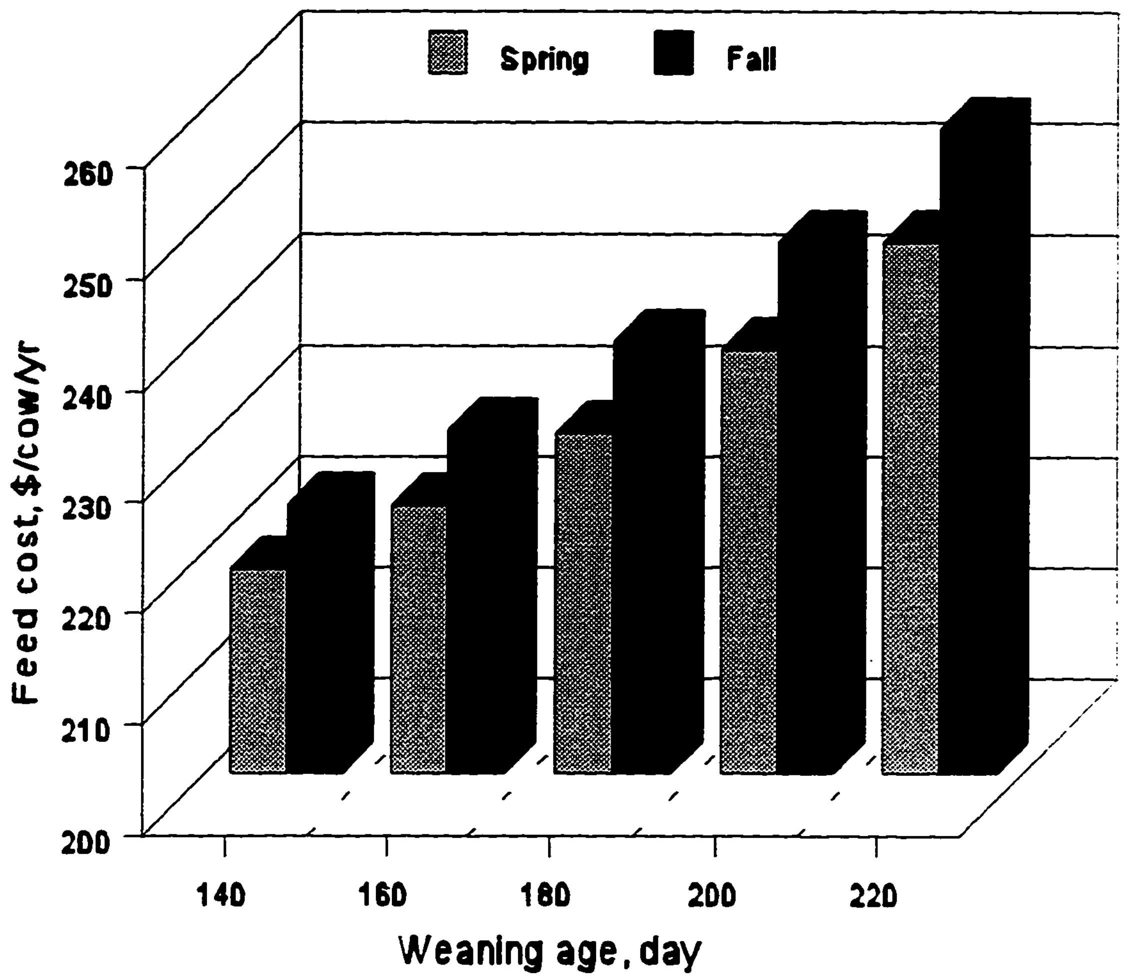

Figure 5.22. Cow feed costs ($/cow/year) for spring- and fall-calving herds when calves were weaned at different ages, and assuming other parameters are constant (5 years old, mature weight=550 kg, peak milk yield=8.2 kg/d, CS=5).

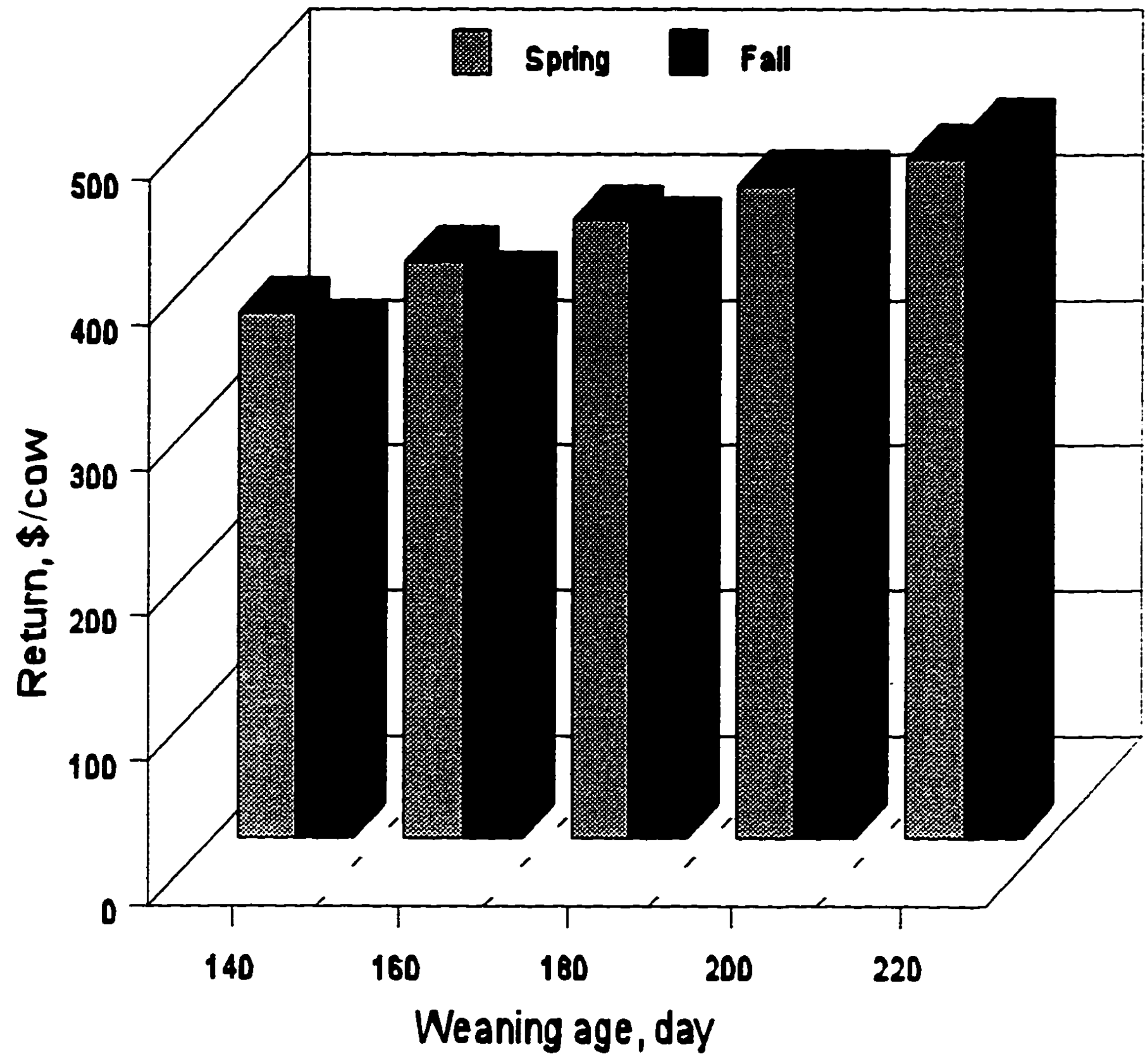

Figure 5.23. Returns from spring- and fall-calving herds when calves were weaned at different ages, and assuming other parameters are constant (5 years old, mature weight= 550 kg, peak milk yield=8.2 kg/d, CS=5).

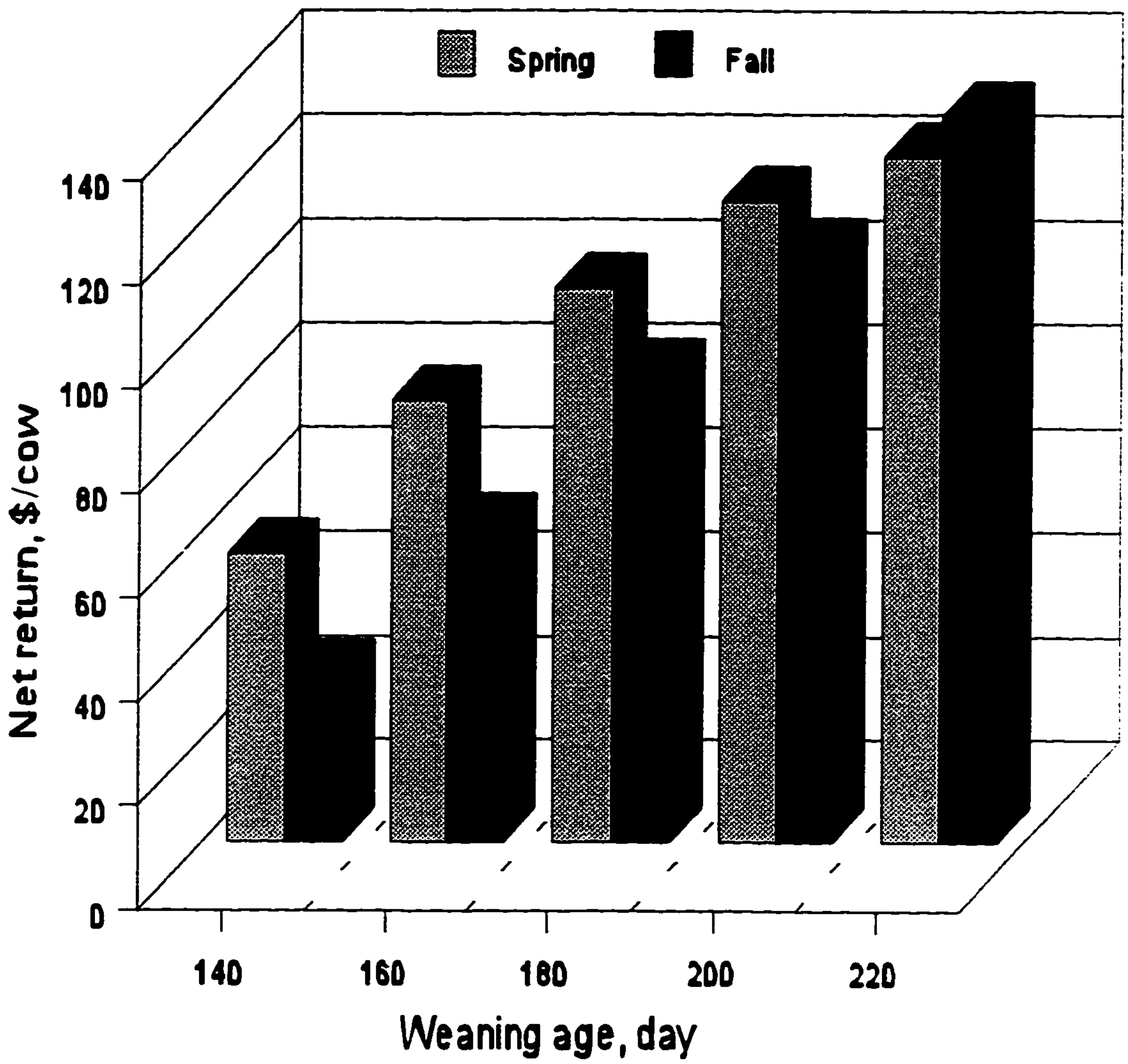

Figure 5.24. Net returns from spring- and fall-calving herds when calves were weaned at different ages, and assuming other parameters are constant (5 years old, mature weight= 550 kg, peak milk yield=8.2 kg/d, CS=5).

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Chapter 6

General Discussion and Conclusions

6.1. Summary and Conclusions

Selection for growth rate and the use of large size continental breeds by commercial producers have resulted in larger cows with higher feed requirements (Barlow, 1984; Scholtz and Roux, 1984). Freking et al. (1992) indicated that increased milk production was associated with improved calf production to weaning. However, this advantage would be offset by: 1) the higher energy cost for milk versus other feed sources available to the calf (Ansotegui et al., 1991; Baker et al., 1976); 2) high milk production is associated with high requirements for maintenance (Montano-Bermudez et al., 1990). Therefore, cow-calf managers have become increasingly aware of the need to match cow size, milk production and management to the available feed, labour and capital resources in order to increase overall production efficiency (Kress et al., 1994; Nickel, 1995; Porter, 1995).

The beef cattle production system is a complex aggregate of subsystems, each somewhat dependent on the others. Maximizing the effect of one particular sector may reduce the functional capability of the total system (Fitzhugh, 1978). Evaluation of interactions among system components leads to greater understanding of the total system (Amer et al., 1994). Computer modelling has the potential to integrate results from larger, more complex systems (Spreen and Laughlin, 1986). If the knowledge of the components can be quantified and presented in a mathematical form, simulation models can be applied for more detailed and mechanistic studies to provide more thorough understanding of the total system (France et al., 1984).

A dynamic deterministic model, **Beef Production Simulation System (BPSS)**, described in Chapter 3 was developed to examine and evaluate the effects of cow size, milk production, calving season, weaning age, market price, and their interactions on bioeconomic efficiency of cow-calf production systems. The model was the result of an multidisciplinary effort that incorporates the interactions of growing crops, grazing beef cattle, energy utilization, and economics in a beef cattle production system. The model is composed of four major submodels: herd inventory, nutrient requirements, forage production, and economic submodels (Chapter 3). The herd inventory submodel simulates dynamic changes of nine age groups in a cow herd, and predicts how many culled cows and weaned calves are available in each age group and in the whole herd. The nutrient requirements submodel is mainly based on the Cornell Net Carbohydrate and Protein System for Evaluating Cattle Diets (CNCPS, Fox et al., 1984, 1988, 1992, 1995), to estimate nutrient requirements (ME, MP) for maintenance, growth, lactation, and pregnancy of a cow, a calf, a cow-calf pair, and a herd. The model also considers the effects of cold stress and lower critical temperature (LCT) on maintenance requirement. The model can simulate cow condition score changes year round based on the diet and animal energy balance. The forage production submodel estimates soil moisture, forage growth rate, cattle grazing rate, forage yield and quality, stocking rate and total hectares required for a herd, based on climatic conditions and common forage species in different soil climatic zones in Alberta (Alberta Agriculture, 1995). The economic submodel estimates feed cost, cow total cost, returns, and net return, or bioeconomic efficiency of the herd (Chapter 3).

The nutrient requirements estimated by BPSS were compared to those recommended by the National Research Council (NRC, 1984, 1987, 1996) and Alberta Agriculture (AA, 1987) for validation. Nutrient allowance values recommended by AA were usually above BPSS and NRC values. Predicted nutrient requirements based on BPSS were generally equal to or slightly higher than those based on NRC. Sensitivity analyses (Chapter 3) showed that: 1) cow size plays an important role in feed requirements during the winter; 2) the model is very sensitive to changes in calf weaning weight and cow milk production during the period from calving to weaning; 3) the model is not sensitive to changes in calf birth weight; 4) the accuracy in the estimation of pasture price and winter feed price are critical in the model.

For the effects of cow size (Chapter 4), the simulated results indicated that the difference in nutrient requirements (ME and MP) of individual cows differing in size was mainly due to the maintenance requirement. Larger cows required more ME and MP for maintenance than smaller cows. Calf forage DMI, ME and DMI for a cow-calf pair, feed cost and total cost per cow, and return increased with larger cow size. **When comparisons of cow size were made at a constant calf weaning age** (220 d), the small cow size group always had the lowest bioeconomic efficiency for each milk production class and each market price level. The medium cow size group had the highest bioeconomic efficiency for each milk production class at the low price level, however, the large cow size group had the highest bioeconomic efficiency for each milk production class at the medium and high price levels. **When comparisons of cow size were made at similar calf weaning weights**, the large cow size group always had the lowest bioeconomic efficiency for each milk production class and each market price level. The medium cow size group had the highest bioeconomic efficiency for the high milk production class at each price level, and for each milk production class at the high price level. The small size group had the highest bioeconomic efficiency only when milk production was at low or medium levels and at low market price level. The results indicated the existence of interactions between cow size and market price level, and between cow size and milk production.

For the effects of milk production (Chapter 4), the differences in nutrient requirements (ME and MP) of individual cows differing in milk production was mainly related to the lactation requirement during the period from calving to weaning, where other parameters were constant. Cows with a high milk production required more ME and MP for lactation than cows with low milk production. **When the comparisons of milk production were made at the same weaning age** (200 d), the calf forage DMI decreased for the higher milk production class. These results agree with other researchers who indicated that calves receiving less milk increase their forage intake (Baker et al., 1976; Ansotegui et al., 1991). The calf milk DMI, ME and DMI for a cow-calf pair, feed cost, total cost, and return per cow increased with higher milk production. The high milk production level, with a higher weaning weight, had the highest bioeconomic efficiency regardless of the market price level or the cow size.

When the comparisons of milk production were made at similar weaning weights, the DMI and total cost per cow for the low milk production level were slightly lower than the other levels, so the low milk production level had the highest bioeconomic efficiency regardless of the market price level or the cow size group (Chapter 4). These results were similar to those of Montano-Bermudez and Nielsen (1990) and Van Oijen et al.

(1993). It can be concluded that, although the weaning age required to reach a predetermined calf weaning weight would be shorter for high milking cows, the saving in feed cost due to a shorter period is offset by the increased cost of the higher milk production. On the basis of the costs and returns specific to this study, to reach a certain weaning weight, increased milk production was not cost effective for a cow-calf beef production system.

Generally, spring born calves had heavier calf weaning weight than fall born calves at each weaning age (Chapter 5). Similar results were reported by McCarter et al. (1991) and Roberson et al. (1986). Nutrient requirements for cows and calves in each month of the year were different for spring- and fall- calving herds. The nutrient requirements of a cow-calf pair in a fall-calving herd was higher than those in a spring-calving herd between November and March, and was lower than those in the spring-calving herd between April and October. In Alberta, the probability of exposure to extreme cold weather after calving is higher for the fall-calving calves. DMI and feed cost were higher in the fall-calving herd than those in the spring-calving herd. Bioeconomic efficiency was higher in the spring-calving herd when the average weaning age was less than 200 days. However, at average weaning age of 220 days, bioeconomic efficiency was higher in the fall-calving herd due to the higher market price of the fall born calves.

In this study, the maximum weaning age was assumed to be 220 days. Under this condition, the bioeconomic efficiency generally increased with weaning age (Chapter 5).

Although the model considers the effect of the diet and energy balance on condition score, it does not respond to the limitation in feed intake as far as other traits are concerded. This study assumed that animals could meet their nutrient requirements based on an unrestricted feed, labor, and capital supply. Further research is needed to examine the changes in bioeconomic efficiency when feed, labor and capital supply are limited. As pointed out in Chapter 3, there were no experimental data available for validating the forage growth curves and soil moisture in the Forage Production submodel. Further studies to validate Forage Production submodel are required.

It can be concluded that BPSS provides a useful method for simultaneous consideration of many factors in an integrated system, which could be helpful to beef cattle extension specialists and cow-calf production managers, for predicting the effects of different management and selection strategies on bioeconomic efficiency. Proper use of the model, when the factors which influence bioeconomic efficiency are well defined, will hopefully lead to a strategy which has a higher probability of success under a defined environment.

6.2. References

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Chapter 7

APPENDIX: THE STELLA II PROGRAMS FOR THE BEEF PRODUCTION SIMULATION SYSTEM (BPSS)

7.1. Nutrient Requirements Submodel

7.1.1. Nutrient requirements for maintenance

```
a2 = .0007*(20-EATp)
 DOCUMENT:  Adjustment factor for acclimtization effects.
breed = 0
 DOCUMENT:  Breed          Breed Code
            Beef               0
            Dairy x Beef       1
            Dairy              2
Cam = .0154*BodyWt/.5
CondScore = 5
 DOCUMENT:  Cow body condition score. Here using the USA 9 point system:
        from 1 (too thin) to 9 (too fat), 5 is desirable.
days = COUNTER(1,365)
DMIcalf = CalfWt^.75*(.1493*NEma-.046*NEma^2-.0196)*BWF*BreedF*TempF*MudF
DMIcow = BodyWt^.75*(.0194+.0545*NEma)*TempF*MudF+.2*MilkYield
 DOCUMENT:  Cow dry matter intake (kg/d).
EATp = 5.17+.75*Temp+.15*Humidity
 DOCUMENT:  Previous effective ambient temperature (°C).
ExtInsu = (7.36-.296*wind+2.55*hair)*mud2*Hide
 DOCUMENT:  External insulation value (0C/(Mcal/m^2))/d.
Feedm = NEm/NEma
 DOCUMENT:  Feed for maintenance (no stress), kg of DM/d.
FeedMenv = NEmenv/NEma
 DOCUMENT:  Feed for maintenance with cold stress, kg DM/d.
GrazActiviety = if Grazing?=0 then 1 else 1.05+.074*GrazArea
 DOCUMENT:  Grazing activity adjustment.
GrazArea = 2
 DOCUMENT:  Grazing area required to sustain a 500 kg dry cow for a grazing season (ha/cow).
hair = 1
 DOCUMENT:  Effective hair depth (cm).
Heatprod = (MEintake-NEpCow)/Surarea
 DOCUMENT:  Heat production (Mcal/m^2/d).
Hide = 1
 DOCUMENT:  External insulation is adjusted for hide thickness:
        1) thin hide: 0.8 (Holstein); 2) average hide: 1 (Angus); 3) heavy hide: 1.2 (Hereford).
HumiV = NORMAL(Humidity,4)
IndigDM = DMIcow*IndigRate*1000
 DOCUMENT:  Indigestible dry matter (g/d).
IndigRate = .2
 DOCUMENT:  Indigestible Rate of dry matter.
Insu = ExtInsu+IntInsu
 DOCUMENT:  Insulation value (°C/(Mcal/m^2))/d.
L = 1.2
```

DOCUMENT: Energy maintenance adjustment for lactation.
LCT = 39-Insu*Heatprod
DOCUMENT: Animal's lower critical temperature (°C).
MEcs = Surarea*(LCT-TempV)/Insu
DOCUMENT: Metablizable energy required due to cold stress (Mcal/d).
MEcsC = SurareaC*(LCT-TempV)/Insu
MEcsS = SurareaS*(LCT-TempV)/Insu
MEforage1 = 2.64
MEintake = DMIcow*MEforage
DOCUMENT: Metablizable energy intake (Mcal/d).
MEm = NEm/.65
MEmenv = NEmenv/.65
MetafecalP = 33.4*DMIcow
DOCUMENT: Metabolic fecal protein (g/d).
MPm = MetafecalP+ScurfProt+UrinProt
DOCUMENT: Metabolizable protein required for maintenance (g/d).
Mud1 = 20
DOCUMENT: Mud (cm): Mild=10-20cm; Severe=30-60 cm.
mud2 = 1
DOCUMENT: External insulation is adjusted for coat condition:
1) dry and clean: 1.0; 2) some mud on lower body: 0.8; 3) mud on lower body and sides: 0.5;
NEm = (.077+a2)*BodyWt^.75*GrazActiviety*BE*L
DOCUMENT: Net energy required for maintenance (Mcal/d). 0.077 is the coefficient for maintenance at thermal neutral zone (Mcal/kg*W^.75).
NEmcs = 1.37*MEcs-.138*MEcs^2+.0105*MEcs^3-1.12
DOCUMENT: Net energy required due to cold stress (Mcal/d).
NEmcsC = 1.37*MEcsC-.138*MEcsC^2+.0105*MEcsC^3-1.12
NEmcsS = 1.37*MEcsS-.138*MEcsS^2+.0105*MEcsS^3-1.12
NEmenv = if NEmcs>0 then NEm+NEmcs else NEm
DOCUMENT: Net energy required for maintenance adjusted for breed, lactation, grazing, acclimatization and cold stress effects (Mcal/d). NEmcs is included only if a positive vale. A negative value means there is surplus heat increment.
NEpCow = (DMIcow-Feedm)*MEforage*.65
DOCUMENT: Net energy available for production for lactating and dry cows (Mcal/d).
Pm = .016*BodyWt/.67
ScurfProt = 2.75*BodyWt^.5/.67
DOCUMENT: Scurl protein (g/d).
Surarea = .09*BodyWt^.666
DOCUMENT: Surface area (m^2).
SurareaC = .09*CalfWt^.666
SurareaS = .09*SteerWt^.666
TempV = NORMAL(Temp,SDTemp)
UrinProt = .2*BodyWt^.6/.67
DOCUMENT: Urinary protein (g/d).
BE = GRAPH(breed)
(0.00, 1.00), (1.00, 1.06), (2.00, 1.12), (3.00, 1.12)
DOCUMENT: Breed energy maintenance requirement factor.
BreedF = GRAPH(breed)
(0.00, 1.00), (1.00, 1.04), (2.00, 1.08), (3.00, 1.08)
DOCUMENT: Breed adjustment factor for DMI.
0) Beef: 1.0 1) Dairy x Beef: 1.04 2) Dairy: 1.08
BWF = GRAPH(CalfWt)

(0.00, 1.00), (60.0, 1.00), (120, 1.00), (180, 1.00), (240, 1.00), (300, 1.00), (360, 0.97), (420, 0.9), (480, 0.82), (540, 0.73), (600, 0.73)
DOCUMENT: Steer equivalent weight (kg) factor.
Grazing? = GRAPH(days)
(0.00, 0.00), (30.4, 0.00), (60.8, 0.00), (91.3, 0.00), (122, 0.00), (152, 1.00), (183, 1.00), (213, 1.00), (243, 1.00), (274, 1.00), (304, 0.00), (335, 0.00), (365, 0.00)
DOCUMENT: Cattle is grazing (1) or not (0). Generally, grazing activity should be considered during June-October each year.
Humidity = GRAPH(days)
(0.00, 71.0), (30.4, 72.0), (60.8, 69.0), (91.3, 53.0), (122, 43.0), (152, 51.0), (183, 57.0), (213, 58.0), (243, 57.0), (274, 53.0), (304, 67.0), (335, 73.0), (365, 73.0)
DOCUMENT: Relative humidity (%). Based on 30 years average climate data (Environment Canada).
IntInsu = GRAPH(CondScore)
(1.00, 6.00), (2.00, 6.75), (3.00, 7.50), (4.00, 8.25), (5.00, 9.00), (6.00, 9.75), (7.00, 10.5), (8.00, 11.3), (9.00, 12.0)
DOCUMENT: Internal (tissue) insulation value (°C/(Mcal/m^2))/d. Based on body condition score.
MEforage = GRAPH(days)
(0.00, 2.10), (30.4, 2.10), (60.8, 2.10), (91.3, 2.10), (122, 2.10), (152, 1.92), (183, 1.92), (213, 1.92), (243, 1.92), (274, 1.92), (304, 2.10), (335, 2.10), (365, 2.10)
DOCUMENT: Metablizable energy content of diet (Mcal/kg). Based on calving season:
1) Jun-Aug: 2.68; 2) Sept-Oct: 2.17; 3) Nov-May: 1.99.
MudF = GRAPH(Mud1)
(10.0, 0.85), (20.0, 0.85), (30.0, 0.7), (40.0, 0.7), (50.0, 0.7), (60.0, 0.7), (70.0, 0.7)
DOCUMENT: Mud adjustment factor for DMI.
NEga = GRAPH(days)
(0.00, 0.42), (30.4, 0.42), (60.8, 0.42), (91.3, 0.42), (122, 0.42), (152, 0.52), (183, 0.52), (213, 0.52), (243, 0.52), (274, 0.52), (304, 0.42), (335, 0.42), (365, 0.42)
DOCUMENT: Net energy value of diet (Brome and Alfalfa) for gain (Mcal/kg).
NEma = GRAPH(days)
(0.00, 0.97), (30.4, 0.97), (60.8, 0.97), (91.3, 0.97), (122, 0.97), (152, 1.07), (183, 1.07), (213, 1.07), (243, 1.07), (274, 1.07), (304, 0.97), (335, 0.97), (365, 0.97)
DOCUMENT: NEma = Net energy value of diet (Brome and Alfalfa) for maintenance (Mcal/kg).
SDTemp = GRAPH(days)
(0.00, 3.80), (30.4, 4.00), (60.8, 3.80), (91.3, 2.50), (122, 1.10), (152, 1.50), (183, 1.10), (213, 1.90), (243, 2.20), (274, 2.50), (304, 3.60), (335, 4.00), (365, 4.00)
DOCUMENT: Standard deviation of daily temperature within each month (days).
Based on 30 years average climate data (Environment Canada).
Temp = GRAPH(days)
(0.00, -16.5), (30.4, -11.4), (60.8, -6.70), (91.3, 3.20), (122, 10.1), (152, 14.1), (183, 15.8), (213, 14.8), (243, 9.80), (274, 4.70), (304, -5.50), (335, -13.1), (365, -16.5)
DOCUMENT: Previous temperature (oC). Based on 30 years average climate data (Environment Canada).
TempF = GRAPH(Temp)
(-30.0, 1.16), (-21.3, 1.16), (-12.5, 1.07), (-3.75, 1.05), (5.00, 1.03), (13.8, 1.03), (22.5, 1.00), (31.3, 0.9), (40.0, 0.9)
DOCUMENT: Temperature adjustment factor for DMI.
wind = GRAPH(days)
(0.00, 13.4), (30.4, 13.4), (60.8, 13.4), (91.3, 15.2), (122, 15.7), (152, 13.6), (183, 11.6), (213, 11.3), (243, 13.0), (274, 13.6), (304, 12.9), (335, 13.1), (365, 13.1)
DOCUMENT: Wind speed each month (km/hr). Based on 30 years average climate data (Environment Canada).

7.1.2. Nutrient requirements for heifer growth

```
BodyWt(t) = BodyWt(t - dt) + (Cowgain) * dt
        INIT BodyWt = HeiferiniWt
  DOCUMENT: Cow current weight (kg). Initial heifer weight is at breeding weight.
Cowgain = if BodyWt>MatureWt then 0 else (-KW*BodyWt*LOGN(BodyWt/MatureWt))
  DOCUMENT: Weight daily gain (kg/d).
Cag = MPgain*.071/.5
Cowage = Cowageday+TIME
Cowageday = if CalvingDay<145 then IniCowage*365-CalvingDay
        else IniCowage*365+(365-CalvingDay)
  DOCUMENT: Cow ages (days). Here assumed heifer from Jan 1 (21.5 months old).
CowSize = if MatureWt<400 then 1 else if MatureWt>670 then 9 else CowSize1
  DOCUMENT: Cow size code, range 1-9 based on cow weight.
EmptyBfat = 22.5*(1-EXP(-.00536*Cowage))
  DOCUMENT: Empty body fat (%).
EmptyBW = .8928*MatureWt-4.7
  DOCUMENT: Mature cow empty body weight (kg).
Emptygain = if Gain=0 then 0 else .8928*Gain-4.7
  DOCUMENT: empty weight gain (kg/d).
Gain = Cowgain*1000
  DOCUMENT: Cow daily gain (g/d).
HeiferiniWt = if Cowage<=641 then HeifPreGain*Cowageday else if Heifergain*Cowageday>MatureWt
        then MatureWt else Heifergain*Cowageday
IniCowage = 2
  DOCUMENT: Cow ages by year when starting the simulation.
KW = 1/(36*MatureWt^.28)
  DOCUMENT: Heifer live weight growth rate.
MatureWt = 550
  DOCUMENT: Average cow mature weight (kg).
MEgain = ((.05603*Gain+.00001265*Gain^2)*(BodyWt*FrameAdj)^.75)/400
  DOCUMENT: Metabolizable energy requirements for gain (Mcal/d).
MPgain = if Emptygain*ProteinGain*.01/.5<0 then 0 else Emptygain*ProteinGain*.01/.5
  DOCUMENT: Metabolizable protein required for gain (g/d).
NEgain = MEgain*.4
Pg = MPgain*.045/.6
ProteinGain = (100-((76.3-.973*EmptyBfat)+EmptyBfat))*.7995
  DOCUMENT: Protein in gain (%).
CowSize1 = GRAPH(MatureWt)
(400, 1.00), (433, 2.00), (467, 3.00), (500, 4.00), (533, 5.00), (567, 6.00), (600, 7.00), (633, 8.00), (667,
9.00), (700, 9.00)
  DOCUMENT: Cow size code, range 1-9 based on cow weight.
FrameAdj = GRAPH(CowSize)
(1.00, 1.45), (2.00, 1.34), (3.00, 1.24), (4.00, 1.16), (5.00, 1.09), (6.00, 1.02), (7.00, 0.97), (8.00, 0.92),
(9.00, 0.87), (10.0, 0.87)
  DOCUMENT: Frame adjustment (for size 1-9: 1.04-1.56).
Heifergain = GRAPH(CowSize)
(1.00, 0.502), (2.00, 0.529), (3.00, 0.566), (4.00, 0.597), (5.00, 0.633), (6.00, 0.665), (7.00, 0.697), (8.00,
0.737), (9.00, 0.77), (10.0, 0.77)
  DOCUMENT: Heifer gain (kg/d) based on Cow Size (1-9).
HeifPreGain = GRAPH(CowSize)
(1.00, 0.74), (2.00, 0.78), (3.00, 0.82), (4.00, 0.86), (5.00, 0.9), (6.00, 0.94), (7.00, 0.98), (8.00, 1.12), (9.00,
```

1.14), (10.0, 1.14)

7.1.3. Nutrient requirements for lactation

```
Am = if Cowage<1065 then 4-.05*DayPeak else if Cowage<1430 then 6.65-.11*DayPeak else
        if Cowage<1795 then 5.85-0.09*DayPeak else 5.3-.075*DayPeak
 DOCUMENT: Wood's equation "a" coefficient for beef cow.
Bm = (LOGN(CoeffAge*10)-LOGN(Am))/(LOGN(DayPeak+14)-1)
 DOCUMENT: Wood's equation "b" coefficient for beef cow.
Cal = MilkYield*1.23/.5
Cm = Bm/(DayPeak+14)
 DOCUMENT: Wood's equation "c" coefficient for beef cow.
CoeffAge = if Cowage<700 then 0 else if Cowage<1065 then .6 else if Cowage<1430 then .825 else
        if Cowage<1795 then .925 else 1
 DOCUMENT: Coefficients based on cow age, as 2, 3, 4 yr old and mature cow.
DayLact = if Cowage<=641 then 0 else if CalvingDay<145 then if days<CalvingDay or days>WeanDay
        then 0 else days-CalvingDay else if days>CalvingDay or days<WeanDay then
        if days>CalvingDay then days-CalvingDay else 365-CalvingDay+days else 0
 DOCUMENT: Day of lactation (d).
DayPeak = if Cowage<1065 then PeakMilk+50 else if Cowage<1430 then PeakMilk+30 else
        if Cowage<1795 then PeakMilk+35 else PeakMilk+40
 DOCUMENT: Day of peak yield for 2, 3 and 4 years old.
MElact = 0.1*MilkYield*(MilkFat+3.4)/.65
 DOCUMENT: Metabolizable energy required for lactation (Mcal/d).
MilkFat = 1.01*PeakFat*(((DayLact+1)/7)^(-.13))*(EXP(.02*((DayLact+1)/7)))
 DOCUMENT: Milk fat for a particular day of lactation (%).
MilkP = 1.14*PeakProtein*(((DayLact+3)/7)^(-.12))*(EXP(.01*((DayLact+3)/7)))
 DOCUMENT: Milk protein on a particular day of lactation (%).
MilkYield = if DayLact=0 then 0 else (Am*((Daylact+14)^Bm) * (EXP(-Cm*(DayLact+14)))) *
        (PeakMilk/(CoeffAge*10))
 DOCUMENT: Milk yield for beef cow (kg/d).
MPlact = 10*MilkYield*MilkP/.65
 DOCUMENT: Metabolizable protein required for lactation (g/d).
NElact = MElact*.65
PeakFat = 3.8
 DOCUMENT: Peak milk fat (%).
PeakMilk = PeakmilkYied*CoeffAge
 DOCUMENT: Peak milk for 2, 3, 4 yr old and mature cow adjusted for production level within breed (kg/d).
PeakmilkYied = if CowSize=1 then PeakMM1 else if CowSize=2 then PeakMM2 else
        if CowSize=3 then PeakMM3 else if CowSize=4 then PeakMM4 else
        if CowSize=5 then PeakMM5 else if CowSize=6 then PeakMM6 else
        if CowSize=7 then PeakMM7 else if CowSize=8 then PeakMM8 else PeakMM9
 DOCUMENT: Breed average peak milk yield based on calf weaning weight and cow size (kg/d).
PeakProtein = 3.5
 DOCUMENT: Peak milk protein (%).
Pl = MilkYield*.95/.67
WeanDay = if CalvingDay<145 then Weanperiod+CalvingDay
        else CalvingDay+Weanperiod-365
 DOCUMENT: Pre-Wean Period (days). Days from calving to weaning is assumed 220 days here.
Weanperiod = 220
 DOCUMENT: Days of calf from born to wean.
WeanWt = 240
```

DOCUMENT: Average calf weaning weight (kg).
PeakMM1 = GRAPH(WeanWt)
(120, 0.225), (140, 0.75), (160, 1.50), (180, 2.70), (200, 5.40), (220, 8.20), (240, 10.2), (260, 11.6), (280, 13.1), (300, 14.5)
DOCUMENT: Predicted peak milk yield in beef cow based on calf weaning weight (7 month weight) and cow size 1 (Fox et al. 1988).
PeakMM2 = GRAPH(WeanWt)
(100, 0.2), (120, 0.3), (140, 0.6), (160, 1.60), (180, 2.70), (200, 5.40), (220, 8.20), (240, 11.0), (260, 13.4), (280, 16.0), (300, 17.9)
DOCUMENT: Predicted peak milk yield in beef cow based on calf weaning weight (7 month weight) and cow size 2 (Fox et al. 1988).
PeakMM3 = GRAPH(WeanWt)
(130, 0.2), (147, 0.4), (164, 0.6), (181, 1.30), (198, 2.70), (215, 5.40), (232, 8.20), (249, 10.9), (266, 13.6), (283, 15.7), (300, 17.7)
DOCUMENT: Predicted peak milk yield in beef cow based on calf weaning weight (7 month weight) and cow size 3 (Fox et al. 1988).
PeakMM4 = GRAPH(WeanWt)
(140, 0.2), (156, 0.4), (172, 0.8), (188, 1.20), (204, 2.70), (220, 5.40), (236, 8.20), (252, 10.9), (268, 13.6), (284, 15.7), (300, 18.0)
DOCUMENT: Predicted peak milk yield in beef cow based on calf weaning weight (7 month weight) and cow size 4 (Fox et al. 1988).
PeakMM5 = GRAPH(WeanWt)
(140, 0.2), (158, 0.3), (176, 0.6), (194, 1.40), (212, 2.70), (230, 5.40), (248, 8.20), (266, 11.2), (284, 14.0), (302, 17.0), (320, 19.8)
DOCUMENT: Predicted peak milk yield in beef cow based on calf weaning weight (7 month weight) and cow size 5 (Fox et al. 1988).
PeakMM6 = GRAPH(WeanWt)
(140, 0.3), (159, 0.3), (178, 0.7), (197, 1.10), (216, 2.70), (235, 5.40), (254, 8.20), (273, 11.4), (292, 14.2), (311, 17.3), (330, 19.9)
DOCUMENT: Predicted peak milk yield in beef cow based on calf weaning weight (7 month weight) and cow size 6 (Fox et al. 1988).
PeakMM7 = GRAPH(WeanWt)
(140, 0.25), (161, 0.375), (182, 0.75), (203, 1.38), (224, 2.70), (245, 5.40), (266, 8.88), (287, 12.6), (308, 16.1), (329, 20.1), (350, 24.6)
DOCUMENT: Predicted peak milk yield in beef cow based on calf weaning weight (7 month weight) and cow size 7 (Fox et al. 1988).
PeakMM8 = GRAPH(WeanWt)
(150, 0.3), (170, 0.4), (190, 0.6), (210, 1.20), (230, 2.70), (250, 5.40), (270, 8.30), (290, 11.4), (310, 14.4), (330, 17.2), (350, 19.9)
DOCUMENT: Predicted peak milk yield in beef cow based on calf weaning weight (7 month weight) and cow size 8 (Fox et al. 1988).
PeakMM9 = GRAPH(WeanWt)
(150, 0.2), (171, 0.3), (192, 0.7), (213, 1.30), (234, 2.70), (255, 5.40), (276, 8.30), (297, 11.2), (318, 14.4), (339, 17.3), (360, 19.4)
DOCUMENT: Predicted peak milk yield in beef cow based on calf weaning weight (7 month weight) and cow size 9 (Fox et al. 1988).
ProdLevel = GRAPH(WeanWt)
(170, 1.00), (184, 2.00), (199, 3.00), (213, 4.00), (228, 5.00), (242, 6.00), (257, 7.00), (271, 8.00), (286, 9.00), (300, 9.00)
DOCUMENT: Adjusted factor for production level within breed. Average calf weaning weight is used to estimate the level of beef cow milk production. A scale of 1 (extremely low for the breed) to 9 (extremely high for the breed) is used for ProdLevel.

7.1.4. Nutrient requirements for pregnancy

AdjBirthWt = if Cowage<1090 then AveBirthWt-2.3 else if (1090<=Cowage) and (Cowage<1455) then AveBirthWt-.9 else if (1455<=Cowage) and (Cowage<3645) then AveBirthWt else AveBirthWt-.9
 DOCUMENT: Birth weight adjusted for the age of dam (kg).
AveBirthWt = 36.4
 DOCUMENT: average birth weight (kg).
BreedingDay = 170
 DOCUMENT: Breeding date. If it's breeding on June 19, Breedday=170.
 Calving date is Breeding date+282 (days), March 28 (day 87).
CalvingDay = if BreedingDay<81 then BreedingDay+282 else BreedingDay+282-365
Cap1 = if DayGest>190 then AdjBirthWt*13.7/90 else 0
CotyleEnergy = .539*CotyleRate
 DOCUMENT: Cotyledon energy (kcal/d).
CotyleProt = .08375*CotyleRate
 DOCUMENT: Cotyledon protein (g/d).
CotyleRate = if DayGest>203 then 28 else (.084047-.0003087*DayGest)*(EXP((.05614-.0001031*DayGest)*DayGest))
 DOCUMENT: Cotyledon accretion rate (g/d).
DayGest = if Cowage<=400 then 0 else if CalvingDay<days and days<BreedingDay then 0 else if days<=CalvingDay then days+(365-BreedingDay) else days-(BreedingDay-1)
 DOCUMENT: Days of gestation (d).
FetalEnergy = 5.505*FetalProtein+9.527*FetalRate
 DOCUMENT: Fetal energy (Kcal/d).
FetalProtein = (.03452-.0001094*DayGest)*EXP((.0589-.00009334*DayGest)*DayGest)
 DOCUMENT: Fetal Protein accretion (g/d).
FetalRate = (.0000681-.000000197*DayGest) * (EXP((.0885-.0001282 * DayGest) * DayGest))
 DOCUMENT: Fetal fat accretion (g/d).
MEpreg = if Cowage<=400 then 0 else if CalvingDay<days and days<BreedingDay then 0 else (TotalEnergyp*(AdjBirthWt/36.4))*.008
 DOCUMENT: Metabolizable energy required for pregnancy (Mcal/d).
MPpreg = if Cowage<=400 then 0 else if CalvingDay<days and days<BreedingDay then 0 else TotalProtp*(AdjBirthWt/36.4)/.5
 DOCUMENT: Metabolizable protein required for pregnancy (g/d).
NEpreg = MEpreg
PlaceEnergy = .539*PlaceRate
 DOCUMENT: Placental energy (kcal/d).
PlaceProt = .08375*PlaceRate
 DOCUMENT: Placental protein (g/d).
PlaceRate = if DayGest>210 then 26 else (.2685-.000932*DayGest) * (EXP((.04378-.000076*DayGest)*DayGest))
 DOCUMENT: Placental accretion rate (g/d).
Pp = if DayGest>190 then AdjBirthWt*7.6/90 else 0
TotalEnergyp = FetalEnergy+CotyleEnergy+PlaceEnergy+UterusEnergy+6.877
 DOCUMENT: Total energy accumulation for pregnancy (kcal/d).
TotalProtp = FetalProtein+CotyleProt+PlaceProt+UterusProt+.134*TotalEnergyp+ 1.13
 DOCUMENT: Net pregnancy protein accretion (g/d).
UterusEnergy = .952*UterusRate
 DOCUMENT: Uterus energy (kcal/d).
UterusProt = .13266*UterusRate
 DOCUMENT: Uterus protein (g/d).

UterusRate = if DayGest>238 then 23 else (1.3664-.0038414*DayGest) *(EXP((.02475-.0000348*
DayGest)*DayGest))
DOCUMENT: Uterus accumulation (g/d).

7.1.5. Body reserve and cow condition score change (NRC, 1996)

New_CS(t) = New_CS(t - dt) + (CSchange) * dt
INIT New_CS = CondScore
CSchange = if DaysCS=0 then 0 else 1/DaysCS
AA1 = .766637-.034506*CondScore
AA2 = .078982-.00438*(CondScore-1)
AF1 = .037683*CondScore
AF2 = .037683*(CondScore-1)
AP1 = .200886-.0066762*CondScore
AP2 = .200886-.0066762*(CondScore-1)
ConvRate = if NEchange>0 then 1 else 0.8
DOCUMENT: Convert rate between tissue energy (RE) and diet NEm.
1) During mobilization, 1 Mcal of RE will substitute for 0.80 Mcal of diet NEm;
2) During repletion, 1 Mcal diet NEm will provide 1 Mcal of RE (reserve energy).
DaysCS = if NEchange=0 then 0 else ER*ConvRate/(NEchange)
EBW = .891*BodyWt
EBW1 = TA1/AA1
EBW2 = TA2/AA2
ER = 9.4*FMob+5.7*PMob
FMob = TF1-TF2
NEchange = 0
DOCUMENT: Assumed Net Energy change based on actual and required DMI.
NEchange = NEreq - NEactual (Mcal/d/cow)
PMob = TP1-TP2
TA1 = AA1*EBW
TA2 = AA2*EBW
TF1 = AF1*EBW1
TF2 = AF2*EBW2
TP1 = AP1*EBW1
TP2 = AP2*EBW2

7.1.6. Body reserve (Fox et al., 1992)

AB = (23.7-.027*RF)*.7995
DOCUMENT: Empty body protein adjusted for available fat reserves (%).
AV = (23.7-.027*AF)*.7995
DOCUMENT: Empty body protein (%).
BP = BR-.75*BT
DOCUMENT: Body protein that can bew mobilized (kg).
BR = BT*(.75+.0625*(CP-1))
DOCUMENT: Body protein available adjusted for condition score (kg).
BT = EW*(AV*.01)
DOCUMENT: Body protein (kg).
CP = if CondScore>3 then 3 else CondScore
DOCUMENT: Condition score with an upper limit for protein accumulation.
EC = (BR/AB)*100
DOCUMENT: Empty body weight adjusted for available protein reserves (kg).

EF = ((RF-5)/100)*EC
DOCUMENT: Body fat that can be mobilized (kg).
EnergyR = 9.499*EF
DOCUMENT: Total body energy reserves (Mcal).
ER1score = EnergyR/(CondScore-1)
EW = .8928*BodyWt-4.7
DOCUMENT: Empty body weight (kg).
RF = 5+(.25*AF-1.25)*(CondScore-1)
DOCUMENT: Empty body fat available for mobilization (%).
AF = GRAPH(CondScore)
(1.00, 5.00), (2.00, 9.40), (3.00, 13.7), (4.00, 18.1), (5.00, 22.5), (6.00, 26.9), (7.00, 31.2), (8.00, 35.6), (9.00, 40.0), (10.0, 40.0)

7.1.7. Nutrient requirements for calf and steer

CalfWt(t) = CalfWt(t - dt) + (birth + CalfADG - CalfTrans) * dt
INIT CalfWt = 0
DOCUMENT: Pre-weaning calf weight (kg).
birth = if Cowage<=641 then 0 else if days=CalvingDay then AdjBirthWt else 0
CalfADG = if Cowage<=700 then 0 else if CalvingDay<145 then if days<CalvingDay or days>=WeanDay then 0 else 13.91*(NEGc^.9116)*(CalfWt*AdjFactor)^(-.6837) else if days<CalvingDay and days>=WeanDay then 0 else 13.91*(NEGc^.9116)*(CalfWt*AdjFactor)^(-.6837)
CalfTrans = if days=WeanDay then CalfWt else 0
DOCUMENT: Weaned calf transfer to feedlot for steer at weaning time (Oct - Nov).
SteerWt(t) = SteerWt(t - dt) + (CalfTrans + SteerADG - SteerSold) * dt
INIT SteerWt = 0
DOCUMENT: Steer post-weaning weight (kg).
CalfTrans = if days=WeanDay then CalfWt else 0
DOCUMENT: Weaned calf transfer to feedlot for steer at weaning time (Oct - Nov).
SteerADG = if FinishDay=0 then 0 else 13.91*(NEFGs^.9116)*(SteerWt*AdjFactor)^(-.6837)
SteerSold = if days=FinishEndDate then SteerWt else 0
a = if DayLact<60 then 0 else 25.67
b = if DayLact<60 then 0 else -2.47
CalfFDMI = if Y<0 then 0 else (Y/(.819*1000))*CalfWt
DOCUMENT: Calf forage DM intake (kg/d).
CalfTDMI = MilkDMI+CalfFDMI
CaSteer = (0.0154*SteerWt+0.071*NPgst)/0.5
CPtotst = MPtotst/0.9
DMIst = SteerWt^0.75*(0.1493*NEmas-0.046*NEmas^2-0.0196)*BreedF*FeedAddF*TempF
FeedAddtive = 4
DOCUMENT: Feed additive code:
1 - No anabolic stimulant; 2 - Monensin only; 3 - Lasalocid only:
4 - Estrogenic only OR plus trenbolone acetate;
5 - Anabolic & monensin; 6 - Anabolic & lasalocid.
FeedFGc = if (CalfTDMI-FeedFMc)<0 then 0 else CalfTDMI-FeedFMc
DOCUMENT: Feed for gain (kg DM).
FeedFGc1 = if (CalfFDMI-FeedFMc1)<0 then 0 else CalfFDMI-FeedFMc1
FeedFMc = if NEmac=0 then 0 else .077*CalfWt^.75/NEmac
DOCUMENT: Feed for maintenance (kg DM).
FeedFMc1 = if NEm1=0 then 0 else .077*CalfWt^.75/NEm1
FFMs = if NEmas=0 then 0 else NEmrs/NEmas

FinishDay = if days>WeanDay then days-WeanDay else
if days<FinishEndDate then (365-WeanDay)+days else 0
FinishEndDate = 183
Foragedate = 152
DOCUMENT: The date (days of year) starting grazing for a calf. Here is 152 days, June 1.
MEg&mc = (NEmenC/.65)+(NEGFc/.4)
MEgst = NEFGs/0.4
MEmst = NEmenS/0.65
MEtotst = MEmst+MEgst
MilkDMI = .12*MilkYield
DOCUMENT: Milk DM available to the nursing calf (kg/d).
MPgc = if CalfADG=0 or (days>CalvingDay and days<=CalvingDay+61) then 0
else (CalfADG*(268-(29.4*(NEGc/CalfADG))))/0.67
DOCUMENT: Motablizable protein for calf gain (g/d).
MPgst = NPgst/0.67
MPmc = if (days>CalvingDay and days<=CalvingDay+61) then 0 else
2.75*CalfWt^.5/.67+.2*CalfWt^.6/.67+.09*DMIcalf*IndigRate*1000
MPmst = NPmst/0.67
MPtotC = MPmc+MPgc
DOCUMENT: Calf total metabolizable protein including maintenance and growth (g/d).
MPtotst = MPmst+MPgst
NEFGs = (DMIst-FFMs)*NEgas*NEgasF
NEg1 = 1.11
NEgac = if CalfTDMI=0 then 0 else NEg1*(CalfFDMI/CalfTDMI)+2.45*(MilkDMI/ CalfTDMI)
DOCUMENT: Diet NEg available to the nursing calf (Mcal/kg DM).
NEGc = FeedFGc*NEgac
DOCUMENT: Net energy available for calf gain (Mcal/d).
NEGFc = if (days>CalvingDay and days<=CalvingDay+61) then 0 else FeedFGc1*NEg1
NEm1 = 1.73
NEmac = if CalfTDMI=0 then 0 else 3.36*(MilkDMI/CalfTDMI)+(CalfFDMI/CalfTDMI)*NEm1
DOCUMENT: Diet MEm available to the nursing calf (Mcal/kg DM).
NEmc = if (days>CalvingDay and days<=CalvingDay+61) then 0 else 0.077*CalfWt^.75
DOCUMENT: Net energy for calf maintenance (Mcal/day).
NEmenC = if NEmcsC>0 then NEmc+NEmcsC else NEmc
NEmenS = if NEmcsS>0 then NEmrs+NEmcsS else NEmrs
NEmrs = (0.077*SteerWt^0.75)*BreedF*SteerCSF
NPgst = if SteerADG=0 then 0 else SteerADG*(268-(29.4*(NEFGs/SteerADG)))
NPmst = 2.75*SteerWt^0.5+0.2*SteerWt^0.6+33.4*DMIst
PSteer = (0.028*SteerWt+0.039*NPgst)/0.85
SteerCondSc = 5
DOCUMENT: Flesh condition score for steers (9 point system).
1 - very thin; 5 - average; 9 - very flesh
X = if CalfWt=0 then 0 else MilkDMI*.929*1000/CalfWt
DOCUMENT: X=milk organic matter intake daily / kg of live weight (g/kg Wt).
Y = a+b*X
DOCUMENT: Y= g of forage organic matter grazed daily / kg live weight (g/kg Wt) (NRC, 1987).
AdjFactor = GRAPH(CowSize)
(0.00, 0.00), (1.00, 1.16), (2.00, 1.07), (3.00, 1.00), (4.00, 0.93), (5.00, 0.87), (6.00, 0.82), (7.00, 0.77), (8.00, 0.73), (9.00, 0.7), (10.0, 0.7)
DOCUMENT: Adjusting factors to get equivalent shrunk weight. Adjusting body weight of growing cattle for frame size to the weight of a medium-framed (size 3) steer of equal composition (NRC, 1984).

FeedAddF = GRAPH(FeedAddtive)
(1.00, 0.94), (2.00, 0.88), (3.00, 0.92), (4.00, 1.00), (5.00, 0.94), (6.00, 0.98), (7.00, 0.98)
DOCUMENT: Adjust factor for feed additive.
NEgas = GRAPH(FinishDay)
(0.00, 0.76), (30.0, 0.82), (60.0, 0.87), (90.0, 0.93), (120, 1.00), (150, 1.08), (180, 1.14), (210, 1.22), (240, 1.28), (270, 1.38)
NEgasF = GRAPH(SteerCondSc)
(1.00, 1.10), (2.00, 1.08), (3.00, 1.05), (4.00, 1.03), (5.00, 1.00), (6.00, 0.975), (7.00, 0.95), (8.00, 0.925), (9.00, 0.9), (10.0, 0.9)
NEmas = GRAPH(FinishDay)
(0.00, 1.36), (30.0, 1.47), (60.0, 1.52), (90.0, 1.54), (120, 1.60), (150, 1.60), (180, 1.60), (210, 1.60), (240, 1.60), (270, 1.60)
SteerCSF = GRAPH(SteerCondSc)
(1.00, 0.955), (2.00, 0.97), (3.00, 0.98), (4.00, 0.99), (5.00, 1.00), (6.00, 1.01), (7.00, 1.02), (8.00, 1.03), (9.00, 1.05), (10.0, 1.05)
SteerEquWt = GRAPH(SteerWt)
(150, 1.00), (200, 1.00), (250, 1.00), (300, 1.00), (350, 1.00), (400, 0.97), (450, 0.9), (500, 0.82), (550, 0.73), (600, 0.7), (650, 0.7)
DOCUMENT: Steer equivalent weight (kg) to show the empty body fat (%).

Empty body fat (%):	21.3	23.8	26.5	29.0	31.5
Equval. weight (kg):	<350	400	450	500	550
Mutiplier:	1.0	0.97	0.90	0.82	0.73

7.1.8. Total nutrient requirements

C&cDMI = MEC&c/MEpasture
Cacowt = SUM(Cam,Cag,Cal,Cap1)
CowDMI = MEtotCow/MEpasture
DOCUMENT: Daily dry matter intake (kg).
DCPc&calf = ((13.4*C&cDMI)+MPC&c/.65)/(C&cDMI*1000)
DCPCow = ((13.4*CowDMI)+MPtotCow/.65)/(CowDMI*1000)
DOCUMENT: The requirement of digistible crude protein in the ration dry matter .
DCPsupp = .454
DOCUMENT: Proportion of digistible crude protein in the supplement .
DMrateSup = .9
DOCUMENT: Proportion of dry matter in fresh supplement .
DMsuppC&Calf = if (DCPforage>DCPc&calf) then 0 else ((DCPc&calf*C&cDMI)-(DCPforage * C&cDMI))/DCPsupp
DMsuppCow = if (DCPforage>DCPCow) then 0 else ((DCPCow*CowDMI) - (DCPforage* CowDMI))/DCPsupp
DOCUMENT: The quantity of supplement dry matter required (kg).
ForReqC&C = if days>=152 and days<304 then FreshfeedC&Calf else 0
ForReqCow = if days>=152 and days<304 then FreshfeedCow else 0
FreshfeedC&Calf = C&cDMI/DMratefora
FreshfeedCow = CowDMI/DMratefora
FreshSuppC&Calf = DMsuppC&Calf/DMrateSup
FreshSuppCow = DMsuppCow/DMrateSup
DOCUMENT: Supplement fresh weight (kg).
HayReqC&C = if days>=152 and days<304 then 0 else FreshfeedC&Calf
HayReqCow = if days>=152 and days<304 then 0 else FreshfeedCow
MEC&c = MEtotCow+MEg&mc
DOCUMENT: Total metabolizable energy including cow and her calf (upto weaning) (Mcal/d).

MEm&g = NEmenv/.65+MEgain
MEpasture = 2.5
MEtotCow = NEmenv/.65+MEgain+MElact+MEpreg
DOCUMENT: The total metabolizable energy require per cow (Mcal/day).
MPC&c = MPtotCow+MPtotC
DOCUMENT: Total motabolizable protein including cow and her calf (g/d).
MPm&g = MPm+MPgain
MPtotCow = MPm+MPgain+MPlact+MPpreg
DOCUMENT: The total metabolizable protein required per cow (g/day).
NEcowt = SUM(NEm,NEgain,NElact,NEpreg)
NEcowte = SUM(NEmenv,NEgain,NElact,NEpreg)
NEtotalAnim = NEmenv+.125*MEpreg+.65*MElact+.4*MEgain
DOCUMENT: The total net energy required per cow (Mcal/day).
Pcowt = SUM(Pm,Pg,Pl,Pp)
DCPforage = GRAPH(days)
(0.00, 0.05), (30.4, 0.05), (60.8, 0.08), (91.3, 0.08), (122, 0.08), (152, 0.14), (183, 0.14), (213, 0.14), (243, 0.14), (274, 0.14), (304, 0.08), (335, 0.05), (365, 0.05)
DOCUMENT: Proportion of digestible crude protein in forage dry matter .
DMratefora = GRAPH(days)
(0.00, 0.9), (30.4, 0.9), (60.8, 0.9), (91.3, 0.9), (122, 0.9), (152, 0.55), (183, 0.55), (213, 0.55), (243, 0.55), (274, 0.55), (304, 0.9), (335, 0.9), (365, 0.9)
DOCUMENT: Proportion of dry matter in fresh forage or hay.
June-Oct: fresh forage (Brome); Nov-May: hay (Alfalfa).

7.2. Herd Inventory Submodel

7.2.1. Calving pattern:

BirthCalves(t) = BirthCalves(t - dt) + (Birth - dieB - CullB - Wean) * dt
INIT BirthCalves = 0
Birth = CalvCow
dieB = BirthCalves*MortB/200
CullB = BirthCalves*CullRateB/200
Wean = pulse(BirthCalves,280,365)
WeanCalves(t)=WeanCalves(t-dt) + (Wean-dieW-FemCullW-MaleCalves-replace) * dt
INIT WeanCalves = 0
Wean = pulse(BirthCalves,280,365).
dieW = WeanCalves*MortW/83
FemCullW = pulse(WeanCalves,ageturn,365)
MaleCalves = pulse(WeanCalves/2,ageturn-1,365)
replace = if (ExpHerdSize-(HerdSize))>WeanCalves then ROUND(WeanCalves*.8) else ROUND(pulse((ExpHerdSize-(HerdSize)),ageturn,365))
ageturn = 364
DOCUMENT: Date from one cow age group to another group. Here assumed change age and culling time at end of each year.
CullRateB = .02
MortB = .04
MortW = 0.02
Calv1To21 = .425
Calv22To42 = .334
Calv43To63 = .162

```
Calv64Plus = .079
CalvCow = ExpHerdSize*CalvDistr/21*CalvingRate
CalvDistr = DELAY(CalvPattern,CalviDate,0)
CalviDate = 70
CalvingRate = .9
day = COUNTER(0,365)
CalvPattern = GRAPH(day)
(0.00, 0.425), (21.0, 0.334), (42.0, 0.162), (63.0, 0.079), (84.0, 0.00), (105, 0.00)
```

7.2.2. Herd dynamics

```
Cow1yr(t) = Cow1yr(t - dt) + (replace&buy - die1 - cull1 - transfer1) * dt
        INIT Cow1yr = Rate1*IniCowHerd
replace&buy = replace+buy1
die1 = Cow1yr*Mort1/365
cull1 = ROUND(pulse(Cow1yr*cullrate1/ExpanRate,ageturn-1,365))
transfer1 = PULSE(Cow1yr,ageturn,365)
Cow2yr(t) = Cow2yr(t - dt) + (transfer1 - die2 - cull2 - transfer2) * dt
        INIT Cow2yr = Rate2*IniCowHerd
transfer1 = PULSE(Cow1yr,ageturn,365)
die2 = Cow2yr*Mort2/365
cull2 = ROUND(pulse(Cow2yr*cullrate2/ExpanRate,ageturn-1,365))
transfer2 = PULSE(Cow2yr,ageturn,365)
Cow3yr(t) = Cow3yr(t - dt) + (transfer2 - die3 - cull3 - transfer3) * dt
   INIT Cow3yr = Rate3*IniCowHerd
transfer2 = PULSE(Cow2yr,ageturn,365)
die3 = Cow3yr*Mort3/365
cull3 = ROUND(pulse(Cow3yr*cullrate3/ExpanRate,ageturn-1,365))
transfer3 = PULSE(Cow3yr,ageturn,365)
Cow4yr(t) = Cow4yr(t - dt) + (transfer3 - die4 - cull4 - transfer4) * dt
   INIT Cow4yr = Rate4*IniCowHerd
transfer3 = PULSE(Cow3yr,ageturn,365)
die4 = Cow4yr*Mort4/365
cull4 = ROUND(pulse(Cow4yr*cullrate4/ExpanRate,ageturn-1,365))
transfer4 = PULSE(Cow4yr,ageturn,365)
Cow5yr(t) = Cow5yr(t - dt) + (transfer4 - die5 - cull5 - transfer5) * dt
   INIT Cow5yr = Rate5*IniCowHerd
transfer4 = PULSE(Cow4yr,ageturn,365)
die5 = Cow5yr*Mort5/365
cull5 = ROUND(pulse(Cow5yr*cullrate5/ExpanRate,ageturn-1,365))
transfer5 = PULSE(Cow5yr,ageturn,365)
Cow6yr(t) = Cow6yr(t - dt) + (transfer5 - die6 - cull6 - transfer6) * dt
   INIT Cow6yr = Rate6*IniCowHerd
transfer5 = PULSE(Cow5yr,ageturn,365)
die6 = Cow6yr*Mort6/365
cull6 = ROUND(pulse(Cow6yr*cullrate6/ExpanRate,ageturn-1,365))
transfer6 = PULSE(Cow6yr,ageturn,365)
Cow7yr(t) = Cow7yr(t - dt) + (transfer6 - die7 - cull7 - transfer7) * dt
   INIT Cow7yr = Rate7*IniCowHerd
transfer6 = PULSE(Cow6yr,ageturn,365)
die7 = Cow7yr*Mort7/365
cull7 = ROUND(pulse(Cow7yr*cullrate7/ExpanRate,ageturn-1,365))
```

```
transfer7 = PULSE(Cow7yr,ageturn,365)
Cow8yr(t) = Cow8yr(t - dt) + (transfer7 - die8 - cull8 - transfer8) * dt
   INIT Cow8yr = Rate8*IniCowHerd
transfer7 = PULSE(Cow7yr,ageturn,365)
die8 = Cow8yr*Mort8/365
cull8 = ROUND(pulse(Cow8yr*cullrate8/ExpanRate,ageturn-1,365))
transfer8 = PULSE(Cow8yr,ageturn,365)
Cow9yrPlus(t) = Cow9yrPlus(t - dt) + (transfer8 - die9 - cull9) * dt
   INIT Cow9yrPlus = Rate9*IniCowHerd
transfer8 = PULSE(Cow8yr,ageturn,365)
die9 = Cow9yrPlus*Mort9/365
cull9 = ROUND(pulse(Cow9yrPlus*cullrate9/ExpanRate,ageturn-1,365))
BullRate = .05
BullSize = HerdSize*BullRate
buy1 = if ExpHerdSize-HerdSize >replace then ROUND(pulse(ExpHerdSize-(HerdSize)-replace,
        ageturn,365)) else 0
cullrate1 = .18
cullrate2 = .18
cullrate3 = .16
cullrate4 = .15
cullrate5 = .16
cullrate6 = .15
cullrate7 = .17
cullrate8 = .17
cullrate9 = .5
ExpanRate = (TargetPop/IniCowHerd)^(1/TargetYr)
 DOCUMENT: ExpanRate is a factor to control cow herd expansion or reduction.
        Because: Xt = ((1+y)^t) * Xo   (Xt=TargetPop; Xo=IniPop; t=Years)
        So, Rate: y = (Xt/Xo)^(1/t) - 1
        1) Expansion: if herd size is expansed from 100 to 150 by 2 yrs:
        ExpanRate=((150/100)^(1/2)-1)+1=0.2247+1=1.2247
        2) When we keep the same cow herd size: ExpanRate=1;
        3) Reduction: if herd size is reduced from 100 to 50 by 2 yrs:
        ExpanRate=((50/100)^(1/2)-1)+1=-0.2929+1=0.07071
ExpHerdSize = if time>TargetYr*365 then IniCowHerd*ExpanRate^TargetYr
        else if time>=0 and time<366 then IniCowHerd*ExpanRate
        else if time>=366 and time<731 then IniCowHerd*ExpanRate^2
        else if time>=731 and time<1096 then IniCowHerd*ExpanRate^3
        else if time>=1096 and time<1461 then IniCowHerd*ExpanRate^4
        else IniCowHerd*ExpanRate^5
HerdSize = SUM(Cow1yr,Cow2yr,Cow3yr,Cow4yr,Cow5yr,Cow6yr,Cow7yr,Cow8yr,Cow9yrPlus)
IniCowHerd = 100
Mort1 = .031
Mort2 = .021
Mort3 = .017
Mort4 = .012
Mort5 = .01
Mort6 = .01
Mort7 = .01
Mort8 = .016
Mort9 = .052
Rate1 = .25
```

Rate2 = .2
Rate3 = .14
Rate4 = .1
Rate5 = .08
Rate6 = .06
Rate7 = .05
Rate8 = .04
Rate9 = .08
TargetPop = 100
TargetYr = 2

7.2.3. Nutrient requirements for herd and each age group

Cow21 = Cow2yr*Calv1To21
Cow22 = Cow2yr*Calv22To42
Cow23 = Cow2yr*Calv43To63
Cow24 = Cow2yr*Calv64Plus
Cow31 = Cow3yr*Calv1To21
Cow32 = Cow3yr*Calv22To42
Cow33 = Cow3yr*Calv43To63
Cow34 = Cow3yr*Calv64Plus
Cow41 = Cow4yr*Calv1To21
Cow42 = Cow4yr*Calv22To42
Cow43 = Cow4yr*Calv43To63
Cow44 = Cow4yr*Calv64Plus
Cow51 = Cow5yr*Calv1To21
Cow52 = Cow5yr*Calv22To42
Cow53 = Cow5yr*Calv43To63
Cow54 = Cow5yr*Calv64Plus
Cow61 = Cow6yr*Calv1To21
Cow62 = Cow6yr*Calv22To42
Cow63 = Cow6yr*Calv43To63
Cow64 = Cow6yr*Calv64Plus
Cow71 = Cow7yr*Calv1To21
Cow72 = Cow7yr*Calv22To42
Cow73 = Cow7yr*Calv43To63
Cow74 = Cow7yr*Calv64Plus
Cow81 = Cow8yr*Calv1To21
Cow82 = Cow8yr*Calv22To42
Cow83 = Cow8yr*Calv43To63
Cow84 = Cow8yr*Calv64Plus
Cow91 = Cow9yrPlus*Calv1To21
Cow92 = Cow9yrPlus*Calv22To42
Cow93 = Cow9yrPlus*Calv43To63
Cow94 = Cow9yrPlus*Calv64Plus
DMIherd = MEherd/MEforage
DMIherd1 = MEherd/MEforage1
ME21 = SUM(MEmg2,MEp2,MEl2,MEc2)
ME22 = MEmg2+DELAY(MEp2,3,0)+DELAY(MEl2,3,0)+DELAY(MEc2,3,0)
ME23 = MEmg2+DELAY(MEp2,6,0)+DELAY(MEl2,6,0)+DELAY(MEc2,6,0)
ME24 = MEmg2+DELAY(MEp2,9,0)+DELAY(MEl2,9,0)+DELAY(MEc2,9,0)
ME31 = SUM(MEmg3,MEl3,MEp3,MEc3)

```
ME32 = MEmg3+DELAY(MEp3,3,0)+DELAY(MEl3,3,0)+DELAY(MEc3,3,0)
ME33 = MEmg3+DELAY(MEp3,6,0)+DELAY(MEl3,6,0)+DELAY(MEc3,6,0)
ME34 = MEmg3+DELAY(MEp3,9,0)+DELAY(MEl3,9,0)+DELAY(MEc3,9,0)
ME41 = SUM(MEmg4,MEl4,MEp4,MEc4)
ME42 = MEmg4+DELAY(MEp4,3,0)+DELAY(MEl4,3,0)+DELAY(MEc4,3,0)
ME43 = MEmg4+DELAY(MEp4,6,0)+DELAY(MEl4,6,0)+DELAY(MEc4,6,0)
ME44 = MEmg4+DELAY(MEp4,9,0)+DELAY(MEl4,9,0)+DELAY(MEc4,9,0)
ME51 = SUM(MEmg5,MEl5,MEp5,MEc5)
ME52 = MEmg5+DELAY(MEp5,3,0)+DELAY(MEl5,3,0)+DELAY(MEc5,3,0)
ME53 = MEmg5+DELAY(MEp5,6,0)+DELAY(MEl5,6,0)+DELAY(MEc5,6,0)
ME54 = MEmg5+DELAY(MEp5,9,0)+DELAY(MEl5,9,0)+DELAY(MEc5,9,0)
ME6to91 = SUM(MEmg6to9,MEl6to9,MEp6to9,MEc6to9)
ME6to92 = MEmg6to9+DELAY(MEp6to9,3,0)+DELAY(MEl6to9,3,0)+DELAY(MEc6to9,3,0)
ME6to93 = MEmg6to9+DELAY(MEp6to9,6,0)+DELAY(MEl6to9,6,0)+DELAY(MEc6to9,6,0)
ME6to94 = MEmg6to9+DELAY(MEp6to9,9,0)+DELAY(MEl6to9,9,0)+DELAY(MEc6to9,9,0)
MEcow = SUM(MEmg5,MEl5,MEp5)
MEforage1 = 2.25
MEherd = SUM(MEt1,MEt2,MEt3,MEt4,MEt5,MEt6,MEt7,MEt8,MEt9plus)
MEt1 = Cow1yr*ME1
MEt2 = Cow21*ME21+Cow22*ME22+Cow23*ME23+Cow24*ME24
MEt3 = cow31*ME31+cow32*ME32+cow33*ME33+cow34*ME34
MEt4 = Cow41*ME41+Cow42*ME42+Cow43*ME43+Cow44*ME44
MEt5 = Cow51*ME51+Cow52*ME52+Cow53*ME53+Cow54*ME54
MEt6 = Cow61*ME6to91+Cow62*ME6to92+Cow63*ME6to93+Cow64*ME6to94
MEt7 = Cow71*ME6to91+Cow72*ME6to92+Cow73*ME6to93+Cow74*ME6to94
MEt8 = Cow81*ME6to91+Cow82*ME6to92+Cow83*ME6to93+Cow84*ME6to94
MEt9plus = Cow91*ME6to91+Cow92*ME6to92+Cow93*ME6to93+Cow94*ME6to94
MP21 = sum(MPmg2,MPl2,MPp2,MPc2)
MP22 = MPmg2+DELAY(MPl2,3,0)+DELAY(MPp2,3,0)+DELAY(MPc2,3,0)
MP23 = MPmg2+DELAY(MPl2,6,0)+DELAY(MPp2,6,0)+DELAY(MPc2,6,0)
MP24 = MPmg2+DELAY(MPl2,9,0)+DELAY(MPp2,9,0)+DELAY(MPc2,9,0)
MP31 = SUM(MPmg3,MPl3,MPp3,MPc3)
MP32 = MPmg3+DELAY(MPl3,3,0)+DELAY(MPp3,3,0)+DELAY(MPc3,3,0)
MP33 = MPmg3+DELAY(MPl3,6,0)+DELAY(MPp3,6,0)+DELAY(MPc3,6,0)
MP34 = MPmg3+DELAY(MPl3,9,0)+DELAY(MPp3,9,0)+DELAY(MPc3,9,0)
MP41 = SUM(MPmg4,MPl4,MPp4,MPc4)
MP42 = MPmg4+DELAY(MPl4,3,0)+DELAY(MPp4,3,0)+DELAY(MPc4,3,0)
MP43 = MPmg4+DELAY(MPl4,6,0)+DELAY(MPp4,6,0)+DELAY(MPc4,6,0)
MP44 = MPmg4+DELAY(MPl4,9,0)+DELAY(MPp4,9,0)+DELAY(MPc4,9,0)
MP51 = SUM(MPmg5,MPl5,MPp5,MPc5)
MP52 = MPmg5+DELAY(MPl5,3,0)+DELAY(MPp5,3,0)+DELAY(MPc5,3,0)
MP53 = MPmg5+DELAY(MPl5,6,0)+DELAY(MPp5,6,0)+DELAY(MPc5,6,0)
MP54 = MPmg5+DELAY(MPl5,9,0)+DELAY(MPp5,9,0)+DELAY(MPc5,9,0)
MP6to91 = SUM(MPmg6to9,MPl6to9,MPp6to9,MPc6to9)
MP6to92 = Mpmg6to9+DELAY(MPl6to9,3,0)+DELAY(MPp6to9,3,0)+DELAY(MPc6to9,3,0)
MP6to93 = Mpmg6to9+DELAY(MPl6to9,6,0)+DELAY(MPp6to9,6,0)+DELAY(MPc6to9,6,0)
MP6to94 = Mpmg6to9+DELAY(MPl6to9,9,0)+DELAY(MPp6to9,9,0)+DELAY(MPc6to9,9,0)
MPherd = SUM(MP1,MPt2,MPt3,MPt4,MPt5,MPt6,MPt7,MPt8,MPt9plus)
MPt1 = Cow1yr*MP1
MPt2 = Cow21*MP21+Cow22*MP22+Cow23*MP23+Cow24*MP24
MPt3 = cow31*MP31+cow32*MP32+cow33*MP33+cow34*MP34
MPt4 = Cow41*MP41+Cow42*MP42+Cow43*MP43+Cow44*MP44
```

MPt5 = Cow51*MP51+Cow52*MP52+Cow53*MP53+Cow54*MP54
MPt6 = Cow61*MP6to91+Cow62*MP6to92+Cow63*MP6to93+Cow64*MP6to94
MPt7 = Cow71*MP6to91+Cow72*MP6to92+Cow73*MP6to93+Cow74*MP6to94
MPt8 = Cow81*MP6to91+Cow82*MP6to92+Cow83*MP6to93+Cow84*MP6to94
MPt9plus = Cow91*MP6to91+Cow92*MP6to92+Cow93*MP6to93+Cow94*MP6to94
DMIsteer = GRAPH(day)
(0.00, 9.01), (21.0, 9.36), (42.0, 9.84), (63.0, 10.2), (84.0, 10.5), (105, 11.0), (126, 11.6), (147, 12.0), (168, 12.8), (189, 0.00), (210, 0.00), (231, 0.00), (252, 0.00), (273, 0.00), (294, 0.00), (315, 7.27), (336, 7.89), (357, 8.61), (378, 8.61)
MEl = GRAPH(day)
(0.00, 17.5), (21.0, 17.9), (42.0, 18.2), (63.0, 18.3), (84.0, 18.3), (105, 18.5), (126, 18.4), (147, 20.3), (168, 20.5), (189, 20.5), (210, 20.7), (231, 20.8), (252, 21.5), (273, 22.3), (294, 22.6), (315, 21.0), (336, 22.2), (357, 22.7), (378, 22.7)
DOCUMENT: Metabolizrble energy (Mcal/day) for a one year old heifer.
MEc2 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 2.48), (168, 2.87), (189, 3.54), (210, 4.48), (231, 6.30), (252, 7.92), (273, 9.66), (294, 11.5), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MEc3 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 3.14), (168, 3.60), (189, 4.83), (210, 6.40), (231, 8.11), (252, 9.93), (273, 11.9), (294, 13.2), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MEc4 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 3.26), (168, 3.71), (189, 4.76), (210, 6.38), (231, 8.14), (252, 10.0), (273, 12.0), (294, 13.4), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MEc5 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 3.34), (168, 3.78), (189, 4.56), (210, 6.18), (231, 7.96), (252, 9.86), (273, 11.9), (294, 13.2), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MEc6to9 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 3.33), (168, 3.77), (189, 4.53), (210, 6.15), (231, 7.92), (252, 9.82), (273, 11.8), (294, 13.2), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MEforage = GRAPH(day)
(0.00, 2.30), (21.0, 2.30), (42.0, 2.30), (63.0, 2.30), (84.0, 2.30), (105, 2.40), (126, 2.40), (147, 2.40), (168, 2.40), (189, 2.25), (210, 2.25), (231, 2.25), (252, 2.25), (273, 2.25), (294, 2.50), (315, 2.50), (336, 2.50), (357, 2.50), (378, 2.50)
MEl2 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 3.43), (105, 3.97), (126, 4.19), (147, 4.20), (168, 4.11), (189, 3.94), (210, 3.74), (231, 3.52), (252, 3.29), (273, 3.06), (294, 2.84), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MEl3 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 5.57), (105, 5.79), (126, 5.70), (147, 5.43), (168, 5.09), (189, 4.71), (210, 4.33), (231, 3.96), (252, 3.61), (273, 3.27), (294, 0.00), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MEl4 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 5.93), (105, 6.45), (126, 6.44), (147, 6.18), (168, 5.78), (189, 5.33), (210, 4.86), (231, 4.44), (252, 3.96), (273, 3.55), (294, 0.00), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MEl5 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 6.11), (105, 6.88), (126, 7.01), (147, 6.80), (168,

6.42), (189, 5.95), (210, 5.45), (231, 4.95), (252, 4.46), (273, 4.00), (294, 0.00), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MEl6to9 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 6.11), (105, 6.88), (126, 7.01), (147, 6.80), (168, 6.42), (189, 5.95), (210, 5.45), (231, 4.95), (252, 4.46), (273, 4.00), (294, 0.00), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MEmg2 = GRAPH(day)
(0.00, 20.8), (21.0, 20.7), (42.0, 20.2), (63.0, 19.7), (84.0, 19.0), (105, 18.9), (126, 18.3), (147, 20.5), (168, 20.4), (189, 20.0), (210, 20.0), (231, 20.0), (252, 20.5), (273, 21.2), (294, 21.1), (315, 18.7), (336, 19.3), (357, 19.6), (378, 19.6)
MEmg3 = GRAPH(day)
(0.00, 19.6), (21.0, 19.0), (42.0, 18.9), (63.0, 18.4), (84.0, 17.7), (105, 17.6), (126, 17.0), (147, 19.4), (168, 19.0), (189, 19.0), (210, 19.0), (231, 19.7), (252, 19.6), (273, 20.4), (294, 17.9), (315, 17.9), (336, 18.5), (357, 18.5), (378, 18.5)
MEmg4 = GRAPH(day)
(0.00, 18.9), (21.0, 18.3), (42.0, 18.3), (63.0, 17.8), (84.0, 17.1), (105, 17.1), (126, 16.5), (147, 19.0), (168, 18.6), (189, 18.6), (210, 18.7), (231, 19.3), (252, 19.3), (273, 20.1), (294, 17.6), (315, 17.6), (336, 18.3), (357, 18.7), (378, 18.7)
MEmg5 = GRAPH(day)
(0.00, 18.7), (21.0, 18.1), (42.0, 18.1), (63.0, 17.6), (84.0, 16.9), (105, 16.9), (126, 16.3), (147, 18.8), (168, 18.5), (189, 18.5), (210, 18.6), (231, 19.2), (252, 19.2), (273, 20.0), (294, 17.5), (315, 17.5), (336, 18.2), (357, 18.6), (378, 18.6)
MEmg6to9 = GRAPH(day)
(0.00, 18.6), (21.0, 18.0), (42.0, 18.0), (63.0, 17.6), (84.0, 16.8), (105, 16.8), (126, 16.3), (147, 18.8), (168, 18.4), (189, 18.4), (210, 18.5), (231, 19.2), (252, 20.0), (273, 20.0), (294, 17.5), (315, 17.5), (336, 17.2), (357, 18.6), (378, 18.6)
MEp2 = GRAPH(day)
(0.00, 2.75), (21.0, 3.60), (42.0, 4.29), (63.0, 4.52), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 0.00), (168, 0.07), (189, 0.08), (210, 0.1), (231, 0.15), (252, 0.24), (273, 0.41), (294, 0.68), (315, 1.10), (336, 1.71), (357, 2.47), (378, 2.47)
MEp3 = GRAPH(day)
(0.00, 3.04), (21.0, 3.86), (42.0, 4.43), (63.0, 4.45), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 0.00), (168, 0.07), (189, 0.09), (210, 0.12), (231, 0.18), (252, 0.3), (273, 0.5), (294, 0.84), (315, 1.34), (336, 2.03), (357, 2.57), (378, 2.57)
MEp4 = GRAPH(day)
(0.00, 3.16), (21.0, 4.02), (42.0, 4.61), (63.0, 4.63), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 0.00), (168, 0.08), (189, 0.09), (210, 0.13), (231, 0.19), (252, 0.31), (273, 0.52), (294, 0.86), (315, 1.37), (336, 2.08), (357, 2.94), (378, 2.94)
MEp5 = GRAPH(day)
(0.00, 3.24), (21.0, 4.12), (42.0, 4.73), (63.0, 4.75), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 0.00), (168, 0.08), (189, 0.09), (210, 0.13), (231, 0.19), (252, 0.31), (273, 0.52), (294, 0.86), (315, 1.37), (336, 2.08), (357, 2.74), (378, 2.74)
MEp6to9 = GRAPH(day)
(0.00, 3.24), (21.0, 4.12), (42.0, 4.73), (63.0, 4.75), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 0.00), (168, 0.08), (189, 0.09), (210, 0.13), (231, 0.19), (252, 0.31), (273, 0.52), (294, 0.86), (315, 1.37), (336, 2.08), (357, 2.64), (378, 2.64)
MEsteer = GRAPH(day)
(0.00, 22.4), (21.0, 24.5), (42.0, 27.2), (63.0, 29.5), (84.0, 31.4), (105, 33.3), (126, 35.0), (147, 36.6), (168, 37.5), (189, 0.00), (210, 0.00), (231, 0.00), (252, 0.00), (273, 0.00), (294, 0.00), (315, 16.0), (336, 17.9), (357, 20.3), (378, 20.3)
MP1 = GRAPH(day)
(0.00, 369), (21.0, 370), (42.0, 364), (63.0, 364), (84.0, 362), (105, 360), (126, 356), (147, 359), (168, 361),

(189, 360), (210, 358), (231, 358), (252, 361), (273, 371), (294, 387), (315, 408), (336, 453), (357, 482), (378, 482)
MPc2 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 190), (168, 231), (189, 270), (210, 305), (231, 335), (252, 361), (273, 385), (294, 400), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MPc3 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 233), (168, 273), (189, 308), (210, 339), (231, 365), (252, 387), (273, 407), (294, 417), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MPc4 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 234), (168, 273), (189, 309), (210, 340), (231, 367), (252, 389), (273, 408), (294, 419), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MPc5 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 232), (168, 271), (189, 307), (210, 338), (231, 365), (252, 387), (273, 407), (294, 418), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MPc6to9 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 231), (168, 270), (189, 306), (210, 337), (231, 364), (252, 387), (273, 407), (294, 418), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MPl2 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 189), (105, 199), (126, 204), (147, 201), (168, 194), (189, 184), (210, 173), (231, 161), (252, 150), (273, 138), (294, 127), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MPl3 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 291), (105, 288), (126, 275), (147, 258), (168, 239), (189, 219), (210, 200), (231, 181), (252, 163), (273, 147), (294, 137), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MPl4 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 309), (105, 320), (126, 312), (147, 294), (168, 271), (189, 248), (210, 224), (231, 201), (252, 180), (273, 160), (294, 147), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MPl5 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 317), (105, 341), (126, 339), (147, 323), (168, 301), (189, 277), (210, 251), (231, 226), (252, 202), (273, 180), (294, 166), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MPl6to9 = GRAPH(day)
(0.00, 0.00), (21.0, 0.00), (42.0, 0.00), (63.0, 0.00), (84.0, 317), (105, 341), (126, 339), (147, 324), (168, 302), (189, 277), (210, 251), (231, 226), (252, 202), (273, 180), (294, 166), (315, 0.00), (336, 0.00), (357, 0.00), (378, 0.00)
MPmg2 = GRAPH(day)
(0.00, 328), (21.0, 325), (42.0, 311), (63.0, 308), (84.0, 313), (105, 313), (126, 308), (147, 314), (168, 310), (189, 307), (210, 303), (231, 300), (252, 296), (273, 295), (294, 292), (315, 275), (336, 283), (357, 282), (378, 282)
MPmg3 = GRAPH(day)
(0.00, 280), (21.0, 268), (42.0, 266), (63.0, 265), (84.0, 280), (105, 280), (126, 276), (147, 283), (168, 281), (189, 278), (210, 275), (231, 273), (252, 271), (273, 271), (294, 253), (315, 252), (336, 262), (357, 262), (378, 262)
MPmg4 = GRAPH(day)
(0.00, 262), (21.0, 250), (42.0, 250), (63.0, 249), (84.0, 267), (105, 269), (126, 266), (147, 274), (168, 272),

(189, 270), (210, 268), (231, 265), (252, 263), (273, 264), (294, 245), (315, 245), (336, 256), (357, 256), (378, 256)
MPmg5 = GRAPH(day)
(0.00, 256), (21.0, 244), (42.0, 244), (63.0, 244), (84.0, 262), (105, 266), (126, 264), (147, 273), (168, 271), (189, 269), (210, 266), (231, 264), (252, 262), (273, 263), (294, 243), (315, 243), (336, 254), (357, 254), (378, 254)
MPmg6to9 = GRAPH(day)
(0.00, 254), (21.0, 243), (42.0, 243), (63.0, 243), (84.0, 261), (105, 265), (126, 263), (147, 271), (168, 270), (189, 268), (210, 266), (231, 263), (252, 262), (273, 262), (294, 242), (315, 242), (336, 254), (357, 254), (378, 254)
MPp2 = GRAPH(day)
(0.00, 184), (21.0, 230), (42.0, 258), (63.0, 255), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 0.00), (168, 5.17), (189, 5.86), (210, 7.70), (231, 11.3), (252, 18.1), (273, 30.1), (294, 50.0), (315, 80.0), (336, 120), (357, 160), (378, 160)
MPp3 = GRAPH(day)
(0.00, 200), (21.0, 242), (42.0, 262), (63.0, 245), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 0.00), (168, 5.38), (189, 6.60), (210, 9.00), (231, 13.6), (252, 22.2), (273, 37.2), (294, 61.1), (315, 96.1), (336, 141), (357, 175), (378, 175)
MPp4 = GRAPH(day)
(0.00, 209), (21.0, 252), (42.0, 272), (63.0, 255), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 0.00), (168, 5.52), (189, 6.77), (210, 9.23), (231, 14.0), (252, 22.8), (273, 38.2), (294, 62.8), (315, 98.6), (336, 145), (357, 180), (378, 180)
MPp5 = GRAPH(day)
(0.00, 214), (21.0, 258), (42.0, 279), (63.0, 261), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 0.00), (168, 5.52), (189, 6.77), (210, 9.23), (231, 14.0), (252, 22.8), (273, 38.2), (294, 62.8), (315, 98.6), (336, 145), (357, 179), (378, 179)
MPp6to9 = GRAPH(day)
(0.00, 214), (21.0, 258), (42.0, 279), (63.0, 262), (84.0, 0.00), (105, 0.00), (126, 0.00), (147, 0.00), (168, 5.52), (189, 6.77), (210, 9.23), (231, 14.0), (252, 22.8), (273, 38.1), (294, 62.7), (315, 98.6), (336, 145), (357, 180), (378, 180)
MPsteer = GRAPH(day)
(0.00, 822), (21.0, 842), (42.0, 872), (63.0, 885), (84.0, 890), (105, 903), (126, 916), (147, 925), (168, 931), (189, 0.00), (210, 0.00), (231, 0.00), (252, 0.00), (273, 0.00), (294, 0.00), (315, 691), (336, 739), (357, 796), (378, 796)

7.2.4. Herd animal biomass

CalfTotalWt = SUM(TotWW2,TotWW3,TotWW4,TotWW5,TotWW6,TotWW7, TotWW8,TotWW9)
Cow1TotWt = Cow1yr*Cow1Wt
Cow1Wt = MatureWt*.7
Cow2TotWt = Cow2yr*Cow2Wt
Cow2Wt = MatureWt*.9
Cow3TotWt = Cow3yr*Cow3Wt
Cow3Wt = MatureWt*.95
Cow4TotWt = Cow4yr*Cow4Wt
Cow4Wt = MatureWt*1
Cow5TotWt = Cow5yr*Cow5Wt
Cow5Wt = MatureWt*1
Cow6TotWt = Cow6yr*Cow6Wt
Cow6Wt = MatureWt*1.04
Cow7TotWt = Cow7yr*Cow7Wt
Cow7Wt = MatureWt*1.05

Cow8TotWt = Cow8yr*Cow8Wt
Cow8Wt = MatureWt*1.03
Cow9TotWt = Cow9yrPlus*Cow9Wt
Cow9Wt = MatureWt*1.02
CowTotalWt = SUM(Cow1TotWt, Cow2TotWt, Cow3TotWt, Cow4TotWt, Cow5TotWt, Cow6TotWt, Cow7TotWt, Cow8TotWt, Cow9TotWt)
cull1Wt = Cow1Wt*cull1
cull2Wt = Cow2Wt*cull2
cull3Wt = Cow3Wt*cull3
cull4Wt = Cow4Wt*cull4
cull5Wt = Cow5Wt*cull5
cull6Wt = Cow6Wt*cull6
cull7Wt = Cow7Wt*cull7
cull8Wt = Cow8Wt*cull8
cull9Wt = Cow9Wt*cull9
MatureWt = 550
TotcullWt = SUM(cull1Wt,cull2Wt,cull3Wt,cull4Wt,cull5Wt,cull6Wt,cull7Wt,cull8Wt,cull9Wt)
TotWW2 = Cow2yr*WeanRate2*WeanWt2
TotWW3 = Cow3yr*WeanRate3*WeanWt3
TotWW4 = Cow4yr*WeanRate4*WeanWt4
TotWW5 = Cow5yr*WeanRate5*WeanWt5
TotWW6 = Cow6yr*WeanRate6*WeanWt6
TotWW7 = Cow7yr*WeanRate7*WeanWt7
TotWW8 = Cow8yr*WeanRate8*WeanWt8
TotWW9 = Cow9yrPlus*WeanRate9*WeanWt9
WeanRate2 = .64
WeanRate3 = .78
WeanRate4 = .85
WeanRate5 = .85
WeanRate6 = .91
WeanRate7 = .87
WeanRate8 = .82
WeanRate9 = .80
WeanWt = 240
WeanWt2 = WeanWt*.89
WeanWt3 = WeanWt*.97
WeanWt4 = WeanWt*1.03
WeanWt5 = WeanWt*1.06
WeanWt6 = WeanWt*1.05
WeanWt7 = WeanWt*1.05
WeanWt8 = WeanWt*1.05
WeanWt9 = WeanWt*.98

7.2.5. Body condition score change at a herd level (NRC, 1996)

New_CS(t) = New_CS(t - dt) + (CSchange) * dt
INIT New_CS = IniCS
CSchange = if New_CS>(IniCS+2) then 0 else if DaysCS=0 then 0 else 1/DaysCS
AA1 = .766637-.034506*IniCS
AA2 = .078982-.00438*(IniCS-1)
AF1 = .037683*IniCS
AF2 = .037683*(IniCS-1)

AP1 = .200886-.0066762*IniCS
AP2 = .200886-.0066762*(IniCS-1)
ConvRate = if NEchange>0 then 1 else 0.8
DOCUMENT: Convert rate between tissue energy (RE) and diet NEm.
1) During mobilization, 1 Mcal of RE will substitute for 0.80 Mcal of diet NEm;
2) During repletion, 1 Mcal diet NEm will provide 1 Mcal of RE (reserve energy).
DaysCS = if NEchange=0 then 0 else ER*ConvRate/(NEchange)
EBW = .891*MatureWt
EBW1 = TA1/AA1
EBW2 = TA2/AA2
ER = 9.4*FMob+5.7*PMob
FMob = TF1-TF2
IniCS = 5
DOCUMENT: Cow body condition score. Here using the USA 9 point system:
from 1 (too thin) to 9 (too fat), 5 is desirable.
PMob = TP1-TP2
TA1 = AA1*EBW
TA2 = AA2*EBW
TF1 = AF1*EBW1
TF2 = AF2*EBW2
TP1 = AP1*EBW1
TP2 = AP2*EBW2

7.3. Forage Production Submodel

DryYield(t) = DryYield(t - dt) + (ConvertRate - DryDecay - DryTrans - GrazDry) * dt
INIT DryYield = 0
DOCUMENT: Amount of dry standing biomass (kg/ha/d).
ConvertRate = if GrazDate=0 then 0 else GreenYield*.005
DOCUMENT: The conversion of green grass to dry grass (kg/ha/d).
DryDecay = DryYield*.001
DOCUMENT: the decay of dry grass (kg/ha/d).
DryTrans = PULSE(DryYield,302,365)
GrazDry = if GrazGreen=0 then 0 else (1-PrefGreen)*1.25*(DMIperHa*DryYield/(DryYield+DV50))
DOCUMENT: Amount of dry grass grazed by cattle (kg/ha/d). It also includes the tramping and waste of about 25% of the forage intake.
GreenYield(t) = GreenYield(t - dt) + (GrowthRate-GrazGreen-ConvertRat-GreenTrans) * dt
INIT GreenYield = 0
DOCUMENT: Accumulated Yield of green forage (kg/ha).
GrowthRate = if GrazDate=0 then 0 else (r*(20+GreenYield)*(1-ForBiomass/K))*SoilFactor*TempFactor
DOCUMENT: Forage (Brome) growth rate (kg/ha/d): dy/dt=g*V*(1-V/K)
g-instantaneous rate, V-biomass, K-maxmum of the forage biomass.
(Unit: 1 t/ha = 1000 kg/ha = 100 g/m^2)
GrazGreen = if GrazDate=0 then 0 else If AvailForage>800 then
PrefGreen*1.25*(DMIperHa*GreenYield/(GreenYield+GV50)) else 0
DOCUMENT: Defoliation by grazing cattle (kg/ha/d). It also includes the tramping and waste of about 25% of the forage intake.
ConvertRate = if GrazDate=0 then 0 else GreenYield*.005
DOCUMENT: The conversion of green grass to dry grass (kg/ha/d).
GreenTrans = PULSE(GreenYield,302,365)
HayWinter(t) = HayWinter(t - dt) + (GreenTrans + DryTrans - RetainHay) * dt

```
    INIT HayWinter = 0
GreenTrans = PULSE(GreenYield,302,365)
DryTrans = PULSE(DryYield,302,365)
RetainHay = PULSE(HayWinter,150,365)
SoilMoisture(t) = SoilMoisture(t - dt) + (RainFall - RunPerc - EvapoTrans - Runoff) * dt
    INIT SoilMoisture = WaterholdCap
RainFall = Preicp
RunPerc = (SoilMoisture-WaterholdCap)*.1
EvapoTrans = .005*SoilMoisture*GreenYield/1000
Runoff = MAX(0,RainFall-1)
AU = MatureWt/450*11.8
  DOCUMENT: Animal Unit (AU): one mature 450kg (1000 lb) cow or the equivalent based on average
        daily forage consumption of 11.8 kg of dry matter per day.
AUG = AU*180*2
  DOCUMENT: Fcrage requirement for one AU during the grazing season (180 days).
        eg. 550 BWt: 550/450*12= 14.67 kg/cow.d, 14.67*180 (days)=2640 kg/AU.
        Generally, only half of the forage can be used, so it need:
        2640*2 = 5280 kg Forage for one AU during the whole grazing season.
AvailForage = ForBiomass*Quality
b = if Zones=1 then b1&2 else if Zones=2 then b2 else if Zones=3 then b3 else
        if Zones=4 or Zones=5 then b4&5 else b6
days1 = COUNTER(1, 365)
DMIact = if GrazGreen=0 then DMIest else GrazGreen*DMIratio*1.03
DMIchange = DMIact-DMIreq
DMIperHa = If Grazing?=0 then 0 else if TotalHa=0 then 0 else DMIherd/TotalHa
DMIratio = if DMIreq1=0 then 0 else DMIreq/DMIreq1
DMIreq = MEcow/MEforage
DMIreq1 = DMIherd/HerdSize
DV50 = 100
ForBiomass = GreenYield+DryYield
GrazDate = if days1>GrazStart and days1<GrazEnd then days1-GrazStart else 0
GrazEnd = 302
  DOCUMENT: Date for ending of the grazing season (days from Jan 1). eg. Oct. 30 = 302.
Grazing? = 1
  DOCUMENT: Grazing code. 1 = cattle grazing, 0 = cattle not grazing.
GrazStart = 110
  DOCUMENT: Date of the forage starting growth (Days from Jan 1). Eg. April 20=110.
GrazTotal = GrazDry+GrazGreen
GV50 = 350
K = if Zones=1 then K1 else if Zones=2 then K2 else if Zones=3 then K3 else
        if Zones=4 or Zones=5 then K4&5 else K6
NEchange = DMIchange*NEforage
NEforage = MEforage*.65
PrefGreen = .8
Preicp = if Zones=1 then Precip1 else if Zones=2 then Precip2 else
        if Zones=3 then Precip3 else Precip4&5
r = if Zones=1 then r1 else if Zones=2 then r2 else if Zones=3 then r3 else
        if Zones=4 or Zones=5 then r4&5 else r6
SM = MAX(7, SoilMoisture)
SoilFactor = if Zones=6 then 1 else 1-EXP(-0.5*(SM-6))
StockRate = if GrazDate=0 then 0 else K*.9/AUG
  DOCUMENT: Stocking Rate (AU/ha) during the grazing season (5-6 month).
```

TotalHa = if StockRate=0 then 0 else HerdSize/StockRate
TotBiomass = AvailForage*TotalHa
WaterholdCap = 10
DOCUMENT: Water holding capture (mm/mm) in rooying zone.
Zone1Spec = 1
DOCUMENT: Forage Species codes in Zone 1:

Alfalfa-Grass Mixture: 1	Smooth Brome: 2
Crested Wheatgrass: 3	Intermediate or Pubescent Wheatgrass: 4
Russian Wildrye: 5	Native Grasses: 6

Zone2Spec = 2
DOCUMENT: Forage Species codes in Zone 2:

Alfalfa-Grass Mixture: 1	Smooth Brome: 2
Crested Wheatgrass: 3	Intermediate or Pubescent Wheatgrass: 4
Russian Wildrye: 5	Native Grasses: 6

Zone3Species = 2
DOCUMENT: Forage Species codes in Zone 3:

Alfalfa-Grass Mixture: 1	Meadow Brome(MB): 2
Smooth Brome(SM): 3	MB x SB: 4
Orchardgrass: 5	Meadow Foxtail: 6
Timothy: 7	Native Grasses: 8

Zone4&5Spec = 2
DOCUMENT: Forage Species codes in Zone 4 and 5:

Alfalfa-Grass Mixture: 1	Meadow Brome(MB): 2
Smooth Brome(SM): 3	Timothy: 4
Creeping Red Fescue: 5	Native Grasses: 6

ZoneIrrigation = 2
DOCUMENT: Forage Species codes in Zone Irrigation:

Alfalfa-Grass Mixture: 1	Meadow Brome(MB): 2
Smooth Brome(SM): 3	Orchardgrass: 4
Timothy: 5	Intermediate or Pubescent Wheatgrass: 6

Zones = 3
DOCUMENT: Alberta Mojor Soil Climatic Zones: (6 zones)

1. Brown: Bow Island, Brooks, Oyen;
2. Dark Brown: Lethbridge, Calgary, Standard, Provost;
3. Black: Red Deer, Lacombe, Edmonton, Olds, Vegreville;
4. Gray Luvisol: Fort Kent, Westlook, Edson;
5. Gray Luvisol: Peace River, Beaverlodge, Falher, High Prairie;
6. Irrigation: Bow Island, Brooks, Lethbridge...

b1&2 = GRAPH(Zone1Spec)
(1.00, 140), (2.00, 60.0), (3.00, 70.0), (4.00, 190), (5.00, 160), (6.00, 130), (7.00, 130)
b2 = GRAPH(Zone2Spec)
(1.00, 90.0), (2.00, 60.0), (3.00, 70.0), (4.00, 190), (5.00, 160), (6.00, 130), (7.00, 130)
b3 = GRAPH(Zone3Species)
(1.00, 90.0), (2.00, 58.0), (3.00, 60.0), (4.00, 78.0), (5.00, 124), (6.00, 155), (7.00, 110), (8.00, 130), (9.00, 130)
b4&5 = GRAPH(Zone4&5Spec)
(1.00, 90.0), (2.00, 60.0), (3.00, 65.0), (4.00, 110), (5.00, 70.0), (6.00, 130), (7.00, 130)
b6 = GRAPH(ZoneIrrigation)
(1.00, 90.0), (2.00, 60.0), (3.00, 60.0), (4.00, 110), (5.00, 80.0), (6.00, 150), (7.00, 150)
DMIest = GRAPH(days1)
(0.00, 9.40), (21.0, 9.45), (42.0, 9.60), (63.0, 9.55), (84.0, 9.50), (105, 10.0), (126, 10.3), (147, 11.8), (168, 11.8), (189, 11.9), (210, 12.5), (231, 13.0), (252, 14.7), (273, 15.0), (294, 15.5), (315, 11.5), (336, 10.0),

(357, 9.20), (378, 9.00)
K1 = GRAPH(Zone1Spec)
(1.00, 6506), (2.00, 6097), (3.00, 3364), (4.00, 4725), (5.00, 3247), (6.00, 2500), (7.00, 2500)
K2 = GRAPH(Zone2Spec)
(1.00, 8675), (2.00, 8130), (3.00, 4485), (4.00, 6300), (5.00, 4330), (6.00, 3150), (7.00, 3150)
K3 = GRAPH(Zone3Species)
(1.00, 7400), (2.00, 6560), (3.00, 8575), (4.00, 7500), (5.00, 6370), (6.00, 4750), (7.00, 5700), (8.00, 3000), (9.00, 3000)
DOCUMENT: Maximum Forage biomass (kg/ha).
K4&5 = GRAPH(Zone4&5Spec)
(1.00, 4500), (2.00, 3250), (3.00, 3410), (4.00, 3990), (5.00, 3380), (6.00, 2600), (7.00, 2600)
K6 = GRAPH(ZoneIrrigation)
(1.00, 12200), (2.00, 12410), (3.00, 10160), (4.00, 10400), (5.00, 10365), (6.00, 11020), (7.00, 11020)
Precip1 = GRAPH(days1)
(0.00, 0.6), (30.4, 0.403), (60.8, 0.423), (91.3, 1.14), (122, 1.45), (152, 2.33), (183, 1.00), (213, 1.05), (243, 1.01), (274, 0.4), (304, 0.427), (335, 0.613), (365, 0.613)
Precip2 = GRAPH(days1)
(0.00, 0.51), (30.4, 0.39), (60.8, 0.513), (91.3, 0.87), (122, 1.54), (152, 2.09), (183, 1.66), (213, 1.22), (243, 1.40), (274, 0.413), (304, 0.533), (335, 0.533), (365, 0.513)
Precip3 = GRAPH(days1)
(0.00, 0.787), (30.4, 0.628), (60.8, 0.516), (91.3, 0.673), (122, 1.36), (152, 2.60), (183, 2.96), (213, 2.52), (243, 1.52), (274, 0.5), (304, 0.557), (335, 0.706), (365, 0.787)
DOCUMENT: Daily Total Precipitation (include rainfall and snowfall) based on the mean of each month (mm/day) and different zones. (30 years data of Environment Canada)
Precip4&5 = GRAPH(days1)
(0.00, 0.806), (30.4, 0.464), (60.8, 0.74), (91.3, 0.8), (122, 1.29), (152, 2.33), (183, 2.74), (213, 2.03), (243, 1.70), (274, 0.806), (304, 0.77), (335, 0.484), (365, 0.484)
Quality = GRAPH(days1)
(0.00, 0.00), (30.4, 0.00), (60.8, 0.00), (91.3, 0.00), (122, 1.00), (152, 0.93), (183, 0.86), (213, 0.79), (243, 0.73), (274, 0.67), (304, 0.61), (335, 0.00), (365, 0.00)
DOCUMENT: Forage quality index (%). Mainly concern with the forage digistibility (%) and protein (%). The index is set the weight factor 0.5 for both traits, the first value of index is 100%, and rest are decreased with time.
Quality Index = 0.5 * Xi / X1 + 0.5 * Yi / Y1
r1 = GRAPH(Zone1Spec)
(1.00, 0.07), (2.00, 0.077), (3.00, 0.11), (4.00, 0.06), (5.00, 0.055), (6.00, 0.075), (7.00, 0.075)
r2 = GRAPH(Zone2Spec)
(1.00, 0.07), (2.00, 0.077), (3.00, 0.11), (4.00, 0.06), (5.00, 0.055), (6.00, 0.075), (7.00, 0.075)
r3 = GRAPH(Zone3Species)
(1.00, 0.07), (2.00, 0.085), (3.00, 0.077), (4.00, 0.09), (5.00, 0.107), (6.00, 0.079), (7.00, 0.08), (8.00, 0.08), (9.00, 0.08)
DOCUMENT: Instantaneous forage growth rate (t/ha).
r4&5 = GRAPH(Zone4&5Spec)
(1.00, 0.07), (2.00, 0.085), (3.00, 0.077), (4.00, 0.08), (5.00, 0.06), (6.00, 0.07), (7.00, 0.07)
r6 = GRAPH(ZoneIrrigation)
(1.00, 0.08), (2.00, 0.085), (3.00, 0.077), (4.00, 0.085), (5.00, 0.08), (6.00, 0.06), (7.00, 0.06)
Temp = GRAPH(days1)
(0.00, -16.5), (30.4, -11.4), (60.8, -6.70), (91.3, 3.20), (122, 10.1), (152, 14.1), (183, 15.8), (213, 14.8), (243, 9.80), (274, 4.70), (304, -5.50), (335, -13.1), (365, -16.5)
TempFactor = GRAPH(Temp)
(-30.0, 0.00), (-23.0, 0.00), (-16.0, 0.00), (-9.00, 0.00), (-2.00, 0.00), (5.00, 0.3), (12.0, 0.7), (19.0, 1.00), (26.0, 0.95), (33.0, 0.7), (40.0, 0.5)

7.4. Economic Submodel

```
Profit(t) = Profit(t - dt) + (Return + Liability - InterestPay - Cost - ProfitYr) * dt
        INIT Profit = 0
Return = if EndpointCode=1 then CullCow+WeanCalf else
        if EndpointCode=2 then CullCow+Background else
        if EndpointCode=3 then CullCow+Finish else Finish
Liability = if EndpointCode=4 then if FBegDate>183 then if days=1 then loan else 0
        else pulse(loan, FBegDate, 365) else if days=1 then loan else 0
InterestPay = if EndpointCode=4 or EndpointCode=3 then
        if FBegDate>183 then if days<FSaleDate or days>FBegDate then
        loan*InterestRate/365 else if days=FSaleDate then loan else 0 else
        if days<FBegDate then 0 else if days<FSaleDate then
        loan*InterestRate/365 else if days=FSaleDate then loan else 0 else
        if days<WeanDate then loan*InterestRate/365 else
        if days=WeanDate then loan else 0
Cost = if EndpointCode=1 then CowCost else if EndpointCode=2 then CowCost+BackgrdCost else
        if EndpointCode=3 then CowCost+FinishCost else FinishCost
ProfitYr = PULSE(Profit, 364, 365)
A1 = .65
A2 = .28
A3 = .068
ac = CalfMaxPrice-bc*136.2
B1 = .002
BackBuy# = 0
BackBuyDate = 304
BackgBuyCost = pulse(WeanWt*WCalfPrFac*BackBuy#, BackBuyDate,365)
BackgFeedC = BackgIntake*BackgFeedPrice*Backgrd#
BackgFeedPrice = 0.07
BackgFixedC = .10*Backgrd#
BackgIntake = 10
Backgrd# = WCalf#*.98+BackBuy#
BackgrdCost = if EndpointCode=2 then if days>BackSaleDate and days<=BackBuyDate
        then 0 else BackgFixedC+BackgFeedC+BackgBuyCost else 0
BackgrdWt = 350
Background = if EndpointCode=2 then pulse(Backgrd#*BackgrdWt*BackPrice
        *BwtFactor*BTfactor, BackSaleDate, 365) else 0
BackSaleDate = 91
bc = (CalfMaxPrice-CalfMinPrice)/(-272.4)
BrkEvPrice = if EndpointCode=4 then if FinishDays=0 then 0 else
        (Fcostf+(FinishCost/FinBuy#*FinTotDay))/FinishWt else 0
 DOCUMENT:
                                      Feeder Ini. Value + Total Cost
        Break Even Sale Price = -----------------------------------------------
                                         Steer Final Weight
CalfMaxPrice = 2.0
 DOCUMENT: Average maximum price ($/kg) for calves with weaning weight 300-400 lb (140-180 kg).
CalfMinPrice = 1.4
 DOCUMENT: Average minimum price ($/kg) for calves with weaning weight 900 lb (408.6 kg).
CalfPrice = ac+bc*WeanWt
CarcassWt = FinishWt*Cutability
```

CarcPrice = FinishPrice/Cutability-Discountg-Discountw
ConditionScore = 3
DOCUMENT: Visual flesh condition (score) categoeies for feeders: 5 classes
1. very thin; 2. thin; 3. average; 4. fleshy; 5. very fleshy.
CowCost = if EndpointCode=4 then 0 else CowTFCost+CowVarC
CowFeedC = if EndpointCode=4 then 0 else if days>121 and days<=304 then FeedIntake* GrassPrice
else FeedIntake*WintFeedPrice
CowFixCost = 65.54
DOCUMENT: Fixed cost per cow per year ($/cow/yr).
CowNonFeed = 68.39
DOCUMENT: Non-feed cost per cow per year ($/cow/yr).
CowPrice = .9
DOCUMENT: Average culled cow price for a year ($/kg).
CowPrice1 = CowPrice*CowPrFac
CowTFCost = CowFixCost/365*HerdSize*WTfactor
CowTNonFeed = (CowNonFeed/365)*HerdSize*WTfactor
CowVarC = if EndpointCode=4 then 0 else (CowFeedC+CowTNonFeed)
CullCow = if EndpointCode=4 then 0 else if days=WeanDate-15 then CowPrice1*MatureWt*CullCow#
else 0
CullCow# = HerdSize*.2
Cutability = 0.57
days = COUNTER(1,365)
Discountg = A1*0+A2*.066+A3*.176+B1*.3304
DOCUMENT: Discount based on carcass grades.
EndpointCode = 1
DOCUMENT: End point of products codes:
1 - Sale Weaned Calves;
2 - Sale Background Calves with culled cows;
3 - Sale Finished Steers or Heifers with culled cows;
4 - Sale Finished Steers or Heifers only (feedlot).
FBegDate = 59
FbuyCost = 14.55/FinTotDay
DOCUMENT: Steer Buying ($10/hd) and Induction ($4.55) costs.
FCostd = ((FCostf+FbuyCost+(ADG*7*FGPrice))*.01)/FinTotDay
DOCUMENT: Steer cost of death loss (1%).
FCostf = FinIniWt*.96*FinIniPrice
FCosts = (6.28+FCostf*.0015)/FinTotDay
DOCUMENT: Steer selling cost include Alberta Cattle Commission ($1.5/hd), brand inspection ($1.0/hd), producer secuity program ($0.1/hd), trucking ($3.68/hd), and transit insurance (0.15% of feeder value Costf).
FCosty = .22
DOCUMENT: Steer cost of yardage ($.22/hd/d).
FeedIntake = DMIherd1/DMRate
FGPrice = 1.06
DOCUMENT: Finish gain price ($/kg gain).
FinBuy# = 100
FinFeedC = if FinishDays=0 then 0 else ADG*FGPrice*Finish#
FinFixC = if FinishDays=0 then 0 else 0.12*Finish#
FinIniPrice = 2.09
FinIniWt = 386
Finish = if EndpointCode=3 or EndpointCode=4 then
pulse(CarcPrice*CarcassWt*Finish#, FSaleDate-1, 365) else 0

Finish# = if EndpointCode=3 then WCalf#*.97+FinBuy# else FinBuy#
FinishBuyCost = pulse(FinIniWt*.96*FinIniPrice*FinBuy#, FBegDate, 365)
DOCUMENT: Feeder value = (initial wt - 4% shrink) * buy price
FinishCost = if EndpointCode=1 or EndpointCode=2 then 0 else if FinishDays=0 then 0
else FinFixC+FinFeedC+FnonfeedCost+FinishBuyCost
FinishDays = if FBegDate<185 then if days<=FSaleDate and days>FBegDate then
days-FBegDate else 0 else if days>FBegDate then days-FBegDate else
if days<FSaleDate then (365-FBegDate)+days else 0
FinishWt = 550
FinTotDay = if FSaleDate>FBegDate then FSaleDate-FBegDate else (365-FBegDate)+FSaleDate
FnonfeedCost = if FinishDays=0 then 0 else (FbuyCost+FCosts+FCostd+FCosty)*Finish#
FSaleDate = 183
GrassPrice = 0.033
InterestRate = .10
loan = 0
loan1 = if EndpointCode=4 then Finish#*370*WTfactor else if EndpointCode=3 then
HerdSize*400*WTfactor else HerdSize*330*WTfactor
WCalf# = HerdSize*.63
WCalfPrice1 = if WeanWt >= 136 and WeanWt<182 then CalfMaxPrice+WtSlide*2 else
if WeanWt >= 182 and WeanWt<227 then CalfMaxPrice+WtSlide else
if WeanWt >= 227 and WeanWt<272 then CalfMaxPrice else
if WeanWt >= 272 and WeanWt<318 then CalfMaxPrice-WtSlide*1 else
if WeanWt >= 318 and WeanWt<363 then CalfMaxPrice-WtSlide*2 else
if WeanWt >= 363 and WeanWt<409 then CalfMaxPrice-WtSlide*3 else
CalfMaxPrice-WtSlide*4
WeanCalf = if EndpointCode=1 then if days=WeanDate then CalfPrice*WeanWt*WCalf# else 0 else 0
WeanDate = 304
WintFeedPrice = 0.06
WtSlide = .04
DOCUMENT: Price weight slide for weaned calves ($/kg).

$/cwt	$/kg
4	.09
2	.04

ADG = GRAPH(FinishDays)
(0.00, 1.00), (21.0, 1.10), (42.0, 1.22), (63.0, 1.37), (84.0, 1.46), (105, 1.51), (126, 1.56), (147, 1.55), (168, 1.53), (189, 1.53), (210, 1.53), (231, 1.53), (252, 1.52)
BackPrice = GRAPH(days)
(1.00, 2.11), (31.3, 2.14), (61.7, 2.13), (92.0, 2.12), (122, 2.13), (153, 2.12), (183, 2.23), (213, 2.21), (244, 2.20), (274, 2.18), (304, 2.15), (335, 2.13), (365, 2.13)
BTfactor = GRAPH(ConditionScore)
(1.00, 0.9), (2.00, 0.95), (3.00, 1.00), (4.00, 1.03), (5.00, 1.00), (6.00, 1.00)
BWtFactor = GRAPH(BackgrdWt)
(100, 0.9), (153, 0.9), (205, 0.9), (258, 0.95), (310, 1.05), (363, 0.95), (415, 0.9), (468, 0.9), (520, 0.9), (573, 0.9), (625, 0.9)
CowPrFac = GRAPH(days)
(1.00, 0.954), (31.3, 0.992), (61.7, 1.04), (92.0, 1.03), (122, 1.02), (153, 1.02), (183, 1.07), (213, 1.03), (244, 1.00), (274, 1.00), (304, 0.977), (335, 0.924), (365, 0.924)
Discountw = GRAPH(FinishWt)
(410, 0.00), (450, 0.00), (490, 0.00), (530, 0.00), (570, 0.066), (610, 0.066), (650, 0.176), (690, 0.176), (730, 0.441), (770, 0.441), (810, 0.441)
DMRate = GRAPH(days)
(0.00, 0.9), (30.4, 0.9), (60.8, 0.9), (91.3, 0.9), (122, 0.55), (152, 0.55), (183, 0.55), (213, 0.55), (243, 0.55),

(274, 0.55), (304, 0.9), (335, 0.9), (365, 0.9)
FinishPrice = GRAPH(days)
(1.00, 1.89), (31.3, 1.92), (61.7, 1.96), (92.0, 1.94), (122, 1.88), (153, 1.80), (183, 1.82), (213, 1.82), (244, 1.80), (274, 1.83), (304, 1.84), (335, 1.84), (365, 1.84)
WCalfPrFac = GRAPH(days)
(1.00, 1.00), (31.3, 1.02), (61.7, 1.03), (92.0, 1.05), (122, 0.954), (153, 0.905), (183, 0.934), (213, 0.98), (244, 1.00), (274, 1.00), (304, 1.00), (335, 0.954), (365, 0.954)
WTfactor = GRAPH(MatureWt)
(400, 0.95), (450, 0.95), (500, 1.00), (550, 1.00), (600, 1.20), (650, 1.20), (700, 1.25), (750, 1.25)