DISSERTATION

THE COLORADO BEEF CATTLE PRODUCTION MODEL: EFFECTS OF SIMULATION WITH REALISTIC LEVELS OF VARIABILITY AND EXTREME WITHIN-HERD DIVERSITY

Submitted by
Wade R. Shafer
Animal Sciences Department

In partial fulfillment of the requirements
for the Degree of Doctor of Philosophy
Colorado State University
Fort Collins, Colorado
Fall, 2003

ProQuest Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

COLORADO STATE UNIVERSITY

September 26, 2003 Fall, 2003

WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY WADE R. SHAFER ENTITLED THE COLORADO BEEF CATTLE PRODUCTION MODEL: EFFECTS OF SIMULATION WITH REALISTIC LEVELS OF VARIABILITY AND EXTREME WITHIN-HERD DIVERSITY BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

Committee on Graduate Work

James S Brinks

Gary Richardson

Advisor

Department Head

ABSTRACT OF DISSERTATION

THE COLORADO BEEF CATTLE PRODUCTION MODEL: EFFECTS OF SIMULATION WITH REALISTIC LEVELS OF VARIABILITY AND EXTREME WITHIN-HERD DIVERSITY

The Colorado Beef Cattle Production Model (CBCPM), a whole-herd, life-cycle simulation model, is described in detail. CBCPM was used to study the impact of simulation with realistic levels of variation as well as examine the consequences of extreme genetic diversity in mature weight and milk production within a herd.

Simulation with less than realistic levels of variation resulted in flawed outcomes for several traits, including pregnancy rates, weights of calf and dam, milk production, intakes, and maintenance requirements. Besides the effects of culling on trait potentials, which was only allowed to occur under realistic levels of variability, outcomes were affected through the level of variability interacting with nonlinear equations.

In general, extreme within-herd diversity in milk production and/or mature weight led to substantial decreases in pregnancy rates, in addition to reductions in efficiency expressed as a ratio of total yearly kg weaned over annual cumulative TDN intake. The impact of concurrent, extreme diversity in mature weight and milk production was greatest when present between, rather than within, animals. Contrasting genotypic levels across herds, lighter mature weight and higher milk genotypes tended to be most efficient.

Wade R. Shafer
Animal Sciences Department
Colorado State University
Fort Collins, Colorado 80523
Fall, 2003

ACKNOWLEDGEMENTS

Life is a journey over a series of paths. Fortunately, I took one that led to Colorado State. I will always look back with fondness on my time there—many, many souls are responsible for that fact. From my first day at CSU when I crossed paths with my advisor who would become one of the most influential figures in my life, to my final stint 18 years later, the memories piled up. To be sure, there were trials, but they only made me stronger, better. Through the trials, there was much triumph, joy, and celebration. And through it all, friendships were built—many, many friendships.

As is tradition, I recognize the members of my graduate committee. Actually, it seems insufficient for me to refer to them as committee members as it doesn't do their contribution justice. First and foremost, they are friends. Thank you good friends. In referencing friends, I must mention the "300-Briarwood-touskers." You know who you are and you know why I must acknowledge you—what a cast of characters. Also, to my fellow graduate students, many of whom vigorously participated in our infamous 300 Briarwood gatherings, thanks for the camaraderie. Though far removed from my graduate program geographically, the "back-home-crew" certainly influenced it. Besides memorable visits to Colorado by many of these long-time friends, their incessant questioning about how my dissertation was going certainly motivated me to complete it. I am hesitant about affirming this, as it's sure to encourage further harassment.

Though not directly involved in my graduate experience, I would be remiss in not mentioning my family, as they are always with me in spirit. None could have a better family. One of the by-products of aging is that I've grown to appreciate each of them more over time. They are my unfailing source of strength and inspiration. I could hardly imagine life without them.

Finally, Yvonne and Rebecca, the path that brought you into my life was the most extraordinary I've taken——greatly enhancing my existence. You will forever occupy a special place in my heart. What the winds can never do…

TO RICK

Before I finished my graduate program my advisor, Rick Bourdon, retired. (It's not that it took me too long—he retired early.) I wrote the following letter with the intention of it being read at his retirement ceremony. Unfortunately, it was not. Consequently, I feel the need to present it here:

Dear Rick,

I wish I could be there to celebrate the beginning of this new chapter of your life with you. Since that wasn't possible, I decided to write some flowery prose to make you uncomfortable. Seriously, I feel a need to express to you the impact the last chapter of your life has had on me. Because I represent half of your first draft of graduate students (Barry Baker being the other) I have license to do this, so just sit back and listen.

I recall my first day at CSU. I arrived with the knowledge that the prodigious Dr. Bourdon was to be my advisor. Several people had informed me that Dr. Bourdon was brilliant to the point of being intimidating.

Needless to say, I was extremely anxious and apprehensive about meeting the genius. Upon arriving at the Animal Science building, I was directed by a helpful student to my destination. Nearly hyperventilating, with legs trembling, I made the journey up the stairs, through the library, to the right, second door on the left. Out of my mouth came an unsteady, "Dr. Bourdon?" It was immediately met with, "Call me Rick." That is your way—always unpretentious, always unassuming

The "call me Rick" statement put me instantly at ease. So much so that I proceeded to spill out my rudimentary and distorted understanding of animal breeding at that first meeting (uncharacteristic behavior for an introvert). You listened intently, judiciously interjecting comments. When I finished you kindly acknowledged my drivel as evidence that I had curiosity for the subject matter (tactfully choosing to gloss over the fact that I had no knowledge of the subject). This pattern occurred repeatedly, though you astonishingly never showed the least bit of impatience.

Although animal breeding was the common currency in many of our interactions, your door was always open to me for any reason. This made me feel important. Unlike many graduate/advisor relationships where the student's worth is derived from their potential to further their advisor's career (God knows I shortchanged you there), your actions made me feel that you cared about me as a person.

Frankly, I doubt that you ever entertained the thought of what a graduate student could do for your career. From early on it became obvious to me that the search for the truth is all that mattered in your professional pursuit; your résumé was an incidental by-product at best. Though this approach may not have feathered your cap to its fullest, it set a powerful example to those around you and it certainly endeared you to me.

Your no-BS approach shined through when I asked you a few months ago about your plans for the future. You responded with "I don't really know". I smiled intensely inside at the admission. You are one of the few people comfortable enough with their existence to answer a question like that with, "I don't know". I came away from the conversation thinking, that's my Rick, never anything but the truth.

Yes, the rumors that trickled down to me before we even met turned out to be true; your intellect is extraordinary. That is only a small part of what makes you exceedingly unique, however. It is your humanity and unending quest for the truth that make you the rarest of the rare. Over the years you have provided me with countless examples of these characteristics. I can unequivocally say that your example has helped me navigate life; you will always serve as a role model to me.

In all the years I have know you I have only addressed you as Dr. Bourdon once—our first meeting. Nevertheless, I respect you like no other. Ironically, the seed for the respect came from the first words I heard from you—"Call me Rick." Knowing you, this will probably only serve to irritate, but I feel compelled to address you that way once again. Godspeed in all that you do, Dr. Bourdon.

With gratitude,

Wade

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

BACKGROUND

For lack of a better (i.e. more flattering) description, this is a unique dissertation. Its uniqueness stems from the fact that its beginnings and endings stretch well over a decade. At the inception of this endeavor, Colorado State University researcher R. M. Bourdon was in the process of developing the Colorado Beef Cattle Production Model (CBCPM). Bourdon's intentions were to craft a tool capable of providing the teaching and research communities with a wide range of utility. Besides creating a device allowing for the comprehensive modeling of animal biology, robust plant and economic models were to be integrated. These additions were intended to provide more holistic simulation capabilities, and ultimately facilitate greater interaction and understanding among disciplines.

When presented the opportunity, I was taken with the idea of working with my advisor, Rick Bourdon, in developing the model. His intentions for the model were certainly admirable and I was intrigued with the possible research topics at my fingertips upon its development.

In life, all things have their time. Eighteen months after starting, at the end of CBCPM's developmental phase, I returned to my family's seedstock operation in Minnesota. Since then, many of Bourdon's designs have come to fruition; CBCPM has been used in several studies (Baker, 1991; Baker et al., 1992; Baker et al., 1993; Foy, 1993; Hart et al., 1993; Fioretti, 1994; Rantanen, 1994; Steffens, 1994; Enns, 1995; Bolortsetseq et al., 1996; Hyde and Bourdon, 1998; Foy et al., 1999; Doyle, 2000), provided the core of a graduate level class (Bourdon, 1991), and has been integrated into the United States Department of Agriculture's Decision Evaluator for the Cattle Industry (DECI) and the Agricultural Research Service's Simulation of Production and Utilization of Rangelands 2 (SPUR2) models. Although it has been used extensively, CBCPM has never been fully documented. In light of this fact, one of my primary objectives was to thoroughly describe CBCPM.

STUDY

Many studies have examined the relationship between a cowherd's genetic levels for mature weight and/or milk production and profit, or at least factors related to profit; most have reported interactions between genetic levels and the environment. Based on these findings, it seems reasonable to speculate that the degree to which these traits vary within a herd may have an impact on its bottom line.

The following example, albeit extreme, helps flesh out this theory. Though great disparity in genetic potentials for mature weight and milk production would exist, a herd composed of half purebred Hereford and half purebred Simmental cows would be considered average with respect to these traits. Viewed independently, each breed would have very different levels of environment (nutritional input for sure) that maximizes profits for its particular genotype. If managed together, however, the ability to provide the ideal environment for each breed is not afforded. From a practical standpoint, some middle ground must be arrived at that, while possibly far from perfect for each genotype, results in the optimal environment for the herd as a whole. In contrast, a herd similar to our Simmental, Hereford combination with respect to mean genetic potentials for weight and milk, yet more uniform for these traits (e.g. purebred South Devon), would permit a closer match between each animal and its ideal environment.

This rationale forms the basis underlying the hypothesis that increased variability within a herd decreases profitability. Given the fact CBCPM has the ability to generate individual animal variation in addition to possessing fairly realistic feeding and grazing routines, I consider it well suited to test this theory.

Besides using the simulation to assess the impact of within-herd variability on profitability, I was curious about the possibility of interactions. In traditional research endeavors, investigators are typically handcuffed by resource limitations when it comes to exploring for interactions. Computer simulation, however, allows for virtually boundless search. To exploit this capability, several simulation scenarios were conceived in an attempt to uncover potential interactive relationships.

While germinating the previously described hypotheses, I contemplated the possibility that running CBCPM with less than realistic levels of variability for mature weight and/or milk production could impact outcomes. To test this theory, a spin-off investigation was undertaken. Because it can generate variation beyond the deterministic equations embedded in the model, CBCPM is uniquely qualified to address this topic.

CHAPTER II

REVIEW OF LITERATURE - MODEL EVALUATION

REVIEW OF LITERATURE

Computer simulation modeling (a.k.a. "modeling"). The term sounds threatening. Though at its core, the notion is uncomplicated—using assumptions about relationships to predict an outcome given a set of circumstances. We do it all the time. For example, though most wouldn't consider it modeling, when we carry an umbrella on a walk as the result of observing black clouds, we are doing just that. Specifically, making an assumption (dark clouds tend to bring rain) to predict an outcome (I may get wet without an umbrella) based on the circumstances (I will be outside). As far as I can tell, this process qualifies as modeling when the assumptions and/or circumstances become complex enough to require the use of a computer to predict outcome.

The concept of simulation modeling has been employed for many years in the field of Animal Science. Models detailed enough to simulate biology at the cellular level to those broad enough to simulate the entire production cycle of a species along with economic implications have been developed by animal scientists. The earliest efforts pertaining to life-cycle beef cattle production were focused on determining the nutrient requirements necessary for set (input) levels of performance (Long, 1972; Long et al., 1975; Wilton et al., 1974).

In his 1977 dissertation, J.O. Sanders published seminal work that culminated in a deterministic, class based model which would later be dubbed the Texas A & M University (TAMU) model. The TAMU was ground breaking in that it was the first model to simulate performance as output rather than input. I.e. levels of production, reproduction and growth were arrived at based on input levels of potentials and nutrition.

In addition, Sander's approach tended towards modeling biology through "mechanistic" rather than empirical type equations—equations aimed at the root of biological function, as opposed to those derived from fitting relationships found in a particular data set. With this approach, he intended for TAMU to be applicable to a broad range of production scenarios. In fact, the model has proven to be just that.

TAMU has been used in a wide range of studies. For example, it has simulated cattle production in Central

Texas (Cartwright, 1977; Sanders, 1977; Nelson et al., 1978), the western high plains of Venezuela (Ordonez, 1978), and disparate regions of Guyana (Davis et al., 1976). Modifications to the model allowed for the simulation of dual-purpose (meat and milk) cattle production in Columbia (Cartwright et al. 1977) and Botswana (ILCA, 1978). The general consensus from these studies is that the model performed quite well.

The last sentence in Sanders and Cartwright's (1979a) introduction of the TAMU model states, "as additional information related to cattle production becomes available, the model will hopefully provide an adequate framework for coordinating the new information with information that already exists". As it turns out, that is precisely what happened. In various forms, TAMU has served as the framework for coordinating information for numerous studies since its creation.

D. R. Notter, working at the US Meat Animal Research Center, altered some of TAMU's biological equations and added the capability of simulating the performance of crossbred cattle. Specifically, his changes allowed the rates of conversion of metabolizable energy to net energy to vary with digestibility, calf capacity to limit milk production, gut fill to vary, and the effects of breed and heterosis to be modeled. He used his version to study the impact of body size (Notter et al., 1979a), milk production (Notter et al., 1979b), and crossbreeding (Notter et al., 1979c) on measures of economic and biological efficiency in a mid-western, cow-calf-feedlot system.

Notter's version was modified by Bourdon (1983). Bourdon built equations that allowed for the simulation of differing growth curve, puberty and fertility potentials. He added updated calving ease equations, incorporated the ability to model cold weather effects, allowed for preferential consumption of feeds and "fine tuned" several existing equations to reflect the enhanced biological knowledge available. Bourdon's version was used to ascertain the impact of differences in growth and milk production (Bourdon and Brinks, 1987a), fertility traits (Bourdon and Brinks, 1987b), and culling strategies and unconventional management systems (Bourdon and Brinks, 1987c) on measures of economic and biological efficiency under various economic scenarios.

Kahn and Spedding (1983) adapted the original TAMU to make it more applicable to very small herds typical of developing countries. They were specifically concerned that TAMU's deterministic approach was inadequate to account for the instability of small herds, due to the randomness inherent in conception, births, deaths and the uncertainty of male/female ratios. They also felt simulating classes rather than animals created an impediment to the conceptualization of the system. Therefore, they calculated performance on an individual animal basis and treated conception, mortality and calf sex stochastically. They also allowed for a 1 to 30-d time-step and included management options, such as simulating the use of animals for draught.

TAMU, along with Notter's (1977) and Bourdon's (1983) upgrades, formed the cornerstone of the Colorado Beef Cattle Production Model (CBCPM). R.M. Bourdon initiated CBCPM's developmental phase in 1987. Like its foundation model, TAMU, CBCPM is a seminal model in that it is the first herd-wide, life-cycle beef cattle production model to: 1) simulate the interaction between forage production and grazing, 2) incorporate the ability to generate realistic levels of genetic and environmental variation on individual animals for several traits, 3) provide an internal means of feeding cattle according to body condition—resulting in the quantity of feed fed being output rather than input, 4) internally derive financial data based on sound, accepted economic theory and, 5) address economic risk. Besides enhancing the existing animal model, we achieved these capabilities through the incorporation of established plant and economic models. Details pertaining to CBCPM and its melding with the other models can be found in the chapter on materials.

Although it has never been formally published, CBCPM has been used in several research efforts. Though only a sub-sample of studies that have utilized the model, the following are referenced as they provide a barometer for evaluating CBCPM.

Baker et al. (1993) used the model to predict the effect global warming would have on cattle production in the United States. The study involved the simulation of cow-calf production across several regions of the country. Base simulation runs were performed and output data was collected on intake, average daily gain, weaning weight, cow weight, body condition, pregnancy rate and milk production and compared with several sources of observed data. Baker concluded that, for the most part, model predictions agreed with observed values.

In a study instituted to validate an upgraded version of SPUR, Foy et al. (1999) simulated conditions typical of northern Texas. Validation data used were collected from the Texas Agricultural Experiment Station in

Throckmorton, Texas. They found stocker performance to fall within the range of expected values based on observed data. In cow-calf production, the model slightly overestimated mean cow weight (103%) and underestimated calf weight (89%) compared to observed. The researchers also varied cow-calf stocking rates. In doing so, they found simulated results to closely agree with observed for conception rate as well as pounds of beef produced per cow and per acre.

In a follow up study to Foy et al. (1999), Teague and Foy (2002) again used data collected at the Texas Agricultural Experiment Station for model validation. In doing so, they calculated R^2 values of 0.98 - 0.99 between observed weaning weights on straight Hereford and Charolais-cross calves under moderate, heavy and deferred rotational grazing and simulated data. They also concluded that the model accurately predicted mean weaning weights per hectare for both Hereford and Charolais-cross calves and under all grazing scenarios.

Steffens (1994) compared various output statistics between a range of milk production potentials under conditions typical of a cow-calf operation in northwestern South Dakota. He found, as expected, that higher producing cows were thinner in the fall. This relationship was especially pronounced in 2-year-olds and diminished substantially with age to the point where little difference existed among mature cows. Conception rates were not appreciably affected by milk production level, however. This was attributed to the fact animals were supplemented through the winter to a 17% empty body fat level and grazing pressure was very light.

He found that higher milk producers consumed more hay. This was anticipated; because they came into winter thinner, they required more supplement to reach target body condition by spring. He did not find an increase in grazed forage intake with increased milk potential, however. This was not anticipated, as several studies have found forage intake to increase with milk production level (e.g. Havstad and Doornbos, 1987; Hatfield et al., 1989). He concluded that the model's biology was inadequately accounting for the relationship.

Steffens also noted that the typical increase in weaning weight associated with good grazing years was not found in calves of very low milk types. Instead, poor milking dams retained the nutritional surplus, which was evident by the fact they became excessively fat by the end of good grazing seasons. He also found that replacement females out of these low producing cows tended to have lower pregnancy rates and later calving dates. These results are in agreement with Steffan et al. (1985).

Enns (1995) used the model to test issues pertinent to modern genetic evaluation. Because his hypotheses required the capability of simulating genetic potential at weaning, he created a new genetic variable (POWW), modeled as a function of birth, yearling and mature weight potentials.

He also added equations to better reflect effects of the interaction between a calf's intake capacity and its dam's milk production. With Enns' new biology, the model was shown to produce output similar to observed data from Mezzadra et al. (1989), in which researchers found that growth potential of the calf influenced its intake capacity as well as its dam's subsequent milk production.

Enns modeled various combinations of growth and milk potentials and estimated variance components for direct and maternal weaning weight on each population. Parameter estimates from the simulated data fell within the range and produced similar patterns to estimates from several studies on comparable populations.

Rantanen (1994) used the model to study the effects of sex, year, age of dam (aod) and all possible 2-way interactions on weaning weight. The environment was indicative of the Pawnee National Grasslands in northeastern Colorado.

As anticipated, she found all main effects to be significant. However, only the interactions between sex x year and sex x aod proved significant. Though year x aod wasn't statistically significant, a trend existed in poor years for calves out of 2-year-olds to be more adversely affected than calves out of mature cows. The magnitude of the results for year, sex x aod and year x aod were in line with literature values, while sex and sex x year differences were higher and age of dam differences lower.

MODEL EVALUATION

In establishing a simulation model's validity, rigid adherence to the "scientific method" would call for simulated outcomes to be compared, via tests of hypotheses, with experimental outcomes resulting from identical treatment effects. The CBCPM is capable of modeling entire production systems, including animals of various physiological states over long periods of time; validating it in the above sense would require years of experimental data from multiple ranches on all inputs and outputs accounted for by the model across the range of production systems and physiological states.

Obviously, data sets of this nature are at best rare and most likely nonexistent. Because of this, the validation of CBCPM as a whole is bound to be somewhat subjective. This may not be much of a shortcoming, however. In fact, besides showing that statistical tests are often not appropriate in model validation, Harrison (1990) suggested that subjective tests are more useful than statistical tests in building confidence in model performance.

In general, based on its performance in the preceding studies, CBCPM appears to have performed reasonably well. Nevertheless, room for improvement exists, as is usually the case for biological models of this size and complexity—if for no other reason, our understanding of biological processes inevitably improves over time.

In order to address my primary hypotheses, several enhancements to the model were required. Documentation from previous studies served as a useful gauge in targeting areas of concern and in making augmentations and alterations to address the shortcomings. Though I made enhancements, and many were made prior to my involvement, I can confidently say there is plenty of room left for model improvement.

CHAPTER III

MATERIALS

OVERVIEW

By itself, CBCPM is commonly described as a whole-herd, life-cycle simulation model that operates on an individual animal level. Though CBCPM could certainly stand alone for many applications, we felt the incorporation of plant and economic simulation capabilities would allow for more far-reaching teaching and research potential, ultimately enhancing the utility of the model. To facilitate this, a search for suitable models to meld with CBCPM was undertaken.

The Agricultural Research Service's Simulation of Production and Utilization of Rangelands (SPUR) model (White and Skiles, 1987; Hanson et al., 1992) was chosen as the plant model. SPUR has the capability of simultaneously simulating production of up to 15 plant species on 36 heterogeneous grassland sites, which gives it the capacity to mimic a wide variety of range-land ecosystems. To model the grazing process, Baker et al. (1992) developed FORAGE, the interface between SPUR and

CBCPM. FORAGE is discussed in more detail in the segment on intake.

To address the economic elements inextricably intertwined with beef cattle production, we were interested in a model with extensive accounting capacity and the ability to speak to economic risk. After considering several options and a great deal of deliberation, the General Firm Level Policy Simulation Model (FLIPSIM, Richardson and Nixon, 1986) was settled on. The original FLIPSIM was developed in 1981 under a cooperative agreement between the Texas Agricultural Experiment Station and the Farm Sector Economics Branch of NED, ESS, and USDA. Major updates and improvements to the model have been made since then.

Its authors classify FLIPSIM as a firm level, recursive, simulation model which simulates the annual production, farm policy, marketing, financial management, growth, and income tax aspects of a firm over a multiple-year planning horizon. In calling it a simulation model, the authors distinguish it from the more typical optimization model in that it does not include an overall objective function to be optimized. Rather, it extensively analyzes the outcome of a given set of input data and assumptions for a firm.

The FLIPSIM is capable of stochastically generating independent or multivariate normal product prices and production levels and can simultaneously simulate the economic implications of beef, dairy and cropping enterprises within a firm. When using the stochastic capabilities, FLIPSIM performs statistical analyses on over 100 output variables, generates cumulative probability distributions for these variables, and estimates the probability of the firm staying solvent over the years simulated. For a deterministic analysis, an income statement, cash flow statement, balance sheet and a miscellaneous output and summary table is generated.

We felt that, given its wide array of capabilities, the integration of FLIPSIM would open the door to more rigorous and accurate economic evaluations than that typically performed by non-economists. For instance, animal breeders commonly rely on input:output ratios and other simple measures of economic efficiency to compare economic worth between genotypes. However, by contrasting these simplistic measures with those derived from economic theories on investment and asset replacement, Melton and Colette (1993) demonstrated that erroneous conclusions could result through use of the prior.

As mentioned, FLIPSIM has the ability to simulate production, though at a rudimentary level. Therefore, we needed to circumvent FLIPSIM's code pertaining to beef cattle production for our purposes. Also, we required code facilitating the exchange of information between the two models. L. W. VanTassell, then a University of Wyoming researcher, accomplished these tasks. The interface between the two models was dubbed FLIPFACE. FLIPSIM and FLIPFACE are discussed in more detail in the segment on economic output.

As mentioned previously, this chapter is devoted to a thorough description of CBCPM. Because SPUR and FLIPSIM are well documented and little adaptation was required for their use, only CBCPM is discussed in detail. In the context of their parameterization and interrelationship to CBCPM, SPUR and FLIPSIM are referred to on occasion.

PART I - MODEL MANAGEMENT

To accommodate a wide variety of future applications, CBCPM is designed to be highly flexible. The model's flexibility arises from a combination of input files (*tape1* - *tape8*) and code changes, allowing for the simulation of an unlimited number of scenarios. Complete utilization of the model's flexibility requires a high level of user sophistication. For many applications, knowledge and use of standard input and code may be sufficient. A discussion of model management accompanied by standard input and code follows. Tables containing variables for *tape1* - *tape8* can be found at the end of this section. A complete listing of CBCPM's variables appears in the appendix.

GENERATING CATTLE FOR SIMULATION

Besides being born into the simulation, animals can enter the simulation as members of a foundation herd (FNHERD), sire group (SIRGRP) or import group (IMPGRP).

GENERATING CATTLE FOR SIMULATION - FOUNDATION HERDS

A foundation herd can be thought of as females purchased by the rancher to initiate cow-calf production. They are dry and pregnant, except for yearlings. Within a single run, any number of foundation herds can be generated through calls to Subroutine HERDGEN. The number of herds (NOHERDS) to be simulated, as well as all inputs relating to foundation herds, is entered in *tape4*. Animal starting date (ASDATE) and foundation day of age (FNDOA) are the only input parameters that can vary among foundation herds. A herd is generated when its ASDATE is equal to the current day. FNDOA is used in establishing the day of year foundation animals are born (FNDOB). Subtracting FNDOA from ASDATE accomplishes this. If the resulting value is negative, it is added to 365 to arrive at the FNDOB. Foundation herds will be identical in all respects except for random variation, which is simulated if the multi-normal generation (MNGEN) parameter in *tape1* is set to 1, and differences arising from varying ASDATE and FNDOA.

A foundation herd consists of foundation groups (FNGRPs). Foundation groups are defined by input parameters. Animals within a foundation group are assigned characteristics based on foundation input parameters for day of gestation (FNDOG), day after calving (FNDAC), condition (FNCON), service sires (FNSSGRP), age distribution (AGEDIS), breed composition of sire (FNBCS), breed composition of dam (FNBCD), and mean breeding values.

HERDGEN transfers the foundation groups' inputs to each foundation animal. For instance, animals over a year of age are assigned a day of gestation (DOG) equivalent to their group's FNDOG, while values for day after calving (DAC) equal to the group's FNDAC are given to animals over two.

The number of animals in a foundation group by year of age category is entered in the cells of the AGEDIS matrix. HERDGEN uses this information to generate the appropriate number of animals of each age for a group.

Breed proportions, specific to a group's sire and dam ancestry, are entered in foundation group by breed matrices. As they are parts of a whole, proportions across breeds must add to one. Ten is the maximum number of breeds that can be simulated.

GENERATING CATTLE FOR SIMULATION - SIRES

Sire parameters for the number of sires (NSPSG), prediction error (SGPEG), simulation status (SGSIM), year of age (SIRYOA), day of age (SIRDOA), condition (SIRCON), starting date (SSDATE), breed composition of sire (SBCS), breed composition of dam (SBCD) and mean breeding values are entered in *tape5* by sire group.

Up to 12 prediction error variance groups may be simulated. Prediction error variances for these groups are input in a group by trait matrix also in *tape5*. Each sire group must be assigned to a prediction error group.

A SGSIM value of 0 indicates the group's sires are used through artificial insemination and are not physically present in the simulation. I.e. they are not fed, do not age, etc.

The SSDATE represents the day of year new sires are introduced into the simulation. During the initial year, sires are generated when the time-step's last day equals their group's SSDATE. After that, sires are generated on their group's SSDATE when needed. Need is created when the number of existing sires falls below the group's NSPSG requirement. Sire attrition is due to death or culling. Sires are generated through calls to subroutine SIREGEN.

GENERATING CATTLE FOR SIMULATION - IMPORTS

Subroutine IMPORT regulates the flow of imported animals during the course of simulation. Any type of livestock (except sires) can be imported in this manner. Importation groups (IGROUPs) are formed through *tape6* input. Information on the group's year of age (IMPYOA), day of age (IMPDOA), sex (IMPSEX), condition (IMPCON), breed composition and mean breeding values are required. Input values for day of gestation (IMPDOG), and day after calving (IMPDAC) are also required for groups of breeding females.

Animals are eligible for import on their IGROUPs import date (IMDATE set in *tape6*). The actual number of animals imported is dependent on the need determined by rules written in IMPORT. If a need exists, subroutine IMGEN is called to generate the animals.

CATTLE FLOW

Production is segmented into three distinct enterprises, cow-calf, stocker and feedlot. The user writes code in subroutine DISPOSE to control the flow of animals among these enterprises. DISPOSE uses a series of conditional statements to accomplish this task. Main conditionals identify animals entering the simulation or meeting criterion for exiting an enterprise. The prior requires an enterprise designation, while the latter need to be moved to another enterprise or sold.

These animals are further segmented by nested conditionals based on category code (CATCD) criterion. The CATCD represent characteristics that cattle are typically sorted on such as sex, age, breed, and slaughter preparedness (fat vs. feeder). These distinctions are required for accounting and pricing by FLIPSIM, allocating feeder cattle to pens, and are helpful in grouping cattle for the output of summary statistics. A listing of the standard CATCDs can be found in Table 1.

Table 1. Standard category code (CATCD).

CATCD	Description
1	3^+ year old females
2	Herd sires
3	2 year old females
4	Bred heifers
5	Maternal weanling females
6	Paternal weanling females
7	Maternal weanling males
8	Paternal weanling males
9	Maternal yearling females
10	Paternal yearling females
11	Maternal yearling males
12	Paternal yearling males
13	Maternal fat females
14	Paternal fat females
15	Maternal fat males
16	Paternal fat males
17	Pregnant females in breeding herd inventory
18	Open females in breeding herd inventory
19	Calves in breeding herd inventory

Animals are processed through the loop of conditional statements until they meet specifications or complete the loop. Upon meeting specifications, the animal is given the appropriate CATCD and, through the use of control vectors, assigned to a new enterprise or sold.

By setting an animal's culling status control vectors (CVCULL and CVNWCL) to true, it is removed from or, in the case of a new import, denied access to the cow-calf enterprise. Culled animals can be sold (CVSELL = true), put in the stocker enterprise (CVPAST = true) or put on feed (CVFEED = true). Cattle exiting the stocker enterprise can be fed or sold while cattle on feed can only be sold.

Rules to remove animals from the breeding herd that are deemed unfit (unsound, open, steers, advanced age, etc.) for breeding are written in subroutine CULL. Rules written in subroutine REPLACE determine which yearling females and heifer calves, of those left after CULL, will be kept for the breeding herd. For example, a rule may be written in CULL to remove all open or unsound yearling heifers at weaning. The remaining yearlings may be further culled by a rule in REPLACE that sets limits on the number of bred females that can be retained.

Culling is simplified through the incorporation of *tape2* input for target size on cull groups (TSIZ1 through TSIZ10) and control vectors indicating membership in a cull group (CVCG1 through CVCG10). For instance, a user may want to make simulation runs holding cowherd size constant while varying the number of steers put on feed at weaning. Depending on the number to be fed, steers may have to be imported or sold to comply with specifications. To accomplish this, TSIZ1 could be set to represent the number of steers to be fed. Code in CULL could designate steer calves as members of cull group 1 (set CVCG1 to true for these animals) and provide a count of its size. The discrepancy between TSIZ1 and the number of animals in cull group 1 would be used to determine the number of steers to be imported or sold. This enables the user to vary the number of steers on feed between runs by simply adjusting TSIZ1, rather than changing code for each run.

The maximum age allowed for sires (MXSAGE) and dams (MXDAGE) are entered in *tape2*. Code in CULL removes old sires at the end of their breeding season and aged cows at weaning.

MANAGEMENT OF NON - BREEDING CATTLE

Control vectors determining the fate of non-breeding animals (CVCULL = true) are set in DISPOSE. Management inputs on stocker and feeder criteria from *tape2* are used in DISPOSE. The parameter TDAYPA (target day on pasture) provides exiting criteria for cattle in the stocker program. If an animal's days on pasture (DAYPA) meets or exceeds the input TDAYPA, the animal is eligible to be fed or sold.

As they enter the feeding period, subroutine PENSORT is called to allocate cattle into pens. Incoming animals are penned by CATCD. When the number of cattle within a CATCD is greater than the pen limit (PENSIZ) set in *tape2*, animals are ranked and sorted into PENSIZ head groups by WT. Unless the number of animals is a multiple of PENSIZ, there will be less than PENSIZ in the lightest group.

The finishing criterion used for animals on feed is dependent on the *tape2* input parameters grade and yield (GRDYLD), target slaughter quality (TSQLT), target slaughter yield (TSYLD), and target slaughter empty body fat (TSEBF). If GRDYLD is set to one, cattle are sold when their pen's average quality grade meets the TSQLT or their average yield grade exceeds the TSYLD. With a

GRDYLD of 0, a pen of cattle is sold when its average empty body fat meets the TSEBF.

MANAGEMENT OF BREEDING CATTLE - MATING

Mating is controlled by a combination of rules written in subroutine BREED and parameters input to *tape2*. The number of breeding seasons (NOBS) and number of breed groups (NOBGPS) are required *tape2* input. A breeding season is defined in *tape2* by the day of year it starts (BSSTRT) and ends (BSEND). A breeding group is composed of females meeting rules for inclusion written in BREED.

The *tape2* mate group (MATGRP) matrix is a breeding season by breed group matrix, with cells containing sire group designations. These designations represent the sire group that females within the breeding group will be exposed to during their breeding season.

The sire a female conceives to is selected at random from the appropriate sire group. For applications requiring such, skewing the servicing capacity of sires within a sire group can easily be accomplished through code modification in subroutine SIREPICK.

MANAGEMENT OF BREEDING CATTLE - CALVING AND WEANING

The number of calving seasons (NOCS) is a *tape2* input parameter. A calving season is defined by *tape2* inputs calving season start (CSSTRT) and calving season end (CSEND) that refer to day of year. Calving seasons may not overlap.

Each calving season must have a corresponding castration date (CSDATE) and weaning day (WNDAY), also *tape2* inputs. Rules are written in subroutine CASTRATE that determine animals to be castrated on a given castration date. The control vector values indicating steer (CVSTR) and newly steered (CVNSTR) statuses are set to true for these animals. Potentials are also altered to reflect their new sex.

At calving, mothers and offspring are assigned a weaning date (WNDATE) based on their calving season. Calves are weaned in subroutine WEAN when the DAY plus STPMN1 (the last day of the time-step) equals their WNDATE. At weaning, a calf's control vector value indicating a newly weaned animal (CVNWN) is set to true, while its control vector value indicating calf status (CVCALF) is set to false.

STORAGE OF ANIMAL ATTRIBUTES

Information on each animal can be thought of as being contained in a matrix with rows referring to animals and columns their attributes (weight, breed composition, etc.). The length of the columns, set through *tape1* input variable N, represents the maximum number of animals that can be present in the simulation at any point in time.

As animals are created and simulated their attributes take on some value. An animal's row must be initialized before it can be assigned to the location. Upon start up, subroutine INITLZ is called to perform this task. No animals exist at start up. Therefore, all columns containing these attributes are initialized at this time.

As new animals are generated their CVLIVE is set to true. CVLIVE is the control vector used to indicate an animal's existence within the simulation. Animals that die or are sold cease to exist. For these animals, CVLIVE is set to false. These locations provide space for newly generated animals. Before they can be used for incoming animals, however, the formerly occupied locations must be re-initialized through a call to subroutine ZERO.

To improve computing efficiency, ZERO is only called when the number of available (initialized) locations becomes less than the minimum allowable (MINSPC) set in *tape1*. MINSPC should be set to allow for the largest influx of new animals that could possibly occur in a single time-step. If the number of incoming animals exceeds the available locations subroutine BOMB is called, terminating the simulation with a corresponding error message to file *output*.

TIME-STEP

Any length time-step can be simulated by CBCPM. The length (STEP) and number (NSTEPS) of time-steps to be simulated are entered in *tape1*. The model requires that each year be complete and end on day 365. Two factors allow this to be accomplished. 1) If necessary, at year's end, subroutine UPDATE shortens STEP to the length that results in DAY being 365. STEP is reset at the beginning of the year (the next time-step). 2) NSTEPS must be set to the number of years simulated multiplied by the number of steps in a year. The number of steps in a year is calculated by simply dividing STEP into 365 and rounding up. Conditions throughout a time-step remain constant and are based on conditions established the time-step's first day. Therefore, reduction in the model's overall accuracy occurs as the size of STEP increases from 1. However, compute time improves as STEP increases. Users must strike a balance between the accuracy in small time-steps and the speed of large time-steps to arrive at a practical STEP for their application. Several trial runs may be required to do so. Also, because monthly adjustments are implemented at 30-d intervals, it may be advisable to settle on a STEP that is a factor of 30.

ADJUSTMENT OF INPUT DATES

Events are assumed to occur on either the last or first day of the time-step. Subroutine DATECNVT converts input dates so they are compatible with this requirement. Depending on the event, the date is converted to the first or last day of the step the original input date falls within. To avoid potential misrepresentation, the user may want to avoid this adjustment (i.e. enter dates that don't require adjustment). A list of events requiring input dates and when they occur within the time-step is in table 2.

Table 2. Events requiring input dates and when they occur within the time-step.

Event	F(irst) or L(ast) day
ASDATE	F
BSEND	L
BSSTRT	F
CSDATE	L
CSEND	L
CSSTRT	F
FPEND	L
FPSTRT	F
IMDATE	F
SSDATE	F
WNDAY	L

OUTPUT

Subroutines DOCUMENT and SUMMARIZ can be thought of as the "drivers" for the generation of output. Both are called from DRIVER at the completion of each time step loop. Control over the output generated by each subroutine is passed from input to *tape1* under the subheadings OUTPUT CODES (OCODES) and SUMMARY CODES (SCODES), to the appropriate statement numbers in DOCUMENT and SUMMARIZ, respectively. OCODES and SCODES reference sections of code in each subroutine that create output consisting of specified data.

Although code currently exists for the generation of a wide variety of output, SUMMARIZ and DOCUMENT are structured to easily facilitate the insertion of code to generate additional output. A discussion of output structure and existing capability follows.

OUTPUT - RAW DATA

DOCUMENT controls the output of raw data from the simulation. Due to their sheer length, the function of most DOCUMENT generated files is limited to providing data for statistical analysis.

Data available on the animal at birth is written to file *ident*. Information such as the animal's number, sire and dam number, breed composition, sex, date of birth, age of dam, calving score, gestation length and birth weight are written to this file.

File *single* contains pertinent information from singly occurring events (weaning, puberty, etc.) in the animal's life. Data from events that occur more than once in an animal's life (calving, calf removal, conception, etc.) are written to file *mult.dir*.

When an animal is removed from the simulation, the animal's identification, reason for and date of removal, along with several other descriptive statistics are recorded in file *disp*. This file is helpful in following the flow of animals out of the simulation.

Nutritional information on each animal in each time-step is accumulated for cows, calves, and stocker/feeder cattle in files *nutrcow.dir*, *nutrclf.dir*, and *nutrfp.dir*, respectively.

OUTPUT - SUMMARIZED DATA

SUMMARIZ controls the output of summary information. SUMMARIZ calls subroutines INOUT, CALFOUT, COWOUT, and FEEDOUT to compile data on input/output, calves, cows, and the non-breeding herd, respectively. Upon completion of the simulation, annual statistics generated by these subroutines are written in year (row) by characteristic (column) form to file *report* under appropriate subheadings. The last row in each summary block is the average of all years.

Due to potential disequilibrium caused by initial conditions, early years of the simulation may not supply representative information on many variables. Because of this, the input variable CUTOFF was added to *tape1*, giving the user the capability of summarizing only the years beginning with CUTOFF to the end of the simulation.

OUTPUT - FLIPSIM DATA

Pertinent data from the biological models are assimilated by FLIPFACE and processed by FLIPSIM, which provides several statistics on the financial performance of the firm. FLIPSIM requires user management of several input options allowing for the simulation of countless economic scenarios and control over output options. For a thorough discussion of FLIPSIM, see Richardson and Nixon (1986).

In addition to providing summary output for *report*, subroutine INOUT produces output files *catinout.dir* and *nutrin.dir*, which are input for FLIPSIM. *Catinout.dir* contains records on incoming and outgoing cattle while *nutrin.dir* provides a tally of yearly feed inputs. The form and contents of both files are given in tables 3 and 4.

Table 3. File *catinout.dir*.

Format	Description	Columns
1-3	I3	Output year
4-7	I4	Day of year
8-10	I3	Category code[a]
11-14	I4	Number of animals
15-20	F6.1	Average weight
21-24	F4.1	Average frame score
25-28	F4.2	Average empty body fat
29-34	F6.1	Average carcass weight
35-39	F5.1	Average quality grade[b]
40-43	F4.1	Average yield grade
44-48	F5.2	Average dressing percentage
49-50	I2	Enterprise code[c]
51-52	I2	Input/output code[d]
53-56	I4	Number of animals purchased
57-58	I2	Replicate

[a] as defined in table 1

[b] 9=select$^+$; 10=choice$^-$; etc.

[c] 1=cow/calf; 2=stocker; 3=feedlot

[d] 0=input; 1=output staying within-simulation; 2=purchased; 3=inventory at year's end; 4=output removed from simulation; 5=inventory at start of simulation.

Table 4. File *nutrin.dir*.

Columns	Format	Description
1-3	I3	Output year
4-10	F7.2	Energy supplement intake
11-17	F7.2	Protein supplement intake
18-24	F7.2	Ration 1 intake
25-31	F7.2	Ration 2 intake
32-38	F7.2	Ration 3 intake
39-45	F7.2	Creep feed intake
46-52	F7.2	Harvested forage intake
53-59	F7.2	Grazed forage intake
60-66	F7.2	Total non-grazed intake
67-73	F7.2	Total intake
74-78	I5	Number of productive female[a]
79-85	I6	Number of days on pasture[b]
86-91	I6	Number of days on feed[c]
92-93	I2	Enterprise code
94-95	I2	Replicate

[*] All intakes are in metric tons on an "as fed" basis

[a] represents the number of pregnant females in the cow herd

[b] the total number of days on pasture for cattle in the stocker enterprise (e.g. 10 head grazing for 100 days = 1000 days on pasture)

[c] the total number of days on feed for cattle in the feedlot enterprise (analogous to days on pasture)

Cow/calf, stocker, and feedlot production are considered separate enterprises with respect to the economic analysis. Therefore, each cattle movement is recorded as a transaction in *catinout.dir*. For example, calves weaned in the fall and placed on pasture are coded as output from the breeding herd and input to the stocker enterprise. If the stocker calves are then put on feed, they are considered output from the stocker program and input to the feedlot enterprise.

To facilitate record keeping in FLIPSIM, cattle sold out of the simulation receive a 4 for an input/output code. This differentiates them from output that moves from one enterprise to another. Inventory on all groups is recorded at the beginning of each economic horizon and on the last day of each year after that. An entry for inventory purposes is given an input/output code of 3.

Cattle are sorted into groups by their CATCD and enterprise code. Fat cattle may be further grouped by grade and yield if the GRDYLD variable in *tape2* is set to 1. For taxation purposes, the number of animals purchased annually is summed for each group and written to *catinout.dir*.

On the last day of each year, the nutrient use of each enterprise is written to *nutrin.dir*. Nutrient intake is expressed in many forms. Total nutrient intake is given by enterprise, along with the total non-grazed nutrients. The total non-grazed nutrients are broken down further into 7 distinct feedstuffs. We did this to accommodate a wide range of sophistication in the pricing of feed. For a detailed description of feedstuffs, see the section on feeding.

A yearly summary of the size of the breeding herd, days on pasture, and days on feed is written to *nutrin.dir* to provide FLIPSIM with multipliers for cost per unit assessments for the cow/calf, stocker, and feedlot enterprise, respectively. Breeding animals are defined as females of breeding age on January 1st. This may need to be redefined for some applications.

FLIPSIM provides an economic analysis over a range of ten years, while CBCPM is capable of 50 consecutive years of output. Data are not written to the output files until the CUTOFF year has been reached. Thus, the year designated as CUTOFF in *tape1* is considered output year (OYEAR) 1. From that point, OYEAR is incremented yearly for 10 years. If the user has set CBCPM to run beyond this point, OYEAR is set back to one and the incremental process is repeated. Each 10-year segment is given a unique replicate number. The need for replication is brought about by the stochastic potentials of both CBCPM and FLIPSIM. For applications with few or no stochastic elements, running replication may be unnecessary. Also, this replication strategy may be invalid for some applications. This would depend on the degree that ending conditions from one replicate affect the following replication.

Table 5. Input parameters found in *tape1* (general simulation and output parameters).

Parameter	Description
CLSEED	Clock seed
CPTOL	Crude protein tolerance
CUTOFF	Cutoff year for beginning of pertinent data
DBCODE	Debug code
DIGTOL	Digestibility tolerance
INTOL	Intake tolerance
IWTOL	Inflection weight tolerance
MERTOL	Metabolizable energy tolerance
MINSPC	Minimum space necessary at all times
MNGEN	Multi-normal random variation is to be generated
MTXSIZ	Matrix size (dimensioned size of MTX12)
N	Number of animals to be simulated (maximum)
N01BLN	Normal 0, 1 maximum block length
NEWHFL	New herd file written
NEWHRD	New herd generated
NOFITS	Number of free iterations of require/limits loop
NOGRPS	Number of groups run in a time-step
NOTITS	Number of total iterations of require/limits loop
NRTRTS	Number of repeated genetic traits
NSTEPS	Number of steps in simulation run
NTRATS	Number of genetic traits

Table 5. Continued.

Parameter	Description
OCODE	Output codes
SCODE	Summary codes
SEED	Seed for random number generators
STEP	Time-step in days
TVBLEN	Total variable block length
U01BLN	Uniform 0, 1 maximum block length

Table 6. Input parameters found in *tape2* (general management parameters).

Parameter	Description
BSEND	Breeding season end (Julian)
BSSTRT	Breeding season start (Julian)
CFCM	Correction factor for calving management
CSDATE	Castration date (Julian)
CSEND	Calving season end (Julian)
CSSTRT	Calving season start (Julian)
GRDYLD	Grade/yield parameters are used for determining slaughter point
IMPPOL	Importation policy
MATGRP	Mating group
MXAGE	Maximum sire age
MXDAGE	Maximum dam age
NOBGPS	Number of breeding groups
NOBS	Number of breeding seasons
NOCS	Number of calving seasons
PENSIZ	Pen size for cattle on feed
TDAYPA	Total days on pasture
TSEBF	Target slaughter empty body fat proportion
TSIZ1-10	Target size for cull groups 1 through 10
TSQLT	Target slaughter quality grade
TSYLD	Target slaughter yield grade
WNDAY	Weaning day (Julian)

Table 7. Input parameters found in *tape3* (nutrition parameters).

Parameter	Description
ALLFIX	All feeds fed on a fixed level basis
CREEP	TDN/crude protein in creep feed
DEMILK	Digestible energy in milk
ESUP	TDN/crude protein in energy supplement
FATFED	Provide feed based on body condition
FIXMAX	Maximum level fed on a fixed basis
FIXVAR	Fixed or variable feeding
FPEND	Feeding period end (Julian)
FPSTRT	Feeding period start (Julian)
HFOR	TDN/crude protein in harvested forage
MEMILK	Metabolizable energy in milk
NFGAPA	Number of feed groups allowed per animal
NOFGPS	Number of feed groups
PSUP	TDN/crude protein in protein supplement
RAT1	TDN/crude protein in ration 1
RAT2	TDN/crude protein in ration 2
RAT3	TDN/crude protein in ration 3
TEBF	Target empty body fat proportion
VARPR	Proportion of variably fed ration

Table 8. Input parameters found in *tape4* (foundation herd variables).

Parameter	Description
AGEDIS	Age distribution matrix (group x age)
ASDATE	Animal starting date (Julian)
FNBCD	Foundation breed composition of dam matrix (group x breed)
FNBCS	Foundation breed composition of sire matrix (group x breed)
FNCON	Foundation condition
FNDAC	Foundation day after calving
FNDOA	Foundation day of age
FNDOG	Foundation day of gestation
FSSGRP	Foundation service sire group
FVAAP	Foundation breeding value for age at puberty
FVAPP	Foundation breeding value for appetite
FVBW	Foundation breeding value for birth weight
FVDDYS	Foundation breeding value for direct dystocia
FVFFC	Foundation breeding value for fat free composition
FVGL	Foundation breeding value for gestation length
FVIMF	Foundation breeding value for intra-muscular fat
FVMDYS	Foundation breeding value for maternal dystocia
FVMF	Foundation breeding value for mature fat

Table 8. Continued.

Parameter	Description
FVMP	Foundation breeding value for milk production
FVMW	Foundation breeding value for mature weight
FVPCON	Foundation value for probability of conception
FVPPI	Foundation value for postpartum interval
FVPSRV	Foundation value for probability of survival
FVRM	Foundation value for requirement for maintenance
FVUNSD	Foundation breeding value for unsoundness
FVYLD	Foundation breeding value for yield grade
FVYW	Foundation breeding value for yearling weight
HERD	Herd identity
NFNGPS	Number of foundation groups
NOHERDS	Number of herds

Table 9. Input parameters found in *tape5* (sire variables).

Parameter	Description
NOSGPS	Number of sire groups
NPEGPS	Number of prediction error groups
NSPSG	Number of sires per sire group
SBCD	Sire group breed composition of dam
SBCS	Sire group breed composition of sire
SGPEG	Sire group prediction error group
SGSIM	Indicates sire group simulation
SIRCON	Sire group condition
SIRDOA	Sire group day of age
SIRYOA	Sire group year of age
SSDATE	Sire group starting date
SVAAP	Sire group breeding value for age at puberty
SVBW	Sire group breeding value for birth weight
SVDDYS	Sire group breeding value for direct dystocia
SVFFC	Sire group breeding value for fat free composition
SVGL	Sire group breeding value for gestation Length
SVIMF	Sire group breeding value for intra-muscular fat
SVMDYS	Sire group breeding value for maternal dystocia
SVMF	Sire group breeding value for mature fat
SVMP	Sire group breeding value for milk production

Table 9. Continued

Parameter	Description
SVMW	Sire group breeding value for mature weight
SVPCON	Sire group breeding value for probability of conception
SVPPI	Sire group breeding value for postpartum interval
SVPSRV	Sire group breeding value for probability of survival
SVRM	Sire group breeding value for requirements for maintenance
SVUNSD	Sire group breeding value for unsoundness
SVYLD	Sire group breeding value for yield grade
SVYW	Sire group breeding value for yearling weight

Table 10. Input parameters found in *tape6* (import variables).

Parameter	Description
IMBCD	Import group breed composition of dam
IMBCS	Import group breed composition of sire
IMDATE	Import group date
IMPCON	Import group conditions
IMPDAC	Import group day after calving
IMPDOA	Import group day of age
IMPDOG	Import group day of gestation
IMPSEX	Import group sex
IMPYOA	Import group year of age
ISSGRP	Import group service sire group
IVAAP	Import group breeding value for age at puberty
IVBW	Import group breeding value for birth weight
IVDDYS	Import group breeding value for direct dystocia
IVFFC	Import group breeding value for fat free composition
IVGL	Import group breeding value for gestation Length
IVIMF	Import group breeding value for intra-muscular fat
IVMDYS	Import group breeding value for maternal dystocia
IVMF	Import group breeding value for mature fat

Table 10. Continued.

Parameter	Description
IVMP	Import group breeding value for milk production
IVMW	Import group breeding value for mature weight
IVPCON	Import group breeding value for probability of conception
IVPPI	Import group breeding value for postpartum interval
IVPSRV	Import group breeding value for probability of survival
IVRM	Import group breeding value for requirements for maintenance
IVUNSD	Import group breeding value for unsoundness
IVYLD	Import group breeding value for yield grade
IVYW	Import group breeding value for yearling weight
NIMGPS	Number of import groups

Table 11. Input parameters found in *tape*7 (variance/covariance and hybrid vigor variables).

Parameter	Description
AMTX	Additive variance/covariance matrix
HYVIG	Hybrid vigor matrix
NAMTX	Non additive variance/covariance matrix
NRTRTS	Number of repeated traits
NTRATS	Number of traits
PEMTX	Permanent environmental variance/covariance matrix
TEMTX	Temporary environmental variance/covariance matrix

Table 12. Input parameters found in *tape8* (miscellaneous variables).

Parameter	Description
BABW	Bull adjustment for birth weight
BADC	Bull adjustment for digestive capacity
BADDYS	Bull adjustment for direct dystocia
BAFFC	Bull adjustment for fat free composition
BAGL	Bull adjustment for gestation length
BAIMF	Bull adjustment for intra-muscular fat
BAMF	Bull adjustment for mature fat
BAMW	Bull adjustment for mature weight
BAPSRV	Bull adjustment for probability of survival
BARM	Bull adjustment for requirements for maintenance
BAUNSD	Bull adjustment for unsoundness
BAYLD	Bull adjustment for yield grade
BAYW	Bull adjustment for yearling weight
BWCF	Birth weight correction factor due to age of dam
CFDAGE	Correction factors for death due to month of age
CFDMO	Correction factor for death due to month of year
CFPDMO	Correction factor for parinatal death due to month of year
CULLF	Culling factors by age of cow
EBPBW	Empty body proportion of birth weight

Table 12. Continued.

Parameter	Description
EBPMW	Empty body proportion of mature weight
EIS1-16	Experimental integer scalars
ELS1-16	Experimental logical scalars
ERS1-32	Experimental real scalars
IDOA	Inflection day of age
MINDYS	Minimum dystocia level
SDC	Standard digestive capacity
SDOPL	Standard day of peak lactation
SWORK	Standard work in grazing

Part II - Model Biology

The biological portion of CBCPM is a composite of previous efforts by J. O. Sanders, D. R. Notter, and R. M. Bourdon, along with many changes and additional features. In general, changes from the aforementioned models reflect an improvement in the understanding of biological processes. Additions, such as the ability to generate individual animal variation, allow for more refinement in the simulation of these processes. Support and reference is provided in the ensuing text when changes or additions were made. Little justification is provided for equations used in prior models. Rationale and specific references for these equations can be found in the doctoral dissertations of Sanders (1977), Notter (1977), and Bourdon (1983). Equations are numbered for cross-referencing with table 18, which identifies the model version each originated, later modifications, and sources for documentation. Table 18 can be found at the end of this chapter.

GROWTH

Several growth related measures are calculated in subroutines INGROW and GROW. INGROW is called from subroutines CONCEIVE, HERDGEN, IMPGEN and SIREGEN to initialize growth variables for animals entering the simulation while GROW is called from subroutine DRIVER each time-step to update these variables through time.

GCW is the theoretical empty body weight of an animal in "normal" condition for its mature fat potential and stage of maturity and can be thought of as structural growth. For animals entering the simulation as fetuses GCW is calculated as:

$$GCW(kg) = EBPBW(BW) \qquad 1$$

where EBPBW represents empty body's proportion of birth weight (BW). EBPBW is controlled through input in *tape8* and is set at 0.96. BW is calculated in CONCEIVE by multiplying the animal's potential for birth weight (POBW) by the appropriate birth weight correction factor (BWCF), which is based on its dam's age and is supplied through input to *tape8*. The BWCFs are set at 0.93, 0.96, 0.98, 1.0 and 0.97 for calves with dams of 2, 3, 4, 5-10 and 10^+, respectively. More details on POBW can be found in the genetic traits segment.

For non-fetuses entering the simulation GCW is calculated as:

$$GCW = EBPBW(POBW) + (DOA / IDOA)(IW - EBPBW(POBW)) \qquad 2$$

when DOA is less than or equal to IDOA and:

$$GCW = EBPMW(POMW) - (EBPMW(POMW) - IW) \; e^{(-KK(DOA - IDOA)} \qquad 3$$

for DOA greater than IDOA. EBPMW represents the proportion of the animal's potential for mature weight (POMW) composed of empty body. EBPMW is provided through input in *tape8* and is set at 0.82. More details on POMW can be found in the genetic trait segment. The age of an animal is expressed in Julian days through DOA. The number of Julian days required for an animal to reach its growth inflection point is IDOA. IDOA is an input variable set in *tape8* to 205. The weight at which inflection occurs (IW) is variable and is calculated in subroutine INFLECT. Structural growth is considered linear from birth to this point and follows Brody's (1945) post-inflection curve from there to maturity. For an IDOA greater than or equal to 365 d, IW is defined by:

$$IW(kg) = (IDOA / 365)(POYW - POBW) + POBW \qquad 4$$

However, when IDOA is less than 365, IW must be solved for iteratively. The iterative procedure solves for the IW that results in the animal achieving its POYW following Brody's curve. Iteration is complete and control is returned to the calling program when differences between animals' yearling weights, projected from their calculated IWs, and POYWs are within the tolerance limit (IWTOL) set in *tape1*. KK is a growth parameter calculated in INGROW and subroutine REQUIRE by:

$$KK = (IW - EBPBW(POBW)) / (IDOA(EBPMW(POMW) - IW)) \qquad 5$$

and is derived by equating the instantaneous rate of change of GCW for both segments of the curve where DOA equals IDOA. The curve simulates female growth.

The increased growth of males is accounted for through input variables to *tape8* for bulls on birth weight (BABW), yearling weight (BAYW) and mature weight (BAMW) and for steers on yearling weight (SAYW) and mature weight (SAMW). These inputs represent the proportion of female growth potential that males possess. Standard sex adjustments for all traits can be found in table 13.

After the initial calculation of GCW in INGROW, GCW increases over time through the following equation in GROW:

$$GCW = GCW + STEP(DGCW) \qquad 6$$

If the animal receives adequate nutrition, DGCW is

Table 13. Sex adjustments.

Variable	Description	*Tape8* input
BABW	Bull adj. on birth weight	1.0700
BADC	Bull adj. on digestive capacity	1.0000
BADDYS	Bull adj. on direct dystocia	0.2000
BAFFC	Bull adj. on fat free carcass	1.0000
BAGL	Bull adj. on gestation length	1.0043
BAIMF	Bull adj. on intra-muscular fat	1.0000
BAMF	Bull adj. on mature fat	0.9000
BAMW	Bull adj. on mature weight	1.7000
BAPSRV	Bull adj. on probability of survival	0.0000
BARM	Bull adj. on requirement for maintenance	1.1500
BAUNSD	Bull adj. on unsoundness	1.2000
BAYLD	Bull adj. on yield	1.0000
BAYW	Bull adj. on yearling weight	1.2200
SADC	Steer adj. on digestive capacity	1.0000
SAMF	Steer adj. on mature fat	0.9500
SAMW	Steer adj. on mature weight	1.1500
SAPSRV	Steer adj. on probability of survival	0.0000
SAUNSD	Steer adj. on unsoundness	1.2000
SAYW	Steer adj. on yearling weight	1.1100

arrived at in subroutine REQUIRE by:

$$\text{DGCW(kg/d)} = (\text{IW} - \text{EBPBW(POBW)}) / \text{IDOA} \quad \text{GCW} \leq \text{IW} \qquad 7$$

$$\text{DGCW(kg/d)} = \text{KK(EBPMW(POMW)} - \text{GCW)} \quad \text{GCW} > \text{IW} \qquad 8$$

If the consumed nutrients are not sufficient enough to meet the animal's needs, however, DGCW will be reduced. The ramifications of insufficient nutrients are discussed in the section on nutrient partitioning.

Structural growth curve weight (SGCW) is the result of adjusting GCW for individual animal variation in the potential for mature fat (POMF). SGCW is calculated in GROW and INGROW by:

$$\text{SGCW(kg)} = (0.97 - \text{SF(POMF} - 0.03))\text{GCW} / (0.97 - \text{SF(SMF} - 0.03)) \qquad 9$$

where stage of fattening (SF) represents the proportion of structural growth beyond birth that has occurred. SF is calculated in INGROW and GROW by:

$$\text{SF} = (\text{GCW} - \text{EBPBW(BW)}) / (\text{EBPMW(POMW)} - \text{EBPBW(BW)}) \qquad 10$$

The standard proportion of fat in the empty body at maturity (SMF) is set at 0.20 in *tape8*. We chose twenty-percent body fat as "standard", as it was the point at which Short et al. (1990) found little or no improvement in reproductive function in breeding females. Based on a consensus between studies by Herd and Sprott, (1986) and Houghton et al. (1990), the 0.20 value represents a condition score 6. To account for the differences in mature fat expected in males, SMF is modified through multiplicative adjustment factors for steers (SAMF) and bulls (SBMF) from *tape8* input. SGCW is used in instances where structural growth independent of individual animal differences in POMF is required.

Expected growth curve weight (EXPGCW) is the theoretical empty body weight of an animal assumed to have been provided with adequate nutrition for uninhibited structural growth and carrying "normal" condition for its stage of maturity and POMF. If DGCW is depressed by inadequate nutrition or if the animal is born to a young or older cow, GCW will be less than EXPGCW. When provided with adequate nutrition, however, the stunted animal's growth curve will resume the shape of the maximum growth curve, though its slope can not exceed the slope of the original growth curve at a given GCW.

For fetuses EXPGCW is calculated in INGROW as:

$$\text{EXPGCW(kg)} = \text{(EBPBW)(POBW)} \qquad 11$$

Cattle entering the simulation are assumed to have experienced uninhibited structural growth prior to entering. Therefore, their EXPGCW is set equal to their GCW. EXPGCW is updated in GROW by:

$$EXPGCW = EBPBW(POBW) + (DOA + STPMN1) (IW - EBPBW(POBW)) / IDOA \qquad 12$$

for DOA less than or equal to IDOA and:

$$EXPGCW = EBPMW(POMW) - (EBPMW(POMW) - IW) e^{-KK(DOA + STPMN1 - IDOA)} \qquad 13$$

for DOA greater than IDOA. EXPGCW is used in relation to GCW in instances where retarded structural size has been shown to have an effect on biological function, such as the phenomenon of increased intake in stunted animals.

Empty body weight (EBW) represents the actual empty body weight of an animal. For animals entering the simulation as fetuses, EBW is simply set equal to GCW. For non-fetuses entering the simulation, EBW is calculated by multiplying the animal's GCW by an input value indicating the proportion EBW is of GCW. The multiplier is essentially a measure of condition as the difference between EBW and GCW is composed entirely of differences in fat content. EBW is calculated in subroutine INGROW when the animal initially enters the simulation and is then accounted for over an animal's life through the equation:

$$EBW(kg) = EBW + STEP(DEBW) \qquad 14$$

which is calculated in subroutine GROW. DEBW is calculated in subroutine PARSE by:

$$DEBW(kg/d) = DGCW + FG \quad 15$$

where fat gain (FG) is the gain in fat tissue above that accompanying an increase in growth curve weight, the result of consumed nutrients being greater than nutrient requirements. The effect of nutrition on empty body growth is discussed further in the segment concerning nutrient partitioning.

The proportion of chemical fat in growth curve weight:

$$PCFGCW = 0.03 + SF(POMF - .03)^{SPGCF} \quad 16$$

is calculated in INGROW and GROW. The shape parameter of growth curve fat (SPGCF) is input from *tape8*. It allows for the flexibility of modeling fat accretion in a nonlinear fashion. SPGCF is currently set at 1.2, which results in lean representing a larger portion of growth curve weight in young animals when compared to linear fat accretion (i.e. setting SPGCF to 1.0). The proportion of chemical fat in the empty body is also calculated in these subroutines through the equation:

$$PCFEB = 1.0 + GCW(PCFGCW - 1.0) / EBW \quad 17$$

Because the model simulates growth independent of gut contents, estimates of fill must be obtained to arrive at whole body weights. Fill has been shown to vary considerably with ration. To permit calculation of whole body measures, independent of differences between animals due to diet, we developed standardized fill (SFILL). SFILL is the expected weight of gut contents for animals on a non-concentrate diet.

SFILL is calculated for all new animals in INGROW and thereafter in GROW by the equation:

$$\text{SFILL(kg)} = \text{PSFILL(SGCW)} / (1.0 - \text{PSFILL}) \qquad 18$$

where PSFILL is the proportion of whole body weight that standardized gut fill represents. For animals younger than 181 days, PSFILL is calculated as:

$$\text{PSFILL} = (1.0 - \text{EBPBW}) + (\text{EBPBW} - \text{EBPMW})(\text{DOA} / 181) \qquad 19$$

and:

$$\text{PSFILL} = (1.0 - \text{EBPMW}) \qquad 20$$

for animals over 180 days. Given the standard empty body proportion inputs (EBPBW = 0.96, EBPMW = 0.82), these equations result in PSFILL increasing linearly from 4 percent at birth to 18 percent at six months and thereafter. These values are in agreement with work by Roy (1970), Schake and Riggs (1972) and Monteiro (1975).

We deem fill to be a function of physical gut capacity. Because SGCW does not include differences between animals due to body condition or POMF, as do EBW and GCW, we consider SGCW to be the weight most indicative of gut capacity. For this reason, SFILL is modeled as a function of SGCW. SFILL is added to SGCW and GCW to provide estimates of whole body weight for animals in "normal" condition, with and without adjusting for POMF. These estimates serve as variables for several functions.

The proportion of gut contents in whole body weight, given the animal's actual diet, is expressed as PFILL. For animals on the standard (non-concentrate) diet, PFILL is set to PSFILL. For animals on a high concentrate diet, the equation:

$$\mathrm{PFILL} = (0.09\mathrm{SGCW} + 4.36) / (1.09\mathrm{SGCW} + 4.36) \qquad 21$$

derived from the ARC (1980) equation:

$$\mathrm{weight(kg)} = 1.09(\mathrm{EBW} + 4.0)$$

is used. To determine the weight of gut contents (FILL) the equation:

$$\mathrm{FILL(kg)} = \mathrm{PFILL(SGCW)} / (1.0 - \mathrm{PFILL}) \qquad 22$$

is used in GROW and INGROW. Actual whole body weight (W) is then calculated in both subroutines by summing EBW and FILL. Fashioning FILL as a function of SGCW allows gut fill to be a larger proportion of W for thin compared to fat cows.

The daily change in weight (DW) is monitored in subroutine GROW by:

$$DW(kg/d) = (W - W') / STEP \quad (23)$$

where W' is the animal's weight for the previous time-step.

Pregnant animals increase in conception weight (CCW) by a factor of 0.447RP per day, where RP represents the animal's requirement for pregnancy. CCW is initially calculated in subroutine CONCEIVE for dams conceiving outside the simulation (foundation and newly imported females) and in subroutine GROW for cows becoming pregnant during the simulation. CCW is then accumulated through gestation in GROW.

FERTILITY

Female fertility is modeled, in subroutine FERT, through equations adapted largely from Tess and Kolstad (2000). Upon being called, FERT identifies all open, anestrus females over 100 days of age as well as those not pregnant, yet cycling. These females are then run through loops to determine those newly entering estrus or conceiving. Animals entering estrus do so on the last day of the time-step and cannot conceive until the next time-step.

For a prepubertal female, the earliest estrus can possibly occur is when her age on the time-step's last day is at least as great as her potential age at puberty (POAAP) minus 0.5STEP, while being less than her POAAP plus 0.5STEP. This conditional ensures that, as long as other thresholds are met, puberty will be initiated as close to the heifer's POAAP as possible. More details on POAAP can be found in the genetic trait segment.

The heifer's SGCW, plus SFILL at this point in time, is considered her target weight for puberty (TWPUB). If the animal's TWPUB is less than or equal to its W, puberty is triggered, which is indicated by its control vectors for cycling (CVCYC) and newly cycling animals (CVNCYC) being set to true. We created CVNCYC and other "new" control vectors to facilitate the tracking of animals as they change biological states (e.g. anestrus to estrus, open to pregnant, suckling to weaned, etc.).

For heifers that haven't reached their SGCW, puberty is delayed for at least another time-step. For these animals, puberty is triggered when their W is greater or equal to their puberty weight (PUBWT):

$$\mathrm{PUBWT(kg)} = \mathrm{TWPUB} - (\mathrm{DOA} + \mathrm{STPMN1} - \mathrm{POAAP}) \\ 0.00267(\mathrm{POMW} - \mathrm{POMW}(\mathrm{POMF} - \mathrm{SMF})) \tag*{24}$$

Equation 24 results in the threshold weight for puberty being reduced with increasing age and mature weight adjusted to the standard mature fat content.

Once a heifer begins cycling, she continues to cycle until conceiving or her PCFEB falls below 0.1. Cycling is reinitiated in thin heifers when they reach a PCFEB of 0.12.

In postpartum females, the initiation of estrus is modeled as a function of the cow's potential for postpartum interval (POPPI), with a series of adjustments for her body condition at calving, condition change post-calving, and the degree of calving difficulty she experienced. More details on POPPI can be found in the genetic traits segment.

For animals with a proportion of chemical fat in the empty body at calving (PCFEBC) of below 0.20, postpartum interval is increased through the correction factor for condition on fertility (CFCONF):

$$\mathrm{CFCONF(d)} = -21.2 + 1.8631 / \mathrm{PCFEBC}^{1.5} \qquad 25$$

At extremely low levels of body condition CFCONF becomes invalid. To address this, we capped CFCONF at 110 d.

In preliminary runs, an equation driven by a rolling 30 d average of post calving weight gain as proposed by Tess and Kolstad (2000) was used to further adjust postpartum interval. We found that, because they experience greater weight gain when provided adequate nutrition, it improved the lot of young, fast growing females more than that of mature cows. This was due to their gain being largely composed of more efficient lean tissue growth. Though it has been shown to impact postpartum interval, we felt simple weight gain was an unnecessarily indirect route to adjust postpartum interval. Under the assumption that change in body fat is more directly linked to postpartum interval, an approximate rolling 30 d average of daily change in the proportion of body fat (PPDPF) was incorporated to drive the correction factor for delta (change) fat on fertility equation:

$$CFDFF(d) = -1000.0PPDPF \qquad 26$$

In keeping with Tess and Kolstad's recommendation for their weight change adjustment, the constant, -1000.0, was found through simulation to be the point at which the maximum achievable PPDPF results in a 7 d reduction in postpartum interval. In cows experiencing dystocia, postpartum interval is lengthened by 4 d for 2-year-olds and 1 d for older cows.

Adding these adjustments to the cow's POPPI results in a threshold value that is then compared to her actual days postpartum on the time-step's last day to determine estrus status. Estrus will occur when the conditions, in the manner described for the initial puberty trigger, are met. However, an additional conditional is required beyond that for the puberty trigger as, unlike with puberty, the threshold value can change from time-step to time-step (due to the CFDFF adjustment). This is addressed by triggering estrus if the cow's postpartum interval is greater than or equal to her adjusted postpartum threshold. Upon the onset of estrus, days to first postpartum estrus (DO1PPE) is calculated and CVNCYC and CVCYC are set to true for newly cycling cows.

After identifying animals entering estrus, open and exposed females that were cycling in the previous time-step are processed through a loop to determine those conceiving. The likelihood that a female will conceive over the next 21 d, based on current conditions, is given by her probability of conception (PCON). PCON is a function of an animal's potential for the probability of conception (POPCON), plus puberty and dystocia adjustments. More details on POPCON can be found in the genetic trait segment. PCON is reduced by .21 during the 21 d ensuing pubertal estrus and .1 in cows experiencing dystocia. The following equation adjusts PCON for time-step:

$$PCON = 1.0 - (1.0 - PCON')^{STEP / 21.0} \qquad 27$$

where PCON′ represents the probability of conception over 21 d.

After all exposed and cycling females have been assigned a PCON, subroutine RANVN is called to supply U(0,1) random numbers for them. If the generated number is less than the female's PCON, her CVP and CVNEWP (control vectors indicating pregnancy and new pregnancy) are set to true. CVCYC is set to false, simulating the cessation of cycling brought about by pregnancy. If the random number is not less than her PCON, the female remains open and continues to cycle.

CALVING

Parturition occurs on the last day of the time-step. It is triggered when the length of time the calf has been carried is at least as long as the calf's potential for gestation length (POGL) minus 0.5STEP, while being less than POGL plus 0.5STEP. More details on POGL can be found in the genetic traits section.

Upon calving, a cow's control vector values indicating that she has calved at least once (CVCLVD), calved during the current time-step (CVNEWC), and is lactating (CVL), are set to true. Conversely, CVP is set to false.

At calving, the probability of dystocia (PDYS) is a function of the potentials for direct (PODDYS) and maternal (POMDYS) dystocia as well as calf birth weight relative to dam size for two-year-olds and birth weight for older cows. The equations:

$$PDYS = PODDYS(POMDYS)(CFDYS2 + 0.0564BWF - 0.0032SGCW) \quad \text{(for AOD = 2)} \qquad 28$$

$$PDYS = PODDYS(POMDYS)(CFDYS3 + 0.02154BWF) \quad \text{(for AOD = 3 or} \geq 13) \qquad 29$$

$$PDYS = PODDYS(POMDYS)(CFDYS4 + 0.00608BW) \quad (\text{for } 4 \leq AOD \leq 12) \qquad 30$$

PODDYS and POMDYS are modeled as traits of the calf and cow, respectively. More details on these variables can be found in the genetic traits segment. The correction factors for dystocia (CFDYS2, CFDYS3, CFDYS4) are *tape8* input set at -0.2038, -0.7227, and -0.223, respectively. The lower end of PDYS is bound by the *tape8* input value for minimum dystocia (MINDYS). MINDYS represents the frequency of malpresentation (assumed to be 0.025).

Each cow's PDYS is compared to RANVN supplied numbers. Dystocia occurs when the generated value is less than PDYS. In the event of dystocia, control vectors indicating dystocia status of the cow (CVDYS) and calf (CVDYSC) are set to true for the dam and its calf.

LACTATION

Jenkins and Ferrell (1982) utilized milk yield data from several breed crosses, derived from weigh-suckle-weigh techniques, to compare the reliability of four models used to estimate milk yields throughout lactation. The models incorporated gamma, inverse polynomial, parabolic exponential, and inverse parabolic exponential functions.

The inverse parabolic function resulted in R^2 values ranging from 79 to 85 percent while the other 3 models accounted for only 9-64 percent of the variation in lactation yield on average. In light of these findings, daily milk production is modeled as the following inverse parabolic exponential function (Jenkins and Ferrell, 1984):

$$MP(kg/d) = t\ /(ae^{kt})$$

where t is the time (week) of lactation, e is the natural log, 1/k is the week of peak lactation, and 1/aek is the yield at peak lactation. The equation, calculated in REQUIRE, becomes:

$$MP = ((DOA + HAFSTP)\ /\ 7.0)\ /\ ((1.0\ /((7.0\ /\ SDOPL)(e)(POMP)))\ e^{((DOA + 0.5STEP)\ /\ SDOPL)}) \qquad 31$$

Standard day of peak lactation (SDOPL) is set at 60 (NRC; 2000) and can be varied through *tape8* input. DOA refers to age of the cow's calf, which is analogous to day of lactation. A half-step (HAFSTP) is added to DOA so that milk production is representative of the time-step's mid-point. Potential milk production (POMP) is modeled as the equivalent of Jenkins and Ferrell's yield at peak lactation. More details on POMP can be found in the genetic traits segment.

Milk production is further adjusted for the effect of heterosis by:

$$MP = MP'(1.0 + NAMP(DOA / 30.0) \qquad 32$$

where NAMP represents the non-additive genetic effects on milk production. Again, DOA pertains to the cow's calf and is divided by 30.0 to put the adjustment on a monthly basis. The equation results in the effect of heterosis increasing with the duration of lactation.

Of all traits modeled in CBCPM with the capacity to directly simulate heterosis, milk production is the only one in which heterosis isn't a component of the trait's potential (in this case POMP). This is because POMP is defined as the peak level of milk production. While peak milk production has been found to be under additive genetic control, the literature suggests that hybrid vigor has little influence on it. Rather, hybrid vigor has been shown to primarily influence milk production through persistence of lactation. I.e., crossbred cows keep their milk production level up longer than straightbreds. Based on data from Cundiff et al.(1974), Bourdon (1983) suggests a value of .045 for NAMP.

The correction factor for age of cow is:

$$CFAGE = 1.0 + 0.01(YOA - 7.0) - 0.01(YOA - 7.0)^2 \qquad 33$$

which results in maximum milk production at 7 and 8 years of age.

Since selection for production is common in very old cows, cows greater than 12 years of age were considered 12 with respect to equation 33 by Bourdon (1983). Due to the individual animal feature of CBCPM, however, this manipulation is unnecessary. I.e. the ability to select among individual cows for production negates the need to adjust an entire age group for the effect of selection.

In our simulation, body condition only becomes relevant to milk production in the event a cow's nutrient intake is insufficient to meet her requirements. As this threshold cannot be tested until the animal's intake and needs are determined, the impact of condition on milk production is modeled in subroutine PARSE. More details pertaining to the relationship between body condition and milk production can be found in the segment on nutrient partitioning.

Besides factors that directly affect the cow, milk production can certainly be affected by the intake capacity of the calf (MIC). In previous versions of the model, an equation developed by Notter (1977) based on the growth curve weight of the calf (GCWC) was used to address this phenomenon:

$$MIC(kg/d) = 0.61GCWC^{0.75}$$

In the event that MIC is less than MP, MP was set equal to MIC for that time-step, with no subsequent impact on milk production. Shortcomings of this approach are that it doesn't account for variability in intake capacity at a given weight or the long-term effect intake capacity limitation has on milk production; studies have shown that growth potential of the calf influences its intake capacity, which in turn affects future milk production of the dam (Mezzadra et al., 1989; Wyatt et al., 1977).

To address this oversight, Enns (1995) developed a set of equations that made MIC a function of a calf's maximum requirements (MAXREQ) and the digestibility of milk (DMILK):

$$MIC = (MAXREQ / DMILK) / 0.14 \qquad 34$$

where the constant 0.14 converts the equation into kilograms of fluid milk and:

$$MAXREQ = RM + RPG + RFINLMT \qquad (35)$$

where RM is the requirement for maintenance, RPG is the requirement for protein gain and RFINLMT is the requirement for maximum fat deposition. RM and RPG will be discussed in further detail in the section on requirements.

RFINLMT is a function of the degree to which an animal's actual fat composition matches a theoretical maximum fat composition. The maximum fat composition can be thought of as the degree of fatness that would occur in an animal fed without nutritional limitation. In general, thinner animals (i.e., animals further from their maximum fat composition) will have larger RFINLMTs.

To simulate the effect of intake capacity limitation on long-term milk production, Enns incorporated a time-step adjusted lag equation. The lag equation dampens subsequent milk production starting on the next time-step. For more details on the methods used to model the milk intake capacity by production interaction see Enns (1995).

DEATH

Non-perinatal death is modeled in subroutine DIE. The base line probability of death during a month is given by:

$$\mathrm{PDEATH} = 0.001\mathrm{CFDMO} \qquad 36$$

where 0.001 is the minimum probability of death and CFDMO the multiplicative correction factor for month of year. The monthly correction factors are *tape8* input and reflect the seasonal effect on death loss. As can be seen from table 14, the correction factors used in this study are largest during the coldest months, but they also increase slightly during the warmest months.

PDEATH is increased in underweight animals (EBW < GCW) through the adjustment:

$$\mathrm{PDEATH} = (\mathrm{PDEATH}')e^{(140.0(1.0 - \mathrm{EBW} / \mathrm{GCW}))^{3.3}} \qquad 37$$

In addition to the previous equation, the adjustment:

$$\mathrm{PDEATH} = \mathrm{PDEATH}' + (1.0 - (\mathrm{GCW} / \mathrm{EXPGCW}))^{0.64}$$

was included for underweight animals under 4 months of age in previous versions of the model. This was found to be too punitive in trial runs, however. Therefore, the equation specific to young animals was removed.

For animals under a year of age, PDEATH is adjusted by the following equation:

$$\mathrm{PDEATH} = 1000.0(1.0 - \mathrm{POPSRV})(\mathrm{PDEATH}')(\mathrm{CFDAGE}) \qquad 38$$

Table 14. Death loss correction factors.

Month of year/age	CFDMO	CFPDMO	CFDAGE
1	1.2	1.5	10.0
2	1.2	1.5	5.0
3	1.1	1.2	2.5
4	1.0	1.0	1.0
5	1.0	1.0	1.0
6	1.0	1.0	1.0
7	1.0	1.1	1.0
8	1.1	1.2	1.0
9	1.0	1.0	1.0
10	1.0	1.0	1.0
11	1.1	1.2	1.0
12	1.2	1.3	1.0

CFDAGE is a correction factor based on the calf's month of age. CFDAGE values are supplied from *tape8* and can be found in table 14. More details on POPSRV can be found in the genetic traits segment.

Cows that are less than a month postpartum are assumed to have a 25 percent greater probability of death. PDEATH is adjusted for time-step by:

$$\text{PDEATH} = 1.0 - (1.0 - \text{PDEATH}')^{(\text{STEP} / 30.0)} \qquad 39$$

RANVN is then called to supply numbers for each live animal. Death occurs if the animal's RANVN supplied value is less than its PDEATH, which is simulated by setting the animal's locations in the death (CVDIED) and new death (CVNDIE) control vectors to true. These values are also set to true for animals flagged for starving (CVSTRV = true) in PARSE.

Death of the mother is assumed to always result in fetal death. For live calves losing mothers, CVORPH (orphan) and CVIRR (irregular) are set to true. CBCPM supports flexibility in the handling of these calves; rules can be written in subroutine GRAFT to provide them with foster mothers or feed-groups may be included in FEED to supply them with a ration. Standard code allows orphaned calves less than 2 months of age to be grafted onto cows that have recently given birth and lost their calf (within 15 d). If the calf is matched to a cow, CVORPH is set to false. If the calf is over 2 months old or no cow is available, the calf is assigned to a high protein and energy ration in FEED. In this case, CVORPH remains true. CVORPH is shut off for all calves at weaning. To distinguish it from other animals, CVIRR remains true throughout the animal's life.

Perinatal death is simulated in subroutine NBDIE. The baseline probability of death used for cows in NBDIE is the 30 d PDEATH calculated for them in DIE. PDEATH is reconverted to a 30 d probability by:

$$\mathrm{PDEATH} = 1.0 - (1.0 - \mathrm{PDEATH}')(30.0\ /\ \mathrm{STEP}) \tag{40}$$

The probability of death at calving (PDAC) for a cow in the absence of dystocia is twice her PDEATH, while it is 52 times PDEATH for cows experiencing calving difficulty. Cows die if their RANVN generated number is less than their PDAC. Calves of these cows are assumed to die also. Their locations in the control vector signifying death at calving (CVDAC) are set to true. CVDAC differentiates perinatal death from all other death (CVDIED). CVNDIE is also set to true for these animals.

Baseline PDAC for calves are calculated on those remaining (calves out of live dams) by:

$$\mathrm{PDAC} = 1.0 - \mathrm{POPSRV}^{12.0} \tag{41}$$

PDAC is adjusted through multiplicative correction factors for calving management (CFCM) and month of year (CFPDMO) as shown:

$$\text{PDAC} = (\text{PDAC}')(\text{CFCM})(\text{CFPDMO}) \tag{42}$$

CFCM values are input by age of dam group in *tape2*. This allows calf loss to vary with intensity of calving management for the group. For example, a rancher's close observation of first calf heifers may decrease calving losses in this group by 50 percent compared to typical calving management. In this case, the first calf heifer CFCM should be set to half of the standard (1.6851). The CFPDMO, which allow for simulation of a seasonal effect on calving losses, are supplied through *tape8* and are listed in table 14.

To account for calves dying due to the death of their mothers, calf PDACs are adjusted through the equations:

$$\text{PDAC} = (\text{PDAC}' - \text{APDACN}) / (1.0 - \text{APDACN}), \tag{43}$$

for births without and

$$\text{PDAC} = (\text{PDAC}' - \text{APDACD}) / (1.0 - \text{APDACD}) \tag{44}$$

for births with dystocia. APDACN and APDACD represent the average probability of death for cows with and without calving difficulty. CVDAC and CVNDIE are set to true for calves with RANVN generated numbers less than their PDAC.

REQUIREMENT/INTAKE/FEEDING LOOP

OVERVIEW

Nutritional requirements and intake limits are calculated for each animal in subroutines REQUIRE and LIMITS. For the first call to REQUIRE and LIMITS within a time-step, the ration digestibility (DIG) and crude protein (CP) used in these calculations are based on the animal's ration from the previous time-step. (Initial DIGs and CPs are arbitrarily set at 60 and 10 percent for animals new to the simulation.)

Subroutine RATION is then called to allocate feedstuffs to each animal and recalculate the DIG and CP of their updated ration. Variables calculated in LIMITS and REQUIRE such as an animal's intake limit (INLMT) or dry matter requirement (DMREQ) affect the proportion and quantity of feeds allocated to it, and therefore the DIG and CP of its ration. In turn, the DIG and CP of an animal's ration affects its DMREQ, INLMT, and several other variables calculated in REQUIRE and LIMITS.

It is this cyclical relationship that necessitates the use of a feedback loop to arrive at appropriate values for these variables. Equilibrium is achieved by executing the loop until differences between key variables in successive loops are acceptable. A detailed discussion of the requirement/intake/feeding loop follows.

REQUIREMENTS - MAINTENANCE

Maintenance requirements are modeled in REQUIRE using an equation derived by Corbett et al. (1987) from work by Graham et al. (1974). Modifications are incorporated when considered biologically justifiable. The initial equation as proposed by Corbett:

$$\mathrm{MEm(Mcal/d)} = \frac{(K)(S)(M)(0.0699LW^{0.75}\ e^{-0.03A})}{Km} + 0.1ME_p + \frac{EWORK}{k_m} + ECOLD$$

where: K = 1.2 for B. indicus, or 1.4 for B. taurus. S = 1.0 for females and steers, or 1.15 for bulls. M = 1.0 + (0.26 - 0.01w), w is week of life and the minimum value of M is 1.0. LW = live weight (kg). A = age in years by monthly increments (e.g. 6 months = 0.5), with a maximum value of 6.0. ME_p = the amount of dietary ME being used directly for production. EWORK = energy expenditure on muscular work. ECOLD = additional energy expenditure in cold stress by animals in below critical temperature environments.

The K variable in Corbett's equation was modified to represent each animal's potential requirements for maintenance (PORM). This allows for the simulation of individual animal variation in maintenance requirement. More details on PORM can be found in the genetic traits segment.

The 15 percent increase in metabolic rate in bulls over steers and heifers is followed by ARC (1980) and supported by evidence from Graham (1968). Van Es (1980) calculated the estimated maintenance requirements of Hereford x Friesian steers and bulls and obtained 17 percent lower maintenance requirements for steers than bulls at both 250 and 450 kg live weight. However, Garrett (1980) detected no significant differences between Hereford heifers and steers. The effect of sex on maintenance is modeled through the input variable BAMR (bull adjustment for maintenance requirement) which is set to increase PORM by 15 percent for intact males.

The predicted net energy required for maintenance (NE_m) of a mature, B. taurus cow on a fasting plane of nutrition is 0.078 Mcal NE/LW(kg)$^{0.75}$ which is similar to ARC (1980) and NRC (2000) recommendations. A week old bull calf under the same conditions is predicted to have a NE_m requirement of 0.134Mcal/kg$^{0.75}$, a 72 percent increase in metabolic rate. This large increase is in agreement with reports from several studies that have used fasting trials to measure maintenance requirements. There is evidence, however, that these estimates may exaggerate the effect of age on maintenance.

Van Es et al. (1978) proposed that the extreme increase in maintenance found in these studies was due to an inordinately stressful reaction by calves to procedures required in measuring fasting heat production. To test their hypothesis, they measured the energy balances of young calves while on liquid milk replacer rations of various compositions allowing for normal or near normal growth. Also, care was taken to minimize any potentially stressful situations. Using these procedures, the metabolism of the calf was found to be 20-30 percent greater than that of mature cows. In another study, Blaxter et al. (1966) estimated the average requirement in steers fed at various levels of maintenance and ranging from 15 to 81 weeks of age to be 0.09 Mcal/LW$^{0.75}$(kg). No increase in metabolism with age was found. Using 0.078 Mcal/LW$^{0.75}$(kg) as an estimate of NE_m required at maturity, Blaxter's estimate translates into a 15 percent increase in young steers over mature cows. In light of these findings, we concluded that maintenance requirements per kg $LW^{0.75}$ of very young cattle are probably only slightly higher than that of older animals. For this reason, the component of Corbett's equation that drastically increases metabolism in very young animals was removed.

This removal results in a predicted 38 percent increase in NE_m for the week old bull calf compared to the mature cow, still excessive given the Van Es and Blaxter findings. Therefore, we modified the equation to reduce the affect of age by changing the exponent of the natural log from -0.03 to -0.02. A corresponding change in the coefficient 0.0699 to 0.063 was required so that NE_m remained stable for mature animals. This modification gives a predicted value of NE_m for the bull calf of $0.101 Mcal/kg^{0.75}$, a 30 percent increase. Multiplying it by 1.4 further modified the 0.063 so that PORM could deviate around 1.0 for B. taurus cattle.

Expressed independently of the effects of alimentation level, physical activity, and cold temperature, the revised equation for the TDN required for maintenance (RM) becomes:

$$RM(kg\ TDN/d) = (0.088PORM(CCW + W)^{0.75} e^{(-\ 0.02MOA/12.0)}$$

$$/\ (0.9MTRMER(MEMILK\ /\ (DEMILK\ /\ 4.4))\ +$$

3.62KM(1.0 - MTRMER)) 45

The net efficiency of using milk for maintenance is assumed to be 0.9 (D. Johnson, personal communication). The metabolizable energy (MEMILK) and digestible energy (DEMILK) of milk are set to 5.59 and 5.88 Mcals/kg (D. Johnson, personal communication) in *tape3*. DEMILK is converted to digestibility through division by 4.4 (NRC, 2000). These inputs result in a kg of milk TDN yielding 4.18 Mcals of ME rather than the 3.62 Mcals of ME typically assumed to be in a kg of TDN. MTRMER (milk to total ration metabolizable energy ratio) gives the portion of the animals total ME intake that is derived from milk. It is initially calculated in REQUIRE and thereafter in RATION.

The efficiency of conversion of ME_m to NE_m (KM) is modeled as a function of digestibility of the diet. The equation is derived from the ARC (1980) equation:

$$k_m = 0.35q_m + 0.503$$

where q_m represents the efficiency of conversion of digestible energy to ME. Assuming a value of 0.82DIG for q_m (NRC, 2000; ARC, 1980), the ARC equation becomes:

$$KM = 0.287DIG + 0.503 \qquad 46$$

In a previous modeling effort, Notter (1977) predicted k_m with the NRC (1970) equation:

$$k_m = 0.243DIG + 0.486$$

This equation will result in lower efficiencies of conversion over all ranges of DIG. The ARC (1980) equation to predict k_m is derived from measurements of the efficiency with which dietary ME is used to spare body tissue from catabolism in animals fed indoors, at levels not exceeding maintenance (zero energy gain), and fasted. The NRC equation is based heavily on work by Lofgreen and Garrett (1968), in which animals were fed outdoors, and energy requirements for maintenance and gain were based on statistical analysis of slaughter data. Therefore, values from the ARC equation probably approach the theoretical maximum for fasting maintenance while those of NRC equation may be diminished due to weather and potential confounding with level of alimentation. Because these effects are accounted for directly in CBCPM, we considered the ARC equation more appropriate.

Maintenance requirements increase in animals exposed to temperatures below the thermoneutral zone (20°C; NRC, 1981). This relationship is simulated by:

$$RBCT(kg\ TDN/d) = 0.013RM(20.0 - EAT) \qquad 47$$

where RBCT are the nutrients required for maintenance in below critical temperatures. Effective ambient temperature (i.e., wind chill factor) is based on work by Ames (1974) and is calculated by:

$$\mathrm{EAT}(\mathrm{C}^{\circ}) = T - (1.9304V - 0.0704V^{2.0} + 0.0019V^{3.0}) / 2.2516 \qquad 48$$

where T is dry bulb temperature (°C) and V is wind velocity (mph).

For non-grazing animals, EWORK is assumed to equal 0.0. This is because the ME_m predicted by Corbett's equation already allows for the expenditure of energy on the physical activities that are normal under non-grazing conditions. The ARC (1980) increments fasting maintenance with an allowance for the greater activity of fed compared to fasted animals. Corbett accounts for this through the rounding up of Graham et al.'s (1974) original coefficient to the 0.0699 value. This adjustment does not account for the energy costs of eating and ruminating. An allowance for these activities is inherent in the KM value used to convert NE_m to ME_m, however. The ME_m requirements include the energy expenditures incurred in eating and ruminating the amount of feed required to achieve a given state, and the value of KM is less than it would be if the energy could have been gained from the diet without these activities.

EWORK is modeled as a function of the time spent grazing by the following equation:

$$\mathrm{RLM}(\mathrm{kg\ TDN/d}) = 8.37(\mathrm{FINGT} / 60.0) / 3.62\mathrm{KM} \qquad 49$$

where RLM is the TDN required for locomotion and FINGT is the final grazing time in minutes. The numerator represents the results of studies by Adam et al. (1984) and Holmes et al. (1978) in which 8.37Mcal/h was found to be the average energy cost involved in grazing. The energy cost of eating, expressed in these terms, showed only small variation among feeds. The efficiency with which ME is used for work is assumed to be the same as for maintenance (KM).

As can be seen, Corbett models the relationship between alimentation level and energy metabolism as a function of ME_p. ME_p is the balance of ME intake available for production (growth and lactation) after inescapable energy expenditures have been assessed. From this standpoint, the ME required to achieve the production of any given live weight gain or quantity of milk will be the energy gain in the production divided by their respective partial efficiencies and then incremented by 10 percent. Alternatively, when an animal's intake doesn't adequately meet its fasting maintenance and pregnancy needs, energy requirements for maintenance are decremented by 10 percent of the deficit.

Through trial runs and literature review, we concluded that this approach was too punitive for animals on high planes of nutrition, while being too conservative for poorly fed cattle. Additionally, it doesn't address an animal's prior nutrient intake, which has been shown to be of primary consideration in determining the impact of alimentation level on energy metabolism. To more accurately model the phenomenon we adapted the following equations as proposed by Tess and Kolstad (2000):

$$\begin{aligned} RM &= RM'(0.9 + 0.1NLAG) && \text{If } NLAG > 1.0 \\ RM &= RM'(NLAG) && \text{If } 1.0 > NLAG > 0.7 \\ RM &= 0.7RM' && \text{If } NLAG \leq 0.7 \end{aligned}$$

where NLAG represents a 30-d rolling average of nutrient intake over maintenance requirements. The approximate 30 d proportion of intake over requirements is calculated as:

$$IOR = CN / RM\ (STEP / 30.0) + PIOR(1.0 - STEP / 30.0) \tag*{50}$$

where consumed nutrients (CN) are in kg of TDN/d and PIOR is set equal to the IOR calculated in the previous time-step. Requirement for alimentation (RAM) depends on IOR. For IOR values over 1.0:

$$RAM = RM(0.9 + 0.1IOR) - RM \qquad 51$$

while for lower values:

$$RAM = RM(IOR)^{1.2} - RM \qquad 52$$

The exponent 1.2 results in a slightly larger reduction in maintenance compared to the Tess and Kolstad equation. Additionally, we did not limit the reduction to 30 percent. In trial runs, however, results appeared more reasonable by taking this route and values for RAM were within bounds noted by the NRC (2000). Maintenance requirements are then calculated as:

$$RM = RM' + RBCT + RLM + RAM \qquad 53$$

REQUIREMENTS - LACTATION

The net efficiency of using ME for milk production (k_l) varies directly with the ME concentration in the cow's diet. ARC (1980) predicts k_l with the equation:

$$k_l = 0.35q_m + 0.42$$

Assuming a value of 0.82DIG for q_m, k_l is modeled as:

$$KL = 0.287DIG + 0.42 \qquad 54$$

The gross energy in milk is assumed to be .72 Mcal/kg (NRC, 2000), which is also the NE required for its production. Thus, the requirement for lactation is modeled as:

$$\mathrm{RL(kg\ TDN/d)} = 0.72\mathrm{MP} / 3.62\mathrm{KL} \tag{55}$$

REQUIREMENTS - PREGNANCY

Requirement for pregnancy (RP) is modeled as a function of the birth weight of the fetus (BWF) and month of gestation by the equation:

$$\mathrm{RP(kg\ TDN/d)} = \mathrm{BWF}(0.000117 - 0.00000608((\mathrm{DOG} + \mathrm{HAFSTP}) / 30.0)e^{(0.97(\mathrm{DOG} + \mathrm{HAFSTP}) / 30.0 - 0.025((\mathrm{DOG} + \mathrm{HAFSTP}) / 30.0)^2)} \tag{56}$$

where DOG is the day of gestation. The constant 30.0 converts DOG to a monthly basis. HAFSTP is added to make RP representative of the time-step's mid-point. Also, pregnancy affects RM through the increased weight of the pregnant animal.

REQUIREMENTS - GROWTH

The requirement for growth (RG) is partitioned into the nutrients needed for protein gain:

$$\mathrm{RPG(kg\ TDN/d)} = 5.64\mathrm{DGCW}\ (0.22)(1.0 - \mathrm{FCDGCW}) / (0.79(\mathrm{MEMILK} / \mathrm{DMILK})\mathrm{MTRMER} + 3.62\mathrm{KP}(1.0 - \mathrm{MTRMER})) \tag{57}$$

and for fat gain:

$$\mathrm{RFG(kg\ TDN/d)} = 9.393\mathrm{DGCW}(\mathrm{FCDGCW}) / (0.87(\mathrm{MEMILK} / \mathrm{DMILK})\mathrm{MTRMER} +$$

$$3.62KF(1.0 - MTRMER)) \tag{58}$$

The coefficients 5.64 and 9.393 are the assumed Mcals in a kg of protein and fat (ARC, 1980). The 0.22 represents the proportion of non-fat empty body growth that is composed of protein. The proportion of fat in a unit gain of GCW is given by:

$$\begin{aligned} FCDGCW = 0.03 + ((POMF - 0.03) / ((EBPMW)(POMW) - \\ (EBPBW)(BW))^{SPGCF} (GCW + (STEP)(DGCW))(GCW + \\ (STEP)(DGCW) - (EBPBW)(BW))^{SPGCF} - (GCW)\ (GCW - \\ (EBPBW)(BW)^{SPGCF} / ((STEP)(DGCW)) \end{aligned} \tag{59}$$

The net efficiency of using milk for protein and fat growth is assumed to be 0.79 and 0.87 (D. Johnson, personal communication). The efficiency of ME utilization for the deposition of fat (KF) and protein (KP) are assumed to be 0.75 and 0.20 for a 71.8 percent TDN ration (Geay, 1984). To simulate the impact of diet energy density on the efficiency of conversion, the Geay estimates are scaled up or down by the ARC (1980) equation:

$$k_g = 0.78q_m + 0.006$$

where k_g depicts the overall efficiency of ME utilization for growth (fat and protein not distinguished).

Assuming a q_m of 0.82DIG, the equations become:

$$KF = 0.75((0.6396DIG + 0.006) / 0.465) \quad (60)$$

$$KP = 0.20((0.6396DIG + 0.006) / 0.465) \quad (61)$$

where 0.465 is the value of k_g at DIG = 0.718. For lactating animals, the ARC (1980) recommendation of $0.95k_l$ for k_g is modeled by reducing Geay's estimates by 5 percent and scaling them by the previously mentioned ARC (1980) equation for k_g. The equations for lactating animals:

$$KF = 0.7125((0.287DIG + 0.42) / 0.626) \quad (62)$$

$$KP = 0.19((0.287DIG + 0.42) / 0.626) \quad (63)$$

result in substantially greater efficiencies compared to equations 60 and 61 for low energy diets, with benefits subsiding with increasing energy content.

For animals in below average condition (EBW < GCW), the portion of the requirement for fat deposition which would result in EBW equaling GCW is calculated in REQUIRE by:

$$\begin{aligned} RFD(kg\ TDN/d) = {} & ERS22(GCW - EBW)9.393 / \\ & (0.87(MEMILK / DMILK)MTRMER + \\ & 3.62KF(1.0 - MTRMER)) \end{aligned} \quad (64)$$

where ERS22 is an input value to *tape8* set at 0.005. In earlier versions of the model, ERS22 was set at 0.01. At the time, however, RFD represented an animal's daily requirement to "catch-up" in its body condition. Because we changed the methodology behind energy partitioning, RFD currently serves a somewhat different function. Its use as an energy-partitioning component in PARSE is discussed later.

An animal's total TDN requirements are calculated in REQUIRE as:

$$\mathrm{REQ}(\mathrm{kg\ TDN/d}) = \mathrm{RM} + \mathrm{RP} + \mathrm{RL} + \mathrm{RG} \qquad 65$$

RFD is not included in REQ because it is not considered essential if nutrients are insufficient. More detail on REQ is provided in the segment on nutrient partitioning. The equation:

$$\mathrm{DMREQ}(\mathrm{kg/d}) = (\mathrm{REQ} / (\mathrm{MTRMER} / (\mathrm{MEMILK} / \mathrm{DMILK}) + (1.0 - \mathrm{MTRMER}) / 3.62))(\mathrm{MTRMER} / \mathrm{MEMILK} + (1.0 - \mathrm{MTRMER}) / 3.62\mathrm{DIG}) \qquad 66$$

calculates the dry matter needed to meet an animal's REQ with the given ration.

INTAKE - OVERVIEW

In previous versions of the model, intake was modeled for all classes of animals as a function of either physiological (reached with highly digestible rations) or physical (reached in low digestibility rations) limitation. The validity of this approach, however, has been questioned of late. Though there is little doubt these factors are related to intake, the skepticism is primarily due to large discrepancies between prediction models based on these factors and real world data. The discrepancies have led many researchers to conclude that these factors do not thoroughly encompass the mechanisms that underlie intake. At the same time, there appears to be no consensus on any system that accounts for the numerous physiological, environmental and management factors that alter feed intake. Due to this, the NRC (2000) suggests that empirical, situation specific equations may be best suited for modeling intake. Though we would rather have used a more seamless, mechanistic approach, in light of the preceding reasoning we chose to model intake for animals on roughage based rations, cattle on feed, and calves, separately.

INTAKE - BASE EQUATIONS FOR ROUGHAGE RATIONS

Intake limits for non-nursing animals on predominately roughage rations (breeding herd, stockers, etc.) are based on equations derived by Jarrige et al. (1986) from data extrapolated from several intake experiments. The equations, as proposed by Jarrige for lactating:

$$FUL = 0.083w^{.75} + 0.244mp + 2.52$$

and non-lactating animals:

$$FUL = 0.09w^{.75} + 1.46$$

where FUL, w and mp represent "fill unit" limit, body weight (kg) and milk production (kg/d), respectively. As described by Jarrige, a single fill unit depicts 1 kg dry matter of 15 percent crude protein, 25 percent crude fiber grass. To predict actual intake limits for a specific feedstuff, Jarrige provides empirically derived fill unit values for numerous forages. To adapt the equations for our purpose, we used the Jarrige data to regress TDN on fill units. The quadratic equation:

$$FU = 5.477 - 13.889DIG + 10.795DIG^{2.0} \qquad 67$$

was found to be the best fit, with an R^2 of 0.51. The equation results in FU hovering around 1.0 at TDN levels between 0.6 to 0.7 and increasing at an increasing rate for values above and below that range. Because fill units are only relevant for forage intake, the independent variable in the above equation is limited to the DIG level in the forage (harvested and/or grazed) portion of the diet. The base intake equations became:

$$INLMT(kg/d) = POAPP((0.083(SGCW + SFILL)^{.75} + 0.244MP + 0.244MP + 2.52) / FU) \qquad 68$$

for lactating and:

$$INLMT(kg/d) = POAPP((0.09(SGCW + SFILL)^{.75} + 1.46) / FU) \qquad 69$$

for non-lactating animals on entirely roughage rations. POAPP represents the animal's potential for appetite. More information on POAPP can be found in the genetic traits segment.

For animals supplemented with concentrate, the intake limit is calculated according to Jarrige et al. (1986) by:

$$INLMT = INLMT' - CONC(1.0 - (FU - 0.975))^{0.33} + CONC \qquad 70$$

where CONC represents kilograms of supplemental concentrate in the diet. Though overall intake increases, the equation results in a reduction of forage intake. In general, the reduction is minimal at very low digestibilities and increases as forage quality improves. The equation was derived from data in which concentrate levels were at or below 30 percent of total diet dry matter. Therefore, it may be inappropriate at higher levels of supplementation.

INTAKE - BASE EQUATIONS FOR CATTLE ON FEED

The base intake equation for cattle on feed:

$$INLMT(kg/d) = 0.1POAPP(SGCW + SFILL)^{0.75} \qquad 71$$

was derived from an equation developed by Fox and Black (1984) from data reported in experiment station bulletins and research reports. They also found that intake began to decline as ration NE_g increased from 1.27. Therefore, as proposed by Fox and Black, intake is adjusted downward for rations above a NE_g of 1.27 by:

$$INLMT = INLMT' + 0.1(SGCW + SFILL)^{.75}(1.27 - NE_g) \quad 72$$

Because TDN is the measure of energy used in this model, the NRC (1981) equation:

$$NEg(Mcals/kg) = 1.42ME - 0.174ME^{2.0} + 0.0122ME^{3.0} - 1.65 \quad 73$$

where ME = 3.62DIG, is used to convert ME to NE_g. A summary of comparisons between Fox and Black's equation and equations developed by other researchers showed the prior to be most accurate ($R^2 = 0.86$) in describing average intake in cattle on feed.

INTAKE - BASE EQUATION FOR CALVES

Intake of dry matter for calves is modeled as a function of age, live weight and intake of milk. The following equations are derived from suggestions by Fox (NRC, 1987) based on work by LeDu et al. (1976):

$$INLMT_1(kg/d) = 0.0435SGCW - 0.4234MPDAM \quad 74$$

$$INLMT_2(kg/d) = 0.0326SGCW - 0.2886MPDAM \quad 75$$

$$INLMT_3(kg/d) = 0.0294SGCW - 0.2981MPDAM \quad 76$$

$$INLMT_4(kg/d) = 0.0219SGCW - 0.2328MPDAM \quad 77$$

$$INLMT_5(kg/d) = 0.0278SGCW - 0.3009MPDAM \quad 78$$

$$INLMT_{6+}(kg/d) = 0.0273SGCW - 0.3540MPDAM \quad 79$$

where subscripts refer to month of age and MPDAM refers to the milk production of the calf's dam. If the calculated INLMT is less than 0.005SGCW, INLMT is set equal to 0.005SGCW, which is the minimum dry matter intake assumed to be required for rumen development.

INTAKE - ADJUSTMENTS BEYOND BASE EQUATIONS

Intake is reduced in aged animals to simulate the decline in consumption that commonly accompanies old age. For cows over eight, the intake reduction due to age (INRA) is calculated as:

$$\mathrm{INRA(kg/d)} = \mathrm{INLMT} - \mathrm{INLMT}(1.0 - 0.02(\mathrm{YOA} - 8.0)) \qquad 80$$

Since culling on teeth loss and other factors associated with reduced intake typically occurs in very old cows, cows greater than twelve years of age were considered twelve by Bourdon (1983) with respect to equation 80. As in equation 33, and for the same reason, the manipulation was considered unnecessary. Though indirectly, intake is also affected by age due to it being modeled as a function of milk production.

For diets in which crude protein (CP) drops below 6 percent, intake is adjusted downward by the formula:

$$\mathrm{INRCP(kg/d)} = \mathrm{INLMT} - \mathrm{INLMT}(\mathrm{CP} / 0.06)^{0.6} \qquad 81$$

where INRCP represents the reduction in intake associated with low levels of crude protein. The function results in a precipitous drop in intake at low levels of protein.

The primary effects of temperature on dry matter intake occur at temperatures less than 15° C and greater than 25° C (NRC, 1981). To calculate the reduction in intake at temperatures over 25°, the NRC (1981) equation:

$$\mathrm{INTEMP(kg/d)} = \mathrm{INLMT}(1.0 \,/\, (1.0 + \mathrm{EAT} \,/\, 40.0))^{5.8769} \qquad 82$$

is used. To account for the effect of temperatures below 15° C, an equation derived from NRC (1984) is implemented:

$$\mathrm{INTEMP(kg/d)} = \mathrm{INLMT}(1.04 - 0.00551\mathrm{EAT} + 0.000216\mathrm{EAT}^2) \qquad 83$$

This equation results in a mild increase in intake down to -10°, after which intake increases dramatically. These equations were developed from information on non-nursing cattle. The relationship between temperature and intake in very young animals is relatively unknown. It seems unlikely that calves would have the same thermoneutral zone or be affected in the same manner as adult cattle. Therefore, only the intake of non-calves is adjusted by these equations.

It is well documented that an animal's physical condition affects intake. To simulate this phenomenon, information from a study by Abdalla (1986) is used. Abdalla found that compensating cattle whose rate of growth had been retarded to about half of maximum daily protein gain consumed an average of 10 percent more dry matter than non-stunted animals of equal weight. The resultant equation:

$$\mathrm{INIRG(kg/d)} = \mathrm{INLMT}(1.2 - 0.2\mathrm{GCW} / \mathrm{EXPGCW}) - \mathrm{INLMT} \qquad 84$$

describes the increase in intake associated with retarded growth. Because GCW will increase at a slower rate than EXPGCW if an animal is nutritionally stressed, equation 84 allows stunted animals to eat more feed if accessible. The magnitude and duration of an animal's increased intake depends on the degree to which it was stunted.

Intake has been shown to decline with increased fatness. This phenomenon was simulated by an equation derived from intake information (NRC, 1987) in which empty body fat percentages of 21.3, 23.8, 26.5, 29.0 and 31.5 are associated with percentage decreases in intake of 0.0, 3.0, 10.0, 18.0 and 27.0, respectively. The equation used to calculate the intake reduction due to fat:

$$\mathrm{INRF(kg/d)} = \mathrm{INLMT} - \mathrm{INLMT}(0.574 + 5.2\mathrm{PCFEB} - 15.0\mathrm{PCFEB}^2) \qquad 85$$

is applied if PCFEB is greater than 0.22. The reduction in intake due to fat is limited by what the animal needs to carry out its basic functions (DMREQ).

Actual intake limits for calves are then calculated by:

$$INLMT(kg/d) = INLMT' + INIRG - INRF \qquad 86$$

and for non-calves:

$$INLMT(kg/d) = INLMT' - INRA - INRCP + INIRG - INRF + INTEMP \qquad 87$$

FEEDING - OVERVIEW

There are several stochastic components in the model that could have an impact on nutrient requirements and/or sources of nutrition. For example, an extremely cold winter may necessitate a significant increase in ration energy or drought conditions might require that grazing cattle be supplemented much earlier than in a typical year. Because of this, the model requires an internal level of intelligence that allows feeding to be altered accordingly.

In developing the artificial intelligence routine, our primary goal was that it be as realistic as possible. To that end, we chose to use body condition (or at least an approximation of it) to drive internal feeding decisions.

Virtually all ranchers base feeding decisions on body condition to some degree. This practice is well justified; the preponderance of evidence suggests that body condition is strongly associated with reproduction and, to a lesser extent, production.

Although body condition is a subjective measure, several researchers have shown it to be highly related to body fat (Bellows et al., 1979; Swingle et al. 1979; Dunn et al., 1983; Thompson et al., 1983; Wagner, 1984; Houghton et al., 1990). Close agreement between work by Herd and Sprott (1986) and Houghton et al. (1990) indicate consistency in empty body fat at a given condition score. In light of the aforementioned information, we feel that feeding cattle according to empty body fat is an appropriate means of adding artificial intelligence to the model.

We dubbed the internal feeding mechanism FATFEED. The user is given the discretion of whether or not to use it through input to *tape3*. It may not be necessary or desirable under certain simulation scenarios and is not appropriate for animals not ordinarily fed according to body condition (e.g. cattle on feed, nursing calves). Given the nature of the model, however, it is likely to be an integral component in most simulation efforts.

Because FATFEED is interwoven with the model's external feeding protocol and grazing functions, they are described jointly. In describing the mechanics of feeding, references to fixed and variable feeding pertain to the external and internal feeding routines.

FEEDING - MECHANICS

Immediately prior to the intake/requirement portion of the loop, subroutines FEED and SEQUENCE are called from DRIVER. In FEED, the user writes code that sorts animals into groups to be fed. For example, a feed-group may be comprised of all first-calf heifers or herd-bulls over the age of 2, etc. The code must be written so that each animal is assigned to a feed-group. Animals not meeting the criterion for a feeding group are not fed. This results in termination of the simulation due to an intake of dry matter (INDM) of 0.0. An error message explaining the reason for termination is written to file *output*. Care should also be taken to ensure that animals are assigned to only one feed-group at a time. If an animal meets the criterion for more than one group, it will be fed in the feed-group it was assigned to last, not necessarily its intended feed-group.

It is possible and appropriate for animals to be in multiple feed-groups over a period of time. Just as a rancher moves a group of young heifers into the cowherd when aged, the user may write code that moves animals from feed-group to feed-group throughout their life. A listing of standard feeding groups can be found in table 15.

The model can simulate the feeding of eight different feeds. A list of standard feeds along with corresponding crude proteins and digestibilities can be found in table 16. The beginning and ending feeding period for each feed by feed-group is provided from user input to *tape3*. From this information, control vectors indicating whether or not an animal has access to a particular feedstuff (including grazed forage) are set in FEED. An animal is granted access to a feed if the day at the beginning of the step falls within the range of its group's feeding period for the feedstuff. Setting a group's starting and ending dates for a feed to 0 denies it access to the feed at any time.

The fixed quantity (kg dry matter) of each non-grazed feedstuff available to animals within a feed-group is transferred to them in FEED. The user, through a feed-group by feed matrix in *tape3*, supplies this data. The quantity is considered fixed in that it is only dependent

Table15. Standard feeding groups.

Feeding group	Description
1	Nursing calves
2	Orphaned calves
3	Cattle on feed for less or equal to 3 weeks
4	Cattle on feed for more than 3 weeks
5	Stocker cattle
6	Yearling heifers
7	Bred heifers
8	Two year old cows
9	Three year old and older cows
10	Yearling and two year old sires
11	Three year old and older sires

Table 16. Crude protein and TDN content of standard feeds.

Code	Description	TDN (%)	CP (%)
ESUP	Energy supplement	90.	9.8
PSUP	Protein supplement	90.	44.6
CREEP	Creep feed	65.	15.0
RAT3	Ration 3	85.	12.0
RAT2	Ration 2	75.	12.0
RAT1	Ration 1	65.	12.0
HFOR	Harvested forage	57.	16.0

on external input and does not vary with the animal's body fat.

The control vector indicating the status of continued variable feeding (CVCVF) for a feed-group is reset each new time-step in FEED. CVCVF is set to true at this time if the group has access to FATFEED. The user allows access by setting the group's fat feed feeding group (FFFGRP) parameter in *tape3* to 1. If an animal is in one of the designated groups, it is assigned its group's target fat. The target, input to *tape3* in a feed-group by month matrix, represents the proportion of chemical fat in the empty body acceptable for the average animal in the group by the end of that month of the year.

SEQUENCE determines the order that animals pass through the requirement/intake/feeding loop. Typically, all non-nursing animals complete the loop first, followed by those nursing. This is due to the requirement that milk production of the dam be determined before biological variables concerning the calf (forage intake, etc.) can be calculated.

Subroutine RATION is called following calls to REQUIRE and LIMITS. RATION apportions feed to animals for both the fixed and variable methods of feeding. Feeding is based on the premise that animals have a distinct hierarchy in their order of preference for feedstuffs. The assumed order of preference is: 1) milk; 2) energy supplement; 3) protein supplement; 4) creep feed; 5) ration 3; 6) ration2; 7) ration 1; 8) harvested forage; 9) grazed forage. Grazed forage can take priority over other feedstuffs in the event that the cattle are being variably fed and grazed forage digestibility is greater than their supplemental ration.

Animals are processed through the fixed protocol when RATION is initially called each time-step. As an animal proceeds through fixed feeding, it is allocated the level of each feed assigned to it until allocation is complete or its INLMT is reached. The animal is considered satiated and further feeding is terminated upon reaching its INLMT. If the animal is not satiated after being fed the fixed quantities of feeds and has access to grazing, its demand (DEMAND) for grazed forage is calculated. DEMAND is calculated by subtracting the animal's INDM accumulated to that point, which is summed after each allocation of a feed, from its INLMT.

After all animals have passed through the fixed feeding routine, subroutine GRAZE is called, which is the driver for FORAGE. FORAGE interacts with SPUR to return parameters to CBCPM for the intake of dry matter from grazed forage (INGFOR) as well as the digestibility (DGFOR) and crude protein (CPGFOR) of the grazed forage for each grazing animal. The intake of grazed forage is a function of the animal's demand, preference, frequency of bites, bite size, forage quality and availability, and the time allowed for grazing. For a detailed description of FORAGE, see Baker et al. (1992). Upon completion of its tasks, GRAZE returns control to RATION.

Based on their current rations, updated values for all animals on INDM, DIG, CP, and for calves on MTRMER are then calculated in RATION. Control is then passed to subroutine CONVERGE, in which the largest difference between the animals' previous and current INDMs, DIGs, CPs and MTRMERs is determined for each variable. These values are compared against tolerance levels for each variable from *tape1*. The tolerances represent the largest deviation allowable between successive executions of the loop. If any of the deviations exceed their tolerance level, the loop is re-executed. This process is repeated until the convergence criterion is met.

Under some conditions, continuous oscillation may occur. To dampen these oscillations, the average of each animal's current and previous MTRMER, DIG and CP are calculated. These average values then become the animals' current values. Therefore, vacillation is reduced by 1/2 each iteration until the convergence criterion is met. Averaging only takes place when the number of free (non-averaged) iterations (NOFITS) exceeds the number allowed per time-step. NOFITS is set in *tape1*.

If no feed-groups have access to FATFEED, the fulfillment of the convergence criterion completes the requirement/intake/feeding loop for non-calves. Calves are then processed through the loop in the same manner. If any feed-groups have access to FATFEED, however, control is passed to subroutine FDGPAV, which is called from RATION.

As discussed previously, our goal was that the internal supplementation mechanism be as realistic as possible. In practice, a rancher makes feeding decisions that result in a group of cattle meeting a target condition by a specific point in time. To do this, he must project the supplementation level required by estimating the discrepancy between what nutrients the herd has available and what they need to reach the target. While some cattle may be too thin and others too fat, the rancher is resigned to feeding on averages, as individual feeding is unfeasible. This practice is simulated in FDGPAV.

Also, ranchers typically base feeding decisions on only the productive animals within a group. For example, if a feed-group consisted of cows nursing calves, as well as those losing calves, a rancher would certainly tailor supplementation to the lactating animals. Therefore, code can be written in FDGPAV to exclude animals' statistics from their group's average for whatever reason. To insure that supplementation decisions are realistic, standard code in FDGPAV excludes data on non-productive cows in feed-groups 7 through 9.

In FDGPAV, all feed-groups that have access to FATFEED are processed one by one. The sums of a feed-group's INDMs, DMREQs, INLMTs, DMRTFDs, INGFORs, DIGs, DGFORs based on the feed the animals were allocated from fixed feeding are calculated and used later in the subroutine.

The additional dry matter required (ADMR) by a group represents the per cow dry matter required, over and above that already provided, for the group to meet its dry matter requirements plus its target fat by the end of the month. This is assuming that the additional dry matter has the same composition as the current ration. ADMR is calculate in FDGPAV by:

$$ADMR(kg/d) = (DMRG + DMRGTF / DTF - INDMG) / NG \quad 88$$

where DMRG is the sum of the group's DMREQs. DMRGTF represents the dry matter required for the group to reach its target fat by the end of the month and is the sum of the group's DMRTFDs. Days to target fat (DTF) is calculated by:

$$DTF = (30.0MO - DAY + 1.0) \quad 89$$

and is set equal to STEP if DTF is less than or equal to 0.0. This gives the group 30 d to meet its monthly target fat. NG is the number of animals contributing to the group totals.

If the ADMR for a feed-group is less than or equal to 0.0 on the first call to FDGPAV, the group's CVCVF is set to false. This indicates that no supplementation is necessary because the group's requirements are met by the feeds and/or grazed forage made available to it through fixed feeding. If ADMR is greater than 0.0, however, the group's CVCVF remains true and the variable dry matter required (VDMR) is set to the variable dry matter required previously (VDMRP). VDMRP is the level of supplementation that was fed to the group the last time-step it was supplemented. This makes the incremental process of arriving at the appropriate level of supplementation more efficient than if the initial level were a constant.

If all CVCVF values are set to false after the feed-groups have been processed, the intake/requirement/feed loop is terminated and the groups are fed the level of feed and/or grazed forage allocated to them by the fixed routine. If any of the values for CVCVF are true, however, subroutine VARFEED is called from RATION.

VARFEED calculates the quantity of each feedstuff that will comprise the supplemental nutrition provided to groups with a CVCVF of true. This is accomplished by multiplying the group's VDMR by its variable proportion of ration (VARPR) for each feed. VARPR is set in *tape3* and is the proportion of a group's variably fed ration that each non-grazed feedstuff represents. As they are proportions, the VARPRs for a feed-group should sum to 1.0 across all feeds.

Upon completion of VARFEED, control is passed back to RATION. In RATION, animals from groups with a CVCVF of true are processed through the variable feeding routine in much the same manner as the fixed feeding protocol. Animals are allocated the levels of each feed calculated for their group through VARFEED, in the same order of preference as the fixed loop, until their INDM reaches their INLMT. At that point they are considered satiated and further feeding is terminated. If an animal is not satiated after being fed the fixed quantities of feed as well as supplemental feed, and it has access to grazing, its demand for grazed forage is calculated. After all animals are fed their non-grazed feed, GRAZE is called to determine grazing statistics for unsatiated animals.

When variable feeding is completed, the MTRMERs, DIGs, CPs and INDMs are recalculated and tested against the convergence criterion. As in fixed feeding, the requirement/intake/feeding loop is executed until the convergence criterion has been met. Upon meeting the convergence criterion, FDGPAV is called from RATION for the second time during the loop.

Because the levels of supplementation set from the first call to FDGPAV are somewhat arbitrary (determined from a prior time-step), the appropriate supplementation will be more or less than set levels. The second call to FDGPAV determines the direction variable feeding (DIRVF) must take to arrive at the proper level of supplementation for each group.

There are 4 possible scenarios that are addressed on the second call to FDGPAV. One occurs when the digestibility of grazed forage is greater than the group's supplemental ration. Under this circumstance, the group is better off to eat as much grazed forage as possible. To simulate this, the group's VDMR and DIRVF are set to 0.0 and 2.0. A DIRVF of 2 results in the group's VDMR being increased by 0.5 kg each time FDGPAV is called. This is done until either the group's requirements are met or grazed forage intake is reduced, at which time its CVCVF is set to false. This allows the animals to graze to their limit without being inhibited by supplemental feed intake.

If the group's supplemental ration is higher in digestible energy than grazed forage, 3 scenarios remain for the second call to FDGPAV. 1) If the group's ADMR is less than 0.0, it is over supplemented. Under this condition DIRVF is set to 1, which results in VDMR being reduced by 0.5 kg each time FDGPAV is called. The group's CVCVF is set to false when its ADMR is greater than or equal to 0.0. 2) If the group's ADMR is greater than or equal to 0.0, yet the animals are able to consume grazed forage, the group is under supplemented. When this occurs, VDMR is increased by 0.5 kg and DIRVF is set to 0. Under a DIRVF of 0, VDMR is incremented by 0.5 kg each time FDGPAV is called until the group's ADMR is greater than 0.0 or the consumption of grazed forage is halted. At which time, the group's CVCVF is set to false. 3) If the group's ADMR is greater than or equal to 0.0 and the animals within the group have reached their intake limit without eating grazed forage, they are being supplemented as heavily as possible. Nevertheless, their requirements cannot be met. This triggers the group's CVCVF to be immediately set to false.

After the second call to FDGPAV, control is returned to RATION and the process, as earlier described, is executed to convergence. Each time convergence is achieved throughout the rest of the time-step, FDGPAV is called to determine if any groups require an adjustment in their level of supplementation. The requirement/intake/feeding loop is executed until all groups' CVCVF are set to false. Upon completion, cattle are processed through subroutine PARSE (the purpose of which is discussed in the nutrient partitioning segment). After PARSE, ages and milk levels are transferred from dams to their offspring through subroutine COWTRAN. Existing calves are then processed through the fixed feeding routine.

NUTRIENT PARTITIONING

PARSE is called from DRIVER upon completion of the requirement/intake/feeding loop. Its primary utility is to assimilate data generated in the loop in order to apportion surplus nutrients to fat gain or, in the event an animal's intake doesn't meet its needs, adjust function levels and reapportion nutrients.

The recalculations of partial efficiencies for growth and lactation are the first order of business in PARSE. This is done to insure they are based on the final digestibility values arrived at through the loop. A discrepancy occurs when the loop requires dampening of oscillation to converge, as the average between successive estimates will be the final digestibility values, rather than that calculated in REQUIRE.

If nutritional intake adequately meets all of an animal's needs (i.e., REQ plus RFD is less than or equivalent to CN), all functions proceed as calculated and nutrients above REQ are allocated to FG by the following equation:

$$\begin{aligned} &FG(kg/d) = (CN - REQ) / (9.393 / (MEMILK / DMILK \\ &\qquad 0.87MTRMER + 3.62KF(1.0 - MTRMER))) \end{aligned} \tag{90}$$

In the case of an energy deficiency, a cascade of events is triggered. Our nutrient partitioning model roughly coincides with work by Short and Adams (1988), in which they prioritized the metabolic use of available energy in ruminants, ranking each physiological state in order of importance as follows: 1) basal metabolism, 2) activity, 3) growth, 4) energy reserves, 5) pregnancy, 6) lactation, 7) additional energy reserves, 8) estrous cycles and initiation of pregnancy, and 9) excess energy reserves. Though there are undoubtedly interactions to be found in the list, the rankings provided a base to work from. In instances where there was information, we attempted to directly model interactions. For example, according to work by Bauman and Currie (1980) and Williams et al. (1989), there is evidence that milk should move up this list in early lactation. To address this, we incorporated a strategy described by Tess and Kolstad (2000), which is described later. Additionally, simply due to the simulation's complexity, interactions in nutrient partitioning are likely to occur while not directly contemplated.

When energy is insufficient, Mechelis-Menten equations are used to adjust lean tissue growth and milk production in a manner similar to Tess and Kolstad (2000) in structure, though somewhat different in parameterization. Specifically, when CN do not meet an animal's RG plus RM and RP, its growth curve gain is dampened by a function of the fraction:

$$\mathrm{F1} = (\mathrm{CN} - \mathrm{RM} - \mathrm{RP}) / \mathrm{RG}$$

which is set to zero when negative; Tess and Kolstad include RL in the numerator.

The function:

$$\mathrm{DGCW} = \mathrm{DGCW}'((\mathrm{ERS18})(\mathrm{F1}) / (\mathrm{ERS18} + \mathrm{F1}) + 1.0 / (1.0 + \mathrm{ERS18})) \tag{91}$$

where ERS18 is a variable set in *tape8*; though 1.0 is used for the value by Tess and Kolstad, we use 0.5. During lactation, when CN doesn't meet an animal's RL in addition to its RM, RP, RG, and RFD, milk production is modeled as a function of the fraction:

$$\mathrm{F2} = (\mathrm{CN} - \mathrm{RM} - \mathrm{RP} - \mathrm{RG} - \mathrm{RFD}) / \mathrm{RL}$$

which is set to zero when negative; RG and RFD are not present in the Tess and Kolstad equation.

The function:

$$\mathrm{MP} = \mathrm{MP}'(\mathrm{F2}(0.001 + \mathrm{ERS17}(\mathrm{DOA} - \mathrm{SDOPL}) + \mathrm{CFCONM}) / (\mathrm{F2} + (0.001 + \mathrm{ERS17}(\mathrm{DOA} - \mathrm{SDOPL}) + \mathrm{CFCONM})) + 1.0 / (1.0 + (0.001 + \mathrm{ERS17}(\mathrm{DOA} - \mathrm{SDOPL}) \div \mathrm{CFCONM}))) \tag{92}$$

where DOA refers to a cow's calf and:

$$\mathrm{CFCONM} = \mathrm{ERS16}(0.1 - \mathrm{PCFEB}) \tag{93}$$

is the correction factor for condition. ERS16 and ERS17 are *tape8* input; we have used values of 100.0 and 0.04 per Tess and Kolstad.

Upon completing adjustments for DGCW and MP, revised requirements are calculated for the reduced levels of production. Now RG (RPG + RFG) is modified to include only the fat considered essential for lean tissue growth (3 percent) plus the fat-free portion of GCW through the equations:

$$RPG = 5.64DGCW / ((MEMILK / DMILK)0.79MTRMER + 3.62KP(1. - MTRMER))0.22(1.0 - FCDGCW) \quad 94$$

and

$$RFG = 9.393DGCW / ((MEMILK / DMILK)0.87MTRMER + 3.62KF(1. - MTRMER))0.03 \quad 95$$

Also, the animal is not required to meet its RFD at this point. If the new requirements are met by CN, DGCW and MP are as revised and any additional nutrients are allocated to fat gain, which is now calculated as:

$$FG = (CN - REQ) / (9.393 / ((MEMILK / DMILK) 0.87MTRMER + 3.62KF(1.0 - MTRMER))) + 0.03DGCW \quad 96$$

The 0.03DGCW term accounts for the 3 percent fat assumed integral to increases in growth curve weight. DEBW is then calculated by adding FG to non fat gain:

$$NFG(kg/d) = (1.0 - FCDGCW)DGCW \quad 97$$

where FCDGCW is recalculated to reflect the modified DGCW.

If the revised requirements still exceed TDN intake, body fat is mobilized. Though not in accordance with the physiological "letter of the law", only fat is considered catabolizable in this model. While this may prove unduly limiting in some cases, we felt the oversight would not appreciably affect outcomes for most applications.

Researchers have shown that the efficiency with which animals use catabolized tissue is dependent on the function for which it is used. Based on summaries of studies in the area, the AAC (1990) suggests that body stores are used at 80 percent efficiency for maintenance and pregnancy while the ARC (1980) proposes the tissue is used at 84 percent efficiency for lactation. D. Johnson (personal communication) estimates that body fat is used at 80 percent efficiency when fueling lean growth. This information is incorporated into the following equation:

$$ANF(kg/d) = 2.595 / REQ\ (0.8(RM + RP) / KM + 0.84RL / KL + 0.8RG / KG)(AFAT) \qquad 98$$

which denotes the available nutrients from fat tissue that can be mobilized daily. 2.595 represents the nutrients in a kg of fat used at 100 percent efficiency (assuming 9.393 Mcals ME per kg of fat and 3.62 Mcals ME per kg of TDN). Through extrapolation of NRC (1989) data, we settled on a value of 187 g per 100 kg of SGCW for the maximum daily fat available (AFAT). In keeping with our 3 percent minimum fat assumption, in the event an animal's PCFEB dips below 0.03, AFAT is set to zero. The partial efficiency of growth is calculated as:

$$KG = KP(0.22(1.0 - FCDGCW) / (0.22 + 0.78FCDGCW)) + KF(1.0 - 0.22(1.0 - FCDGCW) / (0.22 + 0.78FCDGCW)) \qquad 99$$

The modified REQ is again compared to the energy now available from CN and ANF. If there is adequate energy to meet REQ, DGCW and MP are as calculated. However, FG is now calculated by:

$$FG = 0.03DGCW - (REQ - CN) / (2.595 / REQ (0.8(RM + RP) / KM + 0.84RL / KL + 0.8RG / KG)) \qquad 100$$

and as previously, added to the newly calculated NFG to arrive at DEBW.

If CN and ANF do not meet the animal's reduced needs, minimum requirements (REQMIN) are established. REQMIN are the nutrients required to meet RM and RP, functions considered necessary for the animal's survival. If REQMIN is greater than the nutrients available from the diet and fat, MP and DGCW are set to 0.0 and ANF is recalculated as:

$$ANF = FAT(2.076 / KG) \tag{101}$$

where the animal's entire fat reserve is calculated by:

$$FAT(kg) = EBW + GCW(PCFGCW - 1.) \tag{102}$$

With the exception of the animal having access to its entire fat store, equation 101 is equivalent to equation 98 for animals not growing or milking. Under conditions of survival, we assume that animals have access to all of FAT. If the revised ANF plus CN do not meet the animal's survival needs, the animal starves on the last day of the step. Its fat stores are considered depleted over the duration of the time-step, which is quantified by:

$$DEBW = -FAT / STEP \tag{103}$$

If, by tapping into its entire fat reserves, the animal's minimum needs are met, its loss in weight is quantified by:

$$DEBW = -(REQMIN - CN) / (2.076 / KM) \tag{104}$$

If the initial ANF plus CN is greater than REQMIN, the animal's maintenance and pregnancy needs are met and additional nutrients are allocated to productive functions. In lactating cows, the surplus nutrients are rationed to milk and lean growth in a manner that results in, though at reduced levels, the same nutrient allocation proportion established through equations 91 and 92. In non-lactating animals, the excess nutrients are apportioned entirely to lean growth. In both cases, DGCW is calculated as the gain in structural size that would be expected given the lean growth. Weight change is calculated as:

$$DEBW = DGCW(1.03 - FCDGCW) - AFAT \qquad 105$$

The value 1.03 rather than 1.0 is used to account for the essential 3 percent fat associated with lean growth.

For a lactating cow, the cascade of events occurring in PARSE result in milk production receiving priority over lean-growth and heavy precedence to fat reserves through peak lactation, as long as she is in 10 percent body fat or better. As her body fat declines from 10 percent, however, the relative importance of milk production decays precipitously at all stages of lactation. After she reaches peak lactation, lean-growth takes precedence over milk production, with its relative priority increasing over time. Also, at this point, milk production is dampened by a function of the magnitude of her RFD, in addition to the 10 percent body condition adjustment. These inter-relationships result in the nutritional energy allocated to the cow's fat reserves increasing as her fat stores decrease and as lactation progresses.

Our method of allocation differs from Tess and Kolstad (2000) in that, relative to milk production, lean-growth is afforded a higher priority throughout lactation, while fat reserves are granted more importance after peak lactation. Our interpretation results in young, high-growth females producing less milk when nutritionally stressed than would be the case under the Tess and Kolstad version; at the same time, they will be heavier. It also leads to somewhat better body condition at the expense of milk production in mature cows.

To provide insight into nutrient partitioning, the output variable RDGCW, representing the reduction in DGCW from what would have been obtained with adequate nutrition, is calculated in PARSE. Also, the variables RMPCF and RMRG quantify the reduction in daily milk production due to a cow's PCFEB and RG, respectively.

POTENTIALS - OVERVIEW

Though any trait exhibiting genetic influence could technically be called a genetic trait, for the sake of simplicity, we limit the designation. In CBCPM, genetic traits are those for which there is the capability of simulating random genetic and environmental variation. CBCPM has the capacity to simulate 20 traits in this manner. There are currently 18 genetic traits (table 17).

Each genetic trait consists of several components. The sum of these components is considered the animal's potential for that trait. Potentials are designated by a PO prefix. The calculation of potentials for traits not expressed as probabilities can be described by the following equation:

$$PO(trait) = SA(BV + NAV + PE) + TE \qquad 106$$

where BV represents breeding value and is the sum of the trait mean, group effect, and breeding value deviate; NAV depicts non-additive value and is the sum of hybrid vigor and the non-additive deviate; PE is the permanent (calculated once) environmental deviate; TE represents the temporary (regenerated as needed) environmental deviate essential for repeated traits; SA is the sex adjustment. CBCPM's repeated traits are POMP, POPCON, POPPI and POMDYS. As mentioned earlier, the baseline equations are representative of female performance. Therefore, potentials for males include a sex adjustment for traits in which sex influences performance.

For traits expressed as probabilities (POPCON, PODDYS, POMDYS and POSRV) the equation:

Table 17. Genetic traits - acronyms and definitions.

Acronym	Definition
BW	Birth weight
YW	Yearling weight
MW	Mature weight
MP	Milk production
AAP	Age at puberty
PCON	Probability of conception
PPI	Postpartum interval
DDYS	Direct dystocia
MDYS	Maternal dystocia
GL	Gestation length
MF	Mature fat
APP	Appetite
UNSD	Unsoundness
PSRV	Probability of survival
RM	Requirement for maintenance
IMF	Intramuscular fat
FFC	Fat free composition
YLD	Yield grade

$$PO(trait) = BV + (NAV + PE + TE)(1.0 - BV) \qquad 107$$

is used. The equation limits the non-breeding value component of the trait to the portion between 0 and 1 unaccounted for by breeding value. This effectively bounds the potential to an upper limit of 1.

Potentials should not be confused with actual phenotype. An animal's phenotype will differ from its potential to the degree in which the fixed effects inherent in the deterministic biological equations as well as the outcomes influenced by random number generation (e.g. conception) impact it.

Just as the PO prefix is representative of the animal's potential for traits, the animal's breeding value, non-additive value, permanent environment, temporary environment and sex adjustment variables are prefaced with BV, NA, PE, TE and SA, respectively.

POTENTIALS - MECHANICS

Base (deterministically generated) breeding values on animals not conceived in the simulation are input for groups of foundation cows, sires and imported replacements in *tape4*, *tape5* and *tape6*, respectively. These values represent expected means for each trait plus the additive effect of group on these traits. Base breeding values for animals conceived in the simulation (fetuses) are the averages of their sire's and dam's breeding values. They are assigned to foundation cows, sires and imported replacements in subroutines HERDGEN, SIREGEN and IMPGEN, respectively, and are calculated for fetuses in CONCEIVE.

Base non-additive values are calculated by summing the products of the animal's breed of sire by breed of dam proportions by the appropriate heterosis values. Values are in actual units for an F_1 mating of the breeds. They are supplied from a 10 x 10 (10 breed limit) matrix in *tape7*, in which rows represent breed of sire and columns represent breed of dam. This structure permits the simulation of both general and specific combining abilities, as well as maternal components. Heterosis is assumed to be proportionate to heterozygosity. The base non-additive values for foundation cows, sires, imported replacements and fetuses are calculated in subroutines HERDGEN, SIRINIT, IMPINIT and CONCEIVE, respectively.

CBCPM's capacity to generate additive, non-additive and environmental (co)variation beyond the deterministic base equations is enabled by setting MNGEN (multivariate normal generation) in *tape1* to 1. Under this option, multivariate normal random deviates simulating additive, non-additive, permanent, and temporary environmental effects, are generated for each animal's traits. The distributions of the deviates are based on population (co)variance parameters entered in matrix form to *tape*7.

When inputting environmental variation parameters, users should be mindful that, in the context of this simulation, permanent environmental effects are environmental effects not requiring regeneration over time. Because the random error component of non-repeated records and the environmental effect constant to repeatedly measured records need only be generated once in an animal's lifetime, they are considered permanent. However, each time a measure is taken on a repeated trait, the error portion of an animal's record must be regenerated, making it a temporary effect.

The generation of breeding value, non-additive value, permanent environmental, and temporary environmental deviates is initiated by calls to BVGEN, NAVGEN, PEGEN and TEGEN, respectively. Subroutine MNRNGEN is called by these subroutines to perform the actual task of generating deviates. To accomplish the matrix multiplication required in generating deviates, square roots of the population parameter matrices are necessary. Additive, non-additive, and permanent environmental square root matrices are created through a call from DRIVER to subroutine A12GEN, while the temporary environmental square root matrix is created by a call from DRIVER to subroutine E12GEN.

Both A12GEN and E12GEN use the same basic steps to arrive at the square root matrices required by MNRNGEN. 1) Subroutine MTXFILU is called to transform the lower diagonal, symmetrically stored *tape7* input to the double precision, upper diagonal matrix required by subroutine DCHDC. 2) DCHDC is then called to generate the square root of the appropriate matrix using Cholesky Decomposition. DCHDC returns a double precision, upper diagonal matrix. 3) Subroutine TRANSPUL is called to transpose the output from DCHDC into the real, lower diagonal matrix required by MNRNGEN. Additional steps which alter the original additive (co)variance matrix are required for animals born within the simulation (fetuses) and sires.

Fetuses are the only animals simulated to have known parentage. Because parental breeding values are known, elements of the additive (co)variance matrix are reduced by half for these animals.

Upon the calculation of their requisite components, potentials are arrived at in HERDGEN, SIREGEN, IMPGEN and

CONCEIVE for foundation animals, sires, imported animals and fetuses, respectively. Potentials are then bound to realistic ranges. For example, an animal with a calculated negative potential for milk production (POMP) would have its POMP set to 0.0.

CBCPM is capable of simulating the prediction error involved in sire selection. Prediction error variances are input to *tape5* in a prediction error group by trait matrix. The number of prediction error groups can be as large as the number of sire groups (maximum of twelve) or as few as one. Sire groups are assigned to a prediction error group in *tape5*. Each prediction error group has its own additive (co)variance matrix, in which the diagonals (variances) are set to the assigned prediction error variances. Because these modified variances change correlations among traits, off diagonals (covariances) of the matrix must be adjusted to maintain known correlations. This is done in subroutine COVGEN.

Table 18. Original source, sources of modifications and sources for documentation of equations used in the biological model.

Equation number	Original source	Sources(s) of modifications	Source(s) for documentation
1	C[a]		C
2	S[b]	C	S,N[c],C
3	S	C	S,N,C
4	C		C
5	S	C	S,N,C
6	C		C
7	S	C	S,N,C
8	S	C	S,N,C
9	B[d]	C	B,C
10	S	C	S,C
11	C		C
12	B	C	C
13	B	C	C
14	C		C
15	C		C
16	S	C	C
17	B	C	B,C
18	C		C
19	C		C
20	C		C
21	C		C
22	C		C
23	C		C
24	C		C
25	C		C
26	C		C
27	C		C
28	B	C	B,C
29	B	C	B,C
30	B	C	B,C
31	C		C
32	B		B,C
33	S		S
34	E[e]		E
35	E		E
36	S		S
37	S	N,C	S,N
38	S	C	S,C
39	C		C
40	C		C
41	C		C
42	N		N,C

Table 18. Continued.

Equation number	Original source	Sources(s) of modifications	Source(s) for documentation
43	C		C
44	C		C
45	C		C
46	N	C	N,C
47	B		B
48	B		B
49	C		C
50	C		C
51	C		C
52	C		C
53	C		C
54	C		C
55	S	N,C	S,N,C
56	N		N
57	S	N,B,C	S,N,B,C
58	S	N,C	S,N,B,C
59	S	N,B,C	S
60	C		C
61	C		C
62	C		C
63	C		C
64	S	N,C	S,N,C
65	S	C	S,C
66	S	N,C	S,N
67	C		C
68	C		C
69	C		C
70	C		C
71	C		C
72	C		C
73	C		C
74	C		C
75	C		C
76	C		C
77	C		C
78	C		C
79	C		C
80	S	B,C	S,N,B,C
81	S		S,N
82	C		C
83	C		C
84	C		C
85	C		C

Table 18. Continued.

Equation number	Original source	Sources(s) of modifications	Source(s) for documentation
86	C		C
87	C		C
88	C		C
89	C		C
90	S	N,B,C	S
91	C		C
92	C		C
93	C		C
94	S	N,B,C	S,N,B,C
95	S	N,C	S,N,B,C
96	S	N,B,C	S
97	S	N,B,C	S
98	S	N,C	S,N,C
99	C		C
100	S	N,B,C	S
101	S	N,C	S,N,C
102	S	B,C	S,C
103	C		C
104	C		C
105	C		C
106	C		C
107	C		C

[a] CBCPM: Shafer (2003)
[b] Sanders (1977)
[c] Notter (1977)
[d] Bourdon (1983)
[e] Enns (1995)

CHAPTER IV

METHODS

STUDY DEVELOPMENT - SIMULATION SCENARIOS

Besides the broad theory that increased variability in mature weight and milk production negatively affects cowherd profitability, I suspected that the capacity for interaction exists between the effect of variability for one trait and the level of the other trait. E.g., the effect of large differences in milk production potential on a herd's bottom line may be influenced by its average mature weight potential.

In addition to interactions between mean trait levels, I also thought that the level of variability in the other trait might result in interactions. For example, the impact of highly disparate genotypes for weight within a herd may be affected by its degree of variability for milk production.

Testing these hypotheses requires the simulation of genotypes representing combinations of extremes in the range of genetic potentials for weight and milk production, as well as intermediate genotypes for these traits.

To form general representation of the broad spectrum of genetic potentials in existence, I settled on categorizing potentials for mature weight and milk production into low (L), medium (M), and high (H). Henceforth, reference to a genotype will refer first to mature weight potential followed by milk production potential. To differentiate the mean genetic level of a herd from the genotype of a group of animals within a herd, the prefixes "H" and "A" are added to the designations for levels of weight and milk production. For example, a low weight, medium milk herd is designated HLM, while ALM depicts a group of animals within a herd with low weight and medium milk production potential.

After breaking things down in this manner, the first order of business became identifying plausible herd categories. As can be seen from table 19, each herd classification has at least one trait at the medium level. This is because the "treatment" (high within-herd variability) requires the combination of high and low genotypes for the trait, which inevitably results in a medium herd level for the trait.

Table 19. Herd classification, genotypic composition within-herd classification and input variance of breeding potentials for mature weight and milk production within-herd x genotypic composition.

Herd classification	Genotypic composition	Var. MW kg^2	Var. MP kg^2
HMM	AMM*	1500.0	6.0
	.5AMH, .5AML	1500.0	15.0
	.5AHM, .5ALM	11500.0	6.0
	.5AHH, .5ALL	11500.0	15.0
	.5AHL, .5ALH	11500.0	15.0
HHM	AHM*	1500.0	6.0
	.5AHH, .5AHL	1500.0	15.0
HMH	AMH*	1500.0	6.0
	.5AHH, .5ALH	11500.0	6.0
HLM	ALM*	1500.0	6.0
	.5ALH, .5ALL	1500.0	15.0
HML	AML*	1500.0	6.0
	.5AHL, .5ALL	11500.0	6.0

* denotes controls

The next step was to come up with the possible combinations of genotypes that result in the same mean herd potentials. Just as every herd classification requires a treatment, a "control" (low within-herd variability) genotype is included for each herd category. From table 19, it can be seen that HMM can be developed through several genotypic combinations. With the other herd classifications, only a single treatment and control genotype is possible.

In considering the various genotypic combinations under the HMM classification, an interesting contrast shows up; there are two distinct routes to a highly diverse herd (1/2AHH, 1/2ALL vs. 1/2AHL, 1/2ALH). In the former the diversity in both traits is between animals, while in the latter there is disparity between animals as well as between trait levels within animals. Although these herds are similar based on mean potentials, they are quite different biologically. It is certainly conceivable that this difference may manifest itself through divergent interactive effects with variability.

Besides the plausible interactions mentioned, I also expected the impact of variability to be influenced by environment. To test this theory, the herd was supplemented during off-peak grazing months to two levels of body condition. Details on the levels simulated and methods used to perform this task are in the segment on feeding.

Input parameters for genetic potentials as well as genetic and environmental (co)variances were adapted from Enns (1995) and can be found in table 20. To simulate the corresponding shift in growth traits typically associated with change in mature weight, birth and yearling weight potentials vary with mature weight according to Enns (1995).

From a practical standpoint, it is difficult or impossible to conceive of "real world" breed crosses that would result in the extreme genetic levels simulated. Therefore, only purebred animals were simulated for the cowherd.

Rules based on expectation theory were used to solve for the increased variance expected in herds composed of diverse genotypes. The corollaries specific to our purpose:

$\sigma^2_X = E(X^2) - E(X)^2$ where

$E(X^2) = p_1(\sigma^2_1 + \mu^2_1) + p_2(\sigma^2_2 + \mu^2_2)$ and

$E(X)^2 = (\mu_X)^2 = (p_1(\mu_1) + p_2(\mu_2))^2$

Table 20. Genetic starting values for each genotype, mean values for herd classification and input (co)variances for growth and milk.

Genetic starting values (kg)

Genotype	BW	YW	MW	MP
ALL	29.7	261.0	450.0	7.0
AMM	36.3	313.5	550.0	10.0
AHH	42.9	357.5	650.0	13.0
ALH	29.7	261.0	450.0	13.0
AML	36.3	313.5	550.0	7.0
AMH	36.3	313.5	550.0	13.0
ALM	29.7	261.0	450.0	10.0
AHM	42.9	357.5	650.0	10.0
AHL	42.9	357.5	650.0	7.0

Mean herd values (kg)

Herd	BW	YW	MW	MP
HMM	36.3	313.5	550.0	10.0
HHM	42.9	357.5	650.0	10.0
HLM	29.7	261.0	450.0	10.0
HMH	36.3	313.5	550.0	13.0
HML	36.3	313.5	550.0	7.0

Input (co)variances (kg^2)

		BW	YW	MW	MP
BW	(G)	7.75	25.0	60.8	0.0
	(E)	16.75	26.6	31.0	0.0
YW	(G)		325.0	500.0	0.0
	(E)		675.0	534.0	0.0
MW	(G)			1500.0	0.0
	(E)			1400.0	0.0
MP	(G)				6.0
	(E)				1.9

E refers to expected value; μ_X and σ^2_X represent the overall mean and variance of the combined populations; p is the proportion of a sub-population present in the combined population; subscripts 1 and 2 identify sub-populations. The calculated variance of potentials for mature weight and milk production within-herd by genotypic composition can be found in table 21.

While contemplating the primary hypotheses, I became curious about the relevance of CBCPM's ability to generate individual animal variability beyond that generated by the biological equations. Obviously, it would be impossible to test our hypotheses as proposed without it, as the model could not generate the levels of variation required. Beyond that however, I was interested in whether or not outcomes could be affected by running the model with and without the random deviate generator (i.e., with and without realistic levels of variation). See table 21 for a contrast in input variability with and without deviates generated.

Intuitively, it seems reasonable to expect that modeling with less than realistic levels of variation should have implications. In fact, from a mechanistic standpoint, the potential always exists for a trait's

Table 21. Herd classification, genotypic composition within-herd classification and input phenotypic variance for mature weight and milk production within-herd x genotypic composition with multi-normal random number generator on and off (+, -).

Herd	Genotypic composition	Var. MW +	Var. MP +	Var. MW -	Var. MP -
HMM	AMM	2900.0	7.9	0.0	0.0
	.5AMH, .5AML	2900.0	16.9	0.0	9.0
	.5AHM, .5ALM	12900.0	7.9	10000.0	0.0
	.5AHH, .5ALL	12900.0	16.9	10000.0	9.0
	.5AHL, .5ALH	12900.0	16.9	10000.0	9.0
HHM	AHM	2900.0	7.9	0.0	0.0
	.5AHH, .5AHL	2900.0	16.9	0.0	9.0
HMH	AMH	2900.0	7.9	0.0	0.0
	.5AHH, .5ALH	12900.0	7.9	10000.0	0.0
HLM	ALM	2900.0	7.9	0.0	0.0
	.5ALH, .5ALL	2900.0	16.9	0.0	9.0
HML	AML	2900.0	7.9	0.0	0.0
	.5AHL, .5ALL	12900.0	7.9	10000.0	0.0

level of variability to interact with any non-linear equation the trait is a function of. For example, maintenance is typically calculated as a function of weight to the ¾ power. Results from this function being applied to pairs of 600.0 kg, 750.0 and 450.0 kg, and 900.0 and 300.0 kg animals, are 242.5, 241.0 and 236.4, respectively. Clearly, all pairs have the same average weight, however increasing variability results in lower total maintenance requirements.

Another point to be considered is that the effect of variability may also be dependent on the trait's mean level. By using the same levels of variability as the previous example and increasing the average weight to 1000 kg, we get sums for our no, medium, and high variability pairs of 355.7, 354.9 and 352.6, respectively. Obviously, a narrower range compared to our first example.

Of course, examples could be given where altering levels of means and variation do not interact with non-linear equations. This would occur in situations where the function has a linear segment and the range of values fall within it. Even when this is not the case, because we are limited to what is biologically justifiable, the level of variation and/or the degree of non-linearity may be insufficient to cause appreciable differences.

As elucidated, there certainly is potential for the level of variability to bias outcome. Yet, given the model's complexities, coming to any conclusions about this is virtually impossible, short of actually making simulation runs. To satisfy my curiosity, a spin-off study was undertaken to determine if modeling with less than realistic levels of variation has the potential to impact outcomes. Though there are likely to be no "real world" implications in determining this, it may prove informative to researchers involved in simulating beef cattle production.

Besides POMW and POMP, I chose POGL, PORM, and POAPP as traits for the spin-off investigation. With the exception of POGL, they are all closely aligned with non-linear, deterministic equations embedded in the model. They are also all linked to each other to varying degrees via deterministic equations (again, with the exception of POGL).

For book keeping purposes, treatments with input variability for POMW, POMP, POGL, PORM, and POAPP exclusively are designated by 10000, 01000, 00100, 00010, and 00001, respectively. Runs were also performed with input variability for all traits (11111), plus POMW and POMP simultaneously (11000). Control (no input variability) is designated as 00000. To simplify differentiation, I dubbed this the multi-normal variance (MNV) study, while the prior study was given the HV (herd variance) acronym.

Means from the AMM genotype and the same (co)variance structure used in the HV study were tapped to parameterize POMW and POMP (see table 20). Also, as in the HV study, means for POGL, PORM, and POAPP were 283.0, 1.0, and 1.0, respectively. Genetic and environmental variability estimates for POGL of 12.6 and 23.4 were adapted from data presented by Bourdon and Brinks (1982). Taylor and Young (1967, 1968) calculated a coefficient of variation of 5.5 percent for maintenance requirements at a constant weight, which was independent of feed intake level. I used this information, combined with a heritability estimate of 0.66, to derive parameters for genetic and environmental variability of 0.002 and 0.001 for PORM. Due to a lack of estimates and for the sake of simplicity, the same values were used for POAPP. No covariances for POGL, PORM, and POAPP were simulated.

To test my premise that the nutritional environment could lead to substantial interactive effects, high and low environments as described for study HV were simulated. All other conditions (herd size, service sires, culling/replacement rules, etc.) are as described for the previous study.

GENERAL SIMULATION OVERVIEW

HERD SIZE, SIMULATION LENGTH, AND REPLICATION

In this study, questions such as whether or not to adjust herd size to reflect differences in pasture carrying capacity due to differences in size or milk are not as critical as if we were comparing genetic levels per se. Nevertheless, herd size could potentially be a confounding factor when simulating a limiting, fixed grazing area. I.e., the effect of variability may depend on stocking pressure. Because of this, grazing was simulated without stocking pressure, which is accomplished by setting the acres available for grazing unrealistically high.

With the potential impact of stocking pressure out of the way, determination of herd size became primarily a question of computational efficiency. Larger herds require more simulation time while, as they tend to yield less variable results, typically requiring less replication.

To strike a balance between herd size, simulation length, and replication required, trial simulation runs were performed. Also under consideration was the "warm up" period. I.e., the time required for variables, such as age distribution, to reach a semblance of equilibrium. As a result, each round of simulation models a 500 head cow herd over the course of 22 years (with the first 2 years not reported to output), which is replicated 3 times.

To avoid any reduction in accuracy due to a multiple day time-step, I settled on a single day. Given the extreme speed of today's computers, the use of anything other than a single day time-step would be hard to justify.

PHYSICAL ENVIRONMENT

The simulated environment is representative of the Pawnee National Grasslands in northeast Colorado. The area is considered semi-arid, short-grass prairie with an average annual precipitation of 7.8 inches and typical stocking rates of between 40 - 60 acres per cow-calf pair (Senft, 1983). To avoid the effects of stocking pressure, the cowherd has access to 50,000 acres of grassland.

Input parameters to SPUR for the climate (rainfall, temperature, solar radiation and wind), as well as the grass, wildlife and insect species indicative of that area were provided by Hanson et al. (1992).

FEEDING

Primary grazing months run from May through October. During this time, cattle may be supplemented with harvested forage if their average empty body fat dips below 6 percent. This should only occur during severe drought conditions.

Supplementation typically occurs from November through April. To simulate contrasts in environment, high (HF) and low fat (LF) levels of supplementation are provided to the cowherd during these months. Empty body fat targets for HF levels are increased two body condition scores (8 percent; Herd and Sprott, 1986; Houghton et al., 1990) relative to the LF level, which is 10, 12 and 14 percent for the months of November - December, January, and February - April, respectively.

Bred heifers are allocated to a separate feed-group from the rest of the cowherd. Both heifers and cows are supplemented with a ration of 20 percent energy supplement and 80 percent harvested forage. Both groups are fed to the same target levels of body fat.

Calves nursing cows are allowed to eat to their limit of harvested forage until May 1 and don't have access to supplement thereafter. Orphan calves are fed RATION1 *ad libitum*.

Sires are in dry lot from the end to the beginning of breeding season. They are fed harvested forage plus 5 kg of RATION3 starting 2 months prior to breeding season. Hay is provided at a level allowing for 16 percent body fat up to 2 months before turn out and then 20 percent body fat by breeding season.

CULLING, MARKETING, AND REPLACEMENT

Cows are culled and sold at weaning if open, unsound or 12 years of age. Sires are culled and sold when they turn unsound or at breeding season end when reaching six years of age. Replacement sires are purchased March 1, unless a sire becomes unsound or dies, in which case he is replaced immediately. All calves are sold at weaning.

Rather than simulating within-herd replacement, replacement females are purchased from outside the operation. Because disparity in mature weight and milk production is primarily manifested in the cowherd, it is unlikely that simulating the replacement heifer phase would shed much light on our topic. And frankly, herds as diverse as those simulated are typically assembled through purchase. Furthermore, for our purposes, the simulation of internal replacements would require associative mating (i.e., like to like), which would be unconventional and could result in confounding of results with service sire.

Pregnant replacement females are purchased when cows are culled (weaning), in the quantity required to return the herd to its target size. To dampen the effect of selection, females (either culled or dying) are replaced by animals from the same gene pool. To mimic a realistic calving distribution for incoming replacements, each replacement group is split into ninths. This allows for enough variation in DOG for calving to be reasonably continuous for first-calf heifers.

BREEDING, CALVING, CASTRATING, AND WEANING

To avoid confounding between parity and service sire, both cows and heifers are bred to an unrelated breed characterized by Enns' (1995) medium mature weight genotype. Levels of hybrid vigor are set at 4 percent for birth and yearling weight, which are derived from means for these parameters reported by Long (1980) in a review of beef cattle crossbreeding literature.

To arrive at the prediction error associated with sire selection, we assume a Beef Improvement Federation accuracy of .35 for all traits. Given our input variability, this assumption translates into prediction error variances of 3.274, 137.312, and 633.75 kg^2 for birth, yearling, and mature weight, respectively. In addition to the previous parameters, the MNV study required prediction error variances of 5.32 d^2 for gestation length as well as 0.0008 kg TDN^2 for both maintenance and appetite.

Bulls are turned out on the first of June and pulled August first. Therefore, calving occurs between mid-March to mid-May. A cow to bull ratio of roughly 30:1 is maintained. June 1 and November 1 are castration and weaning dates.

OUTPUT

Though I would like to think my strategy in determining appropriate output can be described as "exploratory surgery" it could be argued that the "shotgun" approach best depicts it. As one of my primary objectives was to thoroughly describe CBCPM, I reasoned that a far-reaching summarization of variables was in order. In addition, in a simulation of this size and complexity, the extensive output provides a practical means of "getting under the hood" to identify causal factors behind outcomes. For example, I summarized data on CFCONF, CFDYSF, CFDFF, and post-partum interval, so that the circumstances behind pregnancy rate could be better understood.

For the first study, besides comparing output between simulation scenarios, I was also curious about the contrast between genotypes within a run (e.g. AHH vs. ALL). Therefore, data were separately summarized for both genotypes within a treatment.

ECONOMICS

Unfortunately, the source code for FLIPSIM and FLIPFACE could not be found. Therefore, the thorough, relevant economic analyses intentioned were not possible. Rather than perform rudimentary economic analyses, I felt that presenting data on factors that influence profitability was adequate. After all, in any kind of economic analysis, the assumptions made can have a significant impact on outcome. Therefore, a broad range of assumptions would need to be explored for the results to have any more than limited applicability. Furthermore, when the analysis is primitive, outcomes may be dubious even within the set of assumptions.

The factors presented that most directly affect profitability are the number of cull cows sold, number of replacement females bought, total kg of weaned calf and total kg of herd TDN intake. The ratio of the latter two is also calculated and presented. Though it has served as a proxy for profitability in many studies, the ratio's value along those lines is questionable. I would expect it to render a reasonable picture of biological efficiency, however.

CHAPTER V

RESULTS AND DISCUSSION

Study MNV: Effects of Modeling with Realistic Levels of Variability

The results of simulation with and without realistic levels of variability are summarized in tables 22.a through 22.d for HF environments and tables 23.a through 23.d for LF environments. Statistical F values derived by one-way analysis of variance for comparison between treatments and their corresponding controls can be found in these tables as well.

The F values, which were also calculated for the HV study, are not provided to delineate levels of significance per se. Their primary utility is in providing an objective, systematic means of focusing attention on specific areas in a sea of data. Several factors taint the use of the F values to draw conclusions regarding significance: 1) the sheer number of comparisons result in the F values being substantially overestimated, 2) because not all traits are modeled with random variation, simulated variation between replicates

Table 22.a. Means (M) and F values [a] derived by one-way analysis of variance for comparison between control (00000) and treatment[b] under HF environment (3 replicates/treatment).

Treatment 10000		Treatment 01000		Treatment 00100		Treatment 00010		Treatment 00001		Treatment 11000		Treatment 11111		Control	Description
M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	
January 1st statistics:															
4.99E+02	0.0E+00	4.99E+02	0.0E+00	4.99E+02	0.0E+00	4.99E+02	0.0E+00	4.99E+02	0.0E+00	4.99E+02	0.0E+00	4.99E+02	0.0E+00	4.99E+02	No. Jan. 1
5.97E+00	1.0E+00	6.00E+00	0.0E+00	5.97E+00	1.0E+00	5.93E+00	4.0E+00	5.97E+00	1.0E+00	5.93E+00	4.0E+00	5.87E+00	1.6E+01	6.00E+00	Age Jan. 1 (yrs)
1.89E-01	4.0E+00	1.88E-01	2.5E+01	1.89E-01	4.0E+00	1.88E-01	2.5E+01	1.88E-01	2.5E+01	1.89E-01	4.5E+00	1.87E-01	2.5E+01	1.90E-01	PCFEB Jan. 1 (prop.)
Calving statistics:															
4.97E+02	0.0E+00	4.97E+02	1.0E+00	4.97E+02	1.0E+00	4.97E+02	0.0E+00	4.97E+02	0.0E+00	4.97E+02	0.0E+00	4.97E+02	0.0E+00	4.97E+02	No. calves born
0.00E+00	0.0E+00	0.00E+00	0.0E+00	5.97E+00	3.2E+03	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	6.16E+00	2.0E+04	0.00E+00	SD in POGL (day)
7.30E-02	1.3E+00	6.93E-02	1.4E-02	7.13E-02	3.7E-01	7.23E-02	7.7E-01	7.23E-02	9.8E-01	7.23E-02	5.1E-01	7.40E-02	2.3E+00	6.97E-02	Dystocia (prop.)
5.40E-02	1.0E+00	5.30E-02	1.2E+01	5.53E-02	1.0E+00	5.47E-02	3.2E-02	5.40E-02	2.5E-01	5.50E-02	0.0E+00	5.83E-02	5.3E+00	5.50E-02	Peri-natal death (prop.)
2.19E-01	0.0E+00	2.18E-01	0.0E+00	2.19E-01	0.0E+00	2.18E-01	0.0E+00	2.18E-01	0.0E+00	2.19E-01	0.0E+00	2.17E-01	0.0E+00	2.19E-01	PCFEB at calving (prop.)
3.25E-02	3.6E+00	3.25E-02	3.8E+00	2.36E-02	1.0E+00	3.31E-02	4.5E+00	3.00E-02	1.2E+00	3.98E-02	1.9E+01	4.60E-02	4.1E+01	2.67E-02	SD in PCFEB at calving (prop.)
8.88E+01	1.7E+00	8.88E+01	2.2E+00	8.89E+01	1.8E-01	8.88E+01	1.7E+00	8.88E+01	2.0E+00	8.92E+01	1.0E+00	8.99E+01	6.1E+01	8.90E+01	Day of year of calving
Fertility statistics:															
4.92E+02	4.0E+00	4.92E+02	1.8E+00	4.91E+02	8.0E+00	4.91E+02	8.0E+00	4.91E+02	2.5E+01	4.92E+02	4.5E+00	4.92E+02	4.5E+00	4.93E+02	No. exposed
1.10E+00	3.8E+00	1.13E+00	4.4E+00	3.00E-01	1.0E+00	1.13E+00	4.4E+00	9.67E-01	2.2E+00	1.93E+00	2.5E+01	2.93E+00	7.8E+01	5.67E-01	CFCONF (day)
1.67E-01	5.0E-01	1.67E-01	5.0E-01	1.67E-01	5.0E-01	1.67E-01	5.0E-01	2.00E-01	4.0E+00	2.00E-01	4.0E+00	2.00E-01	4.0E+00	1.33E-01	CFDYSF (day)
-1.93E+00	2.4E+00	-1.64E+00	1.3E+00	-1.92E+00	4.9E+00	-1.74E+00	5.4E-02	-1.80E+00	3.2E-01	-1.46E+00	8.6E+01	-1.71E+00	4.2E-01	-1.76E+00	CFDFF (day)
4.86E+01	1.1E+00	4.89E+01	5.8E+00	4.78E+01	3.7E+00	4.89E+01	5.7E+00	4.87E+01	3.5E+00	4.98E+01	5.0E+01	5.06E+01	9.6E+01	4.83E+01	Post partum interval (day)
3.43E+00	3.1E+00	4.33E+00	1.1E+01	1.93E+00	5.0E-01	3.55E+00	4.2E+00	3.56E+00	4.4E+00	5.84E+00	3.5E+01	8.11E+00	9.6E+01	2.34E+00	SD post partum interval (day)
9.69E-01	0.0E+00	9.67E-01	8.0E+00	9.68E-01	5.3E-01	9.67E-01	3.2E+00	9.66E-01	6.4E+01	9.65E-01	2.9E+01	9.57E-01	5.8E+02	9.69E-01	Pregnancy rate (prop.)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

[b] Traits varied: 10000=POMW; 01000=POMP; 00100=POGL; 00010=PORM; 00001=POAPP; 11000=POMW, POMP; 11111=POMW, POMP, POGL, PORM, POAPP.

Table 22.b. Means (M) and F values [a] derived by one-way analysis of variance for comparison between control (00000) and treatment[b] under HF environment (3 replicates/treatment).

Treatment 10000		Treatment 01000		Treatment 00100		Treatment 00010		Treatment 00001		Treatment 11000		Treatment 11111		Control	Description
M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	
Differential culling statistics:															
-2.00E+00	1.3E+00	0.00E+00	1.0E+00	0.00E+00	1.0E+00	0.00E+00	1.0E+00	0.00E+00	1.0E+00	0.00E+00	2.2E-03	-3.00E+00	1.5E+00	0.00E+00	POMW on preg. females (kg)
0.00E+00	0.0E+00	-2.00E-02	8.2E-02	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	2.0E+00	-8.00E-02	1.1E+01	0.00E+00	POMP on preg. females (kg/day)
0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	2.1E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	5.1E-01	0.00E+00	POGL on preg. females (day)
0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	1.4E-01	0.00E+00	0.0E+00	0.00E+00	0.0E+00	-2.00E-03	1.2E+01	0.00E+00	PORM on preg. females (kg TDN/day)
0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	-1.00E-03	4.0E+00	0.00E+00	0.0E+00	0.00E+00	6.9E+00	0.00E+00	POAAP on preg. females (kg TDN/ day)
Weaning statistics:															
4.51E+02	1.0E+00	4.49E+02	4.0E+00	4.49E+02	5.7E-01	4.49E+02	7.5E-01	4.49E+02	1.6E+01	4.50E+02	1.4E-01	4.48E+02	4.9E+01	4.50E+02	No. weaned
2.32E+02	4.9E+00	2.30E+02	4.2E+01	2.32E+02	2.6E+01	2.32E+02	3.4E+01	2.31E+02	7.8E+00	2.29E+02	1.1E+02	2.28E+02	2.3E+02	2.31E+02	Weaning weight (kg)
2.60E+01	3.9E+00	2.13E+01	4.0E-02	1.88E+01	5.2E-01	1.87E+01	5.7E-01	1.79E+01	1.1E+00	2.83E+01	8.0E+00	2.90E+01	9.6E+00	2.07E+01	SD in weaning weight (kg)
2.28E-01	3.8E+00	2.26E-01	0.0E+00	2.28E-01	7.0E+00	2.25E-01	3.1E-02	2.25E-01	3.1E-01	2.22E-01	2.0E+01	2.24E-01	3.6E+00	2.26E-01	Cow PCFEB at weaning (prop.)
2.07E-02	3.5E+00	2.85E-02	2.5E+01	1.33E-02	1.1E+00	2.56E-02	1.4E+01	2.64E-02	1.7E+01	3.39E-02	5.1E+01	4.32E-02	1.2E+02	1.59E-02	SD in cow PCFEB at weaning (prop.)
5.51E+02	7.1E-01	5.54E+02	1.7E+00	5.54E+02	8.5E+00	5.53E+02	4.0E-01	5.53E+02	1.7E-02	5.49E+02	5.2E+00	5.48E+02	3.7E+00	5.52E+02	Cow weight at weaning (kg)
5.02E+01	4.0E+00	2.77E+01	2.8E-01	2.36E+01	9.7E-01	2.70E+01	3.7E-01	2.72E+01	3.4E-01	5.23E+01	5.0E+00	5.68E+01	7.5E+00	3.24E+01	SD in cow weight at weaning (kg)
5.30E+01	4.0E+00	0.00E+00	1.0E+00	0.00E+00	1.0E+00	0.00E+00	1.0E+00	0.00E+00	1.0E+00	5.32E+01	4.1E+00	5.41E+01	4.3E+00	1.76E+01	SD in dam's POMW at weaning (kg)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

[b] Traits varied: 10000=POMW; 01000=POMP; 00100=POGL; 00010=PORM; 00001=POAPP; 11000=POMW, POMP; 11111=POMW, POMP, POGL, PORM, POAPP.

Table 22.c. Means (M) and F values [a] derived by one-way analysis of variance for comparison between control (00000) and treatment[b] under HF environment (3 replicates/treatment).

Treatment 10000		Treatment 01000		Treatment 00100		Treatment 00010		Treatment 00001		Treatment 11000		Treatment 11111		Control	Description
M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	
Milk production statistics:															
5.61E+00	6.3E+00	5.47E+00	2.9E+01	5.62E+00	6.4E+01	5.61E+00	1.1E+00	5.60E+00	4.5E+00	5.46E+00	8.4E+01	5.43E+00	2.4E+03	5.59E+00	Milk production (kg/day)
9.14E+00	7.2E+00	8.92E+00	2.2E+01	9.15E+00	4.0E+00	9.15E+00	4.0E+00	9.14E+00	7.2E+00	8.94E+00	5.8E+01	8.86E+00	6.4E+02	9.16E+00	Peak milk production (kg/day)
6.53E-01	4.9E+00	2.17E+00	1.3E+04	6.23E-01	4.0E-01	6.27E-01	1.0E-01	6.23E-01	4.0E-01	2.24E+00	2.3E+03	2.15E+00	2.9E+03	6.30E-01	SD in peak milk production (kg/day)
0.00E+00	0.0E+00	2.78E+00	2.3E+05	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	2.85E+00	7.9E+03	2.76E+00	4.0E+03	0.00E+00	SD POMP in cows at weaning (kg/day)
1.83E-02	1.8E+00	2.17E-02	4.8E-02	2.09E-02	3.7E-01	1.94E-02	1.0E+00	1.88E-02	2.1E+00	2.80E-02	4.9E+00	3.00E-02	8.3E+00	2.24E-02	RMPCF over lactation (kg/day)
3.24E-02	6.5E-01	3.23E-02	8.3E-01	3.56E-02	1.9E-01	3.33E-02	2.9E-01	3.13E-02	2.7E+00	3.53E-02	7.1E-02	3.25E-02	9.5E-01	3.47E-02	RMRG over lactation (kg/day)
1.93E-03	1.8E+00	2.00E-03	1.4E-01	1.90E-03	4.0E+00	1.93E-03	8.2E-01	1.90E-03	4.0E+00	2.23E-03	7.2E+00	2.07E-03	2.0E-01	2.03E-03	RDGCW over lactation (kg/day)
Requirement/intake at peak lactation statistics:															
8.36E+00	2.2E+00	8.29E+00	2.6E+01	8.39E+00	1.2E+00	8.37E+00	8.0E-01	8.37E+00	1.4E+00	8.27E+00	2.5E+01	8.22E+00	2.0E+02	8.38E+00	REQ at peak lactation (kg TDN/day)
4.41E-01	4.0E+00	7.10E-01	4.3E+01	2.65E-01	9.4E-01	2.95E-01	2.1E-01	2.97E-01	1.8E-01	8.00E-01	6.2E+01	8.02E-01	6.3E+01	3.22E-01	SD in REQ at peak lactation (kg TDN/day)
5.32E+00	1.5E+00	5.32E+00	5.3E+00	5.34E+00	2.0E+00	5.32E+00	1.0E+00	5.33E+00	8.1E-01	5.29E+00	9.5E+00	5.26E+00	3.6E+01	5.33E+00	RM at peak lactation (kg TDN/day)
3.94E-01	4.2E+00	2.31E-01	5.8E-01	2.22E-01	8.2E-01	2.55E-01	1.2E-01	2.47E-01	2.3E-01	3.98E-01	4.4E+00	4.47E-01	8.6E+00	2.75E-01	SD in RM at peak lactation (kg TDN/day)
8.80E+00	1.2E-01	8.71E+00	1.3E+01	8.86E+00	2.8E+00	8.81E+00	4.5E-02	8.80E+00	1.2E-01	8.65E+00	2.4E+01	8.61E+00	2.7E+01	8.81E+00	CN at peak lactation (kg TDN/day)
6.93E-01	4.2E+00	7.21E-01	5.6E+00	4.39E-01	8.6E-01	4.72E-01	2.9E-01	5.09E-01	1.2E-02	8.99E-01	1.9E+01	9.50E-01	2.4E+01	5.18E-01	SD in CN at peak lactation (kg TDN/day)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

[b] Traits varied: 10000=POMW; 01000=POMP; 00100=POGL; 00010=PORM; 00001=POAPP; 11000=POMW, POMP; 11111=POMW, POMP, POGL, PORM, POAPP.

Table 22.d. Means (M) and F values [a] derived by one-way analysis of variance for comparison between control (00000) and treatment[b] under HF environment (3 replicates/treatment).

Treatment 10000		Treatment 01000		Treatment 00100		Treatment 00010		Treatment 00001		Treatment 11000		Treatment 11111		Control	Description
M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	
Daily nutritional statistics:															
6.63E+00	0.0E+00	6.60E+00	4.0E+01	6.65E+00	2.5E+01	6.65E+00	3.2E+00	6.65E+00	8.0E+00	6.59E+00	1.4E+01	6.56E+00	3.7E+01	6.63E+00	Cow CN (kg/day)
2.36E+00	0.0E+00	2.37E+00	4.0E+00	2.36E+00	0.0E+00	2.36E+00	0.0E+00	2.36E+00	0.0E+00	2.37E+00	4.0E+00	2.35E+00	4.0E+00	2.36E+00	Calf CN (kg/day)
6.50E+00	1.0E+00	6.48E+00	2.5E+01	6.52E+00	1.6E+01	6.52E+00	3.0E+00	6.52E+00	4.0E+00	6.46E+00	2.8E+01	6.43E+00	7.6E+01	6.51E+00	Cow REQ (kg/day)
5.04E+00	1.0E+00	5.04E+00	0.0E+00	5.06E+00	0.0E+00	5.06E+00	4.0E+00	5.06E+00	4.0E+00	5.02E+00	9.1E+00	5.01E+00	4.2E+01	5.05E+00	Cow RM (kg/day)
7.10E+00	9.3E-01	7.04E+00	5.4E-03	7.12E+00	3.0E+00	7.07E+00	3.1E-01	7.04E+00	1.4E-02	6.93E+00	6.0E+01	6.96E+00	2.3E+00	7.04E+00	Cow GF (kg/day)
2.22E+00	4.0E+00	2.26E+00	1.0E+02	2.22E+00	4.0E+00	2.22E+00	1.0E+00	2.22E+00	4.0E+00	2.26E+00	1.0E+02	2.25E+00	1.8E+01	2.23E+00	Calf GF (kg/day)
2.87E+00	1.8E+00	2.89E+00	5.4E-01	2.89E+00	9.2E-01	2.92E+00	6.8E-03	2.93E+00	2.2E-01	2.93E+00	1.0E+00	2.87E+00	1.4E+00	2.92E+00	Cow HF (kg/day)
8.00E-02	4.0E+00	9.00E-02	2.5E+01	7.33E-02	0.0E+00	7.67E-02	5.0E-01	8.00E-02	4.0E+00	9.00E-02	2.5E+01	9.00E-02	2.5E+01	7.33E-02	Calf HF (kg/day)
7.40E-01	1.0E-01	7.37E-01	5.0E-01	7.33E-01	1.8E+00	7.43E-01	0.0E+00	7.53E-01	1.8E+00	7.63E-01	1.8E+01	7.57E-01	2.0E+00	7.43E-01	Cow ES (kg/day)
Economic/bioefficiency statistics:															
5.49E+01	2.8E+00	5.60E+01	1.4E-01	5.59E+01	1.2E-01	5.62E+01	1.3E+00	5.60E+01	6.9E-01	5.74E+01	3.1E+00	6.00E+01	4.8E+01	5.57E+01	No. cull cows sold
6.43E+01	1.0E+00	6.47E+01	5.7E-01	6.50E+01	0.0E+00	6.60E+01	0.0E+00	6.60E+01	0.0E+00	6.63E+01	4.9E+01	6.97E+01	2.9E+02	6.40E+01	No. of replacements
1.04E+05	3.0E+00	1.03E+05	2.3E+01	1.04E+05	1.3E+01	1.04E+05	1.7E+01	1.04E+05	1.2E+01	1.03E+05	5.6E+01	1.02E+05	1.4E+02	1.04E+05	Total kg weaned
1.42E+03	4.4E-02	1.42E+03	4.5E+00	1.43E+03	7.0E+00	1.42E+03	1.2E+00	1.42E+03	1.4E+00	1.41E+03	2.0E+01	1.41E+03	1.2E+02	1.42E+03	Total herd TDN intake (m ton/year)
7.34E+01	5.0E+00	7.29E+01	2.6E+00	7.30E+01	3.4E-01	7.31E+01	1.5E-01	7.30E+01	7.0E+00	7.29E+01	1.9E+00	7.27E+01	1.8E+01	7.31E+01	Total kg weaned / total TDN intake

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

[b] Traits varied: 10000=POMW; 01000=POMP; 00100=POGL; 00010=PORM; 00001=POAPP; 11000=POMW, POMP; 11111=POMW, POMP, POGL, PORM, POAPP.

Table 23.a. Means (M) and F values [a] derived by one-way analysis of variance for comparison between control (00000) and treatments [b] under LF environment (3 replicates/treatment).

Treatment 10000		Treatment 01000		Treatment 00100		Treatment 00010		Treatment 00001		Treatment 11000		Treatment 11111		Control	Description
M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	
January 1st statistics:															
4.99E+02	0.0E+00	4.99E+02	0.0E+00	4.99E+02	0.0E+00	4.99E+02	0.0E+00	4.99E+02	0.0E+00	4.99E+02	0.0E+00	4.99E+02	0.0E+00	4.99E+02	No. Jan. 1
5.33E+00	1.2E+02	5.07E+00	3.6E+02	5.67E+00	1.0E+00	5.40E+00	1.6E+02	5.47E+00	4.9E+01	4.83E+00	1.7E+02	4.63E+00	1.0E+03	5.70E+00	Age Jan. 1 (yrs)
1.30E-01	0.0E+00	1.33E-01	1.6E+01	1.30E-01	0.0E+00	1.32E-01	3.2E+00	1.32E-01	7.2E+00	1.35E-01	2.8E+01	1.39E-01	3.6E+02	1.30E-01	PCFEB Jan. 1 (prop.)
Calving statistics:															
4.97E+02	0.0E+00	4.97E+02	1.0E+00	4.97E+02	1.0E+00	4.97E+02	1.0E+00	4.97E+02	1.0E+00	4.97E+02	1.0E+00	4.97E+02	0.0E+00	4.97E+02	No. calves born
0.00E+00	0.0E+00	0.00E+00	0.0E+00	6.19E+00	1.9E+03	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	6.02E+00	2.9E+04	0.00E+00	SD in POGL (day)
8.70E-02	1.3E+01	8.67E-02	1.1E+01	8.03E-02	1.4E+00	7.90E-02	4.8E-01	8.07E-02	2.0E+00	1.01E-01	7.0E+01	1.02E-01	7.6E+01	7.73E-02	Dystocia (prop.)
5.17E-02	0.0E+00	5.50E-02	1.6E+00	5.30E-02	1.6E+00	5.27E-02	8.2E-01	5.53E-02	1.5E+01	5.40E-02	3.1E+00	5.63E-02	1.8E+01	5.17E-02	Peri-natal death (prop.)
1.40E-01	1.0E+00	1.37E-01	4.1E+01	1.40E-01	1.0E+00	1.40E-01	2.0E+00	1.40E-01	1.0E+00	1.37E-01	1.0E+02	1.35E-01	1.1E+02	1.40E-01	PCFEB at calving (prop.)
3.81E-02	2.8E+02	3.88E-02	2.1E+02	3.10E-02	2.5E+00	3.60E-02	2.2E+02	3.45E-02	1.2E+02	4.39E-02	8.5E+02	4.73E-02	1.6E+03	3.04E-02	SD in PCFEB at calving (prop.)
9.60E+01	1.3E+01	9.66E+01	4.1E+01	9.54E+01	1.1E+00	9.59E+01	1.1E+01	9.56E+01	4.7E+00	9.64E+01	3.4E+01	9.62E+01	2.2E+01	9.51E+01	Day of year of calving
Fertility statistics:															
4.92E+02	1.0E+00	4.92E+02	0.0E+00	4.91E+02	5.0E-01	4.92E+02	1.0E+00	4.91E+02	5.0E-01	4.91E+02	2.0E-01	4.92E+02	0.0E+00	4.92E+02	No. exposed
1.99E+01	8.3E+02	2.19E+01	2.9E+02	1.75E+01	1.6E+01	1.96E+01	1.5E+03	1.90E+01	2.2E+03	2.43E+01	1.6E+03	2.67E+01	1.8E+03	1.74E+01	CFCONF (day)
2.00E-01	0.0E+00	2.00E-01	0.0E+00	2.00E-01	0.0E+00	2.00E-01	0.0E+00	2.00E-01	0.0E+00	3.00E-01	1.1E+15	3.00E-01	1.1E+15	2.00E-01	CFDYSF (day)
-3.93E+00	1.1E-01	-4.53E+00	3.4E+00	-3.89E+00	2.6E-01	-4.01E+00	1.5E-04	-4.12E+00	1.4E-01	-4.74E+00	6.7E+00	-5.09E+00	2.1E+01	-4.01E+00	CFDFF (day)
6.50E+01	1.2E+02	6.63E+01	1.1E+02	6.25E+01	2.0E+00	6.45E+01	8.8E+01	6.39E+01	3.9E+01	6.87E+01	3.0E+02	7.09E+01	6.4E+02	6.22E+01	Post partum interval (day)
1.77E+01	3.3E+02	2.10E+01	4.7E+02	1.16E+01	7.0E+00	1.68E+01	1.9E+03	1.58E+01	4.6E+02	2.60E+01	1.9E+03	2.98E+01	3.2E+03	1.13E+01	SD post partum interval (day)
8.91E-01	2.1E+02	8.65E-01	1.5E+02	9.32E-01	5.0E+00	9.01E-01	2.9E+02	9.07E-01	1.2E+02	8.32E-01	4.5E+02	8.02E-01	1.3E+03	9.40E-01	Pregnancy rate (prop.)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

[b] Traits varied: 10000=POMW; 01000=POMP; 00100=POGL; 00010=PORM; 00001=POAPP; 11000=POMW, POMP; 11111=POMW, POMP, POGL, PORM, POAPP.

Table 23.b. Means (M) and F values [a] derived by one-way analysis of variance for comparison between control (00000) and treatments [b] under LF environment (3 replicates/treatment).

Treatment 10000		Treatment 01000		Treatment 00100		Treatment 00010		Treatment 00001		Treatment 11000		Treatment 11111		Control	Description
M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	
Differential culling statistics:															
-1.90E+01	5.2E+02	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	-1.70E+01	1.4E+03	-1.30E+01	2.9E+02	0.00E+00	POMW on preg. females (kg)
0.00E+00	0.0E+00	-1.32E+00	2.3E+02	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	-1.23E+00	1.7E+03	-1.04E+00	5.5E+02	0.00E+00	POMP on preg. females (kg/day)
0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	4.9E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	5.5E+00	0.00E+00	POGL on preg. females (day)
0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	-1.90E-02	1.1E+03	0.00E+00	0.0E+00	0.00E+00	0.0E+00	-1.90E-02	4.5E+02	0.00E+00	PORM on preg. females (kg TDN/day)
0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	2.00E-02	2.6E+02	0.00E+00	0.0E+00	2.00E-02	3.2E+02	0.00E+00	POAAP on preg. females (kg TDN/ day)
Weaning statistics:															
4.51E+02	1.4E-01	4.49E+02	2.0E+00	4.50E+02	1.8E+00	4.51E+02	0.0E+00	4.51E+02	8.0E-01	4.49E+02	7.0E+00	4.49E+02	1.3E+01	4.51E+02	No. weaned
2.23E+02	5.9E+01	2.18E+02	9.4E+01	2.25E+02	1.7E+00	2.25E+02	5.9E+00	2.25E+02	9.9E+00	2.16E+02	7.9E+02	2.18E+02	2.9E+02	2.26E+02	Weaning weight (kg)
2.50E+01	5.3E+03	1.82E+01	2.8E+00	1.88E+01	1.4E+02	1.94E+01	1.4E+03	1.82E+01	1.0E+02	2.53E+01	4.4E+02	2.75E+01	1.7E+03	1.77E+01	SD in weaning weight (kg)
1.83E-01	7.5E-01	1.87E-01	2.8E-01	1.83E-01	5.8E-01	1.85E-01	1.4E-02	1.87E-01	7.7E-01	1.88E-01	1.5E+00	1.91E-01	7.7E+00	1.85E-01	Cow PCFEB at weaning (prop.)
2.75E-02	7.0E+02	3.67E-02	3.9E+02	1.97E-02	3.6E+00	3.07E-02	1.7E+03	3.25E-02	1.9E+03	4.06E-02	1.6E+03	4.95E-02	2.2E+03	1.93E-02	SD in cow PCFEB at weaning (prop.)
5.09E+02	1.7E+02	5.26E+02	2.2E+00	5.27E+02	1.4E+00	5.27E+02	1.0E+00	5.28E+02	5.4E-04	5.11E+02	1.2E+02	5.15E+02	1.4E+02	5.28E+02	Cow weight at weaning (kg)
4.12E+01	1.5E+03	3.39E+01	3.5E+02	2.62E+01	6.7E+00	3.05E+01	4.8E+03	3.12E+01	2.1E+03	5.15E+01	1.7E+03	5.74E+01	5.0E+03	2.59E+01	SD in cow weight at weaning (kg)
4.88E+01	4.2E+03	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	5.16E+01	5.4E+03	5.26E+01	2.0E+04	0.00E+00	SD in cow POMW at weaning (kg)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

[b] Traits varied: 10000=POMW; 01000=POMP; 00100=POGL; 00010=PORM; 00001=POAPP; 11000=POMW, POMP; 11111=POMW, POMP, POGL, PORM, POAPP.

Table 23.c. Means (M) and F values [a] derived by one-way analysis of variance for comparison between control (00000) and treatments [b] under LF environment (3 replicates/treatment).

Treatment 10000		Treatment 01000		Treatment 00100		Treatment 00010		Treatment 00001		Treatment 11000		Treatment 11111		Control	Description
M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	
Milk production statistics:															
5.56E+00	2.2E+01	4.94E+00	1.5E+02	5.63E+00	2.6E+00	5.60E+00	9.4E+00	5.61E+00	6.8E+00	4.85E+00	7.7E+02	4.92E+00	7.0E+02	5.65E+00	Milk production (kg/day)
8.99E+00	1.1E+02	7.91E+00	2.6E+02	9.09E+00	2.3E+00	9.03E+00	1.1E+02	9.03E+00	4.0E+01	8.05E+00	2.0E+03	8.02E+00	6.3E+02	9.10E+00	Peak milk production (kg/day)
7.10E-01	0.0E+00	1.91E+00	5.1E+03	6.60E-01	0.0E+00	6.80E-01	0.0E+00	6.80E-01	0.0E+00	2.00E+00	8.7E+03	2.02E+00	1.2E+03	6.50E-01	SD in peak milk production (kg/day)
0.00E+00	0.0E+00	2.57E+00	6.5E+03	0.00E+00	0.0E+00	0.00E+00	0.0E+00	0.00E+00	0.0E+00	2.72E+00	9.5E+04	2.76E+00	2.2E+03	0.00E+00	SD POMP in cows at weaning (kg/day)
3.67E-02	4.0E+01	5.66E-02	4.6E+01	2.48E-02	9.5E+00	3.25E-02	2.6E+01	3.09E-02	4.9E+01	6.76E-02	1.3E+02	8.71E-02	5.3E+02	2.10E-02	RMPCF over lactation (kg/day)
3.81E-02	3.6E+00	3.68E-02	1.8E+01	3.66E-02	6.3E+00	3.72E-02	8.4E+00	3.50E-02	6.7E+00	3.72E-02	5.2E+01	3.96E-02	1.2E+02	3.29E-02	RMRG over lactation (kg/day)
2.70E-03	1.9E+01	2.90E-03	9.2E+00	2.33E-03	1.0E+00	2.53E-03	6.2E+00	2.47E-03	4.0E+00	3.17E-03	2.5E+01	3.30E-03	9.1E+01	2.20E-03	RDGCW over lactation (kg/day)
Requirement/intake at peak lactation statistics:															
7.97E+00	2.2E+02	7.76E+00	1.7E+02	8.12E+00	1.2E+00	8.05E+00	7.4E+01	8.11E+00	1.6E+00	7.61E+00	1.5E+03	7.63E+00	4.6E+02	8.13E+00	REQ at peak lactation (kg TDN/day)
3.81E-01	3.5E+03	6.01E-01	7.6E+03	2.66E-01	4.0E-02	2.74E-01	2.4E+01	3.14E-01	5.5E+02	6.65E-01	2.5E+03	7.11E-01	1.4E+03	2.66E-01	SD in REQ at peak lactation (kg TDN/day)
4.93E+00	2.1E+02	5.01E+00	3.0E+01	5.07E+00	1.1E+00	5.00E+00	7.0E+01	5.07E+00	2.0E-01	4.89E+00	3.3E+02	4.87E+00	2.6E+02	5.07E+00	RM at peak lactation (kg TDN/day)
3.35E-01	5.3E+03	2.31E-01	3.4E+01	2.20E-01	1.6E-01	2.32E-01	4.5E+01	2.59E-01	3.9E+02	3.70E-01	1.1E+03	4.15E-01	2.6E+03	2.21E-01	SD in RM at peak lactation (kg TDN/day)
8.85E+00	3.8E+01	8.83E+00	2.0E+01	9.02E+00	2.2E+00	9.03E+00	1.9E+00	9.13E+00	7.0E-01	8.66E+00	1.1E+02	8.73E+00	6.4E+01	9.08E+00	CN at peak lactation (kg TDN/day)
6.02E-01	1.8E+02	5.45E-01	3.5E+01	4.82E-01	1.2E+01	4.68E-01	5.7E+00	6.53E-01	3.0E+02	6.49E-01	3.1E+02	8.57E-01	1.3E+03	4.40E-01	SD in CN at peak lactation (kg TDN/day)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

[b] Traits varied: 10000=POMW; 01000=POMP; 00100=POGL; 00010=PORM; 00001=POAPP; 11000=POMW, POMP; 11111=POMW, POMP, POGL, PORM, POAPP.

Table 23.d. Means (M) and F values [a] derived by one-way analysis of variance for comparison between control (00000) and treatments [b] under LF environment (3 replicates/treatment).

Treatment 10000		Treatment 01000		Treatment 00100		Treatment 00010		Treatment 00001		Treatment 11000		Treatment 11111		Control	Description
M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	
Daily nutritional statistics:															
6.16E+00	2.0E+02	6.08E+00	1.1E+02	6.28E+00	3.2E+00	6.21E+00	1.7E+02	6.26E+00	2.0E+01	5.96E+00	7.4E+02	5.91E+00	2.6E+03	6.30E+00	Cow CN (kg/day)
2.29E+00	1.2E+01	2.25E+00	1.1E+02	2.30E+00	1.0E+00	2.29E+00	4.5E+00	2.29E+00	4.5E+00	2.24E+00	3.6E+02	2.25E+00	2.6E+02	2.30E+00	Calf CN (kg/day)
6.07E+00	2.6E+02	5.98E+00	9.6E+01	6.18E+00	4.0E-01	6.10E+00	1.3E+02	6.15E+00	2.0E+01	5.86E+00	5.5E+02	5.82E+00	1.2E+03	6.19E+00	Cow REQ (kg/day)
4.63E+00	2.9E+02	4.64E+00	2.4E+02	4.74E+00	1.0E+00	4.66E+00	6.3E+02	4.71E+00	2.7E+01	4.52E+00	6.0E+02	4.46E+00	1.7E+03	4.74E+00	Cow RM (kg/day)
7.23E+00	2.2E+01	7.27E+00	7.4E+00	7.42E+00	1.6E+00	7.38E+00	2.5E+00	7.49E+00	2.4E-02	7.13E+00	2.8E+01	7.21E+00	2.6E+01	7.48E+00	Cow GF (kg/day)
2.13E+00	8.0E-01	2.23E+00	1.2E+02	2.14E+00	2.0E-01	2.13E+00	8.0E-01	2.13E+00	2.5E-01	2.23E+00	1.2E+02	2.22E+00	1.5E+02	2.13E+00	Calf GF (kg/day)
2.23E+00	4.7E-01	2.10E+00	5.1E+00	2.24E+00	6.7E-01	2.17E+00	4.1E-01	2.15E+00	1.1E+00	2.04E+00	1.0E+01	1.93E+00	4.6E+01	2.20E+00	Cow HF (kg/day)
7.00E-02	0.0E+00	9.00E-02	0.0E+00	7.00E-02	0.0E+00	7.00E-02	0.0E+00	7.00E-02	0.0E+00	1.00E-01	0.0E+00	1.00E-01	0.0E+00	7.00E-02	Calf HF (kg/day)
5.63E-01	1.6E+00	5.27E-01	3.8E+00	5.57E-01	4.0E-01	5.43E-01	3.1E-01	5.40E-01	5.0E-01	5.13E-01	9.3E+00	4.90E-01	3.6E+01	5.50E-01	Cow ES (kg/day)
Economic/bioefficiency statistics:															
8.63E+01	3.2E+02	9.60E+01	1.3E+02	7.06E+01	3.2E+01	8.23E+01	6.6E+02	7.96E+01	4.7E+02	1.09E+02	8.3E+02	1.22E+02	9.9E+02	6.62E+01	No. cull cows sold
9.53E+01	1.8E+02	1.05E+02	9.8E+01	7.93E+01	1.4E+01	9.13E+01	5.3E+02	8.97E+01	4.2E+02	1.19E+02	3.6E+02	1.31E+02	9.1E+02	7.60E+01	No. of replacements
1.01E+05	2.9E+01	9.79E+04	4.8E+01	1.01E+05	1.8E+00	1.02E+05	3.0E+00	1.01E+05	5.3E+00	9.71E+04	4.0E+02	9.76E+04	1.5E+02	1.02E+05	Total kg weaned
1.32E+03	1.5E+02	1.30E+03	7.4E+01	1.35E+03	1.1E+00	1.33E+03	9.2E+01	1.34E+03	8.3E+01	1.28E+03	4.4E+02	1.27E+03	2.3E+03	1.35E+03	Total herd TDN intake (m ton/year)
7.61E+01	1.0E+01	7.52E+01	1.8E+00	7.53E+01	2.0E+00	7.63E+01	1.2E+01	7.55E+01	1.0E-04	7.59E+01	4.7E+00	7.68E+01	5.2E+01	7.55E+01	Total kg weaned / total TDN intake

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

[b] Traits varied: 10000=POMW; 01000=POMP; 00100=POGL; 00010=PORM; 00001=POAPP; 11000=POMW, POMP; 11111=POMW, POMP, POGL, PORM, POAPP.

is not the same as would be measured among actual ranches, 3) the homogeneity of variance assumption is directly violated in this study.

TREATMENT 00100

To streamline discussion of the other treatments, treatment 00100 is examined independently. Though there are a handful of F values that could be deemed significant, for all practical purposes, adding variation for gestation length did not affect outcomes under either the HF or LF environments.

Gestation length has no deterministic equations directly affecting it, which results in an animal's POGL being equivalent to its phenotype for gestation length (GL) under a one-day time-step. Because of this, any impact on outcomes due to variability in gestation length would necessarily be caused by longer POGL cows being culled because they are open. Though we didn't find it here, it is conceivable that a poorer environment than our LF or a longer gestation genotype may have resulted in culling against increased POGL, which in turn could impact other outcomes.

To quell my curiosity along these lines, runs with a mean POGL of 287 d were made. Under the LF environment only, culling reduced the population's mean POGL by approximately a half-day. The resultant impact of shorter gestation on other outcomes was not investigated.

TREATMENTS 10000, 01000, 00010, 00001, 11000, 11111

Other than the variability of traits under treatment (with input variation) and the variability of PCFEB (a trait strongly influenced by them), the magnitude of differences between control and treatment variables were, for the most part, negligible under the HF environment. Notwithstanding, the disparities between control and treatment outcomes were quite pronounced in many instances under the LF environment. For the sake of efficiency, the following discussion pertains only to the LF environment unless otherwise stated.

CULLING

As mentioned previously, open cows were culled. Under this practice, any factors related, either directly or indirectly, to an animal being open could influence culling. Because treatments allowed for culling based on differences in trait potentials (henceforth referred to as "differential culling"), herd potentials could be altered. Herd potentials were a constant under controls, however, as the lack of individual animal variation made differential culling impossible. This fact exposes another possible liability of simulating without realistic levels of variation.

Using this study as an example, it could be argued that the effects of differential culling constitute confounding with treatment—that to get at the "true" treatment effect it must be avoided. Obviously, this is contingent on what is being investigated. If the interest were in outcomes given specific, constant potential levels (largely an academic exercise) this would be a fair assessment. If the goal is to simulate reality, as is typically the case, incorporating the potential for differential culling is imperative, given it is inescapable in nature.

To describe the impact of culling, the differences in POMW, POMP, PORM, and POAPP between all animals and those becoming pregnant were calculated. As can be seen from table 23.b, all treatment potentials with variability were different to some degree from control. POMW was decreased by 19.0, 17.0, and 13.0 kg under treatments 10000, 11000, and 11111, respectively, which was the precise reduction in W at weaning over the treatments. The reduction in POMP over the same treatments was 1.32, 1.23, and 1.04 kg, respectively, with a corresponding actual decrease in peak production of 1.19, 1.05, and 1.08 kg. Under treatments 00010 and 11111 PORM was decreased by over a third of a standard deviation, while POAPP increased as much, respectively.

An interesting culling pattern exists for both POMW and POMP across treatments where they vary; as the number of potentials with variability increase from one (10000 or 01000) to two (00011) and finally to all (11111), the impact of culling pressure on POMW and POMP is lessened. This is presumably due to culling on the other variables easing pressure on milk and growth. E.g., in a given environment, the efficiency gained by a reduction in PORM should result in more nutrients being available for milk and growth—relaxing culling pressure against them.

The fact that culling had as much impact on POAPP as PORM is somewhat surprising; given our nutritional scenario, I anticipated that culling against poorer doing animals would be more pronounced than culling against sub par appetites. I.e., culling should have a stronger impact on PORM than POAPP because intake is severely limited through the winter months, which allows for differences between animals in PORM to be manifested in traits such as body condition at levels impacting pregnancy status. Under conditions of restricted intake, however, differences in POAPP between animals would be allowed little expression, and thus, have limited influence on fertility.

Though I do not have data to prove it, the prior theory may still hold. However, a counter effect may have served to equalize culling pressure; it is conceivable that pressure on PORM was dampened by our alimentation equations. The rationale is that animals with extreme PORMs may have a disproportionately larger reduction in their maintenance requirements compared to those with lesser PORMs—essentially reducing variability in maintenance requirements, and therefore culling pressure on PORM.

Besides prohibiting differential culling, simulating without individual animal variability prevents the very real phenomenon of selection from occurring. Though selection was not simulated in our study, had we produced rather than purchased our replacements, for instance, it is quite possible that treatment effects on herd potential levels would have been even more pronounced, as the impact would have been cumulative over generations.

FERTILITY

Pregnancy rate is modeled largely as a function of PCFEB at calving. Therefore, based on the fact PCFEB at calving was essentially identical between control and all treatments, a perfunctory assessment may lead to the conclusion that pregnancy rates should be similar.

To the contrary, adding variability reduced pregnancy rates under all treatments (ranging from 3.3 to 13.8 hundredths). The bulk of the reduction can be attributed to the level of variability in PCFEB at calving. As can be seen from table 23.a, as the variability in PCFEB increases from the control level, pregnancy rates decrease.

The impact of increased variability is directly measured through the CFCONF variable. Compared to control, the treatment with the greatest variability in PCFEB (11111) adds an additional 9.3 d to CFCONF, which is the largest disparity. Besides increasing CFCONF, PCFEB variability is also strongly aligned with the level of variability in post-partum interval; treatment 11111 increased the standard deviation in post-partum interval by 1.85 d.

The discrepancies between control and treatments for CFDYSF and CFDFF are also most pronounced for treatment 11111. In comparing 11111 with control, CFDYSF and CFDFF add and deduct roughly one day from post-partum interval, respectively.

The increase in CFDYSF is due to more heifers calving under treatment 11111—primarily a result of decreased pregnancy rates—though some confounding is likely. I.e., besides attributing the larger number of heifers to poorer pregnancy rates brought about by increased variability, the increased dystocia associated with these heifers also reduces pregnancy rates, which in turn leads to more heifers calving.

The decrease in post-partum interval measured by PPDPF is presumably due to differential culling; animals in the 11111 treatment group are lower for growth, milk and maintenance, while having more intake capacity than controls. These factors could certainly lead to more rapid fat accretion post-calving. From this, it is reasonable to infer that the disparity in pregnancy rates between treatments and control would have been even greater sans differential culling.

Though I wasn't certain there would be a treatment effect on pregnancy rate, if there were, I did anticipate its direction. My expectation was based on the fact that as body fat declines, fertility is unfavorably impacted at an escalating rate. This results in differences between animals at the lower ranges of body fat having a greater impact on fertility than differences at higher ranges. Increasing the level of variability spreads out the population—yielding both higher highs and lower lows. Because the lows have more influence, however, the cumulative impact should be a reduction in pregnancy rates.

Though the variability in PCFEB at calving was greater in treatments vs. control under the HF environment, pregnancy rates were not impacted as under the LF environment. The contrast in outcome is due to animals in the HF environment being primarily in the range where fertility is largely unaffected, or at least linearly so, by differences in body fat.

MILK PRODUCTION

Milk production averages over lactation as well as peak levels were notably diminished by treatments 01000, 11000, and 11111 (the treatments in which POMP is varied). There appear to be multiple underlying factors behind this. Though at first blush, the fact that culling decreased POMP by up to 1.32 kg (treatment 01000) seems reason enough for the reduction in milk production. And, given the relatively miniscule impact of the other factors, we would be justified in looking no further from a practical standpoint.

Digging deeper, however, unearths an interesting point; all three output variables quantifying reductions in milk production or growth (RMPCF, RMRG, RDGCW) are larger for these treatments than control, which is surprising given that POMP is decreased for all treatments and POMW is diminished where the prospect exists (treatments 11000 and 11111).

Independent of the effect of variability, lower POMP and POMW should lead to reductions in these output variables under a given environment. This expectation is based on the variables being reflective of the degree to which available energy is insufficient in meeting an animal's needs. With needs reduced due to lowered potentials, it should certainly be easier for animals to meet them under a given environment. An additional caveat is that in the 11111 treatment PORM is decreased and POAPP is increased, which should also affect a reduction in the output variables.

Though the change in potentials likely served to dampen reductions in milk production and growth, based on the output variables actually increasing under the treatments, the cumulative effect due to the interaction between nonlinear equations and variability level was apparently of a greater magnitude in the opposing direction.

Though the change in potentials associated with treatment likely served to reduce the output variables, the effects brought about by the interaction between the nonlinear relationships built into them and the level of variation apparently were of a greater magnitude in the opposing direction.

The reduction in milk production under the 01000, 11000, and 11111 treatments were associated with a corresponding decrease in weaning weight of 8.0, 10.0, and 8.0 kg, respectively. Treatments 11000 and 11111 also led to a significant increase in variability in weaning weight compared to control, however 01000 did not.

In looking at the entire picture, it appears that only by adding variability to direct growth is variability in weaning weight increased appreciably. I based this assumption on the fact that only treatments with variability for growth (10000, 11000, 11111) have much additional variability in weaning weight compared to control.

It is surprising to me that increased variability in milk production did not translate into increased variability in weaning weights. One could speculate that non-milk intake simply offset corresponding differences in milk production. If this were the case, however, the lighter weaning weights found in treatments with reduced milk production are difficult to reconcile—"why didn't calves make up the difference through non-milk nutrition?" being the operative question. As such, I have no plausible explanation why weaning weight variability was not affected by increased variability in milk production.

The disparity between variability in POMP and that actually observed in peak milk production was consistently larger under the LF as compared to the HF environment. This was anticipated, as animals are generally able to produce more closely to their potential under better environments.

INTAKE - REQUIREMENTS

I selected peak-lactation as a point of reference to make inferences about intake and requirements. This seemed logical as, unlike a specific date in time, it represents a clearly defined physiological state consistent to all sample units. It is also the point at which discrepancies arising from differences in milk production are likely most pronounced.

As can be seen from table 23.c, virtually all treatment effects pertaining to intake and requirements are different from control. Given that trait levels were altered due to culling, this is not surprising. What's more, in all instances, the difference is in the direction expected when considering the discrepancies in trait potentials. I.e., REQ, RM, and CN are reduced for treatments with reductions in POMW, POMP, and PORM. With an increase in POAPP (treatment 00001), however, REQ and RM are held in check, while CN is raised slightly.

Beyond variability affecting results through differential culling, it is certainly conceivable that increased variability itself may have impacted outcomes. E.g., because both intake and requirements are partial functions of weight to the ¾ power, increasing variability in weight has the potential to change outcomes for these traits. This is just the tip of the iceberg of possible scenarios where variability may interact with intake and requirements. Unfortunately, variables allowing for parsing outcomes into causal factors were not printed to output.

All treatments increased variability in REQ, RM, and CN. The magnitude of the increase varied widely, however. Treatment 11111 resulted in the largest increase in variability across the board, which stands to reason; because varying each potential individually increased variability to some degree, it seems reasonable to assume that varying them simultaneously should elevate it even more so.

For the most part, the variability in REQ, RM, and CN caused by treatments can be rationalized by shining a light on their inner-workings. For example, because RM, RG, and RL are components of REQ, it is fair to assume that by varying traits that influence them, variability in REQ will be impacted. Further, it also makes sense that the level of influence on REQ variability is reflective of the trait's impact on the components of REQ and in turn the components' contribution to REQ. Thus, because varying POMP caused a dramatic increase in REQ variability, (increasing its standard deviation by 3.35 kg TDN over control), it is safe to assume that POMP strongly affected influential components of REQ.

The component most substantially impacted by POMP is undoubtedly RL; though POMP can influence RM and RG indirectly, it would be inconsequential compared to its much more direct influence on RL. The miniscule (0.1 kg TDN) increase in standard deviation in RM under treatment 01000 lends support for this claim. Also, because even the young cows' growth has tapered off dramatically by this stage, RG's impact on REQ is likely to be minimal under any circumstances. Not only is it reasonable to assume POMP primary influence on REQ is through RL, it appears that RL comprises a weighty portion of REQ. This stands to reason, as our observations are taken at peak lactation.

Obviously, having actual output on RG and RP, as we did for RM, would have served to back up my prior line of reasoning. Though RG and RP may have sufficed for this example, many more variables would have been required to thoroughly describe the roots of the treatment effects on variability for REQ, RM, and CN. Unfortunately, in this area and others, I did not collect data on the entire spectrum of variables needed for making definitive determinations. Though not definitive, in the absence of hard data, I feel speculation derived from knowledge of the model's underlying mechanisms certainly has utility, which is why I offer it up throughout this chapter.

DAILY NUTRITIONAL STATISTICS

As can be seen from table 23.d, with the exception of treatment 00001, cows ate less and needed less to eat on a daily basis when comparing treatments to control. This was presumably due to the reduction in POMW, POMP, and

PORM associated with these treatments. As usual, the largest discrepancies between treatment and control were found in 11111. As would be expected, calves tended towards greater intake of grazed and harvested forage under treatments with lower milk production (01000, 00011, 11111).

I broke down daily intake into the source of nutrition (grazed forage, harvested forage, and energy supplement) with the thought that it would allow for a more refined economic analysis on the data in the event one was undertaken.

ECONOMIC/BIOEFFICIENCY STATISTICS

As can be seen from table 23.d, large discrepancies in the number of cull cows and replacement heifers exist between treatments and control. The most glaring being treatment 11111, under which the firm is required to purchase 55 more replacements annually compared to control. Even 00001, the treatment with the replacement rate most similar to control, requires 13.7 additional replacements.

Replacements required were consistently 9-10 head above cull cows sold across treatments and control—the result of uniform death loss. As death loss was steady, the dramatic differences in replacement rates can be fully attributed to the wide range in pregnancy rates.

Treatments in which POMW and/or POMP varied were associated with lower total kg of calf weaned. This reduction was due to weaning weights being lighter, as treatments did not significantly affect the number of calves weaned. The reduction in kg weaned was met with corresponding reductions in total TDN intake. Because of this, there was little difference between treatment and control for the ratio of kg weaned per ton of TDN consumed (henceforth referred to as the "efficiency ratio"). In fact, only treatment 11111 was found to be significantly different from control. Even so, it only improved the ratio by little more than a single kg per ton of TDN.

Though there are numerous variables that must be considered in determining precise measures of profitability, given the large replacement rate differences, I feel safe in concluding that a substantial disparity in profitability exists between treatments and control.

SUMMARY AND CONCLUSIONS

By proving that outcomes can be affected by doing so, our study calls into question the practice of modeling the biology of cattle production without realistic levels of variability—at least for some traits. As clearly evidenced by the differences between treatments and control in pregnancy rate, a trait's level of variation can interact substantially with nonlinear equations—resulting in flawed outcomes for less than realistic levels of variation. Additionally, without variation in trait potentials, differential culling can not take place, which prevents its very real effects from being expressed.

In our study, compared to the other traits, varying POMW and POMP had the most substantial impact on outcomes; varying PORM and POAPP affected results to a much lesser degree, while varying POGL appeared to have no impact. From these results, one may conclude that varying POMW and POMP is all that is necessary. While that may be true for our specific configuration, I can conceive of several, only slightly different, scenarios that may have led to very different conclusions. A handful of examples follow: 1) if the HF was our only simulated environment, we could have fairly opined that using realistic levels of variability was not necessary for any traits. 2) by simulating longer gestation length potentials, POGL would have been impacted by culling, which may have impacted results. 3) increasing the variability for PORM and POAPP would have likely increased their influence. (The increased variability could be justified biologically. In fact, Johnson et al. (2003) suggests approximately twice the level of variability compared to what we used in parameterizing PORM.)

The point behind these examples is that only relatively minor changes have the potential to alter assessments about which traits need to be varied. Even within the confines of this study, these examples represent a small sub-sample of plausible configurations. If small changes in our limited study could yield such different conclusions about which traits to vary, a fair assumption may be that over the entire spectrum of possible scenarios in a model of CBCPM's nature, most any trait will ultimately warrant variation.

Models like CBCPM are designed with the intention of producing valid results across a vast array of scenarios. In my opinion, providing the capability of simulating trait variability as close as possible to reality should be a goal for model developers. This would provide users with the means to alleviate what appears to be a legitimate concern—that unrealistic levels of variability might impair results—ultimately yielding a model capable of being more robust and valid.

Study HV: Effects of Within-Herd Variability

In this study only growth potentials (POBW, POYW, and POMW) and POMP varied within a base genotype. The MNV study showed that outcomes resulting from varying these traits (treatment 11000) were quite similar to varying all traits (treatment 11111). Further, if we were to go beyond varying growth potentials and POMP, there would certainly be justification for varying several others besides the 3 additional potentials from the MNV study. Backed by extensive literature estimates, I felt comfortable with our growth and POMP parameters. I was concerned, however, that parameterizing a whole gamut of traits, many with little or no data available, had the potential to bias outcomes—though, as we've shown, not doing so may as well.

Although profitability isn't calculated directly, the following discussion focuses primarily on the outcomes likely to impact it. Unlike my synopsis of the MNV study, unless directly related to profitability, the underlying biological intricacies are generally not delved into. Herd levels are used to parse discussion as well as delineate output to tables. As HMM represents the intermediate herd, outcomes from other herds are contrasted with it.

HERD MM

Means and corresponding F values allowing for comparison between treatments and control can be found in tables 24.a - 24.d under HF and 26.a - 26.d under LF environments. Means by subgroups within treatments can be found in tables 25.a - 25.d and 27.a - 27.d under HF and LF environments, respectively.

Output summarized in tables 24.b and 26.b gives rise to the conclusion that differential culling took place under both environments. Under the HF environment, control POMW and POMP values were not impacted by culling; all treatment values are reduced slightly for either one or both potentials, however. As would be expected, culling had a much stronger impact under the LF environment; all treatments and control potentials are substantially below their starting values.

Though a consistent pattern did not exist, the treatment with the most diverse genotypes (AHH,ALL) is the most strongly impacted by culling under both environments. This stands to reason, as profound

Table 24.a. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HMM between control (AMM) and treatments under HF environment (3 replicates/treatment).

Treatment AMH,AML		Treatment AHM,ALM		Treatment AHH, ALL		Treatment AHL, ALH		Control	Description
M	F	M	F	M	F	M	F	M	
January 1st statistics:									
4.99E+02	0.0E+00	4.99E+02	0.0E+00	4.99E+02	0.0E+00	4.99E+02	0.0E+00	4.99E+02	No. Jan. 1
5.90E+00	1.0E+00	5.90E+00	1.0E+00	5.80E+00	1.6E+01	5.93E+00	0.0E+00	5.93E+00	Age Jan. 1 (yrs)
1.88E-01	5.0E-01	1.91E-01	3.2E+01	1.93E-01	1.7E+02	1.90E-01	4.5E+00	1.89E-01	PCFEB Jan. 1 (prop.)
Calving statistics:									
4.97E+02	1.0E+00	4.97E+02	1.0E+00	4.97E+02	0.0E+00	4.97E+02	1.0E+00	4.97E+02	No. calves born
7.33E-02	9.8E-02	7.53E-02	1.1E+00	7.73E-02	3.0E+00	7.57E-02	1.6E+00	7.23E-02	Dystocia (prop.)
5.47E-02	4.5E-02	5.73E-02	3.1E+00	5.47E-02	4.5E-02	5.53E-02	1.0E-01	5.50E-02	Peri-natal death (prop.)
2.18E-01	4.0E+00	2.22E-01	1.0E+02	2.24E-01	2.0E+02	2.20E-01	0.0E+00	2.19E-01	PCFEB at calving (prop.)
4.42E-02	1.3E+02	4.99E-02	2.8E+02	6.08E-02	2.5E+03	4.10E-02	5.5E+00	3.98E-02	SD in PCFEB at calving (prop.)
8.95E+01	2.3E+00	8.96E+01	4.2E+00	9.05E+01	4.7E+01	8.93E+01	1.3E-01	8.92E+01	Day of year of calving
Fertility statistics:									
4.92E+02	1.0E+00	4.92E+02	2.0E+00	4.91E+02	5.0E-01	4.92E+02	0.0E+00	4.92E+02	No. exposed
2.57E+00	7.2E+01	3.13E+00	1.2E+02	4.47E+00	7.2E+02	2.10E+00	3.6E+00	1.93E+00	CFCONF (day)
2.00E-01	0.0E+00	2.00E-01	0.0E+00	2.00E-01	0.0E+00	2.00E-01	0.0E+00	2.00E-01	CFDYSF (day)
-1.31E+00	1.5E+00	-1.41E+00	4.7E-01	-5.67E-01	1.5E+02	-1.78E+00	1.0E+01	-1.46E+00	CFDFF (day)
5.05E+01	4.8E+01	5.10E+01	5.3E+01	5.30E+01	1.8E+03	4.97E+01	1.4E+00	4.98E+01	Post partum interval (day)
7.25E+00	3.2E+02	7.90E+00	8.4E+01	9.82E+00	1.6E+03	5.89E+00	6.2E-02	5.84E+00	SD post partum interval (day)
9.62E-01	6.1E+00	9.59E-01	1.5E+01	9.52E-01	6.0E+01	9.64E-01	3.1E-01	9.65E-01	Pregnancy rate (prop.)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 24.b. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HMM between control (AMM) and treatments under HF environment (3 replicates/treatment).

Treat. AMH,AML		Treat. AHM,ALM		Treat. AHH, ALL		Treat. AHL, ALH		Control	Description
M	F	M	F	M	F	M	F	M	
Differential culling statistics:									
0.00E+00	2.6E-02	-3.00E+00	2.9E+00	-5.00E+00	1.1E+01	0.00E+00	1.0E-03	0.00E+00	POMW on preg. females (kg)
-5.00E-02	7.7E-01	-7.00E-02	1.1E+01	-1.80E-01	3.3E+01	-5.00E-02	2.2E+00	0.00E+00	POMP on preg. females (kg/day)
Weaning statistics:									
4.48E+02	1.8E+00	4.48E+02	2.5E+00	4.49E+02	2.5E-01	4.49E+02	5.7E-01	4.50E+02	No. weaned
2.27E+02	1.6E+01	2.27E+02	3.6E+01	2.23E+02	1.4E+03	2.25E+02	3.9E+02	2.29E+02	Weaning weight (kg)
3.29E+01	1.6E+02	3.10E+01	4.7E+01	3.94E+01	5.6E+02	3.07E+01	4.0E+01	2.83E+01	SD in weaning weight (kg)
2.23E-01	4.5E+00	2.25E-01	6.4E+00	2.21E-01	1.3E+01	2.28E-01	1.3E+01	2.22E-01	Cow PCFEB at weaning (prop.)
4.17E-02	4.5E+02	4.12E-02	5.9E+01	5.77E-02	2.0E+03	3.22E-02	4.5E+00	3.39E-02	SD in cow PCFEB at weaning (prop.)
5.50E+02	6.3E-01	5.46E+02	3.3E+00	5.41E+02	3.8E+01	5.52E+02	2.2E+00	5.49E+02	Cow weight at weaning (kg)
5.48E+01	5.7E+00	9.81E+01	3.7E+03	8.65E+01	1.2E+03	1.12E+02	7.9E+03	5.23E+01	SD in cow weight at weaning (kg)
5.34E+01	3.8E-02	1.11E+02	3.5E+03	1.12E+02	2.6E+03	1.13E+02	4.4E+03	5.32E+01	SD in cow POMW (kg)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 24.c. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HMM between control (AMM) and treatments under HF environment (3 replicates/treatment).

Treat. AMH,AML		Treat. AHM,ALM		Treat. AHH, ALL		Treat. AHL, ALH		Control	Description
M	F	M	F	M	F	M	F	M	
Milk production statistics:									
5.33E+00	6.1E+00	5.41E+00	4.9E+00	5.29E+00	6.3E+01	5.28E+00	2.9E+01	5.46E+00	Milk production (kg/day)
8.73E+00	7.0E+00	8.86E+00	5.1E+00	8.70E+00	3.9E+01	8.64E+00	4.1E+01	8.94E+00	Peak milk production (kg/day)
3.13E+00	7.1E+02	2.19E+00	5.9E-01	3.11E+00	3.5E+02	3.09E+00	3.3E+02	2.24E+00	SD in peak milk production (kg/day)
4.04E+00	1.3E+03	2.82E+00	1.7E-01	3.97E+00	4.3E+02	4.08E+00	4.9E+02	2.85E+00	SD POMP (kg/day)
3.11E-02	3.7E+00	2.92E-02	1.5E-01	5.52E-02	4.1E+01	2.20E-02	1.6E+01	2.80E-02	RMPCF over lactation (kg/day)
3.16E-02	4.2E+00	3.22E-02	2.5E+00	3.19E-02	3.8E+00	3.16E-02	8.0E+00	3.53E-02	RMRG over lactation (kg/day)
2.07E-03	1.3E+01	2.20E-03	2.5E-01	2.27E-03	5.0E-01	2.13E-03	4.5E+00	2.23E-03	RDGCW over lactation (kg/day)
Requirement/intake at peak lactation statistics:									
8.18E+00	7.1E+00	8.22E+00	6.2E+00	8.09E+00	5.6E+01	8.17E+00	1.7E+01	8.27E+00	REQ at peak lactation (kg TDN/day)
1.07E+00	3.3E+02	1.01E+00	1.3E+02	1.57E+00	1.6E+03	8.08E-01	1.7E-01	8.00E-01	SD in REQ at peak lactation (kg TDN/day)
5.27E+00	2.4E+00	5.26E+00	5.7E+00	5.18E+00	6.2E+01	5.29E+00	1.7E-02	5.29E+00	RM at peak lactation (kg TDN/day)
4.07E-01	1.3E+00	7.29E-01	2.4E+03	7.39E-01	1.8E+03	7.42E-01	3.6E+03	3.98E-01	SD in RM at peak lactation (kg TDN/day)
8.53E+00	1.3E+01	8.60E+00	3.5E+00	8.35E+00	1.0E+02	8.65E+00	4.1E-02	8.65E+00	CN at peak lactation (kg TDN/day)
1.10E+00	1.4E+02	1.28E+00	3.6E+02	1.79E+00	2.5E+03	9.87E-01	2.1E+01	8.99E-01	SD in CN at peak lactation (kg TDN/day)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 24.d. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HMM between control (AMM) and treatments under HF environment (3 replicates/treatment).

Treat. AMH,AML		Treat. AHM,ALM		Treat. AHH, ALL		Treat. AHL, ALH		Control	Description
M	F	M	F	M	F	M	F	M	
Daily nutritional statistics:									
6.55E+00	3.1E+00	6.55E+00	5.0E+00	6.53E+00	1.5E+01	6.51E+00	3.3E+01	6.59E+00	Cow CN (kg/day)
2.36E+00	5.0E-01	2.35E+00	1.8E+01	2.32E+00	2.0E+02	2.36E+00	4.0E+00	2.37E+00	Calf CN (kg/day)
6.43E+00	3.5E+00	6.43E+00	1.0E+01	6.42E+00	1.4E+01	6.38E+00	6.2E+01	6.46E+00	Cow REQ (kg/day)
5.01E+00	6.4E-01	5.00E+00	4.5E+00	5.01E+00	8.2E-01	4.97E+00	2.8E+01	5.02E+00	Cow RM (kg/day)
6.93E+00	0.0E+00	6.89E+00	5.0E+00	6.74E+00	9.9E+01	6.97E+00	4.8E-01	6.93E+00	Cow GF (kg/day)
2.27E+00	1.0E+00	2.24E+00	4.9E+01	2.22E+00	1.2E+02	2.27E+00	3.0E+00	2.26E+00	Calf GF (kg/day)
2.89E+00	3.5E+00	2.87E+00	5.2E+01	2.93E+00	3.6E-02	2.78E+00	1.8E+01	2.93E+00	Cow HF (kg/day)
1.07E-01	2.5E+01	9.00E-02	0.0E+00	1.00E-01	0.0E+00	1.20E-01	0.0E+00	9.00E-02	Calf HF (kg/day)
7.57E-01	8.0E-01	7.90E-01	6.4E+01	8.23E-01	1.6E+02	7.50E-01	1.6E+00	7.63E-01	Cow ES (kg/day)
Economic/bioefficiency statistics:									
5.79E+01	2.1E-01	5.92E+01	3.9E+00	6.07E+01	1.2E+01	5.79E+01	1.3E-01	5.74E+01	No. cull cows sold
6.70E+01	4.0E+00	6.73E+01	4.5E+00	7.00E+01	3.0E+01	6.63E+01	0.0E+00	6.63E+01	No. of replacements
1.01E+05	3.4E+02	1.02E+05	3.4E+02	1.00E+05	3.4E+02	1.01E+05	3.4E+02	1.03E+05	Total kg weaned
1.41E+03	3.7E+00	1.41E+03	1.1E+01	1.40E+03	3.2E+01	1.40E+03	3.4E+01	1.41E+03	Total herd TDN intake (m ton/year)
7.21E+01	1.7E+01	7.24E+01	1.6E+01	7.18E+01	3.7E+01	7.20E+01	4.6E+01	7.29E+01	Total kg weaned / total TDN intake

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 25.a. Means (M) by subgroups within HMM under HF environment.

M AMH	M AML	M AHM	M ALM	M AHH	M ALL	M AHL	M ALH	Description
January 1st statistics:								
2.49E+02	2.49E+02	2.50E+02	2.49E+02	2.50E+02	2.50E+02	2.50E+02	2.49E+02	No. Jan. 1
5.83E+00	6.00E+00	5.83E+00	5.97E+00	5.63E+00	5.93E+00	5.90E+00	5.97E+00	Age Jan. 1 (yrs)
1.64E-01	2.13E-01	1.67E-01	2.16E-01	1.46E-01	2.40E-01	1.87E-01	1.92E-01	PCFEB Jan. 1 (prop.)
Calving statistics:								
2.49E+02	2.49E+02	2.49E+02	2.49E+02	2.49E+02	2.48E+02	2.49E+02	2.49E+02	No. calves born
7.43E-02	7.27E-02	7.30E-02	7.80E-02	7.67E-02	7.83E-02	7.03E-02	8.07E-02	Dystocia (prop.)
5.23E-02	5.70E-02	5.77E-02	5.70E-02	5.43E-02	5.47E-02	5.40E-02	5.73E-02	Peri-natal death (prop.)
1.99E-01	2.38E-01	1.88E-01	2.57E-01	1.74E-01	2.74E-01	2.02E-01	2.37E-01	PCFEB at calving (prop.)
4.30E-02	3.59E-02	4.21E-02	2.78E-02	4.18E-02	2.54E-02	3.99E-02	3.36E-02	SD in PCFEB at calving (prop.)
9.03E+01	8.86E+01	9.06E+01	8.87E+01	9.20E+01	8.89E+01	8.96E+01	8.89E+01	Day of year of calving
2.46E+02	2.46E+02	2.46E+02	2.46E+02	2.46E+02	2.46E+02	2.46E+02	2.46E+02	No. exposed
Fertility statistics:								
4.50E+00	6.33E-01	6.13E+00	1.00E-01	8.93E+00	0.00E+00	3.57E+00	6.00E-01	CFCONF (day)
2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	CFDYSF (day)
-7.00E-02	-2.56E+00	-1.30E+00	-1.52E+00	7.03E-01	-1.85E+00	-2.80E+00	-7.57E-01	CFDFF (day)
5.36E+01	4.75E+01	5.41E+01	4.80E+01	5.84E+01	4.75E+01	5.01E+01	4.93E+01	Post partum interval (day)
8.54E+00	3.48E+00	9.98E+00	2.31E+00	1.13E+01	1.89E+00	7.27E+00	3.87E+00	SD post partum interval (day)
9.58E-01	9.66E-01	9.53E-01	9.65E-01	9.40E-01	9.65E-01	9.62E-01	9.65E-01	Pregnancy rate (prop.)

Table 25.b. Means (M) by subgroups within HMM under HF environment.

M AMH	M AML	M AHM	M ALM	M AHH	M ALL	M AHL	M ALH	Description
Differential culling statistics:								
1.00E+00	0.00E+00	-5.00E+00	1.00E+00	-6.00E+00	-1.00E+00	-1.00E+00	1.00E+00	POMW on preg. females (kg)
-1.00E-01	1.00E-02	-2.70E-01	1.00E-01	-3.00E-01	2.00E-02	-6.00E-02	0.00E+00	POMP on preg. females (kg/day)
Weaning statistics:								
2.25E+02	2.24E+02	2.24E+02	2.24E+02	2.25E+02	2.24E+02	2.24E+02	2.25E+02	No. weaned
2.39E+02	2.14E+02	2.41E+02	2.13E+02	2.50E+02	1.97E+02	2.26E+02	2.23E+02	Weaning weight (kg)
2.69E+01	3.37E+01	2.80E+01	2.74E+01	2.69E+01	3.16E+01	3.41E+01	2.66E+01	SD in weaning weight (kg)
1.98E-01	2.49E-01	1.99E-01	2.51E-01	1.72E-01	2.69E-01	2.25E-01	2.31E-01	Cow PCFEB at weaning (prop.)
3.62E-02	2.96E-02	3.80E-02	2.46E-02	3.66E-02	2.27E-02	3.52E-02	2.84E-02	SD in cow PCFEB at weaning (prop.)
5.35E+02	5.66E+02	6.27E+02	4.66E+02	6.08E+02	4.73E+02	6.48E+02	4.55E+02	Cow weight at weaning (kg)
4.91E+01	5.56E+01	5.52E+01	5.52E+01	5.02E+01	5.66E+01	5.78E+01	5.34E+01	SD in cow weight at weaning (kg)
5.31E+01	5.35E+01	5.29E+01	5.45E+01	5.12E+01	5.41E+01	5.20E+01	5.47E+01	SD in cow POMW (kg)

Table 25.c. Means (M) by subgroups within HMM under HF environment.

M AMH	M AML	M AHM	M ALM	M AHH	M ALL	M AHL	M ALH	Description
Milk production statistics:								
6.68E+00	3.99E+00	5.36E+00	5.46E+00	6.63E+00	3.97E+00	3.95E+00	6.61E+00	Milk production (kg/day)
1.09E+01	6.53E+00	8.84E+00	8.88E+00	1.09E+01	6.46E+00	6.50E+00	1.08E+01	Peak milk production (kg/day)
1.88E+00	2.50E+00	2.25E+00	2.12E+00	1.89E+00	2.37E+00	2.48E+00	1.94E+00	SD in peak milk production (kg/day)
2.71E+00	2.82E+00	2.80E+00	2.82E+00	2.71E+00	2.74E+00	2.74E+00	2.80E+00	SD POMP (kg/day)
4.97E-02	1.25E-02	3.61E-02	2.23E-02	9.61E-02	1.49E-02	1.36E-02	3.06E-02	RMPCF over lactation (kg/day)
4.14E-02	2.17E-02	3.14E-02	3.30E-02	4.13E-02	2.25E-02	2.16E-02	4.16E-02	RMRG over lactation (kg/day)
1.07E-03	1.00E-03	1.40E-03	8.00E-04	1.47E-03	8.00E-04	1.40E-03	7.67E-04	RDGCW over lactation (kg/day)
Requirement/intake at peak lactation statistics:								
8.87E+00	7.49E+00	8.83E+00	7.61E+00	9.43E+00	6.74E+00	8.12E+00	8.22E+00	REQ at peak lactation (kg TDN/day)
6.73E-01	9.30E-01	7.53E-01	8.45E-01	6.24E-01	9.44E-01	8.64E-01	7.42E-01	SD in REQ at peak lactation (kg TDN/day)
5.26E+00	5.28E+00	5.85E+00	4.67E+00	5.79E+00	4.58E+00	5.90E+00	4.68E+00	RM at peak lactation (kg TDN/day)
3.77E-01	4.31E-01	4.01E-01	4.47E-01	3.71E-01	4.63E-01	4.15E-01	4.23E-01	SD in RM at peak lactation (kg TDN/day)
9.08E+00	7.98E+00	9.55E+00	7.65E+00	9.87E+00	6.83E+00	9.13E+00	8.18E+00	CN at peak lactation (kg TDN/day)
8.45E-01	1.03E+00	8.67E-01	8.30E-01	8.97E-01	9.13E-01	9.50E-01	7.54E-01	SD in CN at peak lactation (kg TDN/day)

Table 25.d. Means (M) by subgroups within HMM under HF environment.

M AMH	M AML	M AHM	M ALM	M AHH	M ALL	M AHL	M ALH	Description
Daily nutritional statistics:								
6.79E+00	6.32E+00	7.21E+00	5.90E+00	7.44E+00	5.63E+00	6.96E+00	6.07E+00	Cow CN (kg/day)
2.46E+00	2.26E+00	2.49E+00	2.21E+00	2.57E+00	2.08E+00	2.40E+00	2.32E+00	Calf CN (kg/day)
6.67E+00	6.19E+00	7.07E+00	5.78E+00	7.32E+00	5.51E+00	6.80E+00	5.96E+00	Cow REQ (kg/day)
5.02E+00	5.01E+00	5.61E+00	4.40E+00	5.64E+00	4.39E+00	5.57E+00	4.38E+00	Cow RM (kg/day)
7.25E+00	6.61E+00	7.74E+00	6.04E+00	7.89E+00	5.58E+00	7.56E+00	6.39E+00	Cow GF (kg/day)
2.08E+00	2.45E+00	2.48E+00	2.01E+00	2.26E+00	2.18E+00	2.68E+00	1.86E+00	Calf GF (kg/day)
2.92E+00	2.86E+00	3.10E+00	2.64E+00	3.25E+00	2.61E+00	2.95E+00	2.61E+00	Cow HF (kg/day)
7.00E-02	1.47E-01	1.10E-01	7.33E-02	8.00E-02	1.20E-01	1.70E-01	6.00E-02	Calf HF (kg/day)
7.57E-01	7.53E-01	7.90E-01	7.90E-01	8.30E-01	8.23E-01	7.50E-01	7.50E-01	Cow ES (kg/day)
Economic/bioefficiency statistics:								
2.96E+01	2.83E+01	3.10E+01	2.83E+01	3.27E+01	2.80E+01	2.97E+01	2.82E+01	No. cull cows sold
3.43E+01	3.23E+01	3.47E+01	3.20E+01	3.73E+01	3.27E+01	3.37E+01	3.27E+01	No. of replacements
5.36E+04	4.80E+04	5.40E+04	4.78E+04	5.62E+04	4.42E+04	5.08E+04	5.00E+04	Total kg weaned
7.28E+02	6.79E+02	7.68E+02	6.38E+02	7.92E+02	6.06E+02	7.42E+02	6.58E+02	Total herd TDN intake (m ton/year)
7.36E+01	7.07E+01	7.03E+01	7.50E+01	7.09E+01	7.28E+01	6.85E+01	7.60E+01	Total kg weaned / total TDN intake

Table 26.a. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HMM between control (AMM) and treatments under LF (3 replicates/treatment).

Treatment AMH,AML		Treatment AHM,ALM		Treatment AHH, ALL		Treatment AHL, ALH		Control	Description
M	F	M	F	M	F	M	F	M	
January 1st statistics:									
4.99E+02	1.0E+00	4.99E+02	0.0E+00	4.99E+02	0.0E+00	4.99E+02	0.0E+00	4.99E+02	No. Jan. 1
4.40E+00	4.2E+01	4.60E+00	1.2E+01	4.17E+00	8.0E+01	4.70E+00	2.3E+00	4.83E+00	Age Jan. 1 (yrs)
1.35E-01	2.9E-01	1.34E-01	1.1E+00	1.37E-01	4.5E+00	1.34E-01	1.6E+00	1.35E-01	PCFEB Jan. 1 (prop.)
Calving statistics:									
4.97E+02	1.0E+00	4.97E+02	0.0E+00	4.97E+02	2.5E-01	4.97E+02	2.0E+00	4.97E+02	No. calves born
1.04E-01	1.4E+00	9.93E-02	5.8E-01	1.08E-01	1.0E+01	1.03E-01	7.7E-01	1.01E-01	Dystocia (prop.)
5.73E-02	6.2E+00	5.70E-02	2.3E+00	5.63E-02	2.2E+00	5.70E-02	6.7E+00	5.40E-02	Peri-natal death (prop.)
1.35E-01	0.0E+00	1.39E-01	0.0E+00	1.37E-01	1.0E+00	1.37E-01	1.0E+00	1.37E-01	PCFEB at calving (prop.)
5.05E-02	2.6E+02	5.21E-02	5.8E+02	6.04E-02	1.7E+03	4.80E-02	1.6E+02	4.39E-02	SD in PCFEB at calving (prop.)
9.65E+01	2.3E+00	9.59E+01	1.5E+01	9.56E+01	1.2E+02	9.69E+01	7.0E+00	9.64E+01	Day of year of calving
Fertility statistics:									
4.91E+02	2.5E-01	4.92E+02	2.0E-01	4.91E+02	1.4E-01	4.91E+02	5.0E-01	4.91E+02	No. exposed
2.85E+01	2.3E+02	2.66E+01	1.8E+02	3.17E+01	1.4E+03	2.64E+01	9.6E+01	2.43E+01	CFCONF (day)
3.00E-01	0.0E+00	3.00E-01	0.0E+00	3.00E-01	0.0E+00	3.00E-01	0.0E+00	3.00E-01	CFDYSF (day)
-4.77E+00	8.5E-03	-4.28E+00	7.8E+00	-4.67E+00	1.6E-01	-4.72E+00	1.0E-02	-4.74E+00	CFDFF (day)
7.32E+01	9.5E+01	7.16E+01	8.2E+01	7.69E+01	5.2E+02	7.10E+01	5.3E+01	6.87E+01	Post partum interval (day)
3.24E+01	2.8E+02	3.09E+01	1.8E+02	3.92E+01	1.2E+03	2.84E+01	5.4E+01	2.60E+01	SD post partum interval (day)
7.78E-01	6.3E+01	7.97E-01	5.6E+01	7.39E-01	3.3E+02	8.07E-01	2.4E+01	8.32E-01	Pregnancy rate (prop.)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 26.b. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HMM between control (AMM) and treatments under LF environment (3 replicates/treatment).

Treatment AMH,AML		Treatment AHM,ALM		Treatment AHH, ALL		Treatment AHL, ALH		Control	Description
M	F	M	F	M	F	M	F	M	
Differential culling statistics:									
-1.40E+01	2.5E+00	-2.70E+01	2.5E+02	-3.40E+01	3.9E+02	-2.10E+01	3.6E+01	-1.70E+01	POMW on preg. females (kg)
-1.49E+00	1.2E+01	-9.00E-01	1.6E+02	-1.35E+00	3.1E-01	-1.00E+00	1.0E+02	-1.32E+00	POMP on preg. females (kg/day)
Weaning statistics:									
4.47E+02	2.5E+00	4.49E+02	0.0E+00	4.48E+02	1.0E+00	4.49E+02	0.0E+00	4.49E+02	No. weaned
2.13E+02	1.1E+02	2.15E+02	7.7E+00	2.13E+02	3.2E+01	2.12E+02	1.4E+02	2.16E+02	Weaning weight (kg)
2.97E+01	8.9E+01	2.61E+01	4.0E+00	3.23E+01	2.3E+02	2.85E+01	8.1E+01	2.53E+01	SD in weaning weight (kg)
1.82E-01	3.1E+00	1.84E-01	3.3E+00	1.81E-01	1.3E+01	1.88E-01	9.1E-02	1.88E-01	Cow PCFEB at weaning (prop.)
5.20E-02	1.2E+02	4.76E-02	1.9E+02	6.56E-02	8.5E+02	4.11E-02	6.7E-01	4.06E-02	SD in cow PCFEB at weaning (prop.)
5.08E+02	7.2E-01	5.07E+02	6.9E+00	5.02E+02	2.3E+01	5.09E+02	1.0E+00	5.11E+02	Cow weight at weaning (kg)
2.05E+02	1.1E+00	8.47E+01	2.1E+03	6.68E+01	5.8E+02	1.05E+02	5.4E+03	5.15E+01	SD in cow weight at weaning (kg)
5.22E+01	2.0E-01	1.10E+02	4.0E+03	1.11E+02	4.1E+03	1.10E+02	4.9E+03	5.16E+01	SD in cow POMW (kg)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 26.c. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HMM between control (AMM) and treatments under LF environment (3 replicates/treatment).

Treatment AMH,AML		Treatment AHM,ALM		Treatment AHH, ALL		Treatment AHL, ALH		Control	Description
M	F	M	F	M	F	M	F	M	
Milk production statistics:									
4.68E+00	1.3E+01	4.91E+00	5.4E+00	4.75E+00	9.1E+00	4.77E+00	7.1E+00	4.85E+00	Milk production (kg/day)
7.76E+00	1.5E+01	8.06E+00	3.0E+01	7.99E+00	4.3E+00	7.78E+00	2.1E+01	7.91E+00	Peak milk production (kg/day)
2.81E+00	1.9E+03	2.10E+00	1.6E+01	2.67E+00	3.1E+02	2.99E+00	1.6E+03	2.00E+00	SD in peak milk production (kg/day)
4.08E+00	1.7E+03	2.85E+00	1.3E+01	4.04E+00	8.9E+02	4.04E+00	2.7E+03	2.72E+00	SD POMP (kg/day)
1.26E-01	3.6E+01	9.66E-02	4.4E+01	1.86E-01	4.9E+02	7.78E-02	4.1E+00	6.76E-02	RMPCF over lactation (kg/day)
4.35E-02	1.1E+02	4.08E-02	1.0E+01	5.28E-02	4.9E+01	3.63E-02	8.6E-01	3.72E-02	RMRG over lactation (kg/day)
1.72E-02	1.1E+00	4.03E-03	1.8E+01	4.73E-03	5.8E+01	3.57E-03	4.5E+00	3.17E-03	RDGCW over lactation (kg/day)
Requirements/intake at peak lactation:									
7.55E+00	3.7E+00	7.66E+00	1.8E+01	7.62E+00	5.2E-01	7.54E+00	2.3E+01	7.61E+00	REQ at peak lactation (kg TDN/day)
8.96E-01	7.1E+02	8.29E-01	2.9E+02	1.33E+00	1.6E+03	6.73E-01	3.6E-01	6.65E-01	SD in REQ at peak lactation (kg TDN/day)
4.87E+00	1.2E+00	4.87E+00	7.3E+00	4.84E+00	2.1E+01	4.86E+00	1.6E+01	4.89E+00	RM at peak lactation (kg TDN/day)
1.86E+00	1.0E+00	6.32E-01	2.5E+03	5.82E-01	1.9E+03	7.10E-01	5.7E+03	3.70E-01	SD in RM at peak lactation (kg TDN/day)
8.58E+00	2.8E+00	8.59E+00	6.9E+00	8.53E+00	2.6E+01	8.59E+00	4.1E+00	8.66E+00	CN at peak lactation (kg TDN/day)
7.49E-01	4.8E+01	9.70E-01	1.4E+03	1.25E+00	7.4E+03	7.71E-01	2.0E+02	6.49E-01	SD in CN at peak lactation (kg TDN/day)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 26.d. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HMM between control (AMM) and treatments under LF environment (3 replicates/treatment).

Treatment AMH,AML		Treatment AHM,ALM		Treatment AHH, ALL		Treatment AHL, ALH		Control	Description
M	F	M	F	M	F	M	F	M	
Daily nutritional statistics:									
5.90E+00	7.2E+00	5.99E+00	4.8E+00	5.94E+00	1.1E+00	5.90E+00	8.0E+00	5.96E+00	Cow CN (kg/day)
2.23E+00	0.0E+00	2.24E+00	1.0E+00	2.22E+00	2.5E+01	2.24E+00	1.0E+00	2.24E+00	Calf CN (kg/day)
5.82E+00	5.6E+00	5.90E+00	6.4E+00	5.89E+00	3.4E+00	5.80E+00	9.3E+00	5.86E+00	Cow REQ (kg/day)
4.50E+00	4.6E+00	4.53E+00	1.1E+00	4.52E+00	5.0E-01	4.47E+00	1.1E+01	4.52E+00	Cow RM (kg/day)
7.06E+00	5.9E-01	7.03E+00	5.5E+00	6.97E+00	6.9E+00	7.07E+00	1.1E+00	7.13E+00	Cow GF (kg/day)
2.24E+00	1.6E+00	2.20E+00	1.4E+01	2.21E+00	1.2E+01	2.23E+00	1.0E-01	2.23E+00	Calf GF (kg/day)
2.02E+00	2.2E-01	2.15E+00	1.0E+01	2.12E+00	4.1E+00	2.01E+00	5.4E-01	2.04E+00	Cow HF (kg/day)
1.13E-01	1.6E+01	1.00E-01	0.0E+00	1.20E-01	1.7E+14	1.20E-01	1.7E+14	1.00E-01	Calf HF (kg/day)
5.13E-01	0.0E+00	5.50E-01	3.0E+01	5.50E-01	1.7E+01	5.17E-01	9.1E-02	5.13E-01	Cow ES (kg/day)
Economic/bioefficiency statistics:									
1.31E+02	9.6E+01	1.25E+02	1.4E+02	1.49E+02	5.7E+02	1.19E+02	5.2E+01	1.09E+02	No. cull cows sold
1.41E+02	6.8E+01	1.35E+02	4.6E+01	1.59E+02	3.0E+02	1.30E+02	1.9E+01	1.19E+02	No. of replacements
9.51E+04	5.8E+01	9.67E+04	3.8E+00	9.57E+04	1.7E+01	9.50E+04	6.8E+01	9.71E+04	Total kg weaned
1.26E+03	9.1E+00	1.28E+03	2.1E+00	1.27E+03	3.0E+00	1.27E+03	6.9E+00	1.28E+03	Total herd TDN intake (m ton/year)
7.52E+01	1.1E+01	7.53E+01	1.8E+01	7.52E+01	2.5E+01	7.50E+01	5.9E+01	7.59E+01	Total kg weaned / total TDN intake

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 27.a. Means (M) by subgroups within HMM under LF environment.

M AMH	M AML	M AHM	M ALM	M AHH	M ALL	M AHL	M ALH	Description
January 1st statistics:								
2.49E+02	2.50E+02	2.50E+02	2.49E+02	2.49E+02	2.50E+02	2.49E+02	2.50E+02	No. Jan. 1
3.40E+00	5.40E+00	3.60E+00	5.60E+00	2.53E+00	5.77E+00	4.67E+00	4.77E+00	Age Jan. 1 (yrs)
1.08E-01	1.61E-01	1.15E-01	1.54E-01	9.30E-02	1.81E-01	1.40E-01	1.29E-01	PCFEB Jan. 1 (prop.)
Calving statistics:								
2.48E+02	2.49E+02	2.49E+02	2.49E+02	2.49E+02	2.49E+02	2.48E+02	2.49E+02	No. calves born
1.24E-01	8.57E-02	1.15E-01	8.27E-02	1.37E-01	7.97E-02	1.00E-01	1.06E-01	Dystocia (prop.)
5.93E-02	5.43E-02	5.83E-02	5.50E-02	5.73E-02	5.53E-02	5.83E-02	5.57E-02	Peri-natal death (prop.)
1.13E-01	1.56E-01	1.12E-01	1.66E-01	9.47E-02	1.80E-01	1.30E-01	1.43E-01	PCFEB at calving (prop.)
4.56E-02	4.54E-02	4.27E-02	4.53E-02	4.28E-02	4.27E-02	4.62E-02	4.82E-02	SD in PCFEB at calving (prop.)
9.98E+01	9.32E+01	9.99E+01	9.19E+01	1.01E+02	8.98E+01	9.75E+01	9.62E+01	Day of year of calving
2.46E+02	2.46E+02	2.46E+02	2.46E+02	2.45E+02	2.46E+02	2.45E+02	2.46E+02	No. exposed
Fertility statistics:								
4.13E+01	1.58E+01	4.10E+01	1.22E+01	5.54E+01	8.03E+00	2.96E+01	2.31E+01	CFCONF (day)
4.00E-01	2.00E-01	4.00E-01	2.00E-01	4.33E-01	2.00E-01	3.00E-01	3.00E-01	CFDYSF (day)
-4.03E+00	-5.50E+00	-4.90E+00	-3.67E+00	-4.11E+00	-5.23E+00	-5.97E+00	-3.47E+00	CFDFF (day)
8.70E+01	5.95E+01	8.58E+01	5.74E+01	1.02E+02	5.20E+01	7.32E+01	6.88E+01	Post partum interval (day)
3.64E+01	1.98E+01	3.49E+01	1.65E+01	4.03E+01	1.33E+01	2.97E+01	2.60E+01	SD post partum interval (day)
6.57E-01	8.99E-01	6.61E-01	9.32E-01	5.27E-01	9.52E-01	7.72E-01	8.42E-01	Pregnancy rate (prop.)

Table 27.b. Means (M) by subgroups within HMM under LF environment.

M AMH	M AML	M AHM	M ALM	M AHH	M ALL	M AHL	M ALH	Description
Differential culling statistics:								
-1.80E+01	-1.10E+01	-1.90E+01	-4.00E+00	-1.20E+01	-1.00E+00	6.28E+02	4.38E+02	POMW on preg. females (kg)
-1.20E+00	-8.60E-01	-1.64E+00	-3.70E-01	-7.00E-01	-3.50E-01	-1.24E+00	-1.00E+00	POMP on preg. females (kg/day)
Weaning statistics:								
2.22E+02	2.25E+02	2.24E+02	2.25E+02	2.25E+02	2.24E+02	2.24E+02	2.25E+02	No. weaned
2.21E+02	2.04E+02	2.22E+02	2.09E+02	2.31E+02	1.96E+02	2.11E+02	2.13E+02	Weaning weight (kg)
2.39E+01	3.23E+01	2.50E+01	2.55E+01	2.40E+01	3.02E+01	3.20E+01	2.43E+01	SD in weaning weight (kg)
1.48E-01	2.16E-01	1.58E-01	2.11E-01	1.24E-01	2.38E-01	1.92E-01	1.83E-01	Cow PCFEB at weaning (prop.)
3.79E-02	4.00E-02	4.25E-02	3.56E-02	3.17E-02	3.33E-02	4.42E-02	3.68E-02	SD in cow PCFEB at weaning (prop.)
4.83E+02	5.34E+02	5.73E+02	4.41E+02	5.48E+02	4.56E+02	6.00E+02	4.19E+02	Cow weight at weaning (kg)
1.89E+02	2.12E+02	5.45E+01	4.99E+01	4.26E+01	5.30E+01	5.95E+01	4.62E+01	SD in cow weight at weaning (kg)
5.38E+01	5.04E+01	5.46E+01	5.25E+01	5.38E+01	5.24E+01	5.05E+01	5.20E+01	SD in cow POMW (kg)

Table 27.c. Means (M) by subgroups within HMM under LF environment.

M AMH	M AML	M AHM	M ALM	M AHH	M ALL	M AHL	M ALH	Description
Milk production statistics:								
5.88E+00	3.54E+00	4.55E+00	5.26E+00	5.73E+00	3.82E+00	3.34E+00	6.19E+00	Milk production (kg/day)
9.73E+00	5.81E+00	7.59E+00	8.52E+00	9.74E+00	6.22E+00	5.53E+00	1.00E+01	Peak milk production (kg/day)
1.74E+00	2.23E+00	2.12E+00	1.97E+00	1.77E+00	2.21E+00	2.14E+00	1.74E+00	SD in peak milk production (kg/day)
2.98E+00	2.56E+00	2.98E+00	2.66E+00	2.97E+00	2.58E+00	2.58E+00	2.76E+00	SD POMP (kg/day)
2.29E-01	2.66E-02	1.58E-01	3.83E-02	3.60E-01	2.18E-02	5.60E-02	9.93E-02	RMPCF over lactation (kg/day)
6.39E-02	2.40E-02	5.19E-02	3.02E-02	8.41E-02	2.32E-02	3.05E-02	4.20E-02	RMRG over lactation (kg/day)
2.31E-02	9.30E-03	3.10E-03	8.67E-04	3.83E-03	8.67E-04	2.43E-03	1.10E-03	RDGCW over lactation (kg/day)
Requirement/intake at peak lactation statistics:								
8.13E+00	6.98E+00	8.11E+00	7.21E+00	8.75E+00	6.48E+00	7.47E+00	7.62E+00	REQ at peak lactation (kg TDN/day)
6.00E-01	7.47E-01	7.11E-01	6.76E-01	6.06E-01	7.68E-01	7.21E-01	6.08E-01	SD in REQ at peak lactation (kg TDN/day)
4.78E+00	4.97E+00	5.38E+00	4.37E+00	5.29E+00	4.39E+00	5.46E+00	4.26E+00	RM at peak lactation (kg TDN/day)
1.81E+00	1.90E+00	3.77E-01	3.76E-01	3.38E-01	3.91E-01	3.98E-01	3.65E-01	SD in RM at peak lactation (kg TDN/day)
8.86E+00	8.30E+00	9.24E+00	7.94E+00	9.52E+00	7.53E+00	8.98E+00	8.21E+00	CN at peak lactation (kg TDN/day)
6.13E-01	7.58E-01	6.39E-01	7.91E-01	6.09E-01	8.63E-01	6.55E-01	6.81E-01	SD in CN at peak lactation (kg TDN/day)

Table 27.d. Means (M) by subgroups within HMM under LF environment.

M AMH	M AML	M AHM	M ALM	M AHH	M ALL	M AHL	M ALH	Description
Daily nutritional statistics:								
6.08E+00	5.72E+00	6.48E+00	5.50E+00	6.67E+00	5.22E+00	6.24E+00	5.56E+00	Cow CN (kg/day)
2.28E+00	2.18E+00	2.32E+00	2.16E+00	2.38E+00	2.07E+00	2.28E+00	2.21E+00	Calf CN (kg/day)
6.04E+00	5.59E+00	6.41E+00	5.40E+00	6.68E+00	5.10E+00	6.12E+00	5.49E+00	Cow REQ (kg/day)
4.51E+00	4.49E+00	5.02E+00	4.05E+00	5.04E+00	4.00E+00	4.97E+00	3.98E+00	Cow RM (kg/day)
7.13E+00	6.99E+00	7.56E+00	6.49E+00	7.64E+00	6.31E+00	7.55E+00	6.60E+00	Cow GF (kg/day)
2.03E+00	2.45E+00	2.42E+00	1.99E+00	2.21E+00	2.21E+00	2.65E+00	1.82E+00	Calf GF (kg/day)
2.17E+00	1.88E+00	2.35E+00	1.95E+00	2.50E+00	1.75E+00	2.09E+00	1.92E+00	Cow HF (kg/day)
7.33E-02	1.57E-01	1.30E-01	7.00E-02	1.07E-01	1.27E-01	1.87E-01	5.00E-02	Calf HF (kg/day)
5.53E-01	4.73E-01	5.93E-01	5.10E-01	6.40E-01	4.60E-01	5.27E-01	5.07E-01	Cow ES (kg/day)
Economic/bioefficiency statistics:								
8.94E+01	4.17E+01	9.04E+01	3.44E+01	1.18E+02	3.08E+01	6.88E+01	5.06E+01	No. cull cows sold
9.47E+01	4.63E+01	9.53E+01	3.90E+01	1.24E+02	3.50E+01	7.40E+01	5.53E+01	No. of replacements
4.91E+04	4.60E+04	4.96E+04	4.70E+04	5.18E+04	4.39E+04	4.72E+04	4.78E+04	Total kg weaned
6.47E+02	6.18E+02	6.85E+02	5.98E+02	7.03E+02	5.69E+02	6.64E+02	6.02E+02	Total herd TDN intake (m ton/year)
7.59E+01	7.44E+01	7.24E+01	7.86E+01	7.37E+01	7.71E+01	7.10E+01	7.93E+01	Total kg weaned / total TDN intake

differences within a herd imply larger nutrient deficiencies in the extreme POMW and POMP animals than in outliers from a more uniform herd, which leads to an increased likelihood that the extreme animals end up open.

As can be seen from tables 24.d and 26.d, controls required the fewest number of replacements under both HF and LF environments. Though there were only small differences between treatments and control under the HF environment, replacement rates were substantially increased by treatments under the LF environment.

Within HMM, as well as all other herds in this study, there were no differences in death loss between treatments and control. Therefore, within all herds, disparities in replacement rates are fully attributable to pregnancy rates. As in the MNV study, it is likely that treatment effects on fertility would have been even greater had culling not reduced potentials.

Treatment AHH,ALL had the poorest pregnancy rate—a reduction of 9.3 hundredths from control. Table 27.a reveals that the AHH and ALL genotypes within this treatment posted PCFEB at calving of 0.095 and 0.180 with corresponding pregnancy rates of 0.527 and 0.952, respectively. The dramatic differences were certainly anticipated, particularly under the LF environment, as the contrast in size and milk production between the genotypes is vast.

Notable data from table 25.a, are the PCFEB (0.174 and 0.274) and pregnancy rates (0.940 and 0.965) for the AHH and ALL genotypes under the HF environment, respectively. As in the LF environment, a large discrepancy in PCFEB exists. At these levels of body fat its impact on fertility is negligible, however.

The other treatment dealing with extremes in both growth and milk production (AHL,ALH) resulted in considerably better pregnancy rates under the LF environment than did AHH,ALL (0.807 for AHL,ALH vs. 0.739 for AHH,ALL). This was due to the extremes existing within animals, rather than between them. This configuration resulted in animals being more similar in their nutrient needs, which is substantiated by their more uniform PCFEB values of 0.130 and 0.143 for AHL and ALH, respectively.

As can be seen from tables 24.d and 26.d, controls had the most favorable efficiency ratios under both HF and LF environments. It can also be seen that controls posted the largest values for the ratio's numerator (total kg weaned). As was the case throughout the entire study, there were no differences in weaning rates. Therefore, any differences in kg weaned are due to differences in weaning weights.

Discrepancies between treatments and control for weaning weight are likely attributable to multiple factors. Though assessing the precise impact of these factors is not possible, I feel illuminating the probable causes has utility. With the exception of treatment AHM,ALM under the LF environment, controls outdo treatments for average daily milk production. This appears to be a plausible outcome, given that controls are towards the upper end for both POMW and POMP. Besides the direct impact of POMW and POMP, it is conceivable that interactions between milk production and calf growth potential influenced weaning weights. The lower pregnancy rates associated with treatment effects are also likely to have reduced weaning weights through treatment herds having a higher percentage of lighter milking, first-parity females.

Though differences were not large enough to result in an efficiency ratio advantage, treatments tended to reduce total TDN intake compared to control. This is surely, in part, due to culling reducing potentials under most treatments. Because first-calf heifers have lower intakes, the fact they were represented in higher portions in treatments vs. control may have also diminished TDN intake. (The reference to heifers having lower intakes is backed up by unpublished data; beyond that published, all output was further segmented by age. I decided against publishing it, as output was already quite extensive.)

HERD HM

Means and corresponding F values allowing for comparison between treatments and control under both HF and LF environments can be found in table 28.a - 28.d. Means by subgroups within treatments can be found in table 29.a - 29.d.

As can be seen from table 28.d, efficiency ratios were slightly lower for treatments under both environments. Though an insignificant difference in replacement rates were found under the HF environment, the firm was required to purchase 19 more females annually in treatment compared to control under the LF environment. The mechanisms underlying these treatment effects are likely similar to that described in the HMM segment.

Table 28.a. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HHM between control (AHM) and treatments under HF and LF environments (3 replicates/treatment).

Environment:H			Environment:L			
Treatment AHH,AHL		Control	Treatment AHH,AHL		Control	Description
M	F	M	M	F	M	
January 1st statistics:						
4.99E+02	0.0E+00	4.99E+02	4.99E+02	0.0E+00	4.99E+02	No. Jan. 1
5.93E+00	4.0E+00	6.00E+00	4.43E+00	1.2E+02	4.80E+00	Age Jan. 1 (yrs)
1.85E-01	8.0E+00	1.87E-01	1.27E-01	2.5E-01	1.27E-01	PCFEB Jan. 1 (prop.)
Calving statistics:						
4.98E+02	4.0E+00	4.97E+02	4.97E+02	0.0E+00	4.97E+02	No. calves born
7.00E-02	2.4E+00	6.80E-02	9.83E-02	1.1E+01	9.20E-02	Dystocia (prop.)
5.33E-02	1.1E+00	5.53E-02	5.43E-02	4.0E-01	5.50E-02	Peri-natal death (prop.)
2.17E-01	0.0E+00	2.18E-01	1.35E-01	0.0E+00	1.37E-01	PCFEB at calving (prop.)
4.32E-02	1.1E+02	3.71E-02	4.91E-02	4.1E+02	4.29E-02	SD in PCFEB at calving (prop.)
8.94E+01	1.7E+01	8.89E+01	9.72E+01	6.2E-01	9.70E+01	Day of year of calving
4.92E+02	4.0E+00	4.91E+02	4.91E+02	5.0E-01	4.92E+02	No. exposed
Fertility statistics:						
2.50E+00	1.6E+02	1.67E+00	2.78E+01	9.6E+02	2.40E+01	CFCONF (day)
1.33E-01	1.0E+00	1.00E-01	3.00E-01	1.1E+15	2.00E-01	CFDYSF (day)
-1.25E+00	2.2E+01	-1.71E+00	-4.00E+00	4.8E-02	-3.97E+00	CFDFF (day)
5.06E+01	6.7E+01	4.93E+01	7.34E+01	4.4E+02	6.93E+01	Post partum interval (day)
6.86E+00	2.4E+02	4.99E+00	3.09E+01	5.7E+02	2.49E+01	SD post partum interval (day)
9.64E-01	5.8E+00	9.66E-01	7.84E-01	1.5E+02	8.29E-01	Pregnancy rate (prop.)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 28.b. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HMM between control (AHM) and treatments under HF and LF environments (3 replicates/treatment).

Environment:H			Environment:L			
Treatment AHH,AHL		Control	Treatment AHH,AHL		Control	Description
M	F	M	M	F	M	
Differential culling statistics:						
0.00E+00	3.0E-01	-1.00E+00	-1.40E+01	2.5E+01	-1.90E+01	POMW on preg. females (kg)
-7.00E-02	1.7E+00	0.00E+00	-1.44E+00	1.8E+01	-1.16E+00	POMP on preg. females (kg/day)
Weaning statistics:						
4.50E+02	0.0E+00	4.50E+02	4.50E+02	0.0E+00	4.50E+02	No. weaned
2.41E+02	4.5E+01	2.44E+02	2.25E+02	1.0E+02	2.30E+02	Weaning weight (kg)
3.40E+01	2.7E+02	2.92E+01	3.02E+01	2.4E+02	2.63E+01	SD in weaning weight (kg)
2.17E-01	5.8E+00	2.20E-01	1.68E-01	5.8E+00	1.73E-01	Cow PCFEB at weaning (prop.)
4.22E-02	1.1E+02	3.19E-02	5.20E-02	6.2E+02	4.17E-02	SD in cow PCFEB at weaning (prop.)
6.44E+02	1.1E+00	6.45E+02	5.91E+02	2.5E+00	5.91E+02	Cow weight at weaning (kg)
6.02E+01	7.3E+00	5.73E+01	6.17E+01	5.5E+01	5.45E+01	SD in cow weight at weaning (kg)
5.34E+01	1.5E+00	5.48E+01	5.26E+01	1.0E+00	5.17E+01	SD in cow POMW (kg)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 28.c. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HMM between control (AHM) and treatments under HF and LF environments (3 replicates/treatment).

Environment:H			Environment:L			
Treatment AHH,AHL		Control	Treatment AHH,AHL		Control	Description
M	F	M	M	F	M	
Milk production statistics:						
5.36E+00	1.5E+01	5.53E+00	4.71E+00	9.2E+01	4.91E+00	Milk production (kg/day)
8.83E+00	1.5E+01	9.08E+00	7.90E+00	2.4E+01	8.10E+00	Peak milk production (kg/day)
3.24E+00	7.0E+02	2.25E+00	2.87E+00	1.3E+03	2.06E+00	SD in peak milk production (kg/day)
4.09E+00	9.9E+02	2.77E+00	4.08E+00	1.8E+03	2.71E+00	SD POMP (kg/day)
3.00E-02	6.0E+01	1.71E-02	1.46E-01	6.7E+01	7.83E-02	RMPCF over lactation (kg/day)
3.17E-02	7.1E-01	3.05E-02	4.66E-02	4.1E+00	4.07E-02	RMRG over lactation (kg/day)
2.70E-03	1.5E+00	2.60E-03	5.07E-03	2.9E+01	4.50E-03	RDGCW over lactation (kg/day)
Requirement/intake at peak lactation statistics:						
8.96E+00	2.1E+01	9.09E+00	8.29E+00	1.7E+01	8.35E+00	REQ at peak lactation (kg TDN/day)
1.09E+00	9.1E+02	8.25E-01	8.80E-01	1.8E+03	6.64E-01	SD in REQ at peak lactation (kg TDN/day)
6.00E+00	1.9E+01	6.04E+00	5.52E+00	6.2E+00	5.54E+00	RM at peak lactation (kg TDN/day)
4.31E-01	8.7E-02	4.33E-01	3.99E-01	2.1E+01	3.78E-01	SD in RM at peak lactation (kg TDN/day)
9.32E+00	1.3E+01	9.51E+00	9.32E+00	7.6E+00	9.37E+00	CN at peak lactation (kg TDN/day)
1.11E+00	4.9E+02	9.35E-01	7.77E-01	8.8E+01	6.97E-01	SD in CN at peak lactation (kg TDN/day)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 28.d. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HMM between control (AHM) and treatments under HF and LF environments (3 replicates/treatment).

Environment:H			Environment:L			
Treatment AHH,AHL		Control	Treatment AHH,AHL		Control	Description
M	F	M	M	F	M	
Daily nutritional statistics:						
7.26E+00	1.2E+01	7.31E+00	6.56E+00	2.3E+01	6.62E+00	Cow CN (kg/day)
2.51E+00	1.0E+00	2.51E+00	2.37E+00	1.8E+01	2.39E+00	Calf CN (kg/day)
7.12E+00	1.2E+01	7.17E+00	6.48E+00	1.9E+01	6.53E+00	Cow REQ (kg/day)
5.65E+00	3.1E+00	5.66E+00	5.09E+00	5.8E+00	5.12E+00	Cow RM (kg/day)
7.54E+00	8.1E+00	7.71E+00	7.57E+00	1.6E+01	7.65E+00	Cow GF (kg/day)
2.50E+00	6.1E+00	2.47E+00	2.45E+00	8.0E-01	2.45E+00	Calf GF (kg/day)
3.29E+00	2.6E+00	3.23E+00	2.45E+00	1.1E+00	2.48E+00	Cow HF (kg/day)
1.27E-01	1.8E+01	1.07E-01	1.33E-01	1.8E+01	1.13E-01	Calf HF (kg/day)
8.63E-01	3.3E+00	8.43E-01	6.23E-01	2.0E-01	6.27E-01	Cow ES (kg/day)
Economic/bioefficiency statistics:						
5.71E+01	4.7E+00	5.61E+01	1.29E+02	1.0E+02	1.10E+02	No. cull cows sold
6.60E+01	5.7E-01	6.53E+01	1.39E+02	9.2E+01	1.20E+02	No. of replacements
1.09E+05	2.3E+01	1.10E+05	1.01E+05	5.2E+01	1.04E+05	Total kg weaned
1.55E+03	5.6E+00	1.56E+03	1.40E+03	2.1E+01	1.41E+03	Total herd TDN intake (m ton/year)
7.00E+01	5.5E+00	7.06E+01	7.25E+01	6.1E+01	7.34E+01	Total kg weaned / total TDN intake

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 29.a. Means (M) by subgroups AHH and AHL within HHM under HF and LF environments.

Environment:HF		Environment:LF		
M AHH	M AHL	M AHH	M AHL	Description
January 1st statistics:				
2.50E+02	2.49E+02	2.49E+02	2.49E+02	No. Jan. 1
5.93E+00	6.00E+00	3.47E+00	5.37E+00	Age Jan. 1 (yrs)
1.61E-01	2.11E-01	1.01E-01	1.52E-01	PCFEB Jan. 1 (prop.)
Calving statistics:				
2.49E+02	2.49E+02	2.48E+02	2.49E+02	No. calves born
6.97E-02	7.00E-02	1.16E-01	8.03E-02	Dystocia (prop.)
5.03E-02	5.60E-02	5.33E-02	5.50E-02	Peri-natal death (prop.)
1.97E-01	2.37E-01	1.14E-01	1.56E-01	PCFEB at calving (prop.)
4.17E-02	3.44E-02	4.31E-02	4.55E-02	SD in PCFEB at calving (prop.)
9.00E+01	8.89E+01	1.00E+02	9.40E+01	Day of year of calving
2.46E+02	2.46E+02	2.46E+02	2.46E+02	No. exposed
Fertility statistics:				
4.43E+00	5.00E-01	3.98E+01	1.59E+01	CFCONF (day)
1.00E-01	1.33E-01	3.33E-01	2.00E-01	CFDYSF (day)
-1.00E-01	-2.40E+00	-3.29E+00	-4.71E+00	CFDFF (day)
5.36E+01	4.75E+01	8.62E+01	6.06E+01	Post partum interval (day)
8.08E+00	3.00E+00	3.47E+01	1.91E+01	SD post partum interval (day)
9.61E-01	9.67E-01	6.65E-01	9.04E-01	Pregnancy rate (prop.)

Table 29.b. Means (M) by subgroups AHH and AHL within HHM under HF and LF environments.

Environment:HF		Environment:LF		
M AHH	M AHL	M AHH	M AHL	Description
Differential culling statistics:				
-2.00E+00	1.00E+00	-1.90E+01	-1.00E+01	POMW on preg. females (kg)
-1.00E-01	-5.00E-02	-1.20E+00	-8.10E-01	POMP on preg. females (kg/day)
Weaning statistics:				
2.26E+02	2.24E+02	2.25E+02	2.25E+02	No. weaned
2.54E+02	2.28E+02	2.33E+02	2.17E+02	Weaning weight (kg)
2.82E+01	3.46E+01	2.43E+01	3.31E+01	SD in weaning weight (kg)
1.91E-01	2.43E-01	1.35E-01	2.02E-01	Cow PCFEB at weaning (prop.)
3.65E-02	2.95E-02	3.63E-02	4.25E-02	SD in cow PCFEB at weaning (prop.)
6.25E+02	6.64E+02	5.60E+02	6.21E+02	Cow weight at weaning (kg)
5.36E+01	6.00E+01	4.66E+01	5.98E+01	SD in cow weight at weaning (kg)
5.34E+01	5.32E+01	5.39E+01	5.10E+01	SD in cow POMW (kg)

Table 29.c. Means (M) by subgroups AHH and AHL within HHM under HF and LF environments.

Environment:HF		Environment:LF		
M AHH	M AHL	M AHH	M AHL	Description
Milk production statistics:				
6.76E+00	3.95E+00	5.89E+00	3.56E+00	Milk production (kg/day)
1.11E+01	6.51E+00	9.90E+00	5.90E+00	Peak milk production (kg/day)
2.02E+00	2.50E+00	1.76E+00	2.31E+00	SD in peak milk production (kg/day)
2.82E+00	2.75E+00	2.97E+00	2.62E+00	SD POMP (kg/day)
5.08E-02	9.10E-03	2.67E-01	2.92E-02	RMPCF over lactation (kg/day)
4.22E-02	2.11E-02	6.97E-02	2.42E-02	RMRG over lactation (kg/day)
1.33E-03	1.37E-03	3.17E-03	1.87E-03	RDGCW over lactation (kg/day)
Requirement/intake at peak lactation statistics:				
9.66E+00	8.26E+00	8.85E+00	7.72E+00	REQ at peak lactation (kg TDN/day)
6.97E-01	9.36E-01	5.78E-01	7.57E-01	SD in REQ at peak lactation (kg TDN/day)
5.97E+00	6.03E+00	5.40E+00	5.65E+00	RM at peak lactation (kg TDN/day)
3.98E-01	4.56E-01	3.49E-01	4.05E-01	SD in RM at peak lactation (kg TDN/day)
9.87E+00	8.77E+00	9.58E+00	9.05E+00	CN at peak lactation (kg TDN/day)
8.69E-01	1.03E+00	6.53E-01	7.92E-01	SD in CN at peak lactation (kg TDN/day)

Table 29.d. Means (M) by subgroups AHH and AHL within HHM under HF and LF environments.

Environment:HF		Environment:LF		
M AHH	M AHL	M AHH	M AHL	Description
Daily nutritional statistics:				
7.49E+00	7.03E+00	6.72E+00	6.40E+00	Cow CN (kg/day)
2.61E+00	2.42E+00	2.41E+00	2.33E+00	Calf CN (kg/day)
7.37E+00	6.88E+00	6.70E+00	6.26E+00	Cow REQ (kg/day)
5.65E+00	5.65E+00	5.08E+00	5.10E+00	Cow RM (kg/day)
7.86E+00	7.21E+00	7.61E+00	7.54E+00	Cow GF (kg/day)
2.29E+00	2.71E+00	2.23E+00	2.67E+00	Calf GF (kg/day)
3.33E+00	3.27E+00	2.61E+00	2.30E+00	Cow HF (kg/day)
8.00E-02	1.77E-01	9.00E-02	1.83E-01	Calf HF (kg/day)
8.63E-01	8.63E-01	6.63E-01	5.80E-01	Cow ES (kg/day)
Economic/bioefficiency statistics:				
2.89E+01	2.82E+01	8.87E+01	4.06E+01	No. cull cows sold
3.27E+01	3.23E+01	9.37E+01	4.50E+01	No. of replacements
5.73E+04	5.12E+04	5.25E+04	4.88E+04	Total kg weaned
8.02E+02	7.50E+02	7.11E+02	6.86E+02	Total herd TDN intake (m ton/year)
7.15E+01	6.82E+01	7.38E+01	7.12E+01	Total kg weaned / total TDN intake

As would be expected, weaning weights were higher in HHM vs. HMM, as were TDN intakes. In contrasting efficiency ratios, HHM control was poorer than HMM control under both environments. In comparing controls, there were little differences in replacement rates, however. This was expected, as both herds were fed to the same body fat target at calving.

Of note is that the efficiency ratios for HHM are the poorest across all herds. The sub par efficiency is presumably attributable to a reverse "terminal sire" effect. I.e., using medium growth sires on high-growth dams is counter to tapping into the increased efficiency associated with using high-growth sires on smaller mature size dams.

HERD MH

Means and corresponding F values allowing for comparison between treatments and control under both HF and LF environments can be found in table 30.a - 30.d. Means by subgroups within treatments can be found in table 31.a - 31.d.

For all practical purposes, there were no differences in weaning weights or TDN intakes between treatment and control under both environments. Consequently, the

Table 30.a. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HMH between control (AMH) and treatments under HF and LF environments (3 replicates/treatment).

Environment:H			Environment:L			
Treatment AHH,ALH		Control	Treatment AHH,ALH		Control	Description
M	F	M	M	F	M	
January 1st statistics:						
4.99E+02	0.0E+00	4.99E+02	4.99E+02	0.0E+00	4.99E+02	No. Jan. 1
5.90E+00	1.0E+00	5.93E+00	4.50E+00	7.5E+01	5.00E+00	Age Jan. 1 (yrs)
1.91E-01	7.2E+01	1.87E-01	1.23E-01	1.2E+01	1.21E-01	PCFEB Jan. 1 (prop.)
Calving statistics:						
4.97E+02	5.0E-01	4.98E+02	4.97E+02	1.0E+00	4.97E+02	No. calves born
7.70E-02	3.4E+00	7.43E-02	1.06E-01	8.1E+01	9.03E-02	Dystocia (prop.)
5.33E-02	0.0E+00	5.33E-02	5.73E-02	1.7E-01	5.63E-02	Peri-natal death (prop.)
2.25E-01	1.7E+02	2.21E-01	1.43E-01	1.6E+01	1.42E-01	PCFEB at calving (prop.)
5.25E-02	7.7E+02	4.02E-02	5.67E-02	1.4E+03	4.45E-02	SD in PCFEB at calving (prop.)
8.98E+01	4.9E+00	8.93E+01	9.63E+01	6.7E+00	9.69E+01	Day of year of calving
Fertility statistics:						
4.92E+02	2.0E+00	4.92E+02	4.91E+02	4.0E+00	4.92E+02	No. exposed
3.10E+00	5.1E+02	1.80E+00	2.64E+01	3.4E+02	2.16E+01	CFCONF (day)
2.00E-01	0.0E+00	2.00E-01	3.00E-01	1.1E+15	2.00E-01	CFDYSF (day)
-3.47E-01	1.6E+01	-4.37E-01	-2.85E+00	1.1E-03	-2.84E+00	CFDFF (day)
5.21E+01	1.4E+03	5.08E+01	7.31E+01	3.0E+02	6.78E+01	Post partum interval (day)
7.38E+00	1.1E+02	5.61E+00	3.18E+01	6.6E+02	2.26E+01	SD post partum interval (day)
9.62E-01	1.3E+01	9.64E-01	7.84E-01	2.2E+02	8.52E-01	Pregnancy rate (prop.)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 30.b. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HMH between control (AMH) and treatments under HF and LF environments (3 replicates/treatment).

Environment:H			Environment:L			
Treatment AHH,ALH		Control	Treatment AHH,ALH		Control	Description
M	F	M	M	F	M	
Differential culling statistics:						
-1.00E+00	8.5E-01	-1.00E+00	-3.50E+01	1.1E+03	-2.00E+01	POMW on preg. females (kg)
1.00E-01	1.3E+00	0.00E+00	-6.00E-01	1.2E+01	-8.00E-01	POMP on preg. females (kg/day)
Weaning statistics:						
4.51E+02	1.0E+00	4.50E+02	4.48E+02	4.5E-01	4.49E+02	No. weaned
2.38E+02	1.2E+01	2.40E+02	2.27E+02	2.8E+00	2.28E+02	Weaning weight (kg)
3.08E+01	1.6E+02	2.77E+01	2.57E+01	7.5E+01	2.52E+01	SD in weaning weight (kg)
2.14E-01	0.0E+00	2.14E-01	1.67E-01	7.8E-01	1.68E-01	Cow PCFEB at weaning (prop.)
4.49E-02	3.3E+02	3.45E-02	4.94E-02	3.4E+02	3.91E-02	SD in cow PCFEB at weaning (prop.)
5.41E+02	1.4E+01	5.44E+02	4.94E+02	3.4E+01	5.00E+02	Cow weight at weaning (kg)
9.43E+01	1.8E+03	5.14E+01	7.57E+01	3.9E+03	4.70E+01	SD in cow weight at weaning (kg)
1.11E+02	3.4E+03	5.25E+01	1.09E+02	6.3E+03	5.14E+01	SD in cow POMW (kg)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 30.c. Means (M) and F values[a] derived by one-way analysis of variance for comparison within HMH between control (AMH) and treatments under HF and LF environments (3 replicates/treatment).

Environment:H			Environment:L			
Treatment AHH,ALH		Control	Treatment AHH,ALH		Control	Description
M	F	M	M	F	M	
Milk production statistics:						
6.71E+00	1.3E-01	6.72E+00	6.24E+00	7.7E+00	6.33E+00	Milk production (kg/day)
1.10E+01	4.5E-01	1.10E+01	1.03E+01	2.9E-01	1.03E+01	Peak milk production (kg/day)
1.98E+00	5.9E-02	1.97E+00	1.85E+00	1.1E+01	1.78E+00	SD in peak milk production (kg/day)
2.80E+00	5.8E-02	2.78E+00	2.84E+00	1.2E+01	2.71E+00	SD POMP (kg/day)
4.35E-02	6.1E+00	3.55E-02	1.49E-01	5.3E+01	9.76E-02	RMPCF over lactation (kg/day)
4.35E-02	1.6E-02	4.32E-02	5.53E-02	4.8E+00	4.71E-02	RMRG over lactation (kg/day)
2.17E-03	7.2E+00	1.97E-03	4.10E-03	8.6E+01	2.87E-03	RDGCW over lactation (kg/day)
Requirement/intake at peak lactation statistics:						
9.00E+00	2.0E-01	9.00E+00	8.38E+00	3.1E-01	8.40E+00	REQ at peak lactation (kg TDN/day)
9.83E-01	1.1E+02	7.23E-01	7.47E-01	7.5E+02	5.78E-01	SD in REQ at peak lactation (kg TDN/day)
5.35E+00	3.7E+01	5.37E+00	4.89E+00	1.2E+01	4.93E+00	RM at peak lactation (kg TDN/day)
7.10E-01	1.5E+03	3.96E-01	5.76E-01	7.9E+03	3.54E-01	SD in RM at peak lactation (kg TDN/day)
9.13E+00	1.7E+00	9.11E+00	8.92E+00	8.7E+00	9.02E+00	CN at peak lactation (kg TDN/day)
1.18E+00	1.9E+02	7.68E-01	9.40E-01	7.1E+02	6.37E-01	SD in CN at peak lactation (kg TDN/day)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 30.d. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HMH between control (AMH) and treatments under HF and LF environments (3 replicates/treatment).

Environment:H			Environment:L			
Treatment AHH,ALH		Control	Treatment AHH,ALH		Control	Description
M	F	M	M	F	M	
Daily nutritional statistics:						
6.91E+00	4.0E+00	6.92E+00	6.32E+00	1.8E+01	6.36E+00	Cow CN (kg/day)
2.46E+00	4.0E+00	2.47E+00	2.35E+00	2.3E+00	2.36E+00	Calf CN (kg/day)
6.80E+00	1.8E+00	6.81E+00	4.95E+00	1.0E+00	6.28E+00	Cow REQ (kg/day)
5.14E+00	4.5E+00	5.15E+00	4.66E+00	3.4E+01	4.71E+00	Cow RM (kg/day)
7.06E+00	2.6E+00	7.10E+00	7.11E+00	1.2E+01	7.25E+00	Cow GF (kg/day)
2.07E+00	7.2E+00	2.09E+00	2.02E+00	0.0E+00	2.02E+00	Calf GF (kg/day)
3.13E+00	1.0E+01	3.19E+00	2.48E+00	1.5E+00	2.44E+00	Cow HF (kg/day)
7.00E-02	0.0E+00	7.00E-02	7.00E-02	0.0E+00	6.00E-02	Calf HF (kg/day)
8.70E-01	3.0E+01	8.33E-01	6.40E-01	7.0E+00	6.17E-01	Cow ES (kg/day)
Economic/bioefficiency statistics:						
5.85E+01	1.2E+00	5.75E+01	1.30E+02	1.4E+02	1.00E+02	No. cull cows sold
6.73E+01	1.1E+00	6.63E+01	1.40E+02	1.2E+02	1.10E+02	No. of replacements
1.07E+05	6.7E+00	1.08E+05	1.02E+05	1.6E+00	1.02E+05	Total kg weaned
1.48E+03	5.0E+00	1.49E+03	1.35E+03	1.5E+01	1.36E+03	Total herd TDN intake (m ton/year)
7.23E+01	3.6E+00	7.26E+01	7.52E+01	2.8E-02	7.52E+01	Total kg weaned / total TDN intake

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 31.a. Means (M) by subgroups AHH and ALH within HMH under HF and LF environments.

Environment:HF		Environment:LF		
M AHH	M ALH	M AHH	M ALH	Description
January 1st statistics:				
2.49E+02	2.50E+02	2.50E+02	2.49E+02	No. Jan. 1
5.80E+00	6.00E+00	3.27E+00	5.73E+00	Age Jan. 1 (yrs)
1.61E-01	2.22E-01	9.97E-02	1.46E-01	PCFEB Jan. 1 (prop.)
Calving statistics:				
2.49E+02	2.49E+02	2.49E+02	2.49E+02	No. calves born
7.30E-02	8.10E-02	1.28E-01	8.37E-02	Dystocia (prop.)
5.23E-02	5.40E-02	6.17E-02	5.33E-02	Peri-natal death (prop.)
1.86E-01	2.63E-01	1.07E-01	1.80E-01	PCFEB at calving (prop.)
4.25E-02	2.77E-02	4.07E-02	4.60E-02	SD in PCFEB at calving (prop.)
9.08E+01	8.89E+01	1.01E+02	9.14E+01	Day of year of calving
2.46E+02	2.46E+02	2.45E+02	2.46E+02	No. exposed
Fertility statistics:				
6.17E+00	3.33E-02	4.43E+01	8.60E+00	CFCONF (day)
2.00E-01	2.00E-01	4.00E-01	2.00E-01	CFDYSF (day)
-2.00E-01	-4.97E-01	-3.87E+00	-1.84E+00	CFDFF (day)
5.51E+01	4.90E+01	9.04E+01	5.59E+01	Post partum interval (day)
9.22E+00	2.05E+00	3.52E+01	1.33E+01	SD post partum interval (day)
9.57E-01	9.66E-01	6.21E-01	9.46E-01	Pregnancy rate (prop.)

Table 31.b. Means (M) by subgroups AHH and ALH within HMH under HF and LF environments.

Environment:HF		Environment:LF		
M AHH	M ALH	M AHH	M ALH	Description
Differential culling statistics:				
-3.00E+00	1.00E+00	-2.60E+01	-6.00E+00	POMW on preg. females (kg)
0.00E+00	1.00E-01	-1.10E+00	-2.00E-01	POMP on preg. females (kg/day)
Weaning statistics:				
2.26E+02	2.25E+02	2.23E+02	2.25E+02	No. weaned
2.52E+02	2.23E+02	2.33E+02	2.20E+02	Weaning weight (kg)
2.77E+01	2.67E+01	2.43E+01	2.55E+01	SD in weaning weight (kg)
1.83E-01	2.45E-01	1.34E-01	2.00E-01	Cow PCFEB at weaning (prop.)
3.77E-02	2.62E-02	3.58E-02	3.72E-02	SD in cow PCFEB at weaning (prop.)
6.19E+02	4.63E+02	5.54E+02	4.34E+02	Cow weight at weaning (kg)
5.17E+01	5.32E+01	4.47E+01	4.73E+01	SD in cow weight at weaning (kg)
5.12E+01	5.34E+01	5.51E+01	5.09E+01	SD in cow POMW (kg)

Table 31.c. Means (M) by subgroups AHH and ALH within HMH under HF and LF environments.

Environment:HF		Environment:LF		
M AHH	M ALH	M AHH	M ALH	Description
Milk production statistics:				
6.77E+00	6.65E+00	5.92E+00	6.55E+00	Milk production (kg/day)
1.12E+01	1.09E+01	9.87E+00	1.07E+01	Peak milk production (kg/day)
1.99E+00	1.94E+00	1.72E+00	1.88E+00	SD in peak milk production (kg/day)
2.80E+00	2.78E+00	2.89E+00	2.76E+00	SD POMP (kg/day)
5.72E-02	3.00E-02	2.53E-01	5.12E-02	RMPCF over lactation (kg/day)
4.20E-02	4.51E-02	7.25E-02	3.91E-02	RMRG over lactation (kg/day)
1.37E-03	8.00E-04	3.27E-03	8.33E-04	RDGCW over lactation (kg/day)
Requirement/intake at peak lactation statistics:				
9.63E+00	8.36E+00	8.80E+00	7.96E+00	REQ at peak lactation (kg TDN/day)
6.85E-01	7.96E-01	5.68E-01	6.58E-01	SD in REQ at peak lactation (kg TDN/day)
5.92E+00	4.78E+00	5.34E+00	4.44E+00	RM at peak lactation (kg TDN/day)
3.90E-01	4.44E-01	3.41E-01	3.66E-01	SD in RM at peak lactation (kg TDN/day)
1.00E+01	8.25E+00	9.57E+00	8.27E+00	CN at peak lactation (kg TDN/day)
8.04E-01	7.36E-01	5.86E-01	7.49E-01	SD in CN at peak lactation (kg TDN/day)

Table 31.d. Means (M) by subgroups AHH and ALH within HMH under HF and LF environments.

Environment:HF		Environment:LF		
M AHH	M ALH	M AHH	M ALH	Description
Daily nutritional statistics:				
7.59E+00	6.22E+00	6.80E+00	5.84E+00	Cow CN (kg/day)
2.59E+00	2.32E+00	2.40E+00	2.30E+00	Calf CN (kg/day)
7.47E+00	6.12E+00	5.31E+00	4.59E+00	Cow REQ (kg/day)
5.76E+00	4.53E+00	5.15E+00	4.19E+00	Cow RM (kg/day)
7.93E+00	6.20E+00	7.64E+00	6.58E+00	Cow GF (kg/day)
2.27E+00	1.86E+00	2.21E+00	1.85E+00	Calf GF (kg/day)
3.41E+00	2.86E+00	2.68E+00	2.29E+00	Cow HF (kg/day)
7.33E-02	6.00E-02	8.00E-02	6.00E-02	Calf HF (kg/day)
8.70E-01	8.70E-01	6.80E-01	6.00E-01	Cow ES (kg/day)
Economic/bioefficiency statistics:				
3.00E+01	2.84E+01	9.83E+01	3.21E+01	No. cull cows sold
3.43E+01	3.30E+01	1.04E+02	3.60E+01	No. of replacements
5.69E+04	5.02E+04	5.20E+04	4.96E+04	Total kg weaned
8.08E+02	6.73E+02	7.15E+02	6.36E+02	Total herd TDN intake (m ton/year)
7.04E+01	7.46E+01	7.27E+01	7.80E+01	Total kg weaned / total TDN intake

efficiency ratios were virtually identical. There was a huge increase (30 head) in the number of replacements required for treatment under the LF environment, however. With the exception of the AHH,ALL genotype in HMM, this was the largest discrepancy between treatment and control for replacements. The disparity in pregnancy rate and PCFEB of 0.325 and 0.073 (table 31.a), between AHH and ALH is also second only to the inequality between AHH and ALL in these areas.

Compared to the HMM controls, HMH controls were very similar for the efficiency ratio. As would be expected, HMH had higher weaning weights, which were countered by greater TDN intake.

While no difference in replacement rate was found under the HF environment, 9 more replacement females were required by HMM under the LF environment. On the surface, this is a difficult result to explain; with uniform genotypes fed to the same target body fat, little difference should be found in replacement rates.

If an advantage did exist, I would have expected HMM to fare a little better than HMH; because animals fend for themselves during the grazing months (i.e. body fat targets don't come into play), HMM's lower milk production should give it an edge in improving body condition during this period.

The actual explanation behind the difference in replacement rate is that HMH was slightly higher (0.5 hundredths) in PCFEB at calving than HMM, resulting in a 2.0 hundredths improvement in pregnancy rate for HMH. This difference in body fat is simply the result of imprecision in the model's ability to feed to a target body fat.

HERD LM

Means and corresponding F values allowing for comparison between treatments and control under both HF and LF environments can be found in table 32.a - 32.d. Means by subgroups within treatments can be found in table 33.a - 33.d.

Under the LF environment, the treatment effect resulted in 25 additional replacement females being required annually. Only a slight decline in the efficiency ratio was associated with treatment.

Comparing controls, HLM had a 2.6 and 3.0 kg advantage over HMM in HF and LF environments, respectively. Furthermore, the highest efficiency ratios across all herds were posted by HLM.

Table 32.a. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HLM between control (ALM) and treatments under HF and LF environments (3 replicates/treatment).

Environment:H			Environment:L			
Treatment ALH,ALL		Control	Treatment ALH,ALL		Control	Description
M	F	M	M	F	M	
January 1st statistics:						
4.99E+02	1.0E+00	4.99E+02	4.99E+02	0.0E+00	4.99E+02	No. Jan. 1
5.90E+00	1.0E+00	5.93E+00	4.33E+00	1.3E+02	4.87E+00	Age Jan. 1 (yrs)
1.90E-01	4.0E+00	1.91E-01	1.41E-01	1.0E+00	1.41E-01	PCFEB Jan. 1 (prop.)
Calving statistics:						
4.97E+02	1.0E+00	4.97E+02	4.97E+02	2.0E+00	4.97E+02	No. calves born
7.97E-02	6.2E-02	8.00E-02	1.18E-01	4.0E+01	1.04E-01	Dystocia (prop.)
5.57E-02	1.1E+00	5.73E-02	5.70E-02	1.0E-01	5.67E-02	Peri-natal death (prop.)
2.19E-01	4.5E+00	2.20E-01	1.35E-01	2.7E+01	1.38E-01	PCFEB at calving (prop.)
4.50E-02	2.9E+01	4.05E-02	5.21E-02	1.0E+02	4.58E-02	SD in PCFEB at calving (prop.)
8.94E+01	4.6E-01	8.92E+01	9.64E+01	5.0E-01	9.63E+01	Day of year of calving
Fertility statistics:						
4.91E+02	0.0E+00	4.91E+02	4.91E+02	0.0E+00	4.92E+02	No. exposed
2.70E+00	4.8E+01	1.97E+00	2.91E+01	6.4E+01	2.47E+01	CFCONF (day)
2.00E-01	0.0E+00	2.00E-01	4.00E-01	5.4E+14	3.00E-01	CFDYSF (day)
-1.65E+00	8.7E-02	-1.74E+00	-5.09E+00	4.9E+00	-4.89E+00	CFDFF (day)
5.02E+01	3.2E+00	4.95E+01	7.33E+01	9.4E+01	6.86E+01	Post partum interval (day)
7.83E+00	6.5E+01	6.03E+00	3.31E+01	8.7E+01	2.67E+01	SD post partum interval (day)
9.62E-01	2.3E+00	9.66E-01	7.78E-01	1.4E+02	8.35E-01	Pregnancy rate (prop.)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 32.b. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HLM between control (ALM) and treatments under HF and LF environments (3 replicates/treatment).

Environment:H			Environment:L			
Treatment ALH,ALL		Control	Treatment ALH,ALL		Control	Description
M	F	M	M	F	M	
Differential culling statistics:						
-1.00E+00	4.7E-01	0.00E+00	-1.70E+01	1.1E+00	-1.80E+01	POMW on preg. females (kg)
-1.50E-01	1.0E+00	0.00E+00	-1.44E+00	3.8E+01	-1.20E+00	POMP on preg. females (kg/day)
Weaning statistics:						
4.49E+02	9.1E-02	4.48E+02	4.49E+02	5.3E-02	4.49E+02	No. weaned
2.09E+02	1.5E+01	2.13E+02	1.97E+02	4.5E+01	2.01E+02	Weaning weight (kg)
3.14E+01	5.5E+01	2.71E+01	2.85E+01	9.6E+01	2.43E+01	SD in weaning weight (kg)
2.33E-01	4.0E-01	2.32E-01	1.94E-01	9.8E+01	1.98E-01	Cow PCFEB at weaning (prop.)
4.00E-02	2.6E+01	3.21E-02	5.16E-02	2.0E+02	4.01E-02	SD in cow PCFEB at weaning (prop.)
4.54E+02	3.1E-02	4.55E+02	4.17E+02	7.9E+00	4.21E+02	Cow weight at weaning (kg)
5.21E+01	2.3E+00	5.00E+01	5.20E+01	1.7E+01	4.76E+01	SD in cow weight at weaning (kg)
5.20E+01	7.2E-02	5.17E+01	5.30E+01	2.9E+00	5.09E+01	SD in cow POMW (kg)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 32.c. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HLM between control (ALM) and treatments under HF and LF environments (3 replicates/treatment).

Environment:H			Environment:L			
Treatment ALH,ALL		Control	Treatment ALH,ALL		Control	Description
M	F	M	M	F	M	
Milk production statistics:						
5.25E+00	5.5E+00	5.41E+00	4.69E+00	9.1E+01	4.88E+00	Milk production (kg/day)
8.53E+00	5.2E+00	8.79E+00	7.70E+00	4.7E+01	7.90E+00	Peak milk production (kg/day)
2.99E+00	3.2E+03	2.12E+00	2.70E+00	5.9E+02	1.91E+00	SD in peak milk production (kg/day)
3.98E+00	9.9E+02	2.81E+00	4.04E+00	4.8E+02	2.70E+00	SD POMP (kg/day)
3.00E-02	1.9E+00	2.34E-02	1.15E-01	1.3E+02	6.68E-02	RMPCF over lactation (kg/day)
2.92E-02	5.9E-02	2.97E-02	3.71E-02	3.2E+00	3.40E-02	RMRG over lactation (kg/day)
1.47E-03	1.6E+01	1.60E-03	2.87E-03	1.1E+02	2.37E-03	RDGCW over lactation (kg/day)
Requirement/intake at peak lactation statistics:						
7.33E+00	5.4E+00	7.45E+00	6.77E+00	1.7E+01	6.84E+00	REQ at peak lactation (kg TDN/day)
1.02E+00	2.9E+03	7.73E-01	8.87E-01	4.2E+02	6.51E-01	SD in REQ at peak lactation (kg TDN/day)
4.50E+00	3.4E+00	4.53E+00	4.14E+00	7.9E+00	4.17E+00	RM at peak lactation (kg TDN/day)
3.93E-01	4.5E-01	3.87E-01	3.70E-01	2.7E+00	3.56E-01	SD in RM at peak lactation (kg TDN/day)
7.69E+00	7.7E+00	7.81E+00	7.71E+00	1.4E+01	7.79E+00	CN at peak lactation (kg TDN/day)
1.07E+00	9.6E+02	8.81E-01	7.67E-01	6.2E+01	6.68E-01	SD in CN at peak lactation (kg TDN/day)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 32.d. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HLM between control (ALM) and treatments under HF and LF environments (3 replicates/treatment).

Environment:H			Environment:L			
Treatment ALH,ALL		Control	Treatment ALH,ALL		Control	Description
M	F	M	M	F	M	
Daily nutritional statistics:						
5.80E+00	2.4E+00	5.85E+00	5.22E+00	4.0E+01	5.28E+00	Cow CN (kg/day)
2.19E+00	4.0E+00	2.20E+00	2.07E+00	4.0E+00	2.08E+00	Calf CN (kg/day)
5.69E+00	3.4E+00	5.74E+00	5.14E+00	2.8E+01	5.19E+00	Cow REQ (kg/day)
4.34E+00	1.3E+00	4.37E+00	3.88E+00	5.0E+01	3.92E+00	Cow RM (kg/day)
6.30E+00	6.4E-02	6.31E+00	6.33E+00	1.2E+01	6.39E+00	Cow GF (kg/day)
2.02E+00	1.0E+00	2.01E+00	2.00E+00	6.4E+01	1.97E+00	Calf GF (kg/day)
2.44E+00	4.6E-01	2.49E+00	1.74E+00	1.2E+01	1.78E+00	Cow HF (kg/day)
9.00E-02	1.6E+01	7.67E-02	9.33E-02	1.6E+01	8.00E-02	Calf HF (kg/day)
6.37E-01	5.2E-01	6.50E-01	4.40E-01	0.0E+00	4.50E-01	Cow ES (kg/day)
Economic/bioefficiency statistics:						
5.85E+01	1.8E+00	5.71E+01	1.32E+02	1.6E+02	1.08E+02	No. cull cows sold
6.80E+01	7.5E-01	6.70E+01	1.42E+02	1.2E+02	1.17E+02	No. of replacements
9.40E+04	7.3E+00	9.54E+04	8.85E+04	2.2E+01	9.01E+04	Total kg weaned
1.25E+03	2.1E+00	1.26E+03	1.13E+03	1.1E+02	1.14E+03	Total herd TDN intake (m ton/year)
7.49E+01	3.8E+01	7.55E+01	7.84E+01	7.9E+00	7.89E+01	Total kg weaned / total TDN intake

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 33.a. Means (M) by subgroups ALH and ALL within HLM under HF and LF environments.

Environment:HF		Environment:LF		
M ALH	M ALL	M ALH	M ALL	Description
January 1st statistics:				
2.50E+02	2.49E+02	2.49E+02	2.49E+02	No. Jan. 1
5.83E+00	5.90E+00	3.30E+00	5.40E+00	Age Jan. 1 (yrs)
1.67E-01	2.14E-01	1.13E-01	1.68E-01	PCFEB Jan. 1 (prop.)
Calving statistics:				
2.49E+02	2.48E+02	2.48E+02	2.49E+02	No. calves born
7.90E-02	7.97E-02	1.42E-01	9.37E-02	Dystocia (prop.)
5.63E-02	5.50E-02	6.00E-02	5.43E-02	Peri-natal death (prop.)
2.00E-01	2.37E-01	1.13E-01	1.56E-01	PCFEB at calving (prop.)
4.50E-02	3.67E-02	4.77E-02	4.69E-02	SD in PCFEB at calving (prop.)
9.01E+01	8.86E+01	9.98E+01	9.30E+01	Day of year of calving
2.46E+02	2.46E+02	2.45E+02	2.46E+02	No. exposed
Fertility statistics:				
4.67E+00	7.33E-01	4.18E+01	1.65E+01	CFCONF (day)
2.00E-01	2.00E-01	5.00E-01	2.67E-01	CFDYSF (day)
-2.70E-01	-3.02E+00	-4.20E+00	-5.97E+00	CFDFF (day)
5.34E+01	4.71E+01	8.71E+01	5.94E+01	Post partum interval (day)
9.28E+00	3.81E+00	3.69E+01	2.06E+01	SD post partum interval (day)
9.57E-01	9.68E-01	6.55E-01	9.02E-01	Pregnancy rate (prop.)

Table 33.b. Means (M) by subgroups ALH and ALL within HLM under HF and LF environments.

Environment:HF		Environment:LF		
M ALH	M ALL	M ALH	M ALL	Description
Differential culling statistics:				
-3.00E+00	0.00E+00	-2.10E+01	-1.40E+01	POMW on preg. females (kg)
-3.00E-01	0.00E+00	-1.20E+00	-8.00E-01	POMP on preg. females (kg/day)
Weaning statistics:				
2.25E+02	2.24E+02	2.24E+02	2.24E+02	No. weaned
2.21E+02	1.98E+02	2.05E+02	1.89E+02	Weaning weight (kg)
2.59E+01	3.21E+01	2.29E+01	3.10E+01	SD in weaning weight (kg)
2.09E-01	2.57E-01	1.60E-01	2.27E-01	Cow PCFEB at weaning (prop.)
3.57E-02	2.81E-02	3.90E-02	3.87E-02	SD in cow PCFEB at weaning (prop.)
4.42E+02	4.67E+02	3.96E+02	4.38E+02	Cow weight at weaning (kg)
4.77E+01	5.30E+01	4.15E+01	5.27E+01	SD in cow weight at weaning (kg)
5.17E+01	5.22E+01	5.30E+01	5.28E+01	SD in cow POMW (kg)

Table 33.c. Means (M) by subgroups ALH and ALL within HLM under HF and LF environments.

Environment:HF		Environment:LF		
M ALH	M ALL	M ALH	M ALL	Description
Milk production statistics:				
6.54E+00	3.98E+00	5.82E+00	3.59E+00	Milk production (kg/day)
1.06E+01	6.46E+00	9.56E+00	5.85E+00	Peak milk production (kg/day)
1.89E+00	2.39E+00	1.69E+00	2.18E+00	SD in peak milk production (kg/day)
2.76E+00	2.75E+00	2.97E+00	2.58E+00	SD POMP (kg/day)
4.64E-02	1.37E-02	2.05E-01	2.80E-02	RMPCF over lactation (kg/day)
3.67E-02	2.17E-02	5.26E-02	2.21E-02	RMRG over lactation (kg/day)
7.33E-04	7.67E-04	1.83E-03	1.10E-03	RDGCW over lactation (kg/day)
Requirement/intake at peak lactation statistics:				
7.98E+00	6.68E+00	7.34E+00	6.21E+00	REQ at peak lactation (kg TDN/day)
6.65E-01	8.85E-01	6.14E-01	7.45E-01	SD in REQ at peak lactation (kg TDN/day)
4.49E+00	4.51E+00	4.07E+00	4.21E+00	RM at peak lactation (kg TDN/day)
3.71E-01	4.12E-01	3.39E-01	3.84E-01	SD in RM at peak lactation (kg TDN/day)
8.21E+00	7.16E+00	8.01E+00	7.42E+00	CN at peak lactation (kg TDN/day)
8.29E-01	1.00E+00	6.20E-01	7.79E-01	SD in CN at peak lactation (kg TDN/day)

Table 33.d. Means (M) by subgroups ALH and ALL within HLM under HF and LF environments.

Environment:HF		Environment:LF		
M ALH	M ALL	M ALH	M ALL	Description
Daily nutritional statistics:				
6.01E+00	5.59E+00	5.41E+00	5.04E+00	Cow CN (kg/day)
2.29E+00	2.08E+00	2.14E+00	2.01E+00	Calf CN (kg/day)
5.91E+00	5.47E+00	5.36E+00	4.92E+00	Cow REQ (kg/day)
4.34E+00	4.34E+00	3.90E+00	3.87E+00	Cow RM (kg/day)
6.59E+00	6.00E+00	6.42E+00	6.23E+00	Cow GF (kg/day)
1.84E+00	2.19E+00	1.81E+00	2.17E+00	Calf GF (kg/day)
2.47E+00	2.42E+00	1.88E+00	1.61E+00	Cow HF (kg/day)
6.00E-02	1.23E-01	6.00E-02	1.30E-01	Calf HF (kg/day)
6.40E-01	6.37E-01	4.77E-01	4.07E-01	Cow ES (kg/day)
Economic/bioefficiency statistics:				
3.00E+01	2.86E+01	9.02E+01	4.15E+01	No. cull cows sold
3.47E+01	3.27E+01	9.53E+01	4.57E+01	No. of replacements
4.97E+04	4.43E+04	4.60E+04	4.24E+04	Total kg weaned
6.50E+02	6.04E+02	5.81E+02	5.48E+02	Total herd TDN intake (m ton/year)
7.63E+01	7.35E+01	7.92E+01	7.74E+01	Total kg weaned / total TDN intake

The heightened efficiency is likely due to low-growth dams allowing for the increased efficiency commonly associated with a disparity between sire and dam lines (i.e., a "terminal sire" effect). In fact, in examining the efficiency ratios by genotypes within treatments, we see that low-growth genotypes consistently have the highest efficiency ratios.

HERD ML

Means and corresponding F values allowing for comparison between treatments and control under both HF and LF environments can be found in table 34.a - 34.d. Means by subgroups within treatments can be found in table 35.a - 35.d.

This was the only circumstance in which the efficiency ratios were actually higher, though only slightly, for treatment than control. Though treatment was associated with significant increases in weaning weights (4.0 and 6.0 kg under HF and LF, respectively), it had minimal impact on TDN intake—the result of treatments having substantially higher POMP, yet lower POMW than controls.

This configuration is likely due to treatment providing more genetic diversity in POMW for culling

Table 34.a. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HML between control (AML) and treatments under HF and LF environments (3 replicates/treatment).

Environment:H			Environment:L			
Treatment AHL,ALL		Control	Treatment AHL,ALL		Control	Description
M	F	M	M	F	M	
January 1st statistics:						
4.99E+02	0.0E+00	4.99E+02	4.99E+02	0.0E+00	4.99E+02	No. Jan. 1
5.90E+00	4.0E+00	5.97E+00	4.63E+00	4.5E+00	4.73E+00	Age Jan. 1 (yrs)
1.98E-01	1.8E+01	2.00E-01	1.50E-01	1.1E+02	1.55E-01	PCFEB Jan. 1 (prop.)
Calving statistics:						
4.97E+02	0.0E+00	4.97E+02	4.97E+02	0.0E+00	4.97E+02	No. calves born
7.47E-02	0.0E+00	7.47E-02	1.04E-01	2.7E+00	9.90E-02	Dystocia (prop.)
5.43E-02	1.5E+00	5.70E-02	5.93E-02	6.3E+00	5.53E-02	Peri-natal death (prop.)
2.20E-01	0.0E+00	2.16E-01	1.35E-01	6.4E+01	1.32E-01	PCFEB at calving (prop.)
4.76E-02	2.6E+02	3.84E-02	4.90E-02	1.5E+02	4.24E-02	SD in PCFEB at calving (prop.)
8.93E+01	2.0E+01	8.88E+01	9.58E+01	2.7E-01	9.59E+01	Day of year of calving
Fertility statistics:						
4.92E+02	0.0E+00	4.92E+02	4.91E+02	2.5E-01	4.91E+02	No. exposed
3.00E+00	1.1E+02	2.07E+00	2.76E+01	1.8E+01	2.65E+01	CFCONF (day)
2.00E-01	0.0E+00	2.00E-01	3.00E-01	0.0E+00	3.00E-01	CFDYSF (day)
-2.46E+00	4.9E+01	-3.32E+00	-5.99E+00	1.4E+02	-6.94E+00	CFDFF (day)
4.98E+01	5.8E+01	4.81E+01	7.10E+01	5.6E+01	6.87E+01	Post partum interval (day)
7.68E+00	2.4E+01	6.10E+00	3.11E+01	7.0E+01	2.79E+01	SD post partum interval (day)
9.59E-01	1.4E+01	9.66E-01	8.00E-01	4.2E+01	8.23E-01	Pregnancy rate (prop.)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 34.b. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HML between control (AML) and treatments under HF and LF environments (3 replicates/treatment).

Environment:H			Environment:L			
Treatment AHL,ALL		Control	Treatment AHL,ALL		Control	Description
M	F	M	M	F	M	
Differential culling statistics:						
-3.00E+00	1.3E+01	-4.00E+00	-2.50E+01	1.3E+02	-1.30E+01	POMW on preg. females (kg)
-7.00E-02	6.2E+01	-8.20E-01	-1.24E+00	1.4E+03	-2.16E+00	POMP on preg. females (kg/day)
Weaning statistics:						
4.48E+02	8.2E-01	4.47E+02	4.46E+02	2.3E+00	4.47E+02	No. weaned
2.12E+02	2.1E+01	2.08E+02	1.96E+02	1.3E+02	1.90E+02	Weaning weight (kg)
3.50E+01	6.0E+00	3.64E+01	3.20E+01	1.0E+01	3.39E+01	SD in weaning weight (kg)
2.38E-01	1.3E+01	2.44E-01	2.02E-01	3.0E+01	2.11E-01	Cow PCFEB at weaning (prop.)
3.82E-02	4.5E+01	3.20E-02	4.78E-02	9.7E+01	3.96E-02	SD in cow PCFEB at weaning (prop.)
5.54E+02	4.8E+01	5.64E+02	5.16E+02	3.8E+01	5.25E+02	Cow weight at weaning (kg)
1.00E+02	3.2E+03	5.45E+01	9.00E+01	1.7E+04	5.49E+01	SD in cow weight at weaning (kg)
1.10E+02	3.0E+03	5.37E+01	1.09E+02	3.5E+03	5.18E+01	SD in cow POMW (kg)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 34.c. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HML between control (AML) and treatments under HF and LF environments (3 replicates/treatment).

Environment:H			Environment:L			
Treatment AHL,ALL		Control	Treatment AHL,ALL		Control	Description
M	F	M	M	F	M	
Milk production statistics:						
3.94E+00	4.1E+01	3.54E+00	3.29E+00	4.7E+02	2.85E+00	Milk production (kg/day)
6.44E+00	5.5E+01	5.80E+00	5.47E+00	1.9E+03	4.71E+00	Peak milk production (kg/day)
2.43E+00	4.7E+00	2.48E+00	2.19E+00	9.3E+00	2.13E+00	SD in peak milk production (kg/day)
2.75E+00	3.5E+00	2.71E+00	2.67E+00	2.3E+01	2.55E+00	SD POMP (kg/day)
1.90E-02	1.8E+01	1.12E-02	7.26E-02	6.3E+01	5.11E-02	RMPCF over lactation (kg/day)
2.29E-02	1.3E+01	1.74E-02	3.08E-02	4.6E+02	2.22E-02	RMRG over lactation (kg/day)
2.23E-03	2.6E+00	2.03E-03	4.20E-03	1.4E+01	3.60E-03	RDGCW over lactation (kg/day)
Requirement/intake at peak lactation statistics:						
7.35E+00	1.9E+01	7.20E+00	6.75E+00	8.8E+02	6.49E+00	REQ at peak lactation (kg TDN/day)
1.05E+00	9.3E+01	9.01E-01	9.43E-01	8.5E+02	7.63E-01	SD in REQ at peak lactation (kg TDN/day)
5.17E+00	2.0E+01	5.22E+00	4.79E+00	1.8E+00	4.80E+00	RM at peak lactation (kg TDN/day)
7.40E-01	3.0E+03	4.14E-01	6.67E-01	2.6E+03	3.81E-01	SD in RM at peak lactation (kg TDN/day)
0.00E+00	0.0E+00	0.00E+00	0.00E+00	0.0E+00	0.00E+00	SD PORM (kg TDN/day)
8.07E+00	4.8E-02	8.07E+00	8.13E+00	1.1E+00	8.11E+00	CN at peak lactation (kg TDN/day)
1.40E+00	1.2E+03	1.05E+00	1.02E+00	2.3E+02	7.00E-01	SD in CN at peak lactation (kg TDN/day)
0.00E+00	0.0E+00	0.00E+00	0.00E+00	0.0E+00	0.00E+00	SD in POAPP (kg TDN/day)
0.00E+00	0.0E+00	0.00E+00	0.00E+00	0.0E+00	0.00E+00	SD in POGL (day)

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 34.d. Means (M) and F values [a] derived by one-way analysis of variance for comparison within HML between control (AML) and treatments under HF and LF environments (3 replicates/treatment).

Environment:H			Environment:L			
Treatment AHL,ALL		Control	Treatment AHL,ALL		Control	Description
M	F	M	M	F	M	
Daily nutritional statistics:						
6.16E+00	9.9E+00	6.09E+00	5.48E+00	6.9E+01	5.33E+00	Cow CN (kg/day)
2.24E+00	9.8E+00	2.21E+00	2.12E+00	5.0E+01	2.08E+00	Calf CN (kg/day)
6.02E+00	9.9E+00	5.95E+00	5.37E+00	1.1E+02	5.21E+00	Cow REQ (kg/day)
4.85E+00	3.6E-02	4.85E+00	4.28E+00	4.8E+01	4.21E+00	Cow RM (kg/day)
6.71E+00	4.0E+00	6.83E+00	6.79E+00	4.6E+00	6.86E+00	Cow GF (kg/day)
2.43E+00	1.8E+01	2.50E+00	2.41E+00	7.5E+01	2.46E+00	Calf GF (kg/day)
2.56E+00	1.8E+01	2.42E+00	1.71E+00	8.7E+02	1.49E+00	Cow HF (kg/day)
1.47E-01	4.9E+01	1.70E-01	1.70E-01	0.0E+00	1.90E-01	Calf HF (kg/day)
6.93E-01	5.0E+01	6.27E-01	4.40E-01	3.6E+02	3.77E-01	Cow ES (kg/day)
Economic/bioefficiency statistics:						
5.90E+01	1.7E+02	5.64E+01	1.23E+02	9.4E+01	1.12E+02	No. cull cows sold
6.87E+01	5.0E+01	6.53E+01	1.33E+02	7.3E+01	1.22E+02	No. of replacements
9.50E+04	3.3E+02	9.28E+04	8.76E+04	3.2E+02	8.49E+04	Total kg weaned
1.32E+03	9.2E+00	1.31E+03	1.18E+03	5.3E+01	1.15E+03	Total herd TDN intake (m ton/year)
7.17E+01	4.4E+01	7.08E+01	7.43E+01	3.1E+01	7.37E+01	Total kg weaned / total TDN intake

[a] Tabular F values for a single comparison with 1 and 4 degrees of freedom are 4.54, 21.2 and 31.33 at the .1, .01, and .005 probability levels, respectively.

Table 35.a. Means (M) by subgroups AHL and ALL within HML under HF and LF environments.

Environment:HF		Environment:LF		
M AHL	M ALL	M AHL	M ALL	Description
January 1st statistics:				
2.49E+02	2.49E+02	2.50E+02	2.49E+02	No. Jan. 1
5.80E+00	5.97E+00	3.93E+00	5.30E+00	Age Jan. 1 (yrs)
1.76E-01	2.19E-01	1.31E-01	1.70E-01	PCFEB Jan. 1 (prop.)
Calving statistics:				
2.49E+02	2.49E+02	2.48E+02	2.49E+02	No. calves born
7.37E-02	7.57E-02	1.17E-01	9.07E-02	Dystocia (prop.)
5.40E-02	5.47E-02	5.97E-02	5.83E-02	Peri-natal death (prop.)
1.88E-01	2.52E-01	1.15E-01	1.56E-01	PCFEB at calving (prop.)
4.03E-02	2.86E-02	4.29E-02	4.56E-02	SD in PCFEB at calving (prop.)
8.98E+01	8.88E+01	9.91E+01	9.25E+01	Day of year of calving
2.46E+02	2.46E+02	2.45E+02	2.46E+02	No. exposed
Fertility statistics:				
5.93E+00	1.33E-01	3.88E+01	1.64E+01	CFCONF (day)
2.00E-01	2.00E-01	4.00E-01	2.33E-01	CFDYSF (day)
-2.27E+00	-2.65E+00	-6.37E+00	-5.62E+00	CFDFF (day)
5.28E+01	4.67E+01	8.23E+01	5.97E+01	Post partum interval (day)
9.53E+00	2.70E+00	3.45E+01	2.15E+01	SD post partum interval (day)
9.52E-01	9.67E-01	6.94E-01	9.05E-01	Pregnancy rate (prop.)

Table 35.b. Means (M) by subgroups AHL and ALL within HML under HF and LF environments.

Environment:HF		Environment:LF		
M AHL	M ALL	M AHL	M ALL	Description
Differential culling statistics:				
-6.00E+00	2.00E+00	-2.10E+01	-5.00E+00	POMW on preg. females (kg)
-2.40E-01	1.40E-01	-1.59E+00	-9.80E-01	POMP on preg. females (kg/day)
Weaning statistics:				
2.25E+02	2.24E+02	2.23E+02	2.23E+02	No. weaned
2.25E+02	1.99E+02	2.04E+02	1.89E+02	Weaning weight (kg)
3.37E+01	3.13E+01	3.18E+01	3.01E+01	SD in weaning weight (kg)
2.16E-01	2.60E-01	1.78E-01	2.26E-01	Cow PCFEB at weaning (prop.)
3.62E-02	2.48E-02	4.50E-02	3.67E-02	SD in cow PCFEB at weaning (prop.)
6.36E+02	4.71E+02	5.86E+02	4.45E+02	Cow weight at weaning (kg)
5.73E+01	5.56E+01	5.80E+01	5.32E+01	SD in cow weight at weaning (kg)
5.15E+01	5.38E+01	5.27E+01	5.32E+01	SD in cow POMW (kg)

Table 35.c. Means (M) by subgroups AHL and ALL within HML under HF and LF environments.

Environment:HF		Environment:LF		
M AHL	M ALL	M AHL	M ALL	Description
Milk production statistics:				
3.84E+00	4.04E+00	3.10E+00	3.48E+00	Milk production (kg/day)
6.32E+00	6.56E+00	5.23E+00	5.72E+00	Peak milk production (kg/day)
2.44E+00	2.40E+00	2.20E+00	2.16E+00	SD in peak milk production (kg/day)
2.68E+00	2.80E+00	2.76E+00	2.54E+00	SD POMP (kg/day)
2.22E-02	1.59E-02	1.03E-01	4.31E-02	RMPCF over lactation (kg/day)
2.21E-02	2.37E-02	3.72E-02	2.46E-02	RMRG over lactation (kg/day)
1.50E-03	7.33E-04	3.13E-03	1.07E-03	RDGCW over lactation (kg/day)
Requirement/intake at peak lactation statistics:				
7.95E+00	6.75E+00	7.30E+00	6.20E+00	REQ at peak lactation (kg TDN/day)
7.91E-01	9.20E-01	7.75E-01	7.54E-01	SD in REQ at peak lactation (kg TDN/day)
5.77E+00	4.56E+00	5.33E+00	4.25E+00	RM at peak lactation (kg TDN/day)
3.97E-01	4.40E-01	3.79E-01	3.88E-01	SD in RM at peak lactation (kg TDN/day)
9.11E+00	7.02E+00	8.82E+00	7.45E+00	CN at peak lactation (kg TDN/day)
8.98E-01	9.64E-01	6.77E-01	8.24E-01	SD in CN at peak lactation (kg TDN/day)

Table 35.d. Means (M) by subgroups AHL and ALL within HML under HF and LF environments.

Environment:HF		Environment:LF		
M AHL	M ALL	M AHL	M ALL	Description
Daily nutritional statistics:				
6.79E+00	5.52E+00	6.00E+00	4.96E+00	Cow CN (kg/day)
2.39E+00	2.09E+00	2.23E+00	2.00E+00	Calf CN (kg/day)
6.64E+00	5.40E+00	5.90E+00	4.85E+00	Cow REQ (kg/day)
5.43E+00	4.27E+00	4.75E+00	3.81E+00	Cow RM (kg/day)
7.56E+00	5.85E+00	7.36E+00	6.22E+00	Cow GF (kg/day)
2.68E+00	2.18E+00	2.63E+00	2.19E+00	Calf GF (kg/day)
2.74E+00	2.38E+00	1.92E+00	1.50E+00	Cow HF (kg/day)
1.80E-01	1.20E-01	2.00E-01	1.40E-01	Calf HF (kg/day)
6.97E-01	6.90E-01	4.83E-01	3.90E-01	Cow ES (kg/day)
Economic/bioefficiency statistics:				
3.08E+01	2.82E+01	8.42E+01	3.87E+01	No. cull cows sold
3.50E+01	3.27E+01	8.93E+01	4.37E+01	No. of replacements
5.05E+04	4.45E+04	4.56E+04	4.20E+04	Total kg weaned
7.26E+02	5.98E+02	6.38E+02	5.41E+02	Total herd TDN intake (m ton/year)
6.96E+01	7.44E+01	7.14E+01	7.77E+01	Total kg weaned / total TDN intake

pressure to work on. Table 35.b shows that, within treatment, culling had a much stronger impact on the high-growth genotype under both environments. Without the high-growth genotype to work on, culling necessarily impacts milk production more severely.

Consistent with previously established patterns, only under the LF environment was there a measurable difference in replacement rates (11 additional females required for treatment) between treatment and control.

The efficiency ratios are lower for HML than HMM. This stands to reason, as the low milk level doesn't allow for the medium growth level to be expressed as well as HMM—leaving potential on the table so to speak.

SUMMARY AND CONCLUSIONS

Under virtually all herd scenarios, it appears that increasing within-herd variability was detrimental to profitability, particularly under the LF environment. In all but HML, efficiency ratios were poorer with increased variability. While the ratio is likely somewhat predictive of profitability, it is the substantial discrepancy in replacement rates that tip the scales strongly towards uniformity under most plausible scenarios. There are, however, conceivable circumstances that would mitigate the treatment advantage; obviously, increased salvage value relative to replacement costs would be an integral component to such circumstances.

Of note is that efficiency ratios were only impacted through treatment effects on weaning weights; weaning rates were not affected by any treatments. Given the extremely low body condition for some genotypes within treatment, I feel weaning rates should have been impacted to some degree. This could be easily addressed through reparameterizing dam body fat to have more influence on calf survivability—a change that would result in uniformity being even more conducive to profitability.

In comparing various potential levels, low-growth females had a decided advantage for the efficiency ratio, while high-growth genotypes were at a disadvantage. Also, the ratio tended to improve with increasing levels of milk production. These are quite plausible trends when the system is defined solely as the cow-calf enterprise. It is doubtful that these advantages would be as pronounced or even hold for that matter, if the feedlot phase were incorporated into the ratio.

The efficiency ratio was consistently better in the LF than the HF environment. This is presumably due to the host of non-linear relationships between input and output favoring animals under poor nutrition and/or body condition. Of course, deducing from this that the LF environment is desirable compared to the HF environment would be somewhat rash. Given the poor pregnancy rates under the LF environment, it is most likely that the HF environment would be the more profitable.

Finally, simulating with the extreme levels of variability found in this study was a good test for the model—stretching its seams so to speak. The genotypes simulated were certainly more diverse than any posed to CBCPM prior to this study, and, based on a search of the literature, possibly more extreme than any ever simulated. Initially, many problems arose from the extreme diversity. Equations that may have been adequate under typical simulation scenarios (e.g. a single genotypic base) were not so for our configurations. This was not surprising—due to equations functioning outside of their "range" as the simulation "window" widens, the likelihood of equations not adequately depicting reality increases. Idealistically, a model's equations are valid across all possible simulation scenarios. Though this is something for a modeler to strive for, from a practical standpoint it is seldom, if ever, the case. Because the extreme diversity unearthed problems, adjustments and enhancements to the model were required to arrive at a reasonable level of confidence in its performance—which ultimately resulted in a more valid, robust model.

LITERATURE CITED

AAC. 1990. Feeding standards for Australian livestock. Ruminants. CSIRO publications. East Melborne, Victoria.

ARC. 1980. The nutrient requirements of ruminant livestock. Agricultural Research Council, Commonwealth Agricultural Bureaux, Farnham Royal, Slough.

Abdalla, H.O. 1986. Compensatory gain in calves following protein restriction. Ph.D. dissertation. Cornell University, Ithaca.

Adam, I., Young, B.A., Nicol, A.M. and Degen, A.A. 1984. Energy cost of eating in cattle given diets of different form. Anim. Prod. 38:53.

Ames, D. 1974. Wind-chill factors for cattle and sheep. Proc. International Livestock Environmental Symposium. Am. Soc. Agr. Eng. SP-0174.

Baker, B.B., R.M. Bourdon, and J.D. Hanson. 1992. FORAGE: a simulation model for the grazing behavior of beef cattle. Ecological Modeling 60:257.

Baker, B.B., J.D. Hanson, R.M. Bourdon, and J.B. Eckert. 1993. Potential effects of climate change on ecosystem processes and cattle production on US rangelands. Climatic Change 25:97.

Bauman, D. E., and W.B. Currie. 1980. Partitioning of nutrients during pregnancy and lactation: A review of mechanisms involving homeostasis and homeorhesis. J. Dairy Sci. 63:1514-1529.

Bellows, R.A., R.B. Staigmiller, J.B Carr and R.E. Short. 1979. Beef reproduction from mature cows on range forage. J. Anim. Sci. 49:654.

Blaxter, K.L., Clapperton, J.L. and Wainman, F.W. 1966. Utilization of the energy and protein of the same diet by cattle of different age. J. Agric. Sci. 67:67.

Bolortsetseg, B., G. Tuvaansuren, L. Erda. 1996. The potential impacts of climate change on pasture and cattle production in Mongolia. Special Issue: Climate change vulnerability and adaptation in Asia and the Pacific. Workshop held in Manila, Philippines, 15-15 Jan. 1996. 92:1-2, 95-105; 11 ref.

Bourdon, R.M. and J.S. Brinks. 1982. Genetic, environmental, and phenotypic relationships among gestation length, birth weight, growth traits and age at first calving in beef cattle. J. Anim. Sci. 55, 543-553.

Bourdon, R.M. 1983. Simulated effects of genotype and management on beef production efficiency. Ph.D. Dissertation. Colorado State Univ., Fort Collins.

Bourdon, R. M. and J.S. Brinks. 1987a. Simulated efficiency of range beef production. I. Growth and milk production. J. Anim. Sci. 65:943.

Bourdon, R. M. and J.S. Brinks. 1987b. Simulated efficiency of range beef production. II. Fertility traits. J. Anim. Sci. 65:956.

Bourdon, R. M. and J.S. Brinks. 1987c. Simulated efficiency of range beef production. III. Culling strategies and nontraditional management systems. J. Anim. Sci. 65:963.

Brody, S. 1945. Bioenergetics and Growth. Reinhold Publishing Corp., New York.

Cartwright, T.C. 1977. Cow-calf herd production, Symposium on Size as a Component of Beef Production Efficiency. American Society of Animal Science. July 25, 1977. University of Wisconsin, Madison.

Cartwright, T.C., Gomez, F.G., Sanders, J.O., and Nelsen, T.C. 1977. Simulated milk-beef production systems in Columbia. J. Anim. Sci. 45 (Supplement 1):13.

Corbett, J.L., Freer, M. and Graham, N.McC. 1987. Energy metabolism of farm animals. Rowman and Littlefield: New Jersey. pp. 62-65.

Cundiff, L.V., K.E. Gregory, F.J. Schwulst and R.M. Koch. 1974. Effects of heterosis on maternal performance and milk production in Hereford, Angus and Shorthorn cattle. J. Anim. Sci. 38:728.

Davis, J. M., Cartwright, T.C., and Sanders, J.O. 1976. Alternative beef productions systems for Guyana. J. Anim. Sci. 43:235.

Doyle, S.P. 2000. Impacts of sexed semen utilization on commercial beef production. Ph.D. Dissertation. Colorado State Univ., Fort Collins.

Dunn, T.G., M.L. Riley, W.J. Murdoch, R.A. Field. Body condition score and carcass energy content in postpartum beef cows. 1983. Proceedings of the annual meeting, American Society of Animal Science. Western Section. 1983. V. 34 p. 56-59.

Enns, R.M. 1995. Simulation of across-breed comparisons for direct and maternal weaning weight in beef cattle. Ph.D. Dissertation. Colorado State Univ., Fort Collins.

Fioretti, C.C. 1994. Simulated rates of maturity and milk production effects on biological efficiency of beef production in Argentina. Ph.D. Dissertation. Kansas State University, Manhattan.

Fox, D.G. and J.R. Black. 1984. A system for predicting body composition and performance of growing cattle. J. Anim. Sci. 58:725.

Foy, J.K., W.R. Teague, J.D. Hanson. 1999. Evaluation of the upgraded SPUR model (SPUR2.4). Ecological Modeling. 118: 2-3, 149-165; 30 ref.

Garrett, W.N. 1980. Energy utilization of growing cattle as determined in 72 comparative slaughter experiments. Energy Metabolism. EAAP Publ. 26:p 3.

Geay, Y. 1984. Energy and protein utilization in growing cattle. J. Anim. Sci. 58:766.

Graham, N.McC. 1968. The metabolic rate of merino rams bred for high and low wool production. Aust. J. Agric. Res. 19:821.

Graham, N.McC., Searle, T.W. and Griffiths, D.A. 1974. Basal metabolic rate in lambs and young sheep. Aust. J. Agric. Res. 25:957.

Hanson, J.D., B.B. Baker and R.M. Bourdon. 1992. SPURII model description and user guide. USDA-ARS. Great Plains Systems Research Unit. GPSR Technical Report No. 1.

Harrison, S.R. 1990. Regression of a model on real-system output: an invalid test of model validity. Agric. Syst. 34:183-190.

Hart, R.H., J.D. Hanson, M.J. Baker. 1993. Managing for economic and ecological stability of range and range-improved grassland systems with the SPUR2 model and the STEERISKIER spreadsheet. Grasslands for our world. SIR Publishing; Wellington; New Zealand. 580-587;37 ref.

Hatfield, P.G., D.C. Clanton, K.M. Eskridge, and D.W. Sanson. 1989. Forage intake by lactating beef cows differing in potential for milk production. J. Anim. Sci. 67:3018.

Havstad, K.M. and D.E. Doornbos. 1987. Effect of biological type on grazing behavior and energy intake. Proc. Grazing Nutrition Conf. Jackson, Wyoming. pp19-15.

Herd, D.B. and L.R. Sprott. 1986. Body condition, nutrition and reproduction of beef cows. Texas Agricultural Extension Service. Circular B01526.

Holmes, C.W., McLean, N.A. and Lockyer, K.J. 1978. Changes in the rate of heat production of calves during grazing and eating. NZ. J. Agric. Sci. 21:107.

Houghton, P.L., R.P. Lemenger, G.E. Moss, K.S. Hendrix. 1990. Prediction of postpartum beef cow body composition using weight to height ratio and visual body condition score. J. Anim. Sci. 68:1428.

Hyde, L.R. and R.M. Bourdon. 1998. Simulated effects of sex control on a rotational-terminal crossbreeding system. Colorado State Univ. Beef Program Report. pp. 199-207.

International Livestock Center for Africa. 1978. Mathematical modeling of livestock production systems: application of the Texas A&M University beef cattle production model to Botswana. International Livestock Center for Africa. Addis Ababa, Ethiopia.

Jarrige, R., C. Demarquilly, J.P. Dulphy, A. Hoden, J. Roelin, C. Beranger, Y. Geay, M. Journet, C. Malterre, D. Micol, and M. Petit. 1986. The INRA "fill unit" system for predicting the voluntary intake of forage-based diets in ruminants: a review. J. Anim. Sci. 63:1737-1758.

Jenkins, T.J. and C.L. Ferrell. 1982. Lactation curves in mature crossbred cows; comparisons of four estimating functions. J. Anim. Sci. 55:supp., p. 189 (abstr.)

Jenkins, T.J. and C.L. Ferrell. 1984. A note on lactation curves of crossbred cows. Anim. Prod. 39:479.

Johnson, D.E., C.L. Ferrell, and T.G. Jenkins. 2003. The history of energetic efficiency research: where have we been and where are we going? J. Anim. Sci. 81:supp.,pp. E27-E38.

Kahn, H.E., and C.R.W. Spedding. 1983. A dynamic model for the simulation of cattle herd production systems. I. General description and the effect of simulation techniques on model results. Agricultural Systems. 12:2, 101-111; 6 ref.

LeDu, Y.L.P., P.D. Baker , and J.M. Barker. 1976. Milk fed calves. 2. The effect of length of milk feeding period and milk intake on herbage intake and performance of grazing calves. J. Agri. Sci. 87:197.

Lofgreen, G.P. and W.N. Garrett. 1968. A system for expressing net energy requirements and feed values for growing and finishing beef cattle. J. Anim. Sci. 27:793

Long, C.R. 1972. Application of mathematical programming to evaluation of systems of beef cattle breeding. Ph.D. Dissertation. Texas A&M University, College Station.

Long, C.R., Cartwright, T.C. and Fitzhugh, H.A., Jr., 1975. Systems analysis of sources of genetic and environmental variation in efficiency of beef production: cow size and herd management. J. Anim. Sci. 40:409.

Long, C.R. 1980. Crossbreeding for beef production: experimental results. J. Anim. Sci. 51:1197-1223.

Melton, B.E. and W.A. Colette. 1993. Potential shortcomings of output:input ratios as indicators of economic efficiency in commercial beef breed evaluations. J. Anim. Sci. 71:579.

Mezzaadra, C., R. Paciaroni, S. Vulich, E. Villarreal, and L. Melucci. 1989. Estimation of milk consumption curve parameters for different genetic groups of bovine calves. Anim. Prod. 49:83.

Montiero, L.S. 1975. Food efficiency in relation to estimated growth of body components in cattle. Anim. Prod. 20:315.

N.R.C. 1970. Nutrient Requirements of Domestic Animals, No. 3. Nutrient Requirements of Dairy Cattle. National Research Council, Washington, D.C.

N.R.C. 1981. Effect of Environment on Nutrient Requirements of Domestic Animals. National Research Council, Washington, D.C.

N.R.C. 1984. Nutrient Requirements of Beef Cattle (6th Rev. Ed.). National Academy Press, Washington, D.C.

N.R.C. 1987. Predicting Feed Intake of Food-Producing Animals. National Academy Press, Washington, D.C.

N.R.C. 1989. Nutrient Requirements of Dairy Cattle (6th Ed.). National Academy Press, Washington, DC.

N.R.C. 2000. Nutrient Requirements of Beef Cattle (7th Rev. Ed.). National Academy Press, Washington, D.C.

Nelsen, T.C., Cartwright, T.C., and Sanders J.O. 1978. Simulated production efficiencies from biologically different cattle in different environments. J. Anim. Sci. 47 (Supplement 1):60.

Notter, D.R. 1977. Simulated efficiency of beef production for a cow-calf feedlot management system. Ph.D. Dissertation. University of Nebraska, Lincoln.

Notter, D. R., J.O. Sanders, G.E. Dickerson, G.M. Smith, and T.C. Cartwright. 1979a. Simulated efficiency of beef production for a midwestern cow-calf-feedlot management system. I. Milk production. J. Anim. Sci. 49:70.

Notter, D. R., J.O. Sanders, G.E. Dickerson, G.M. Smith, and T.C. Cartwright. 1979b. Simulated efficiency of beef production for a midwestern cow-calf-feedlot management system. II. Mature body size. J. Anim. Sci. 49:83.

Notter, D. R., J.O. Sanders, G.E. Dickerson, G.M. Smith, and T.C. Cartwright. 1979c. Simulated efficiency of beef production for a midwestern cow-calf-feedlot management system. III. Crossbreeding systems. J. Anim. Sci. 49:92.

Ordonez, J. 1978. Systems analysis of beef production in the Western High Plains of Venezuela. Ph.D. Dissertation. Texas A&M University. College Station.

Rantanen, E. 1994. Biological simulation: environmental effects on weaning weight and prototype interface. M.S. Thesis. Colorado State University, Ft. Collins.

Richardson, J.W. and C.J. Nixon. 1986. Description of FLIPSIM V: a general firm level policy simulation model. Texas Agricultural Experiment Station Pub. B-1528.

Roy, J.H. 1970. The calf (management and feeding). 3rd ed. Pennsylvania State University Press. University Park. 183pp.

Sanders, J.O. 1977. Application of a beef cattle production model to the evaluation of genetic selection criteria. Ph.D. Dissertation, Texas A&M University, College Station.

Sanders, J.O. and T.C. Cartwright. 1979a. A general cattle production systems model. Part I: structure of the model. Agr. Systems. 4:217.

Sanders, J.O., and T. C. Cartwright. 1979b. A general cattle production systems model. Part II: procedures used for simulating animal performance. Agr. Systems. 4:289.

Schake, L.M., and J.K. Riggs. 1972. Behavior of beef cattle in confinement, a technical report. Texas Agr. Exp. Sta. Tech. Rep. No. 27. 12p.

Senft, R.L. 1983. The redistribution of nitrogen by cattle. Ph.D. Dissertation, Colorado State Univ., Fort Collins.

Short, R.E., and D.C. Adams. 1988. Nutritional and hormonal interrelationships in beef cattle reproduction. Can. J. Anim. Sci. 68:29-39.

Short, R.E., R.A. Bellows, R.B. Staigmiller, J.G. Berardinellli, and E.E. Custer. 1990. Physiological mechanisms controlling anestrus and infertility in postpartum beef cattle. J. Anim. Sci. 68:799-816.

Steffan, C.A., D.D. Kress, D.E. Doornbos, and D.C. Anderson. 1985. Performance of crosses among Hereford, Angus and Simmental cattle with different levels of Simmental breeding. III. Heifer post weaning growth and early reproductive traits. J. Anim. Sci. 61:1111.

Steffens, T. 1994. Grazing behavior and intake as affected by cattle biological type on mixed grass prairie. Ph.D. Dissertation. Colorado State University, Fort Collins.

Swingle, R.S., C.B. Roubicek, R.A. Wooten, J.A. Marchello and F.D. Dryden. 1979. Realimentation of cull range cows. I. Effect of final body condition and dietary energy level on rate, efficiency and composition of gains. J. Anim. Sci. 48:913.

Taylor, St. C.S., and G.B. Young. 1967. Variation in growth and efficiency in twin cattle on constant feeding levels. Anim. Prod. 9:295.

Taylor, St. C.S., and G.B. Young. 1968. Equilibrium weight in relation to food intake and genotype in twin cattle. Anim. Prod. 10:393.

Teague, W.R. and J.K. Foy. 2002. Validation of SPUR2.4 rangeland simulation model using a cow-calf field experiment. Ecological Modeling. In press.

Tess, M.W. and B.W. Kolstad. 2000. Simulation of cow-calf production systems in a range environment: I. Model development. J. Anim. Sci. 78:1159.

Thompson, W.R., D.H Theunick, J.C. Meiske, R.D. Goodrich, J.R. Rust and F.M. Byers. 1983. Linear measurements and visual appraisal as estimators of percentage empty body fat of beef cows. J. Anim. Sci. 56:755.

Tyrrell, H.F. and J.T. Reid. 1965. Prediction of the energy values of cow's milk. J. Dairy Sci. 48:1215-1223.

Van Es, A.J.H. 1978. Feed evaluation for ruminants. Livest. Prod. Sci. 5:331.

Van Es, A.J.H. 1980. Ann. Zootech. 29H.S.:73.

Wagner, J.J., K.S. Lusby, J.W. Oltjen, J. Rakestraw, R.P. Wettemann, L.E. Walters. 1988. Carcass composition in mature Hereford cows: estimation and effect on daily metabolizable energy requirements during winter. J. Anim. Sci. 66: 603.

Wight, J.R. and J.W. Skiles, eds. 1987. SPUR: Simulation of production and utilization of rangelands. Documentation and User Guide. U.S. Department of Agriculture, Agricultural Research Service, ARS 63.

Williams, C.B., P.A. Oltenacu, and C. J. Sniffen. 1989. Application of neutral detergent fiber in modeling feed intake, lactation response, and body weight changes in dairy cattle. J. Dairy Sci. 72:652-663.

Wilton, J.W., Morris, C.A., Jenson, E.A., Leight, A.O. and Pfeiffer, W.C. 1974. A linear programming model for beef cattle production. Can. J. Anim. Sci. 54:693.

Wyatt, R.D., M.B. Gould and R. Totusek. 1977. Effects of single vs. simulated twin rearing on cow and calf performance. J. Anim. Sci. 45:1409.

APPENDIX

Glossary of variables

Name	Description
AFAT	actual kg of daily Available FAT
AGEDIF	AGE DIFference
AGEDIS	AGE DIStribution matrix (group, age) for foundation animals
ALLFIX	input variable indicating All Feeds fed on a FIXed level basis
AMTX	Var/cov MaTriX in symmetric storage mode for Additive effects
ANF	Available Nutrients from Fat (kg TDN/d)
ANUMP	Available Nutrients Used for Milk Production
APDACD	a cow's Average Probability of Death At Calving with Dystocia
APDACN	a cow's Average Probability of Death At Calving with No dystocia
ASDATE	Animal Starting DATE
ATDN	Available TDN beyond RALMIN
AV1FC	AVerage 1 year old Fat at Calving
AV1FW	AVerage 1 year old Fat at Weaning
AV1WC	AVerage 1 year old Weight at Calving
AV1WW	AVerage 1 year old Weight at Weaning
AV2DY	AVerage DYstocia in 2 year olds
AV2FC	AVerage 2 year old Fat at Calving
AV2FW	AVerage 2 year old Fat at Weaning
AV2MP	AVerage 2 year old's Milk Production
AV2WC	AVerage 2 year old Weight at Calving
AV2WW	AVerage 2 year old Weight at Weaning
AV3DY	AVerage DYstocia in 3 year olds
AV3FC	AVerage 3 year old Fat at Calving
AV3FW	AVerage 3 year old Fat at Weaning
AV3MP	AVerage 3 year old Milk Production
AV3WC	AVerage 3 year old Weight at Calving
AV3WW	AVerage 3 year old Weight at Weaning
AV4FC	AVerage 4 year old Fat at Calving
AV4FW	AVerage 4 year old Fat at Weaning
AV4MP	AVerage 4 year old Milk Production
AV4WC	AVerage 4 year old Weight at Calving
AV4WW	AVerage 4 year old Weight at Weaning
AVAAP	AVerage Age At Puberty
AVACCW	AVerage Age At Calving: CoW
AVADCCW	AVerage Age At Death: CoW
AVADG	AVerage Average Daily Gain
AVADGM	AVerage Average Daily Gain for Males
AVAOP1	AVerage Age Of Pregnancy for 1 year olds
AVAWCF	AVerage Age at Weaning: CalF
AVAWCFM	AVerage Age at Weaning: CalF: Male
AVAWCW	AVerage Age at Weaning: CoW
AVAWWT	AVerage Adjusted Weaning Weight (205 days of age)
AVAWWTM	AVerage Adjusted Weaning WeighT for Males
AVBDCF	AVerage Birth Date: CalF
AVBDCFM	AVerage Birth Date: CalF: Males
AVBW	AVerage Birth Weight

AVBWM	AVerage Birth Weight for Males
AVCVDT	AVerage CalVing DaTe
AVCWF	AVerage Carcass Weight on Females
AVCWFT	AVerage Carcass Weight for Females: Terminal
AVCWM	AVerage Carcass Weight on Males
AVCWMT	AVerage Carcass Weight on Males: Terminal
AVDAP	AVerage Day At Puberty
AVDCCF	AVerage Death at Calving: Calf
AVDCCFM	AVerage Death at Calving: CalF: Males
AVDCCW	AVerage Death at Calving: CoW
AVDCF	AVerage Death: CalF
AVDCFM	AVerage Death: CalF: Male
AVDCW	AVerage Death: CoW
AVDF	AVerage Death of cattle on Feed
AVDFF	AVerage Days on Feed for Females
AVDFFT	AVerage Days on Feed for Females: Terminal
AVDFM	AVerage Days on Feed for Males
AVDFMT	AVerage Days on Feed for Males: Terminal
AVDFP	AVerage Death on Feed and Pasture (stockers)
AVDFT	AVerage Death of cattle on Feed: Terminal
AVDMFF	AVerage Dry Matter on Feed for Females
AVDMFM	AVerage Dry Matter on Feed for Males
AVDNPF	AVerage Digestible Nutrients for Pastured Females (stockers)
AVDNPM	AVerage Digestible Nutrients for Pastured Males (stockers)
AVDOCY	AVerage Day Of CYcling
AVDOP1	AVerage Day Of Pregnancy for 1 year olds
AVDOPR	AVerage Day Of PRegnancy
AVDP	AVerage Death of cattle on Pasture (stockers)
AVDPF	AVerage Dressing Percentage on Females
AVDPFT	AVerage Dressing Percentage for Females: Terminal
AVDPM	AVerage Dressing Percentage on Males
AVDPMT	AVerage Dressing Percentage on Males: Terminal
AVDPT	AVerage Death of cattle on Pasture (stockers): Terminal
AVDWFF	AVerage Delta Weight on Feed for Females
AVDWFM	AVerage Delta Weight on Feed for Males
AVDWPF	AVerage Delta Weight for Pastured Females (stockers)
AVDWPM	AVerage Delta Weight for Pastured Males (stockers)
AVDYCF	AVerage Dystocia: CalF
AVDYCFM	AVerage DYstocia: CalF: Males
AVFAFF	AVerage Final Age on Feed for Females
AVFAFFM	AVerage Final Age on Feed for Males
AVFAFFT	AVerage Final Age on Feed for Females: Terminal
AVFAFMT	AVerage Final Age on Feed for Males: Terminal
AVFAPF	AVerage Final Age on Pasture (stockers) for Females
AVFAPFT	AVerage Final Age on Pasture for Females: Terminal
AVFAPM	AVerage Final Age on Pasture (stockers) for Males
AVFAPMT	AVerage Final Age on Pasture for Males: Terminal
AVFBCF	AVerage Fat at Birth: CalF
AVFBCFM	AVerage Fat at Birth: CalF: Males
AVFCCW	AVerage Fat at Calving: CoW
AVFCFF	AVerage Feed Conversion on Feed for Females

AVFCFM	AVerage Feed Conversion on Feed for Males
AVFCPF	AVerage Feed Conversion on Pasture for Females (stockers)
AVFCPM	AVerage Feed Conversion on Pasture for Males (stockers)
AVFFFF	AVerage Fat on Feed for Females
AVFFFFT	AVerage Final Fat on Feed for Females: Terminal
AVFFFM	AVerage Fat on Feed for Males
AVFFFMT	AVerage Final Fat on Feed for Males: Terminal
AVFFPF	AVerage Fat on Pasture for Females
AVFFPFT	AVerage Final Fat on Pasture for Females: Terminal
AVFFPM	AVerage Fat on Pasture for Males
AVFFPMT	AVerage Final Fat on Pasture for Males: Terminal
AVFWCF	AVerage Fat at Weaning: CalF
AVFWCFM	AVerage Fat at Weaning: CalF: Male
AVFWCW	AVerage Fat at Weaning: CoW
AVFWFF	AVerage Final Weight on Feed for Females
AVFWFFT	AVerage Final Weight on Feed for Females: Terminal
AVFWFM	AVerage Final Weight on Feed for Males
AVFWFMT	AVerage Final Weight on Feed for Males: Terminal
AVFWPF	AVerage Final Weight on Pasture for Females
AVFWPFT	AVerage Final Weight on Pasture for Females: Terminal
AVFWPM	AVerage Final Weight on Pasture for Males
AVFWPMT	AVerage Final Weight on Pasture for Males: Terminal
AVGLF	AVerage Gestation Length on Females
AVGLM	AVerage Gestation Length on Males
AVICY	AVerage Interval to CYcling
AVIPR	AVerage Interval to PRegnancy
AVKILA	AVerage KILl Age
AVKILF	AVerage KILl Fat
AVKILW	AVerage KILl Weight
AVMDY	AVerage DYstocia in Mature cows
AVMFC	AVerage Mature Fat at Calving
AVMFW	AVerage Mature Fat at Weaning
AVMMP	AVerage Mature Milk Production
AVMP	AVerage Milk Production
AVMWC	AVerage Mature Weight at Calving
AVMWW	AVerage Mature Weight at Weaning
AVPRG	AVerage PReGnant (all ages)
AVPRG1	AVerage PReGnant (1 year olds)
AVPRG2	AVerage PReGnant (2 year olds)
AVPRG3	AVerage PReGnant (3 year olds)
AVPRG4	AVerage PReGnant (4 year olds)
AVPRGM	AVerage PReGnant (Mature cows)
AVQGF	AVerage Quality Grade on Females
AVQGFT	AVerage Quality Grade for Females: Terminal
AVQGM	AVerage Quality Grade on Males
AVQGMT	AVerage Quality Grade on Males: Terminal
AVSAFF	AVerage Starting Age on Feed for Females
AVSAFFT	AVerage Starting Age on Feed for Females: Terminal
AVSAFM	AVerage Starting Age on Feed for Males
AVSAFMT	AVerage Starting Age on Feed for Males: Terminal
AVSAPF	AVerage Starting Age on Pasture for Females

AVSAPFT	AVerage Starting Age on Pasture for Females: Terminal
AVSAPM	AVerage Starting Age on Pasture for Males
AVSAPMT	AVerage Starting Age on Pasture for Males: Terminal
AVSFFF	AVerage Starting Fat on Feed for Females
AVSFFFT	AVerage Starting Fat on Feed for Females: Terminal
AVSFFM	AVerage Starting Fat on Feed for Males
AVSFFMT	AVerage Starting Fat on Feed for Males: Terminal
AVSFPF	AVerage Starting Fat on Pasture for Females
AVSFPFT	AVerage Starting Fat on Pasture for Females: Terminal
AVSFPM	AVerage Starting Fat on Pasture for Males
AVSFPMT	AVerage Starting Fat on Pasture for Males: Terminal
AVSLAF	AVerage SaLe Age for Females
AVSLAM	AVerage SaLe Age for Males
AVSLFF	AVerage SaLe Fat for Females
AVSLFM	AVerage SaLe Fat for Males
AVSLWF	AVerage SaLe Weight for Females
AVSLWM	AVerage SaLe Weight on Males
AVSWFF	AVerage Starting Weight on Feed for Females
AVSWFFT	AVerage Starting Weight on Feed for Females: Terminal
AVSWFM	AVerage Starting Weight on Feed for Males
AVSWFMT	AVerage Starting Weight on Feed for Males: Terminal
AVSWPF	AVerage Starting Weight on Pasture for Females
AVSWPFT	AVerage Starting Weight on Pasture for Females: Terminal
AVSWPM	AVerage Starting Weight on Pasture for Males
AVSWPMT	AVerage Starting Weight on Pasture for Males: Terminal
AVWCCW	AVerage Weight at Calving on CoWs (all ages)
AVWWCW	AVerage Weight at Weaning on CoWs (all ages)
AVWWT	AVerage Weaning Weight
AVWWTM	AVerage Weaning WeighT for Males
AVYGF	AVerage Yield Grade on Females
AVYGFT	AVerage Yield Grade for Females: Terminal
AVYGM	AVerage Yield Grade on Males
AVYGMT	AVerage Yield Grade on Males: Terminal
BABW	Bull Adjustment for Birth Weight
BADC	Bull Adjustment for Digestive Capacity
BADDYS	Bull Adjustment for Direct DYStocia
BAFFC	Bull Adjustment for Fat Free Carcass
BAGL	Bull Adjustment for Gestation Length
BAIMF	Bull Adjustment for IntraMuscular Fat
BAMF	Bull Adjustment for Mature Fat
BAMW	Bull Adjustment for Mature Weight
BAPSRV	Bull Adjustment for Probability of SuRVival
BARM	Bull Adjustment for Requirement for Maintenance
BAUNSD	Bull Adjustment for UNSounDness
BAYLD	Bull Adjustment for YeiLD grade
BAYW	Bull Adjustment for Yearling Weight
BEE	Constant used in growth rate calculation
BRDCMP	BReeD CoMPosition array (row = individual, column = breed)
BRDGRP	BReeDing GRouP
BSEND	julian date of Breeding Season END
BSSTRT	julian date of Breeding Season STaRT

BSTRIG	Breeding Season TRIGger (programming tool)
BVAAP	Breeding Value for Age AT Puberty
BVAPP	Breeding Value for APPetite
BVBW	Breeding Value for Birth Weight
BVDDYS	Breeding Value for Direct DYStocia
BVFFC	Breeding Value for Fat Free Carcass
BVGL	Breeding Value for Gestation Length
BVIMF	Breeding Value for IntraMuscular Fat
BVMDYS	Breeding Value for Maternal DYStocia
BVMF	Breeding Value for Mature Fat
BVMP	Breeding Value for Milk Production
BVMW	Breeding Value for Mature Weight
BVPCON	Breeding Value for Probability of CONception
BVPPI	Breeding Value for PostPartum Interval
BVPSRV	Breeding Value for Probability of SuRVival
BVRM	Breeding Value for the Requirement for Maintenance
BVUNSD	Breeding Value for UNSounDness
BVXXXX	Breeding Value for new trait development
BVYLD	Breeding Value for YeiLD grade
BVYW	Breeding Value for Yearling Weight
BVZZZZ	Breeding Value for new trait development
BW	Birth Weight (actual)
BWCF	Birth Weight Correction Factor (age of dam)
BWF	Birth Weight of Fetus
CAFIND	CAlF INDex (subscript indicating calf's location in the vector)
CARWT	CARcass WeighT
CATCD	CATegory CoDe
CCW	ConCeptus Weight
CEE	Constant used in growth rate calculation
CFAGE	Correction Factor for AGE
CFCM	Correction Factor for Calving Management
CFCODE	variable indicating output is desired on calves
CFCONF	Correction Factor for CONdition on Fertility
CFCONM	Correction Factor for CONdition on Milk
CFDAGE	Correction Factor for Death due to month of AGE
CFDFF	Correction Factor for change (Delta) in Fat on Fertility
CFDMO	Correction Factor for Death due to MOnth of year
CFDW	Correction Factor for change (Delta) in Weight
CFDYS	Correction Factor for DYStocia (YOA) (intercept value in equation)
CFDYSF	Correction Factor for DYStocia in Fertility
CFMAT	Correction Factor for MATurity
CFPDMO	Correction Factor for Perinatal Death by MOnth of year
CFTIME	Correction Factor for TIME since calving
CIICNT	Current Id Index CouNT (I think)
CLSEED	CLock SEED (0 = no, 1 = yes)
CLTIME	Time of day in HH:MM:SS
CN	Consumed Nutrients (kg TDN)
CON	indicates CONvergence status of nutrition loop
COUNT	COUNTer
CP	Crude Protein content of total ration (a proportion)
CPCREP	Crude Protein of CREeP feed

CPESUP	Crude Protein of Energy SUPplement
CPGFOR	Crude Protein of Grazed FORage
CPHFOR	Crude Protein of Harvested FORage
CPMILK	Crude Protein of MILK
CPPSUP	Crude Protein of Protein SUPplement
CPRAT1	Crude Protein of RATion 1
CPRAT2	Crude Protein of RATion 2
CPRAT3	Crude Protein of RATion 3
CPTOL	TOLerance level for deviations in Crude Protein
CSDATE	CaStration DATE
CSEND	julian date of Calving Season END
CSSTRT	julian date of Calving Season STaRT
CSTRIG	CaStration TRIGger (programming device)
CULLF	CULL Factor (decimal culling factor by age of cow)
CUTOFF	Number of years before output is generated in SUMARIZ
CV1	General purpose Control Vector
CV2	General purpose Control Vector
CV3	General purpose Control Vector
CV4	General purpose Control Vector
CV5	General purpose Control Vector
CV6	General purpose Control Vector
CV7	General purpose Control Vector
CVBRD	Control Vector indicating female is presently exposed to a bull
CVCALF	Control Vector indicating a CALF
CVCG1	Control Vector indicating Cull Group 1
CVCG10	Control Vector indicating Cull Group 10
CVCG2	Control Vector indicating Cull Group 2
CVCG3	Control Vector indicating Cull Group 3
CVCG4	Control Vector indicating Cull Group 4
CVCG5	Control Vector indicating Cull Group 5
CVCG6	Control Vector indicating Cull Group 6
CVCG7	Control Vector indicating Cull Group 7
CVCG8	Control Vector indicating Cull Group 8
CVCG9	Control Vector indicating Cull Group 9
CVCLVD	Control Vector indicating a cow has CaLVeD at least once
CVCREP	Control Vector indicating feeding of CREeP feed
CVCULL	Control Vector indicating animals to be CULLed (not kept for breeding purposes)
CVCVF	Control Vector indicating Continued Variable Feeding
CVCYC	Control Vector indicating female is presently CYCling
CVDAC	Control Vector indicating animal Died At Calving
CVDIED	Control Vector indicating animal DIED (not perinatally)
CVDYS	Control Vector indicating DYStocia
CVDYSC	Control Vector indicating Calf experienced DYStocia at birth
CVESUP	Control Vector indicating feeding of Energy SUPplement
CVFEED	Control Vector indicating animal is to be fed in a lot (FEED)
CVFETS	Control Vector indicating animal is a FETuS
CVGEN	Control Vector indicating all animals to be GENerated
CVGENF	Control Vector indicating GENeration of a Fetus
CVGET	Control Vector indicating animals for which we need to GET (generate) values
CVGFOR	Control Vector indicating feeding of Grazed FORage
CVGONE	Control Vector indicating animal is GONE from the simulation

CVGRAZ	Control Vector indicating GRAZing animals
CVGRP	Control Vector determining group to be run within a time-step
CVHFOR	Control Vector indicating feeding of Harvested FORage
CVIMP	Control Vector indicating an IMPorted female
CVIRR	Control Vector indicating IRRegular animals (orphans, foster calves)
CVKILL	Control Vector indicating animal is to be slaughtered (KILLed)
CVL	Contol Vector for Lactation
CVLIVE	Control Vector indicating animal is aLIVE
CVMILK	Control Vector indicating feeding of MILK
CVNBRN	Control Vector indicating calf is a newborn in the current time-step
CVNCYC	Control Vector indicating animals that have Newly CYCled
CVNDIE	Control Vector indicating animals that Newly DIE (die during the current step
CVNEWC	Control Vector indicating NEWly calved cow
CVNEWI	Control Vector indicating NEWly Imported female
CVNEWN	Control Vector indicating NEWly weaNed animal
CVNEWP	Control Vector indicating NEWly Pregnant animal
CVNEWS	Control Vector indicating NEWly generated (purchased) Sire
CVNSTR	Control Vector indicating a Newly STeeRed male
CVNWCL	Control Vector indicating NeWly CuLled animal
CVNWFN	Control Vector indicating NeW FouNdation cow
CVORPH	Control Vector indicating an ORPHan
CVP	Control Vector for Pregnancy
CVPAST	Control Vector indicating animal is to be PASTured
CVPSUP	Control Vector indicating feeding of Protein SUPplement
CVRAT1	Control Vector indicating feeding of RATion 1
CVRAT2	Control Vector indicating feeding of RATion 2
CVRAT3	Control Vector indicating feeding of RATion 3
CVSATE	Control Vector indicating maximum intake has been achieved
CVSELL	Control Vector indicating animal is to be sold (SELL)
CVSIM	Control Vector indicating animal functions are to be SIMulated
CVSIRE	Control Vector indicating animal is a SIRE
CVSTRV	Control Vector indicating STaRVation condition
CVTERM	Control Vector indicating TERMinal breed designation
CVUNSD	Control Vector indicating UNSounD animal
CVVIRG	Control Vector indicating female has never been pregnant
CVWC	Control Vector indicating animal Weaned a Calf after her last calving
CWCODE	variable indicating output is desired on cows
DAC	Day After Calving
DAMAGE	DAM's AGE in years
DAMID	Unique DAM ID
DAMIND	DAM's vector INDex
DATE	DATE (dummy function variable)
DAY	julian DAY of the year
DAYFD	DAYs on FeeD accumulated by cattle on feed
DAYPA	DAYs on PAsture accumulated by stockers
DBCODE	DeBug CODE
DCOUNT	Dam COUNT (count of dams qualifying for grafting)
DCREP	Digestibility of CREeP feed
DEBW	change (delta) in Empty Body Weight
DEMAND	DEMAND (kg DM) for grazed forage
DEMILK	Digestible Energy (mcal) from 1 kg dm MILK

DESUP	Digestibility of Energy SUPplement
DGCW	Change (Delta) in Growth Curve Weight
DGFOR	Digestibility of Grazed FORage
DHFOR	Digestibility of Harvested FORage
DIG	DIGestibility
DIGTOL	TOLerance level for deviations in DIGestibility
DIRVF	indicates the DIRection of Variable Feeding
DMILK	Digestibility of MILK
DMREQ	Dry Matter REQuirements
DMRTFD	Dry Matter Required for Target Fat Deposition
DO1PPE	Day Of 1st PostPartum Estrus
DOA	Day Of Age
DOB	julian Day Of Birth
DOG	Day Of Gestation
DPSUP	Digestibility of Protein SUPplement
DRAT1	Digestibility of RATion 1
DRAT2	Digestibility of RATion 2
DRAT3	Digestibility of RATion 3
DRSPCT	DReSsing PerCenTage
DSEED	Double precision SEED for GGNSM (IMSL) routine.
DSEED	Double precision SEED required by GGNSM
DW	Change (Delta) in Weight
EATCM	Effective Ambient Temperature of Current Month
EBPBW	Empty Body's Proportion of Birth Weight
EBPMW	Empty Body's Proportion of Yearling Weight
EBPYW	Empty Body's Proportion of Yearling Weight
EBW	Empty Body Weight
EFFDOA	EFFective Day Of Age
EFFDOM	EFFective Degree Of Maturity
EFFMSC	EFFective Months Since Calving
EIS1-16	Experimental Integer Scalar (1-16; tape8 input)
ELS1-16	Experimental Logical Scalar (1-16; tape8 input)
ERCODE	ERror CODE
ERS1-32	Experimental Real Scalar (1-32; tape8 input)
EXPGCW	EXPected Growth Curve Weight
FAT	Catabolizable FAT (kg)
FCDGCW	Fat Content of gain in Growth Curve Weight
FDGRP	FeeDing GRouP as defined in subroutine FEED
FETIND	FETus' vector INDex
FFFGRP	variable indicating Fat Feeding status of the Feed GRouP
FFW	Fat Free Weight
FG	Fat Gain (kg)
FILL	FILL
FIXCON	variable indicating FIXed CONvergence for the nutrition loop
FIXMAX	FIXed levels of supplementation MAXima (by feeding group and feed)
FIXVAR	Vector indicating FIXed (1) or VARiable (0) maximum feed levels
FNBCD	FouNdation Breed Composition of Dams (foundation group, breed)
FNBCS	FouNdation Breed Composition of Sires (foundation group, breed)
FNCON	FouNdation group CONdition (W/GCW)
FNDAC	FouNdation group Day After Calving
FNDOA	FouNdation Day Of Age

FNDOB	FouNdation Day Of Birth
FNDOG	FouNdation Day Of Gestation
FNGPSZ	FouNdation GrouP SiZe
FNGRP	FouNdation GRouP
FNHERD	FouNdation HERD
FNNASV	FouNdation Non-Additive Starting Value (foundation group, trait)
FNTOTL	TOTaL number of animals in FouNdation herd
FPCODE	variable indicating output is desired on cattle on feed or pasture (stockers)
FPEND	Feeding Period ENDing date (by feeding group and feed)
FPSTRT	Feeding Period STaRTing date (by feeding group and feed)
FRAME	FRAME score
FSSGRP	Foundation Service Sire GRouP
FVAAP	Foundation Value (BV) for Age At Puberty
FVAPP	Foundation Value (BV) for APPetite
FVBW	Foundation Value (BV) for Birth Weight
FVDDYS	Foundation Value (BV) for Direct DYStocia
FVFFC	Foundation Value (BV) for Fat Free Carcass
FVGL	Foundation Value (BV) for Gestation Length
FVIMF	Foundation Value (BV) for IntraMuscular Fat
FVMDYS	Foundation Value (BV) for Maternal DYStocia
FVMF	Foundation Value (BV) for Mature Fat
FVMP	Foundation Value (BV) for Milk Production
FVMW	Foundation Value (BV) for Mature Weight
FVPCON	Foundation Value (BV) for Probability of CONception
FVPPI	Foundation Value (BV) for PostPartum Interval
FVPSRV	Foundation Value (BV) for Probability of SuRVival
FVRM	Foundation Value (BV) for Requirement for Maintenance
FVUNSD	Foundation Value (BV) for UNSounDness
FVXXX	Foundation Value (BV) for new trait development
FVYLD	Foundation Value (BV) for YeiLD grade
FVYW	Foundation Value (BV) for Yearling Weight
FVZZZZ	Foundation Value (BV) for new trait development
FXCREP	FiXed quantity of CREeP fed
FXESUP	FiXed quantity of Energy SUPplement fed
FXHFOR	FiXed quantity of Harvested FORage fed
FXPSUP	FiXed quantity of Protein SUPplement fed
FXRAT1	FiXed quantity of RATion1 fed
FXRAT2	FiXed quantity of RATion2 fed
FXRAT3	FiXed quantity of RATion3 fed
GAM12	Square root Matrix for General Additive effects
GCCPCT	Gross Calf Crop PerCenTage
GCW	Growth Curve Weight
GCWC	Growth Curve Weight of Calf
GLF	Gestation Length of Fetus
GRDYLD	variable indicating animals are to be sold on GRaDe and YieLD parameters
GRPCNT	GRouP CouNTer for groups run within a time-step
HAFSTP	HAlFSTeP or 1/2 * STEP
HCOUNT	Heifer COUNT (count of available replacements)
HCTARS	HeCTARS
HERD	HERD counter
HH	Hour of day

HYVIG	HYbrid VIGor array (F1 vigor in trait units by J: trait, L: breed of sire, M:bod
ICPGF	Input Crude Protein of Grazed Forage
ID	ID number
IDGF	Input Digestibility of Grazed Forage
IDOA	Inflection Day Of Age
IER	Integer ERror code returned from GGNSM.
IGROUP	Import GROUP (scalar indicator variable)
ILPM	Intake Limit at Peak Milk production
IMBCD	IMport group Breed Composition of Dam (import group, breed)
IMBCMP	IMported animal Breed CoMPosition (import group, breed)
IMBCS	IMport group Breed Composition of Sire (import group, breed)
IMDATE	IMportation DATE (julian date)
IMNASV	IMport group Non-Additive Starting Value (import group, trait)
IMPCON	IMPort group CONdition (W/GCW)
IMPDAC	IMPort group Day After Calving
IMPDOA	Day Of Age for IMPorted animals in this import group
IMPDOG	IMPort group Day Of Gestation
IMPGRP	IMPort GRouP
IMPPOL	IMPort POLicy (1 = importation allowed, 0 = importation not allowed)
IMPSEX	IMPort group SEX
IMPYOA	IMPort group Year Of Age
INCOND	INitial CONDition
INCREP	INtake of CREeP feed (calves only, kg dry matter)
INDM	INtake of Dry Matter
INDMP	INtake of Dry Matter from Previous step
INESUP	INtake of Energy SUPlement (kg dry matter)
INGFOR	INtake of Grazed FORage (kg dry matter)
INHFOR	INtake of Harvested Forage (kg dry matter)
INIRG	INtake Increase due to Retarded Growth
INLFAT	proportionate reduction in INtake due to FAT
INLMT	INtake LiMiT (kg dry matter)
INLMT1	INtake LiMiT 1 (physiological limit)
INLMT2	INtake LiMiT 2 (physical (bulk) limit)
INMILK	INtake of MILK (kg dry matter)
INPSUP	INtake of Protein SUPlement (kg dry matter)
INRA	INtake Reduction due to Age
INRAT1	INtake of RATion 1 (grower, kg dry matter)
INRAT2	INtake of RATion 2 (moderate, kg dry matter)
INRAT3	INtake of RATion 3 (hot, kg dry matter)
INRCP	INtake Reduction due to low levels of Crude Protein
INRF	INtake Reduction due to Fat
INTEMP	INtake fluctuation due to TEMPerature
INTOL	TOLerance level for deviation in INtake
IOCODE	variable indicating ouput is desired on cattle and feed entering or exiting
IOR	Intake Over Requirements
IPTRIG	ImPort date TRIGger (programming tool)
IR	Row dimension required by GGNSM.
ISORT	vector containing sort index produced by QSORT
ISORTD	SORT vector for dams generated by QSORT (reversed in some versions)
ISORTO	SORT vector for orphans generated by QSORT (reversed in some versions)
ISSGRP	Import group Service Sire GRouP

ITCNT	ITeration CouNTer for DIG/CP loop
ITEMP1	Temporary integer storage vector used in Q8VCMPRS etc.
ITEMP2	Integer TEMPorary vector 2
ITEMP3	Integer TEMPorary vector 3
ITEMP4	Integer TEMPorary vector 4
ITSCAL	Integer Temporary SCALer
ITSCL2	Integer Temporary SCaLer 2
IVAAP	Imported animal Value (BV) for Age At Puberty
IVAPP	Imported animal Value (BV) for APPetite
IVBW	Imported animal Value (BV) for Birth Weight
IVDDYS	Imported animal Value (BV) for Direct DYStocia
IVGL	Imported animal Value (BV) for Gestation Length
IVIMF	Imported animal Value (BV) for IntraMuscular Fat
IVMDYS	Imported animal Value (BV) for Maternal DYStocia
IVMF	Imported animal Value (BV) for Mature Fat
IVMP	Imported animal Value (BV) for Milk Production
IVMW	Imported animal Value (BV) for Mature Weight
IVPCON	Imported animal Value (BV) for Probability of CONception
IVPPI	Imported animal Value (BV) for PostPartum Interval
IVPSRV	Imported animal Value (BV) for Probability of SuRVival
IVRM	Imported animal Value (BV) for Requirement for Maintenance
IVUNSD	Imported animal Value (BV) for UNSounDness
IVYW	Imported animal Value (BV) for Yearling Weight
IW	Inflection Weight
IWTOL	Inflection Weight TOLerance value
K1	Constant used in growth rate calculation
K2	Constant used in growth rate calculation
KF	Partial efficiency of Fat gain
KG	partial efficiency of gain
KK	Growth curve parameter
KL	Partial efficiency of Lactation
KM	Partial efficiency of Maintenance
KP	Partial efficiency of Protein gain
LCODE	Intake Limit CODE (1 to 7)
LCSCAL	Local Character SCAlar
LISCAL	Local Integer SCALar
LN	LeNgth parameter -- dimensioned general vector length PARAMETER
LOCIND	LOCation INDex
LWRBND	LoWeR BouND of range for a particular sire (sire)
M12PNT	Matrix 12 (square root) PoiNTer (indicates appropriate square root matrix)
MAT	Maturity
MATGRP	input array showing sire groups for MATing GRouPs (breed groups/breeding seasons)
MAXDEV	MAXimum DEViation
MAXID	MAXimum ID number in herd
MAXK	MaXimum dimensioned size of a square root matrix.
MAXP	MAXimum number of records (animals) that can be generated in one call
MEMILK	Metabolizable Energy (mcal) from 1 kg dm of MILK
MERTOL	Metabolizable Energy Ratio Tolerance
MIC	Maximum Intake of Calf
MINDYS	MINimum amount of DYStocia (malpresentation)
MINSPC	MINimum SPaCe (# of "gone" records) necessary at all times

MM	Minute of the hour
MNGEN	Multivariate Normal GENeration of deviates for traits
MO	MOnth of the year
MOA	Month Of Age
MP	Milk Production (actual)
MPDAM	Milk Production of the DAM (kg)
MTRMER	Milk to Total Ration Metabolizable Energy Ratio
MTXSIZ	MATrix SIZe -- dimensioned size of MTX12 (normally 20)
MXCREP	MaXimum (kg DM) that may be fed of CREeP feed
MXDAGE	MaXimum DAM AGE
MXDEVD	MaXimum DEViation in Digestibility found after iteration of DIG/CP loop
MXDEVI	MaXimum DEViation in Intake
MXDEVP	MaXimum DEViation in crude Protein found after iteration of DIG/CP loop
MXDEVR	MaXimum DEViation for milk/total ration me Ratio
MXDIAG	MaXimum dimensioned number of lower diagonal elements in a matrix.
MXDIAG	MaXimum dimensioned number of lower diagonal elements in a matrix.
MXESUP	MaXimum (kg DM) that may be fed of Energy SUPplement
MXHFOR	MaXimum (kg DM) that may be fed of Harvested FORage
MXPEN	MaXimum PEN (largest number associated with feedlop pens to that point in time)
MXPSUP	MaXimum (kg DM) that may be fed of Protein SUPplement
MXRAT1	MaXimum (kg DM) that may be fed of RATion 1
MXRAT2	MaXimum (kg DM) that may be fed of RATion 2
MXRAT3	MaXimum (kg DM) that may be fed of RATion 3
MXSAGE	MaXimum Sire AGE (for simulated sires)
N	Maximum number of animals to be simulated -- vector length
N01BLN	Normal 0,1 maximum Block LeNgth
NAAAP	Non-Additive value for Age AT Puberty
NAAPP	Non-Additive value for APPetite
NABW	Non-Additive value for Birth Weight
NADDYS	Non-Additive value for Direct DYStocia
NAFFC	Non Additive value for Fat Free Carcass
NAGL	Non-Additive value for Gestation Length
NAIMF	Non Additive value for IntraMuscular Fat
NAM12	Square root Matrix for NonAdditive effects
NAMDYS	Non-Additive value for Maternal DYStocia
NAMF	Non-Additive value for Mature Fat
NAMP	Non-Additve value for Milk Production
NAMTX	Var/cov MaTriX in symmetric storage mode for NonAdditive effects
NAMW	Non-Additive value for Mature Weight
NAPCON	Non-Additive value for Probability of CONception
NAPPI	Non-Additive value for PostPartum Interval
NAPSRV	Non-Additive value for Probability of SuRVival
NARM	Non Additive value for the Requirement for Maintenance
NAUNSD	Non-Additive value for UNSounDness
NAXXXX	Non Additive value for new trait development
NAYLD	Non Additive value for YeiLD grade
NAYW	Non-Additive value for Yearling Weight
NAZZZZ	Non Additive value for new trait development
NBDATE	New Beginning (beginning of time-step) DATE (function)
NCALVS	Number of CALVeS needing a sire
NDIAG	Number of elements in lower DIAGonal matrix.

NDIY	Number of Days In Year
NEDATE	New Ending (end of time-step) DATE
NEEDED	number of replacements (or animals in general) NEEDED
NETCCP	NET Calf Crop Percentage
NEWHFL	NEW Herd FiLe to be written (0 = no, 1 = yes)
NEWHRD	Input variable indicating a NEW HeRD is to be generated
NFG	Non Fat Gain (kg)
NFGAPA	Number of Feed Groups Allowed Per Animal
NFNGPS	Number of FouNdation GrouPS
NGMR	Necessary Gain for Maximum Reproduction
NIMGPS	Number of IMportation GrouPS
NLAST	Location index Number for LAST animal generated
NLEFT	Number of animals LEFT to be generated
NOBCV1	Number of On Bits in Control Vector 1
NOBGPS	Number Of Breeding GrouPS
NOBITS	Number of On BITS
NOBS	Number Of Breeding Seasons (may overlap)
NOCS	Number Of Calving Seasons (contiguous)
NOFGPS	Number Of Feeding GrouPS
NOFITS	Number Of Free ITerationS allowed before oscillation damper is used
NOGRPS	Number Of GRouPS run in a time-step
NOHRDS	Number Of HeRDS being simulated
NOSGPS	Number Of Sire GrouPS
NOTITS	Number Of Total ITerationS allowed before program is killed
NPEGPS	Number of Prediction Error GrouPS
NR	Number of Records needed from GGNSM.
NRTRTS	Number of Repeated genetic TRaiTS
NSIRES	Number of SIRES in sire group
NSPSG	Number of Sires Per Sire Group (sire group)
NSTART	Number of location index for STARTing animal in current herd
NSTEPS	Total Number of STEPS in simulation run
NSTRT	Number for STARTing location index of a herd
NTRATS	Number of genetic TRAiTS.
NU2C	NUmber of 2 year olds Calving
NU2W	NUmber of 2 year olds at Weaning
NU312C	NUmber of 3 and 12+ cows that Calve
NU411C	NUmber of 4-11 year olds that Calve
NUCCF	NUmber at Calving: CalF
NUCCFM	NUmber Calved: Calf: Male
NUCCW	NUmber at Calving: CoW
NUCYC	NUmber CYCling
NUDCCF	NUmber Died at Calving: CalF
NUDCCFM	NUmber Died at Calving: CalF: Male
NUDCCW	NUmber Died at Calving: CoW
NUDCF	NUmber Died: CalF
NUDCFM	NUmber Died: CalF: Male
NUDCW	NUmber Died: CoW
NUDF	NUmber Died on Feed
NUDFP	NUmber Died: Feed and Pasture (stockers)
NUDFT	NUmber Died on Feed: Terminal
NUDP	NUmber Died on Pasture

NUDPT	NUmber Died on Pasture: Terminal
NUDY2	NUmber experiencing DYstocia as 2 year olds
NUDY3	NUmber experiencing DYstocia as 3 year olds
NUDYCF	NUmber experiencing DYstocia: CalF
NUDYCFM	NUmber experiencing DYstocia: CalF: Male
NUDYM	NUmber experiencing DYstocia as Mature cows
NUEXP	NUmber of females EXPosed to a bull
NUFFF	NUmber on Final Feed: Females
NUFFFT	NUmber Finishing on Feed for Females: Terminal
NUFFM	NUmber on Final Feed: Males
NUFFMT	NUmber Finishing on Feed for Males: Terminal
NUFPF	NUmber on Final Pasture (stockers): Females
NUFPM	NUmber on Final Pasture (stockers): Males
NUFPMT	NUmber Finishing on Pasture for Males: Terminal
NULCW	NUmber Live: CoW
NUMC	NUmber Mature at Calving (7-8 years of age)
NUMW	NUmber Mature at Weaning (7-8 years of age)
NUP1	NUmber reaching Puberty within-year
NUPCW	NUmber of Pregnant CoWs
NUPRG	NUmber PReGnant: at weaning (all ages)
NUPRG1	NUmber PReGnant: at weaning (1 year of age)
NUPRG2	NUmber PReGnant: at weaning (2 years of age)
NUPRG3	NUmber PReGnant: at weaning (3 years of age)
NUPRG4	NUmber PReGnant: at weaning (4 years of age)
NUPRGM	NUmber PReGnant: at weaning (mature cows)
NUPUB	NUmber reaching PUberty
NUS3MP	NUmber of Steps in 3 year old Milk Production
NUS4MP	NUmber of Steps in 4 year old Milk Production
NUSFF	NUmber Started on Feed: Female
NUSFFT	NUmber Starting on Feed for Females: Terminal
NUSFM	NUmber Started on Feed: Male
NUSFMT	NUmber Starting on Feed for Males: Terminal
NUSFP	NUmber Started on Feed and Pasture
NUSLF	NUmber SoLd: Female
NUSLM	NUmber SoLd: Male
NUSMMP	NUmber of Steps in Mature Milk Production
NUSMP	NUmber of Steps in Milk Production
NUSPF	NUmber Started on Pasture: Female
NUSPFT	NUmber Starting on Pasture for Females: Terminal
NUSPM	NUmber Started on Pasture: Male
NUSPMT	NUmber Starting on Pasture for Males: Terminal
NUSTFF	NUmber of STeps for Fed Females
NUSTFM	NUmber of STeps for Fed Males
NUSTPF	NUmber of STeps for Pastured Females
NUSTPM	NUmber of STeps for Pastured Males
NUWCF	NUmber Weaned: CalF
NUWCFM	NUmber Weaned: Calf: Male
NUWCW	NUmber Weaned: CoW
NXP	N by P -- the total number of deviates to be generated
OAM12	Square root Matrix for Offspring Additive effects
OCODE	Output CODE

OCOUNT	Orphan COUNT (count of orphans qualifying for grafting)
OFFSET	Length of variable length vector
OFFST1	OFFSeT 1 (utility variable)
ORGSTP	ORiGinal STeP
PBCYC	Probability of Beginning CYCling
PCCYC	Probability of Continuing CYCling
PCFEB	Proportion of Chemical Fat in the Empty Body
PCFGCW	Percent Chemical Fat in Growth Curve Weight
PCON	Probability of Conception
PCTPRG	Percent PReGnant (all ages)
PCWPCE	Pounds of Calf Weaned Per Cow Exposed
PDAC	Probability of Death At Calving
PDEATH	Probability of DEATH (non-perinatal)
PDYS	Probability of DYStocia
PEAAP	Permanent Environmental effect for Age At Puberty
PEAPP	Permenant Environmental effect for APPetite
PEBW	Permanent Environmental effect for Birth Weight
PEDDYS	Permanent Environmental effect for Direct DYStocia
PEFFC	Permanent Environmental value for Fat Free Carcass
PEGL	Permanent Environmental effect for Gestation Length
PEIMF	Permanent Environmental value for IntraMuscular Fat
PEM12	Square root Matrix for Permanent Environment
PEMDYS	Permanent Environmental effect for Maternal DYStocia
PEMF	Permanent Environmental effect for Mature Fat
PEMP	Permanent Environmental effect for Milk Production
PEMTX	Var/cov MaTriX in symmetric storage mode for Permanent Environmental effects
PEMW	Permanent Environmental effect for Mature Weight
PEN	PEN assignment
PENSIZ	feedlot PEN SIZe
PEPCON	Permanent Environmental effect for Probability of CONception
PEPPI	Permanent Environmental effect for PostPartum Interval
PEPSRV	Permanent Environmental effect for Probability of SuRVival
PERM	Permanent Environmental value for the Requirement for Maintenance
PEUNSD	Permanent Environmental effect for UNSounDness
PEXXXX	Permanent Environmental value for new trait development
PEYLD	Permanent Environmental value for YeiLD grade
PEYW	Permanent Environmental effect for Yearling Weight
PEZZZZ	Permanent Environmental value for new trait development
PFILL	Proportion of whole body composed of FILL
PIOR	Prior Intake Over Requirements
PMP	Peak Milk Production
POAAP	POtential for Age At Puberty
POAPP	POtential for APPetite
POBW	POtential for Birth Weight
PODDYS	POtential for Direct DYStocia
POFFC	POtential for Fat Free Carcass
POGL	POtential for Gestation Length
POIMF	POtential for IntraMuscular Fat
POMDYS	POtential for Maternal DYStocia
POMF	POtential for Mature Fat
POMP	POtential for Milk Production

POMW	POtential for Mature Weight
POPCON	POtential for Probability of CONception
POPPI	POtential for PostPartum Interval
POPSRV	POtential for Probability of SuRVival
PORM	POtential for the Requirement for Maintenance
POUNSD	POtential for UNSounDness (<1>)
POXXXX	POtential value for new trait development
POYLD	Potential for YeiLD grade
POYW	POtential for Yearling Weight
POZZZZ	POtential value for new trait development
PPDPF	PostPartum change (Delta) Proportion Fat
PSFILL	Proportion of whole body composed of Standardized FILL
PUBWT	PUBerty WeighT
QLTGRD	QuaLiTy GRaDe
RALMIN	MINimum Requirement to Allow Lactation
RAM	Requirements for level of AliMentation
RANGE	RANGE for 0-1 partitioning
RANRP	Ratio of Available Nutrients to Requirement for Production
RBCT	Requirement(TDN) for Below Critical Temperature
RCOUNT	Record COUNT (# of records required from generators)
RDGCW	Reduction in DGCW
REQ	REQuirement (total nutritional requirement)
REQMIN	MINimum REQuirements (kg TDN)
REQPRO	REQuirement for PROduction
RFD	Requirement for Fat Deposition
RFG	Requirement for Fat Gain
RG	Requirement for Gain
RL	Requirement for Lactation
RLM	Requirements for LocoMotion
RM	Requirement for Maintenance
RMPCF	Reduction in Milk production due to Percent Chemical Fat empty body
RMRG	Reduction in Milk production due to RG
RP	Requirement for Pregnancy
RPG	Requirement for Protein Gain
RRL	Remainder of Requirement for Lactation
RTFD	Requirements for Target Fat Deposit
RVEC	Return VECtor required by GGNSM
S1012	Square root Matrix for Sire group 10
S1112	Square root Matrix for Sire group 11
S112	Square root Matrix for Sire group 1
S1212	Square root Matrix for Sire group 12
S212	Square root Matrix for Sire group 2
S312	Square root Matrix for Sire group 3
S412	Square root Matrix for Sire group 4
S512	Square root Matrix for Sire group 5
S612	Square root Matrix for Sire group 6
S712	Square root Matrix for Sire group 7
S812	Square root Matrix for Sire group 8
S912	Square root Matrix for Sire group 9
SAAP	Standard Age AT Puberty
SADC	Steer Adjustment for Digestive Capacity

SAMF	Steer Adjustment for Mature Fat
SAMW	Steer Adjustment for Mature Weight
SAPSRV	Steer Adjustment for Probability of SuRVival
SAUNSD	Steer Adjustment for UNSounDness
SAYW	Steer Adjustment for Yearling Weight
SBCD	Sire group Breed Composition of grandDam (sire group, breed)
SBCMP	Sire group Breed CoMPosition (sire group, breed)
SBCS	Sire group Breed Composition of grandSire (sire group, breed)
SBVMW	Standardized Breeding Value for Mature Weight
SCOUNT	Sire COUNT (counter).
SDC	Standard Digestive Capacity
SDOPL	Standard Day Of Peak Lactation
SEED	Initial SEED for random number generators
SEX	SEX (1 = F, 2 = B, 3 = S)
SF	Stage of Fattening
SFILL	Standardized FILL
SGCW	Standardized Growth Curve Weight (adjusted for mature body fat)
SGPEG	Sire Group Prediction Error Group (sire group)
SGROUP	Current Sire GROUP
SGSIM	Input vector indicating Sire Group is to be SIMulated
SIRCON	SIRe group CONdition (W/GCW)
SIRDOA	Day Of Age for SIRe group (sire group)
SIREID	Unique SIRE ID
SIRGRP	SIRe GRouP for 1) sires, 2) dams, 3) fetuses
SIRIND	Location INDex for animal's SIRe
SIRPEV	SIRe Prediction Error variance
SIRYOA	Input vector indicating SIRe group Year Of Age
SMF	Standard Mature Fat
SNASV	Sire group Non-Additive Starting Value (sire group, trait)
SPGCF	Shape Parameter for Growth Curve Fat
SS	Second of the minute
SSDATE	Sire Starting DATE (sire group)
STEP	Time STEP in days (1,2,3,5,6,10,15,30)
STPCNT	STeP CouNT
STPMN1	STeP MiNus 1
STRIG	Sire TRIGger (utility variable)
SU1FC	SUm of 1 year olds Fat at Calving
SU1FW	SUm of 1 year olds Fat at Weaning
SU1WC	SUm of 1 year olds Weight at Calving
SU1WW	SUm of 1 year olds Weight at Weaning
SU2FC	SUm of 2 year olds Fat at Calving
SU2FW	SUm of 2 year olds Fat at Weaning
SU2WC	SUm of 2 year olds Weight at Calving
SU2WW	SUm of 2 year olds Weight at Weaning
SU3FC	SUm of 3 year olds Fat at Calving
SU3FW	SUm of 3 year olds Fat at Weaning
SU3MP	SUm of 3 year olds Milk Production
SU3WC	SUm of 3 year olds Weight at Calving
SU3WW	SUm of 3 year olds Weight at Weaning
SU4FC	SUm of 4 year olds Fat at Calving
SU4FW	SUm of 4 year olds Fat at Weaning

SU4MP	SUm of 4 year old Milk Production
SU4WC	SUm of 4 year olds Weight at Calving
SU4WW	SUm of 4 year olds Weight at Weaning
SUAAP	SUm Age At Puberty
SUACCW	SUm Age At Calving: CoW
SUADCCW	SUm of Age Died at Calving: CoW
SUADCF	SUm of Age of Death: CalF
SUADCFM	SUm of Age at Death: CalF: Male
SUADCW	SUm of Age of Death: CoW
SUADG	SUm of Average Daily Gain
SUADGM	SUm of Average Daily Gains for Males
SUAOP1	SUm of Age Of Pregnancy (1 year olds)
SUAWCF	SUm of Age at Weaning: CalF
SUAWCFM	SUm of Age at Weaning: CalF: Male
SUAWCW	SUm of Age at Weaning: CoW
SUAWWT	SUm of Adjusted Weaning WeighT (adjusted to 205d)
SUAWWTM	SUm of Adjusted Weaning Weights for Males
SUBDCF	SUm of Birth Date: CalF
SUBDCFM	SUm of Birth Date: CalF: Male
SUBIT	indicates the number of SUBITerations in nutrition loop
SUBW	SUm of Birth Weights
SUBWM	SUm of Birth Weight for Males
SUCRCH	SUm of CReep fed to the Cow Herd
SUCRFP	SUm of CReep fed to cattle on Feed and Pasture (stockers)
SUCVDT	SUm of CalVing DaTes
SUCWF	SUm of Carcass Weight on Females
SUCWFT	SUm of Carcass Weight on Females: Terminal
SUCWM	SUm of Carcass Weight on Males
SUCWMT	SUm of Carcass Weight on Males: Terminal
SUDAP	SUm of Day At Puberty
SUDFF	SUm of Days on Feed for Females
SUDFFT	SUm of Days on Feed for Females: Terminal
SUDFM	SUm of Days on Feed for Males
SUDFMT	SUm of Days on Feed for Males: Terminal
SUDMFF	SUm of Dry Matter on Feed for Females
SUDMFM	SUm of Dry Matter on Feed for Males
SUDNPF	SUm of Digestible Nutrients on Pasture for Females
SUDNPM	SUm of Digestible Nutrients on Pasture for Males
SUDOCY	SUm of Day Of CYcling (date returned to estrus post-calving)
SUDOP1	SUm of Day Of Pregnancy (1 year olds)
SUDOPR	SUm of Day Of PRegnancy
SUDPF	SUm of Dressing Percent on Females
SUDPFT	SUm of Dressing Percent on Females: Terminal
SUDPM	SUm of Dressing Percentage Male
SUDPMT	SUm of Dressing Percentage Male: Terminal
SUDWFF	SUm of Delta Weight on Feed for Females
SUDWFM	SUm of Delta Weight on Feed for Males
SUDWPF	SUm of Delta Weight on Pasture for Females
SUDWPM	SUm of Delta Weight on Pasture for Males
SUDYFD	SUm of DaYs on FeeD
SUDYPA	Sum of DaYs on PAsture

SUESCH	SUm of Energy Supplement fed to Cow Herd
SUESFP	SUm of Energy Supplement fed to cattle on Feed and Pasture (stockers)
SUFAFF	SUm of Final Age on Feed for Females
SUFAFFT	SUm of Final Age on Feed for Females: Terminal
SUFAFM	SUm of Final Age on Feed for Males
SUFAFMT	SUm of Final Age on Feed for Males: Terminal
SUFAPF	SUm of Final Age on Pasture for Females
SUFAPFT	SUm of Final Age on Pasture for Females: Terminal
SUFAPM	SUm of Final Age on Pasture for Males
SUFBCF	SUm of Fat at Birth: CalF
SUFBCFM	SUm of Fat at Birth: CalF: Male
SUFCCW	SUm of Fat at Calving: CoW
SUFFFF	SUm of Final Fat on Feed for Females
SUFFFFT	SUm of Final Fat on Feed for Females: Terminal
SUFFFM	SUm of Final Fat on Feed for Males
SUFFFMT	SUm of Final Fat on Feed for Males: Terminal
SUFFPF	SUm of Final Fat on Pasture for Females
SUFFPFT	SUm of Final Fat on Pasture for Females: Terminal
SUFFPM	SUm of Final Fat on Pasture for Males
SUFWCF	SUm of Fat at Weaning: CalF
SUFWCFM	SUm of Fat at Weaning: CalF: Male
SUFWCW	SUm of Fat at Weaning: CoW
SUFWFF	SUm of Final Weight on Feed for Females
SUFWFFT	SUm of Final Weight on Feed for Females: Terminal
SUFWFM	SUm of Final Weight on Feed for Males
SUFWFMT	SUm of Final Weight on Feed for Males: Terminal
SUFWPF	SUm of Final Weight on Pasture for Females
SUFWPFT	SUm of Final Weight on Pasture for Females: Terminal
SUFWPM	SUm of Final Weight on Pasture for Males
SUGFCH	SUm of Grazed Forage eaten by the Cow Herd
SUGFFP	SUm of Grazed Forage eaten by cattle on Feed and Pasture
SUGLF	SUm of Gestation Lengths on Females
SUGLM	SUm of Gestation Lengths on Males
SUHFCH	SUm of Harvested Forage fet to the Cow Herd
SUHFFP	SUm of Harvested Forage fed to cattle on Feed and Pasture (stockers)
SUICY	SUm of the Interval to CYcling
SUIPR	SUm of the Interval to PRegnancy
SUKILA	SUm of KILl Age
SUKILF	SUm of KILl Fat
SUKILW	SUm of KILl Weight
SUMFC	SUm of Mature Fat at Calving
SUMFW	SUm of Mature Fat at Weaning
SUMMP	SUm of Mature Milk Production
SUMP	SUm of Milk Production
SUMWC	SUm of Mature Weight at Calving
SUMWW	SUm of Mature Weight at Weaning
SUPFCH	SUm of Productive Females in the Cow Herd
SUPSCH	SUm of Protein Supplement fed to the Cow Herd
SUPSFP	SUm of Protein Supplement fed to cattle on Feed or Pasture
SUQGF	SUm of Quality Grade on Females
SUQGFT	SUm of Quality Grade for Females: Terminal

SUQGM	SUm of Quality Grade on Males
SUQGMT	SUm of Quality Grade on Males: Terminal
SUR1CH	SUm of Ration 1 fed to the Cow Herd
SUR1FP	SUm of Ration 1 fed to cattle on Feed and Pasture
SUR2CH	SUm of Ration 2 fed to the Cow Herd
SUR2FP	SUm of Ration 2 fed to cattle on Feed and Pasture (stockers)
SUR3CH	SUm of Ration 3 fed to the Cow Herd
SUR3FP	SUm of Ration 3 fed to cattle on Feed and Pasture (stockers)
SUSAFF	SUm of Starting Age on Feed for Females
SUSAFFT	SUm of Starting Age on Feed for Females: Terminal
SUSAFM	SUm of Starting Age on Feed for Males
SUSAFMT	SUm of Starting Age on Feed for Males: Terminal
SUSAPF	SUm of Starting Age on Pasture for Females
SUSAPFT	SUm of Starting Age on Pasture for Females: Terminal
SUSAPM	SUm of Starting Age on Pasture for Males
SUSAPMT	SUm of Starting Age on Pasture for Males: Terminal
SUSFFF	SUm of Starting Fat on Feed for Females
SUSFFFT	SUm of Starting Fat on Feed for Females: Terminal
SUSFFM	SUm of Starting Fat on Feed for Males
SUSFFMT	SUm of Starting Fat on Feed for Males: Terminal
SUSFPF	SUm of Starting Fat on Pasture for Females
SUSFPFT	SUm of Starting Fat on Pasture for Females: Terminal
SUSFPM	SUm of Starting Fat on Pasture for Males
SUSFPMT	SUm of Starting Fat on Pasture for Males: Terminal
SUSLAF	SUm of SaLe Age for Females
SUSLAM	SUm of SaLe Age for Males
SUSLFF	SUm of SaLe Fat for Females
SUSLFM	SUm of SaLe Fat for Males
SUSLWF	SUm of SaLe Weight for Females
SUSLWM	SUm of SaLe Weight for Males
SUSNCH	SUm of Supplemental Nutrients fed to Cow Herd
SUSNF	SUm of Supplemental Nutrients fed to cattle on FEED
SUSNP	SUm of Supplemental Nutrients fed to cattle on Pasture (stockers)
SUSWFF	SUm of Starting Weight on Feed for Females
SUSWFFT	SUm of Starting Weight on Feed for Females: Terminal
SUSWFM	SUm of Starting Weight on Feed for Males
SUSWFMT	SUm of Starting Weight on Feed for Males: Terminal
SUSWPF	SUm of Starting Weight on Pasture for Females
SUSWPFT	SUm of Starting Weight on Pasture for Females: Terminal
SUSWPM	SUm of Starting Weight on Pasture for Males
SUSWPMT	SUm of Starting Weight on Pasture for Males: Terminal
SUTNCH	SUm of Total Nutrient fed to Cow Herd
SUTNFP	SUm of Total Nutrient fed to cattle on Feed and Pasture
SUWCCW	SUm of Weight at Calving: CoW
SUWWCW	SUm of Weight at Weaning: CoW
SUWWT	SUm of Weaning Weight
SUWWTM	SUm of Weaning WeighTs for Males
SUYGF	SUm of Yield Grade on Females
SUYGFT	SUm of Yield Grade for Females: Terminal
SUYGM	SUm of Yield Grade on Males
SUYGMT	SUm of Yield Grade on Males: Terminal

SVAAP	Sire group Value (BV) for Age At Puberty
SVAPP	Sire group Value (BV) for APPetite
SVBW	Sire group Value (BV) for Birth Weight
SVDDYS	Sire group Value (BV) for Direct DYStocia
SVFFC	Sire group Value (BV) for Fat Free Carcass
SVGL	Sire group Value (BV) for Gestation Length
SVIMF	Sire group Value (BV) for IntraMuscular Fat
SVMDYS	Sire group Value (BV) for Maternal DYStocia
SVMF	Sire group Value (BV) for Mature Fat
SVMP	Sire group Value (BV) for Milk Production
SVMW	Sire group Value (BV) for Mature Weight
SVPCON	Sire group Value (BV) for Probability of CONception
SVPPI	Sire group Value (BV) for PostPartum Interval
SVPSRV	Sire group Value (BV) for Probability of SuRVival
SVRM	Sire group Value (BV) for Requirement for Maintenance
SVUNSD	Sire group Value (BV) for UNSounDness
SVXXXX	Sire group Value (BV) for new trait development
SVYLD	Sire group Value (BV) for YeiLD grade
SVYW	Sire group Value (BV) for Yearling Weight
SVZZZZ	Sire group Value (BV) for new trait development
TARAY1	Temporary ARrAY 1 (holds gathered breed composition values for sires)
TARAY2	Temporary ARrAY 2 (holds compressed breed composition values for dams)
TDAYPA	Target DAYs on PAsture for stockers
TEM12	Square root Matrix for Temporary Environment
TEMDYS	Temporary Environmental effect for Maternal DYStocia
TEMP	Temporary Environmental effect for Milk Production
TEMP1	Temporary storage vector used in Q8VCMPRS etc.
TEMP2	Temporary storage vector used in Q8VCMPRS etc.
TEMP3	Temporary storage vector used in Q8VCMPRS etc.
TEMP4	TEMPorary storage vector
TEMP5	TEMPorary storage vector
TEMP6	TEMPorary storage vector
TEMP7	TEMPorary storage vector
TEMP8	TEMPorary storage vector
TEMP9	TEMPorary storage vector
TEMTX	Var/cov MaTriX in symmetric storage mode for Temporary Environmental effects
TEPCON	Temporary Environmental effect for Probability of CONception
TEPPI	Temporary Environmental effect for PostPartum Interval
TFAT	Target FAT (expressed as a proportion of empty body)
TFATFG	Target FAT for the Feed Group (expressed as a proportion of empty body)
TLEFT	Total number of animals LEFT to generate
TSCAL	Temporary SCAlar
TSEBF	Target Slaughter Empty Body Fat
TSIZ1	Target SIZe for cull group 1
TSIZ10	Target SIZe for cull group 10
TSIZ2	Target SIZe for cull group 2
TSIZ3	Target SIZe for cull group 3
TSIZ4	Target SIZe for cull group 4
TSIZ5	Target SIZe for cull group 5
TSIZ6	Target SIZe for cull group 6
TSIZ7	Target SIZe for cull group 7

TSIZ8	Target SIZe for cull group 8
TSIZ9	Target SIZe for cull group 9
TSQLT	Target Slaughter QuaLiTy
TSYLD	Target Slaughter YieLD
TVBLEN	Total Variable Block Length (typically 65,532)
TVEC	Temporary storage VECtor
TWPUB	Target Weight for PUBerty
U01BLN	Uniform 0,1 maximum Block LeNgth
UPRBND	UPpeR BouND of range for a particular sire (sire)
VARMAX	VARiable supplementation level MAXima (by feeding group and feed)
VDMR	Variable Dry Matter Required
VDMRP	Variable Dry Matter Required from Previous step
W	Weight (actual)
WKSPAC	WorK SPACe vector of length N * P
WKVEC	WorK VECtor required by GGNSM
WKVECA	WorK VECtor containing Additive standard deviations
WNDATE	julian WeaNing DATE
WNDAY	julian date of WeaNing DAY appropriate to a calving season
WNTRIG	WeaNing TRIGger (indicates a weaning date)
WTAREA	WeighT sold per AREA of land required to produce it
XTRANS	X TRANSpose, P by N output matrix for multivariate normal deviates in columns
YEAR	Current simulation YEAR
YLDGRD	YieLD GRaDe
YOA	Year Of Age
YOB	Year Of Birth