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UNIVERSITY OF ALBERTA

MODELLING OVERALL EFFICIENCY IN BEEF PRODUCTION SYSTEMS

by

AUGUSTINE NAAZIE

A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND
RESEARCH IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE
DEGREE

OF DOCTOR OF PHILOSOPHY
IN
ANIMAL BREEDING AND GENETICS

DEPARTMENT OF ANIMAL SCIENCE
EDMONTON, ALBERTA

SPRING 1992

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(signed)

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled MODELLING OVERALL EFFICIENCY IN BEEF PRODUCTION SYSTEMS submitted by AUGUSTINE NAAZIE in partial fulfilment of the requirements for the degree of DOCTOR OF PHILOSOPHY in ANIMAL BREEDING AND GENETICS.

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DEDICATION

To the memory of

My mother

She would have loved to see me through this!

Abstract

A deterministic Beef Efficiency Model (BEM) was developed and used to evaluate production efficiency in traditional, sex-ratio controlled and dairy-beef production systems. In traditional beef production systems, efficiency declined with age at turnover up to 6 years of age and then increased marginally in most breed groups thereafter. Improving the reproductive rate by 10% resulted in 5% to 9% improvement in overall efficiency. However with a concomitant increase in dam feed cost of 10% - 15% (i.e., dams are being over fed) this improvement in efficiency disappeared. There were substantial breed differences in overall efficiency, attributable mainly to differences in maturing rates. Month of calving had little influence on overall efficiency. Maximum overall efficiency was generally obtained when offspring from the herd were slaughtered at 30% - 60% of mature weight, usually at 40% maturity. Turning over the herd as quickly as possible appeared to be the most efficient strategy. In sex-ratio controlled systems of production, 'all male' systems were more efficient (4% - 79% at the point of maximum efficiency, depending on the breed group and the age at turnover) than 'all female' systems. A single-sex bred heifer (SSBH) system was at least 21% and 27% more efficient than the 'all male' and traditional systems respectively. The cost of sex-ratio control would have to be unreasonably high (about 80 times that in a traditional system) for the SSBH to be less efficient than a traditional system operated at maximum efficiency. Trends in efficiency between ages at turnover and breed groups were similar to those in the traditional system, though efficiency values were higher for sex-ratio controlled systems. In the dairy-beef production system, efficiency increased with increasing age at turnover, in contrast to the other systems. Yearly increases in efficiency ranged from 1% -17% depending on the degree of maturity of offspring at slaughter. This system was

also 9% - 87% more efficient than the SSBH system at a turnover age of 4 years, but was 10% - 265% more efficient at 10 year, depending on the degree of maturity of offspring at slaughter. It was thought that discounts to beef from the dairy-beef system will have to be very high to make this system not efficient.

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1. General introduction

Efficiency in agriculture has received considerable attention in recent years (see Spedding et al., 1981) with the realization that natural resources are finite and exhaustible and that such resources ought to be used sustainably and held in trust for future generations. Improving efficiency implies "increasing output per unit of input" or conversely, "reducing input per unit of output". Efficiency in animal production often is expressed solely in biological terms to avoid the effects of variable costs and prices (Dickerson, 1978).

In beef production, "biological efficiency" is defined as the ratio of output (usually liveweight, or weight of lean meat) to input (usually food units expressed in dry weight, kg, or metabolizable energy - ME, Thompson and Barlow, 1986). The physical output and input may then be weighted by their value or cost to convert them to economic terms (Cartwright and Fitzhugh, 1974; Cartwright, 1982). Though the question of efficiency in beef cattle production is not new (Cartwright, 1982; Ferrell and Jenkins, 1985), it has not received sufficient attention until recently. This is related to the difficulty and expense of measuring food intake accurately in beef cattle, and ruminants generally. In those cases that efficiency has been studied, it has been restricted to individual (slaughter animal) efficiency (Thiessen et al., 1984) and most of the research has stressed output components with little attention to input components (Ferrell and Jenkins, 1985; Cartwright and Doren, 1986).

Implicitly, at least, the overall objective of the application of genetics to beef cattle production has always been to improve efficiency of the production unit or herd (Cartwright, 1982). Selection on the basis of individual efficiency and/or other traits (as in index selection) implies that the individual is the production unit. This assumes that assigning relative economic values to each unit of each character appropriately accounts for associated inputs and outputs (costs and returns). This is an unrealistic simplification as pointed out by

Cartwright (1982), as the linearities assumed are difficult or impossible to accommodate and interactions between individual animals in a production unit cannot be traced.

There are always more breeding than slaughter cattle in an average beef herd. Cartwright (1970) estimated that two cattle are maintained in the herd for each calf sold whereas Fitzhugh (1978) estimated that the breeding female and replacements numerically constitute 40 to 70% of the production unit. Estimates of the nutritional requirements for a cow throughout the period needed to produce a saleable calf range from 50 to 80% of the total requirement of the production unit, depending on the age at which the calf is sold (Thiessen et al., 1984). Obviously, the cost of maintaining mature females and their replacements is a major portion of the input to the production unit. This suggests that efficiency of individual slaughter animals alone cannot accurately reflect efficiency of the whole system. The importance of considering efficiency on a herd basis (Joandet and Cartwright, 1969) with the breeding male, the breeding female and nonbreeding produce as the smallest operational unit (Fitzhugh et al., 1975) is intuitive.

Production efficiency is a function of nutrition, physiology, genetics, forage science, production economics, and marketing. These components often interact in a complicated non-linear fashion (Joandet and Cartwright, 1975), and thus knowledge of individual components *per se* has proven insufficient for understanding their interactions in complex systems such as beef production. Evaluating efficiency on a herd basis requires the simultaneous study of all components as integrated effects, to better understand the effects of different alternatives. This approach requires interdisciplinary effort within animal science and between animal science and other disciplines (Joandet and Cartwright, 1975).

In a cow - calf production system, conventional wisdom suggests that the cow be retained in the herd because long as possible as feed costs, when spread over a larger number of calves, are reduced (Taylor et al., 1985). However, this has adverse effects on generation interval and besides cull cow meat is produced less efficiently the later the dam is slaughtered. Recent simulation studies in sex-controlled beef production systems indicate that if a cow can produce guaranteed female offspring, then slaughtering her soon after her first offspring would markedly improve efficiency of the system since most of the conventional maternal overhead of producing a calf becomes associated with productive growth (Taylor et al., 1985). However, recent empirical studies failed to indicate an advantage in biological efficiency in a once-calved heifer system relative to heifers conventionally reared for slaughter (Vincent, 1990). However, it was suggested that the value of the calf might have been underestimated and that the economics of the systems could be different since heifers in the once-calved system were generally fed roughages.

Current advances in reproductive technology suggest that the production of sexed calves is attainable and therefore it seems appropriate to evaluate the impact of such biotechnological advances on the efficiency of beef production in the Canadian context. Conventional experimentation to evaluate overall efficiency would involve very large time consuming and expensive experiments. Advancements in computer technology have spurred the development of simulation languages and/or techniques which have been successfully applied to the orderly evaluation of complex systems in varied fields such as ecology, sociology, plant sciences, physical sciences and engineering (Joandet and Cartwright, 1975). Application of this technology to beef production could provide an inexpensive, fast and effective means of evaluating total production systems.

1.1. Modelling and simulation

A model is a representation of a process or object or "system", be it a physical replica on a reduced scale (iconic model, Churchman, 1971), a graphical representation (visual model), or a mathematical approximation of the physical attributes of the system (symbolic or abstract model). Symbolic models can be further classified as statistical (analytic) models (e.g. a regression model) or as simulation models. A simulation model is a mathematical - logical abstraction and simplification of the real world, specified so as to capture the principal interactions and behaviour of the system under study and capable of experimental manipulation to project the consequences of changes in the determinants of the system's behaviour (Spedding, 1988). The abstraction of the model frees it from the limits of physical form, thus rendering this type of model considerable flexibility in both the mode of its construction and the manner of its use (Dent and Blackie, 1979). Such models may be static (no time variable) or dynamic. They may also be deterministic (all variables fixed) or stochastic (at least one random variable). Depending on the level of detail, a model may be empirical (predictive) or mechanistic (attempt to explain higher levels of organization from lower levels). The level of detail to which a model is built depends on the objective, the amount of factual information available and the level of precision required for the answer (Joandet and Cartwright, 1975). However, the more detail one puts into a model the more one tends to miss the essence of the system and the more severe is the lack of information. Model construction and the decisions and processes leading up to it are often referred to as "modelling".

A "system" is a less well defined concept but implies some boundary (be it physical or conceptual) within which are related components that interact for a common purpose and react as a "whole" to external or internal stimuli (Spedding, 1988). The complex interrelationships between components precludes legitimate study of sectors of the system in isolation; i.e., the "whole" is more comprehensive than simply the "sum of the components"

(Dent and Blackie, 1979).

If a system can be represented by a model, and in terms acceptable to a computing system, and if the system can be characterized by a set of variables with each set of variable values representing a unique state of the system, then manipulation of the variable values simulates movement of the system from state to state. Simulation is therefore the art of mimicking the dynamic behaviour of the system by moving it from state to state in accordance with defined operating rules (Pritsker and Pegden, 1979). Simulation deals primarily with the relationships between computers and models, whereas modelling deals with the relationships between real systems and models (Zeigler, 1984).

The study of systems is called systems research or systems analysis. It usually involves an analysis of the components of a system and their interrelationships, construction of a simulation model and simulation. Systems analysis of beef cattle systems provides new avenues for more effective research and its application. The effects of newly developed or anticipated technology may be evaluated over a wide range of conditions rather than in isolated situations to which we may be limited because of facilities, personnel or funds (Joandet and Cartwright, 1975).

1.2. Objectives

The purpose of this research is to develop a simulation model for evaluating overall efficiency in beef production systems with respect to the degree of maturity of the offspring at slaughter. The model will then be used to study overall efficiency in :

i. Traditional cow - calf systems

ii. Sex ratio-controlled systems

iii. Dairy - beef systems

In all cases, mature size, reproductive rate, feed costs and the number of calvings per dam will be allowed to vary. The model will be developed for an integrated production system - a system starting from the cow and her calf through to slaughter.

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2. The simulation model

Efficiency, for the purposes of this study, will be defined as the ratio of total physical output to input. Output includes all lean meat produced by slaughter offspring, culled cows and bulls as well as any excess milk that might be available for sale (mainly in the dairy-beef system). Input includes all feed consumed by the herd as well as the initial cost of the herd and cost of maintaining bulls for breeding (breeding cost). Management costs among systems were assumed to be comparable. Therefore, the model had to be constructed to provide a fair estimate of the output and input to the system. To obtain the input and output, the numbers of animals of different categories (e.g., bulls, cows, etc.) and their sizes and growth rates at each point in time are required. Feed intake is then computed on a daily basis as a function of current weight and growth rate. It was therefore convenient to group the growth and feed intake prediction aspects into a submodel. The numbers of animals available in the herd at any time as well as the overall efficiency were also programmed as separate submodels. The entire model, named the **Beef Efficiency Model** (BEM), was therefore developed as a combination of three submodels:

i. growth and feed intake submodel,
ii. herd submodel,
iii. efficiency submodel.

BEM is schematically represented by Figure II.1. The symbols employed in this diagram are explained in Figure II.2. The herd submodel passes output to the growth and feed intake submodel for computation of the total input and total output. These are then passed to the efficiency submodel for computation of overall efficiency. The entire model was programmed in the 'C' programming language using Turbo C (Borland, 1988). Derivation of the separate submodels follows.

2.1. The Growth and feed intake submodel

This submodel employs a growth function to predict weight and growth rate. These are then used to predict the daily feed requirement. The daily feed requirements are cumulated and scaled by the mature weight of the breed and a relation is developed between cumulated feed intake and degree of maturity (current weight scaled by mature weight).

2.1.1. Growth

Growth is defined as an increase in mass of an animal or tissue over time and usually is measured as an increase in weight per unit of time (Beitz, 1985). Two functions were considered for modelling growth:

1. The Richards function (Richards, 1959):

$$Y = A\,(1 - be^{-kt})^{m} \quad \ldots\ldots\ldots\ldots \quad 1$$

The growth ratē (instantaneous absolute growth rate) computed as the first derivative of the above equation is given by (see Fitzhugh, 1976):

$$dY/dt = (mkYbe^{-kt}) \,/\, (1 - be^{-kt}) \quad \ldots\ldots\ldots\ldots \quad 2$$

2. The Brody function (Brody, 1945):

$$Y = A\,(1 - be^{-kt}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 3$$

where A is the asymptotic mature size (kg), b is an integration constant, k is the maturing index (also termed maturing rate, e.g., Brown et al., 1976) and t is age of the animal in days and m, determines the point of inflection for the Richards function, i.e., shape of the curve. The growth rate in the latter case is given by:

$$dY/dt = (kYbe^{-kt}) \,/\, (1 - be^{-kt}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 4$$

Growth functions usually provide a mathematical summary of time-course data on the growth of an organism or part of an organism. They reflect the lifetime interrelationships between an individual's inherent impulse to grow and mature in all body parts and the environment in which these impulses are expressed (Fitzhugh, 1976). The use of growth functions is largely empirical but selecting a function that has some biological plausibility and whose parameters may be useful is preferred (France and Thornley, 1984).

To determine the more appropriate function, each was fitted to weight-age records from females of four breed groups obtained from the University of Alberta beef ranch in Kinsella. These included 79 purebred Hereford females born between 1980 and 1984, 375 Beef Synthetic #1 (SY1) born between 1980 and 1985, 259 Dairy Synthetic (SD) born between 1980 and 1983, and 384 Beef synthetic #2 (SY2), born between 1980 and 1982. The SY1 population is a composite of Charolais, Angus, and Galloway. The SD population contains approximately 2/3 dairy breeding (Holstein, Brown Swiss and Simmental) and the rest from traditional beef breeds. The SY2 group is a recently synthesized composite with approximately 2/3 Hereford, 10% dairy and the remainder from other beef breeds. The numbers of animals declined as the age at which weights were taken increased and was less than 20 per breed by age of 3088 days (approx. 8.5 years). These were the oldest animals weighed in the current data set.

In addition to the above, data was obtained from Dr. R. Peterson of the University of British Columbia (UBC) on 160 Holstein females for the simulation of Dairy - Beef systems. These records came from cows born in 1985 and 1986 and the maximum age at which weights were available was 1656 days (approx. 4.5 years).

Growth curve parameters have been reported for some of the breed groups in this study. Goonewardene et al. (1981) compared the Brody, Richards, Von Bertalanffy and the Logistic growth functions using data from the Herefords and SY1. They concluded that the Richards and Brody functions provided the best overall fits. However, the Brody function tended to consistently overestimate the birth weight. Rosen and Berg (1981) and Rosen (1982) reported parameters for the Richards function for Herefords, SY1 and SD. The results of Brown (1970) and DeNise and Brinks (1985) comparing the growth functions using cattle data also indicated that the Richards' model is slightly superior to Brody's. Brown et al. (1976) concluded that the Richards function with a variable point of inflection is most appropriate for fitting weight - age data when goodness of fit, especially prior to 10 months of age is critical.

Because of selection in these populations and the lack of parameters for the SY2, it was felt necessary to estimate more current parameters, since at the very least the mature size would have changed in the last decade. This also made it possible to compare the two functions and decide which best suited the data and which should be used in the modelling.

To determine which function best described the growth data, prediction error mean squares (PEMS) were calculated by the formula of Brown et al. (1976).

$$PEMS = \sum_{j=1}^{N} \sum_{i=1}^{t} (O_{ij} - P_{ij})^2 / \sum_{j=1}^{N} (t_j - p) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 5$$

where N is the number of animals, O_{ij} and P_{ij} are the observed and predicted weights of animal j at age i, t is the number of weights on the jth animal and p is the number of parameters fitted. The PEMS calculated for each function are presented in Table II.1. For the beef data, the predicted error means squares were much higher for the Brody than for the Richards functions hence supporting the conclusion of Goonewardene et al. (1981). The two functions were comparable for the dairy data, the Brody function being slightly better.

Since weights were not always measured at the same age, mean growth curves for use in the model were then generated for each breed group by reclassifying and averaging the data using the formula:

$$Age' = 1 + \mathrm{floor}(age^{0.75}/30) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 6$$

where floor(x) is a function that returns an integer $\leq$ x, and Age' is a new age - weight class. This was necessary because not all animals were recorded at the same age. The logic of equation 6 was to group and average weights of animals very close in age (and hence weight) early in their life, when growth rate is high, and to group together animals more spread out in age (but still close in weight) later in life, since at this stage growth rates are low and there is not much bias in estimating the mean weight. This resulted in 14 age - weight classes for all breed groups at the University beef ranch. Since the data from UBC were only recorded to a maximum age of 1656 days, a slight modification of the above formula was used to generate 14 age - weight classes as well:

$$\text{Age}' = \text{floor}(\text{age}^{0.75}/18) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 7$$

There was no reason for generating 14 different classes but this process appeared to be a good choice. The mean estimated parameters for both functions are presented in Table II.2, and the predicted and observed weights at each age are plotted against time in Figures II.3a - II.3e. These figures show considerable smoothing out of the irregularities in growth that might be expected from field data, and good fits by both functions. The Brody function, however, does overestimate birth weight consistently in the beef data. This is probably because it was actually meant to be a post inflection function, though Brody (1945) never restricted the function to this age range. However, in the dairy data, the Brody function slightly underestimated the birth weight and over estimated the mature weight but had a slightly better overall fit than the Richards function (see Table II.1). The Richards function with the parameters reported in Table II.2 was therefore taken as the best function for fitting 'normal' growth for the breed groups of this study, since it predicted the growth curve in both beef and dairy data as well as or better than the Brody function.

2.1.1.1. Degree of maturity

Computing the efficiency of beef production systems must consider the point at which 'product' is removed i.e., at what point animals are slaughtered. However, differences in mature size and other genetic effects influence maturing rates. Hence, comparisons at the same age usually means comparison of animals at different stages of maturity (different metabolic states), while conversely, comparison at the same weight means a comparison of animals at different ages and metabolic states. Taylor (1980, 1982, 1985) and Taylor et al. (1985) argue that, in both theory and practice, an animal's stage of development is more fully represented by its degree of maturity (weight scaled by mature weight) than by its age. He postulates that since maturity is the point when body size is normally or potentially in an unchanging state, mature body weight could be considered 'genetic body size' - a factor responsible for any differences among and within species. Hence, scaling 'cumulative variables' such as weight (genetic size scaling) by mature weight eliminates the all pervasive influence of body size and is thus a more valid basis for comparison, since animals at the same degree of maturity are similar in metabolic status and body composition.

Comparisons of efficiency in the various systems were therefore made at the same degrees of maturity of the slaughter offspring. This also made it possible to determine optimum degrees of maturity at slaughter for each system. However, recent studies indicate that within species (cattle) size scaling may not completely account for differences in body composition between breeds of varying frame sizes, i.e., small, medium or large (Korver et al., 1987). Hence, the decision was to simulate breeds of different frame sizes. The Herefords were assumed to be of medium size with a frame size of 5 based on the frame size classification of Fox et al. (1988). The other breed groups were all of large but different frame sizes as follows: SY1 = 7, SY2 = 8 and SD = 9. Degree of maturity was computed as W/A, where W is the current weight and A is the mature weight estimated for the breed. Alternatively, using the Richards function, the degree of maturity (μ) was computed as:

$$\mu = (1 - be^{-kt})^m \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 8$$

Since only female data were available, the mature weights for bulls and steers were assumed to be 1.4 and 1.2 times the mature weight of females, respectively (Taylor et al., 1985). Though this makes males grow faster than females, their growth rate will probably be less than in the feedlot when they are fed high energy rations. A male to female mature weight ratio of 1.5 is widely used (Cartwright and Doren, 1986; Doren et al., 1989) but there are suggestions that such estimates are high (Malowe, 1962; Taylor, 1968). A ratio of 1.6 has also been reported (Brown et al., 1972). However, as long as this assumption did not cause systematic bias, comparisons among systems would be valid irrespective of the value assumed.

The computed degrees of maturity for each breed are plotted by age in Figure II.4, and by metabolic age (age' / mature weight$^{0.27}$, where age' is the age taken 3.5 days after conception, Taylor, 1980) in Figure II.5. The rate of maturity of the dairy synthetics was slowest. The other beef breed groups were fairly similar in maturing patterns, but the beef synthetic #1 matured fastest among beef breeds. The Holsteins matured slightly slower early in life but much faster than all the beef breeds beyond 2 years of age (Figure II.4). When degree of maturity was plotted against metabolic age (Figure II.5), the maturing patterns were similar to those when plotted against actual age.

2.1.2. Feed intake

To predict the efficiency in the system of production as a whole, cumulative feed intake is required for each animal from birth until slaughter. There are few published relations between the weight of an animal and the amount of feed consumed to reach that weight, probably because lifetime feed consumption is rarely recorded. However, the relation between weight and cumulative feed intake is generally thought to be exponential (Brody, 1945; Parks, 1970, 1982).

Parks (1970, 1982) presented the following equations to describe cumulative feed intake in pigs and other species.

$$W - w = (A - w)(1 - e^{-BF}) \quad \text{.......} \quad 9$$

$$dF/dt - D = (C - D)(1 - e^{-t/\tau}) \quad \text{.......} \quad 10$$

where W is the weight (biomass) of the animal, w is the initial weight (birth weight), A is the mature weight and F is the cumulative feed intake. B, C, D, and τ are constants, C being the mature feed intake and D the initial feed intake. The second equation (10) is the daily feed intake. Both of these equations have been standardized by the genetic size scaling procedures of Taylor (1980) and used to predict cumulative feed consumption in cattle in Australia (Thompson and Barlow, 1986). The equations derived by Thompson and Barlow (1986) were:

$$dF'/dt = C'(1 - e^{-t'/t_{*}'}) \quad \text{.......} \quad 11$$

$$\mu - \mu_o = 1 - e^{-(AB)F'} \quad \text{.......} \quad 12$$

Equation 11 is the standardised rate of food intake (kg/week $kg^{0.73}$), t' is the metabolic age (weeks/$kg^{0.27}$) and t_{*}' is the standardized exponential time constant for food intake (weeks/$kg^{0.73}$, $1/t_{*}'$ denoting appetite of the animal). Equation 12 represents the standardized cumulated feed consumed to a degree of maturity μ, μ_o is the initial degree of maturity and F' is cumulative standardized feed intake. The constant AB was termed the standardized feed efficiency constant (kg body weight per MJ of ME), free of the maintenance component of body weight (Parks, 1982). Taylor (1982) reported a value of 0.023 for this constant in beef cattle, while Thompson and Parks (1983) and Thompson et al. (1985) reported values of 0.023 and 0.026 respectively for sheep. A value of 0.023 was therefore adopted by Thompson and Barlow (1986).

Taylor et al. (1985) using data from the Animal Breeding Research Organization's (ABRO) multibreed cattle experiment (Thiessen et al., 1984) derived empirically a relation between degree of maturity and cumulative (scaled) feed intake. Their relationship was:

$$F' = (1/0.023)\{-\log_e(1 - \mu) - 0.0736\} \quad \ldots\ldots \quad 13$$

There are no reports of the application of cumulative feed intake equations in the evaluation of lifetime herd production or efficiency under North American conditions to provide some validation of such equations. However, equations relating weight to daily feed requirements which have been validated exist (NRC, 1984, 1987, 1989; Fox and Black, 1984). It should be possible to derive cumulative functions using predictions from daily requirements. A logarithmic equation of the form

$$F' = e^{a} * \mu^{b} \quad \ldots\ldots \quad 14$$

was chosen because it transforms in logarithmic form to a simple linear equation ($\mathrm{Log}_e F' = a + b\mathrm{Log}_e \mu$) which is easy to program and is a good predictor (see later, section 2.4). This equation has exponential properties except at the extremes of $\mu = 0$ or $\mu = 1$.

A feed intake submodel was therefore developed employing the prediction equations reported by the National Research Council (NRC, 1984, 1987, 1989) and Fox et al. (1988). The feeding period was broken into two periods; pre- and post weaning periods. The diet was assumed to be the same (2.6 Mcal ME kg^{-1} DM) during the pre- and post weaning periods for slaughter animals irrespective of gender. Milk was, however, assumed to be available during the preweaning phase. A diet consisting of 43% alfalfa hay (DM basis) and

53% barley grain was formulated to provide the required 2.6 Mcal ME kg^{-1} DM. This is similar to ration #2 of the Alberta Agriculture recommendations for calves gaining 0.9 kg day^{-1} (Alberta Agriculture, 1989). This diet was evaluated to cost $0.15 kg^{-1} and all other costs relative to diet were evaluated to this base. For breeding animals, a roughage diet (2.0 Mcal ME kg^{-1} DM) was assumed post weaning with intake limited to 2.5% body weight. If the required feed intake exceeded this limitation, the 2.6 Mcal ME kg^{-1} DM diet was substituted to redress the situation.

2.1.2.1. Pre - weaning feed intake

Growth rate is typically high in this phase of growth and equations for predicting intake based on body weight alone may not be very accurate. Total daily requirement was therefore predicted as the sum of the requirements for maintenance and growth. Corrections for environmental influences were computed separately (see section 2.1.2.4). Milk was assumed to be available during this phase, and was always the first choice. The total requirement for energy was computed in net energy terms as follows:

$$NE_p = NE_m + NE_g \quad \ldots \quad 15$$

where NE_p is the total net energy of production (Mcal day^{-1}) required and NE_m and NE_g are the net energy requirements (Mcal day^{-1}) for maintenance and gain respectively. The amount of milk required (MR) to satisfy this net requirement can be approximated as:

$$MR\ (kg\ day^{-1}) = NE_m\ (Mcal\ day^{-1})\ /\ NEM_m\ (Mcal\ kg^{-1}) + NE_g\ (Mcal\ day^{-1})\ /\ NEG_m\ (Mcal\ kg^{-1}) \quad \ldots \quad 16.$$

where NEM_m and NEG_m are the net energies of maintenance and gain content (Mcal kg^{-1}) of milk respectively and NE_m and NE_g are defined by equation 15. The net energy of production content of milk (NEP_m, Mcal kg^{-1}) was hence computed as:

$$NEP_m \text{ (Mcal kg}^{-1}) = NE_p \text{ (Mcal) } / \text{ MR (kg)} \quad \dots\dots\dots\dots\dots\dots\dots \quad 17$$

The total net energy of production available from milk is then the product of the available milk dry matter (DMM) and the net energy of production content (NEP_m, Mcal kg^{-1}).

$$TNEP_m \text{ (Mcal)} = DMM \text{ (kg)} * NEP_m \text{ (Mcal kg}^{-1}) \quad \dots\dots\dots\dots\dots\dots \quad 18$$

The total net energy of production from milk ($TNEP_m$) was then compared with the total net energy of production required. If $TNEP_m \geq NE_p$, it was assumed that only milk was consumed and any excess milk was discarded. If $NEM_m < NE_p$, the deficit was assumed to be made up for with the diet supplied. The net energy of production for the diet (NEP_d, Mcal kg^{-1}) was approximated by the procedures of equations 16 and 17 above, replacing NEM_m and NEG_g with the appropriate values for the diet (NEM_d and NEG_d).

If $TNEP_m \geq NE_p$, then the actual amount consumed was NE_p, so that:

$$DMIM = NE_p / NEP_m \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 19$$

where DMIM is the quantity of milk consumed (in dry matter terms). In this case, dry matter or energy intake from diet is zero. If, however, $TNEP_m < NE_p$, the amount supplied by the diet was computed as:

$$DMID = (NE_p - TNEP_m) / NEP_d \quad \text{. . . . .} \quad 20$$

where DMID is the dry matter intake (kg) from diet and all other terms are defined above. The total daily dry matter and metabolizable energy intakes were then computed as:

$$TDMI = DMIM + DMID \quad \text{. . . . .} \quad 21$$

$$TMEI = MEIM + MEID \quad \text{. . . . .} \quad 22$$

where TDMI is the total daily dry matter intake, DMIM and DMID are the dry matter intakes from milk and the diet respectively. Similarly, TMEI is the total daily requirement in terms of metabolizable energy, and MEIM and MEID are the metabolizable energy consumptions (Mcal day^{-1}) from milk and diet, computed as products of DMIM, DMID and their respective metabolizable energy contents. The requirement for maintenance was computed as:

$$NE_m = B * 0.077 * LWT^{0.75} \quad \text{. . . . .} \quad 23$$

(NRC, 1984; Fox et al., 1988), where NE_m is the net energy (Mcal day^{-1}) required for maintenance, B is a breed effect and LWT is the body weight corrected to a medium frame steer equivalent. The factors used to correct weight to a medium frame steer equivalent are those reported by Fox et al. (1988) and are shown in Table II.3 by frame size (breed group). The breed effect accounts for the fact that Holsteins have maintenance requirements 12% higher than beef breeds (Haaland et al., 1980, 1981; Jenkins and Ferrell, 1984; Fox and

Black, 1984). Hence B was set at 1.12 for Holsteins and 1.0 for all other breed groups. Thus for dairy animals, NE_m was computed as:

$$NE_m = 0.086 * LWT^{0.75} \qquad 24$$

It is possible that the Dairy Synthetic breed group in the present study, which has some Holstein breeding, may have higher maintenance requirements. However, this was not considered because of lack of an estimate. The average daily gain (ADG, kg) was predicted by equation 2 and used to compute the requirements for growth. The formula used was the 'requirement for live weight gain' formula of the NRC (1984) given by:

$$NE_g = a * LWT^{0.75} * ADG^b \qquad 25$$

In this case, NE_g (Mcal) is the net energy required for live weight gain and the constants *a*, *b* are shown in Table II.4, by frame size and gender. For Holsteins, NEG was computed by the equation of NRC (1989) for heifers as follows:

$$NE_g = 0.035 * LWT^{0.75} * ADG^{1.119} + ADG \qquad 26$$

and for bulls:

$$NE_g = 0.025 * LWT^{0.75} * ADG^{1.097} + ADG \qquad 27$$

Steers and other market animals of dairy - beef were treated as large frame sized beef animals and hence their requirement for NE_g was computed by equation 24. It was assumed that calves from the beef breeds were weaned at 180 days (6 months) of age or when they achieved a live weight of 200 kg, which ever happened first.

A modified Wood's equation (Wood, 1967, 1969; George, 1984) represented the lactation curve for each breed group (see sec. 2.1.2.6). For the beef groups, all the calculated production was assumed available to and consumed by the calf. In the dairy, calves were assumed to have been weaned at birth and fed milk at the rate of 5 kg d^{-1}. This is similar to the recommendation by Webster (1989) that such calves be fed 1.5 kg of milk three times per day. The total milk consumed by the calf was then deducted from the total milk production of its dam and the rest was considered a saleable product.

2.1.2.2. Post weaning feed intake

After weaning, intake was predicted by the intake equation of NRC (1984) as modified by Fox et al. (1988):

$$TDMI = LWT^{0.75} * \{(a * NEM_d) - (b * NEM_d^2) - c\} * B. \quad \ldots\ldots\ldots\ldots \quad 28$$

where NEM_d is the net energy of maintenance content of the diet (Mcal kg^{-1}) and *a, b, c* are constants defined in Table II.5. B is a breed effect, increasing intake by 8% for dairy (Holstein) type (Fox et al., 1988). Equation 28 provides the requirement under thermoneutral conditions. The requirements under inclement weather conditions were computed separately (see section 2.1.2.4). The metabolizable energy consumed each day was then computed as the product of TDMI and the ME content (Mcal kg^{-1}) of the diet.

$$TMEI = TDMI * MED \quad \ldots\ldots \quad 29$$

where MED is the maintenance energy content of the diet and TDMI is the total dry matter intake.

2.1.2.3. Cumulative feed intake

The daily dry matter and metabolizable energy intakes predicted by the above equations were cumulated and scaled by the mature weight for each gender and breed. The natural logarithm of scaled cumulated feed intake was then regressed on the logarithm of degree of maturity (μ) to generate four equations of the type of equation 14 ($Log_eF' = a + bLog_e\mu$) for each breed: one each for breeding females and bulls, and for growing (fattening) females and steers. The amount of feed consumed from birth to any specific degree of maturity could then be computed from these equations and used in the efficiency model.

The equations (regression coefficients) obtained are presented in Table II.6 for dry matter intake and for metabolizable energy intake. The nature of these equations are shown by Figures II.6 and II.7, for dry matter and metabolizable energy intakes.

2.1.2.4. Environmental corrections for feed intake

The procedures described above compute feed intake for a thermoneutral environment. The environment in Alberta and the whole of North America can be harsh for some parts of the year. Functions to correct feed and energy intake for deviations from thermoneutrality were therefore developed. To do this, mean monthly environmental conditions were generated from daily records of weather conditions at the University of Alberta beef research ranch, Kinsella, Alberta, obtained over the years 1987 to 1989. The mean monthly temperatures and wind speeds are presented in Figures II.8 & II.9. Monthly averages were used instead of daily figures partly because it was more pragmatic (convenience) but more important, because adjustment for these effects is more accurate if the average environmental state for a period of a week or month rather than daily fluctuations is used (NRC, 1987).

The function developed for correcting for environmental effects is based on the equations of Fox et al. (1988) which are basically equations of the NRC (1981, 1984) with small modifications:

$$\mathrm{MECS} = \mathrm{SA}\ (\mathrm{LCT} - \mathrm{T}) / \mathrm{I} \tag{30}$$

$$\mathrm{SA} = 0.09\ \mathrm{W}^{0.67} \tag{31}$$

$$\mathrm{LCT} = 39 - (\mathrm{I} * \mathrm{HP}) \tag{32}$$

$$\mathrm{I} = \mathrm{I}_i + \mathrm{I}_e \tag{33}$$

$$\mathrm{HP} = (\mathrm{EI} - \mathrm{NE}_p) / \mathrm{SA} \tag{34}$$

$$\mathrm{NE}_p = 0.65\mathrm{LE} + 0.125\mathrm{PE} + \mathrm{NE}_g \tag{35}$$

In the above, MECS is the daily metabolizable energy (Mcal) required for cold stress, SA is the surface area (m^2), W is the live weight (kg), LCT is the lower critical temperature (°C), I is the total insulation (°C $Mcal^{-1}$ m^{-2} day^{-1}) or the sum of the internal (I_i) and external (I_e) insulations, HP is the heat of production (Mcal m^{-2} day^{-1}), NE_p is the net energy (Mcal day^{-1}) required for production, EI is the total daily metabolizable energy intake (Mcal day^{-1}) including the energy required for pregnancy (PE) and lactation (LE) whenever applicable, NE_g is the net energy (Mcal day^{-1}) required for gain, and T is the current temperature (°C).

The internal tissue insulation factor was determined using values of NRC (1984) and Fox et al. (1988), Table II.8, and the values for external insulation were from the same sources, Table II.9. In all cases, average flesh condition was assumed. Determination of I_e requires knowledge of the coat depth (length of hair), thickness of the hide and the condition of the coat. Webster et al. (1968), Young (1969), and Young and Berg (1970) reported some values for calves 6-12 months of age and mature cows. Mean values adopted from their results are summarized in Table II.7. In the absence of empirical values, newborn calves were assumed to have less than 0.5 cm coat depth and 1 - 6 month old calves were assumed to have a coat depth of 1.0 cm. For calves, 6 -12 month values reported in Table II.8 were used. For all other age groups, a minimum of 3.0 cm coat depth was assumed. This is partly because these other age groups were not well represented in the data obtained, but also because it was thought that older age groups have longer hair. Animals younger than 6 months were assigned the hide thickness values reported in Table II.8, with 0.5 cm assumed for Herefords and SY2. For other age groups, a hide thickness of 1.0 cm (average) was assumed for all breeds. It was also assumed that the coat was dry and clean and hence required no further adjustment.

The effect of previous temperature was also computed as follows (Fox, et al., 1988):

$$PTE = 0.0007 * (20 - PT)/0.65 \quad \ldots\ldots\ldots\ldots \quad 36$$

where PTE is the previous temperature effect per unit metabolic body weight (Mcal kg^{-1}), and PT is the previous temperature (°C). Because corrections for environmental conditions are made only during certain periods of the year, the relation between the cumulated requirements for adverse environment and degree of maturity cannot be accurately modelled by regression. Hence the actual cumulated environmental corrections up to specified degrees of maturity were computed and used.

2.1.2.5. Feed intake requirements for pregnancy

The equations of George (1984) and Fox et al. (1988) were used to predict requirements for pregnancy. Basically, the prediction is a sum of the cumulations of energy in the fetal protein, fat, fetal fluids, placenta, cotyledons and the uterus. The growth of these tissues is predicted using the quadratic exponential models of Prior and Laster (1979) and the equivalent energy was calculated by multiplying the weight of the tissue by its energy content. The growth equations are listed below:

i. Protein accretion (Y_p):

$$Y_p = .586e^{(.0589 - .00009334t)*t} \qquad 37$$

$$dY_p/dt = (.0345154 - .000109394t)e^{(.0589 - .00009334t)*t} \qquad 38$$

ii. Fat accretion (Y_f):

$$Y_f = .0007696e^{(.0885 - .0001282t)*t} \qquad 39$$

$$dY_f/dt = (.0000681096 - .0000001972t)e^{(.0885 - .0001282t)*t} \qquad 40$$

iii. Accretion of fetal fluids (Y_{ff}):

$$Y_{ff} = 52.1t - 4150 \qquad 41$$

The rate of accretion (dY_{ff}/dt) is therefore constant and equal to 52.1.

iv. Accretion of cotyledons (Y_c):

$$Y_c = 1.497e^{(.05614 - .0001031t)*t} \quad \text{42}$$

$$dY_c/dt=(.08404158 - .0003086814t)e^{(.05614 - .0001031t)*t} \quad \text{43}$$

v. Placental accretion (Y_n):

$$Y_n = 6.133e^{(.04378 - .000076t)*t} \quad \text{44}$$

$$dY_n/dt =(.26850274 - .000932216t)e^{(.04378-.000076t)*t} \quad \text{45}$$

vi. Accretion of the uterus (Y_u):

$$Y_n = 55.208e^{(.02475 - .00003479t)*t} \quad \text{46}$$

$$dY_n/dt =(1.366398 - .0038413726t)e^{(.02475-.00003479t)*t} \quad \text{47}$$

In all the above equations, Y_x is the total accretion in grams up to day t, of tissue x, and dY_x/dt is the daily accretion in grams of the xth tissue, and t is time in days. The gross energy contents of these tissues (Ferrell et al., 1976) are 5.505, 9.527, 0.132, 0.539, 0.539, and 0.953 kcal gm^{-1} respectively for the protein, fat, fetal fluids, cotyledons, placenta, and uterus. Hence, by multiplying the daily accretion of each tissue in grams by its energy content, summing the results and dividing by 1000, the total energy requirement in megacalories for that day can be computed.

The gross efficiency of metabolizable energy (ME) use for conceptus development has been estimated as 11 to 15% (Ferrell et al., 1976) for cattle. The NRC (1984) uses an average value of 13%. Dividing the amount of energy computed as above by the efficiency of ME use for pregnancy (0.13), gives the daily metabolizable energy requirements. Total requirements over a 281 day gestation can therefore be computed.

The above equations were developed on the basis of a birth weight of 36.4 kg. To adjust the predictions for a different birth weight, the predicted energy for pregnancy is computed according to the equation of Fox et al. (1988):

$$PE_r = PPE * BW/36.4 \quad \ldots\ldots 48$$

where PE_r is the actual gestation requirement for a birth weight of BW, and PPE is that predicted for a 36.4 kg calf. Birth weight was further adjusted for age of dam at birth according to the equations of Fox et al. (1988). The actual age of dam adjustment factors used, however, were computed from the results obtained by Sharma et al. (1982). Their results on pure Herefords and the Beef Synthetic #1 indicated that relative to mature cows, 2, 3 and 4 year old cows had calves that were respectively 5.0, 2.9 and 1.2 kg lighter for Herefords and 5.2, 2.9, and 1.5 kg lighter for the SY1 at birth. Since no results were reported for the other breed groups of this study, and considering the similarity of the results for the two breed groups reported, values of the SY1 were assumed for the other breed groups.

2.1.2.6. Feed requirements for lactation.

Predicting the feed required for lactation implies a knowledge of the daily milk production, milk composition and the length of the lactation period. Lactation curves have been extensively examined for dairy cattle but are relatively unavailable for beef cows mainly because of the difficulties in measuring milk production in beef cows over the duration of the lactation period. Hence very few equations and their coefficients are available for beef cattle (George, 1984).

Perhaps, the most widely used equation for the prediction of lactation performance in dairy cattle is that of Wood (1967, 1969):

$$M_t = A * t^{b} * e^{-ct} \tag{49}$$

where M_t is the milk yield on day t, and A, b, c are constants, and e is the base of natural logarithm. Parameters of this equation can be obtained by non linear procedures or by multiple regression techniques using the logarithmic transform:

$$\ln M_t = \ln A + b\ln(t) - ct \tag{50}$$

Wood (1976) further proposed the inverse of equation 49 for predicting the composition (e.g., Fat % or protein %) of milk:

$$MC_t = A * t^{-b} * e^{ct} \tag{51}$$

with the logarithmic transform:

$$\ln MC_t = \ln a - b\ln(t) + ct \tag{52}$$

In this case, MC_t is the milk constituent (e.g., fat%) and t is the time, in weeks.

Equation 49 describes the fairly quick rise in milk yield to a peak and the almost linear decline thereafter in dairy cattle. A similar pattern has been reported for sheep and goats (Aboul-Naga et al., 1981; Torres-Hernandez and Hohenboken, 1980). This inherent pattern may be quite different in beef cattle, but a similar pattern is often assumed, although it is recognized that low production, poor estimation methods, difficulty in estimation and environmental influences (ambient environment, feed supply) make this rhythm much less obvious (George, 1984). Some studies in beef cows have, however, reported a lactation pattern similar to that of dairy cows (Sommerville, 1977; Chenette and Frahm, 1981; Holloway et al., 1982). The results of Gleddie and Berg ([illegible]) using Hereford, Angus, Galloway and crosses indicated a linear decline of 0.02 kg milk per day of lactation from June through to October. Milking was, however, started 40 - 45 days after calving providing not much information of milk yield in the first month of lactation.

George (1984) modified Wood's equation for predicting lactation performance in beef cattle. Equation 49 was modified to:

$$M_t = A * (t + 14)^b * e^{-c(t+14)} \quad \ldots\ldots 53$$

where t is the day of lactation. This modification shifts the curve to the left (by 14 time units) and ensures a non zero value of milk yield when t = 0. George (1984) also claims that the modification corrects for under- and over estimation of milk yield immediately before and after the peak. The milk composition was then predicted as:

$$MC_t = A * [(t + 1)/7]^{-b} * e^{c[(t+1)/7]} \quad \ldots\ldots 54$$

This modification also shifts the curve to the left (one time unit) and ensures that MC_t is not zero when t=0. The divisor, 7, converts time to days as Wood's original model was in weeks. A final modification to equation 54 was made by replacing parameter A by 1.01PF, where PF is average fat content of milk over the entire lactation period. Hence the equation used for predicting milk fat content was:

$$MC_t = 1.01 * PF * [(t + 1)/7]^{-b} * e^{c[(t+1)/7]} \quad \ldots\ldots\ldots\ldots\ldots\ldots 55$$

The model of George (1984) was adopted mainly because it provides approximate methods for estimating the parameters of the lactation curve using point estimates of peak milk yield. The estimate of peak milk yield is used to estimate the time of the peak yield and the two estimates are then used in conjunction to compute the parameters of the Wood's equation. The formulae for estimating these parameters are as follows:

$$T_{pm} = 40 + M_m \quad \ldots\ldots\ldots\ldots\ldots\ldots 56$$

$$T_{p4,>10} = T_{pm} - 5 \quad \ldots\ldots\ldots\ldots\ldots\ldots 57$$

$$T_{p3} = T_{pm} - 10 \quad \ldots\ldots\ldots\ldots\ldots\ldots 58$$

$$T_{p2} = T_{pm} + 10 \quad \ldots\ldots\ldots\ldots\ldots\ldots 59$$

$$A_m = 5.30 - (0.075 * T_{pm}) \quad \ldots\ldots\ldots\ldots\ldots\ldots 60$$

$$A_{4,>10} = 5.85 - (0.090 * T_{p4,>10}) \quad \ldots\ldots\ldots\ldots\ldots\ldots 61$$

$$A_3 = 6.65 - (0.110 * T_{p3}) \quad \ldots\ldots\ldots\ldots\ldots\ldots 62$$

$$A_2 = 4.00 - (0.050 * T_{p2}) \quad \ldots\ldots\ldots\ldots\ldots\ldots 63$$

$$b_m = (\log_e m_m - \log_e a_m) / [\log_e(T_{pm} + 14) - 1] \quad \ldots\ldots\ldots\ldots\ldots\ldots 64$$

$$b_{4,>10} = (\log_e m_{4,>10} - \log_e a_{4,>10}) / [\log_e(T_{p4,>10} + 14) - 1] \quad \ldots\ldots\ldots\ldots 65$$

$$b_3 = (\log_e m_3 - \log_e a_3) / [\log_e(T_{p3} + 14) - 1] \tag{66}$$

$$b_2 = (\log_e m_2 - \log_e a_2) / [\log_e(T_{p2} + 14) - 1] \tag{67}$$

$$C_m = b_m / (T_{pm} + 14) \tag{68}$$

$$C_{4,>10} = b_{4,>10} / (T_{4,>10} + 14) \tag{69}$$

$$C_3 = b_3 / (T_3 + 14) \tag{70}$$

$$C_2 = b_2 / (T_2 + 14) \tag{71}$$

The above equations are given with respect to age of the cow. T_{pm} is the time of peak lactation for a mature cow. $T_{p4,>10}$, T_{p3}, T_{p2}, are the times of peak yield for cows 4 or greater than 10 years old, 3 and 2 year old cows respectively. The parameters A, b, c of the lactation curve are also specified according to age of the dam as explained above for time of peak milk yield. M_{pm} is the mature peak yield.

Variation in milk yield is maximum at the peak (Wood, 1969). Hence, George (1984) provided an equation for varying the peak yield of an average mature cow of a specific breed for production level (PL) within breed:

$$M_{pm} = [(PL * 0.125) + 0.575] * M_{pb} \tag{72}$$

where M_{pm} is the peak yield of a specified cow and M_{pb} is the peak yield of the breed. M_{pm} can vary from 50 to 150% of M_{pb}. For purposes of this study PL was set equal to 5 for all breeds (i.e., average) so that $M_{pm} = M_{pb}$. George (1984) also assumed that cows that are 2-, 3-, and 4- or older than 10-years had peak lactation yields 60, 82.5 and 92.5% of mature (5- to 10-year-olds) peak yield. These assumptions were accepted for Holsteins but were modified in line with the results of Jeffrey et al. (1971) and Butson and Berg (1984) for the other breed groups so that for each breed group,

$$M_{pi} = a_i * M_{pm} \quad \dots\dots \quad 73$$

where M_{pi} is the peak milk yield of age group i and a_i is a multiplicative effect, given in Table II.10 by breed group. The mature peak milk yields used in this study were from Butson and Berg (1984). Their figures were the daily averages for June and since calving began in April, they were assumed to be close to the peak milk yields for each of the breed groups. The peak yield figures together with assumed fat contents are given in Table II.11. It would be noticed that in the Dairy synthetic breed group, animals 4 years old or older than 10 years had greater peak milk yield than mature cows (5 - 10 years old). This anomaly was an artifact of the data available, suggesting the need for better estimates. It was not thought critical to change these figures for current purposes. Lactation curves for each breed group are shown by Figures II.9 for the beef breeds. Daily net energy requirements (Mcal) for lactation were then computed according to NRC, (1989):

$$NEM_l = (0.3512 + (0.0962 * DMF)) * M_t \quad \dots\dots \quad 74$$

where DMF is the daily milk fat content (%) and M_t is the daily milk yield.

2.1.3. Timing of events

The program begins with a female calf at the start of the calving season (e.g., April 1 for spring calving). Her live weight and growth rate are predicted by equations 1 and 2 (section 2.1.1) and feed required to meet such growth is then computed together with the necessary environmental corrections throughout her productive life in the herd. A gestation length of 281 days is assumed. A heifer is bred to first calve at two years of age and hence is assumed to be pregnant by June 23 (for spring calving) or March 27 (for winter calving) after her first year of life (these being computed 281 days backwards). After calving, a lactation length of 180 days (305 days for Holsteins) is assumed i.e., to coincide with weaning at 6 months of age of the offspring. Hence, beyond 2 years of age, the first 3 months of gestation overlap the last three months of lactation. Milk production was assumed identical for any month of calving. The growth and feed consumption of the offspring of this female are simulated similarly. However, to simulate efficiency curves at varying degrees of maturity at slaughter of the offspring, growth and intake predictions were carried on for 10 years by which time all breed groups attain a degree of maturity close to unity.

The time step is one day. Each day in the span of the simulation is reduced to a point in a 365-day cycle (leap years are not considered) from which the month of the year is determined:

$$\text{day} = \text{time} - (365 * \text{yr}) \quad \ldots\ldots 75$$

where day is the point in the 365-day cycle, time is the actual number of days in the simulation (e.g., day 2000) and yr is year-1, so that the yr = 0 in the first year, 1 in the second year etc. Having determined the month, environmental conditions for the month are then obtained from arrays of monthly values, and used to compute environmental corrections. As explained in section 2.1.2.4, these adjustments for environmental conditions are considered to be more accurate if the average environmental state for a period of about a week or month is used rather than the daily environmental fluctuations (NRC, 1987). The growth and feed intake submodel is shown schematically by Figure II.11 (adapted from Emmans and Oldham, 1988). It indicates the interrelationships between the animal, the feed and environment. While the environment and the feed provide the animal with resources to carry out its purposes, they can also act as constraints to the animal (e.g. inclement weather or poor diet) and act to prevent it from carrying out those purposes. For the present model, constraints from the diet are assumed not to exist (i.e., the diet is adequate) and those from the environment are assumed to have been appropriately catered for.

2.2. Herd submodel

This submodel is responsible for generating numbers of animals of different classes to be used in the efficiency submodel. It traces the numbers of offspring of different classes (sex and breeding) produced by the cow throughout her life in the herd. Each herd has an array of age groups and the possibility of three gender types. Modelling the movement of animals between age classes and the numbers of animals within each gender type requires knowledge of input to the herd (reproduction, immigration) and offtake from the herd (culling, death, emigration) and the rates at which these forces operate, as well as the probability of obtaining a particular gender. Culling occurs for various reasons such as old age, disease, low productivity or marketing of animals originally intended for sale. In the latter case, the age at culling is fairly easy to determine (e.g., 18 months) whereas in other cases the age at culling is a fairly random process, hard to determine. Hence modelling herd dynamics becomes a difficult process, and is often treated as a stochastic (probabilistic) process. For example, by treating culling as a Markov chain (an event whose probability of occurrence depends only on the probability of its occurrence in the preceding period), Azzam et al. (1990) computed the age distributions in herds under various culling strategies.

The process can, however, be simplified and reduced to a deterministic process by assuming a stable, average, equilibrium herd age structure (e.g., Taylor et al., 1985). For each herd, average production figures can be computed; e.g., the average reproductive rate could be 0.8 or the average age at turnover could be 6 years. Hence a conceptual 'average cow' can be simulated with production characteristics identical to the average herd characteristics. For purposes of this model, the average female and her offspring then adequately represents the basic unit of the herd and the herd is now considered as the sum of the number of females in it and their offspring. It is then easy to trace the female and her offspring over her productive lifespan and to categorize the offspring by function (replacement or market). The age at culling of the female is then the average turnover age of the herd and can be varied to investigate the behaviour of efficiency with age at culling. The number of offspring produced over each period of residence in the herd can then be computed and partitioned to males and females depending on the sex ratio. The offspring can be further classified as crossbred or purebred depending on whether dam replacements are obtained from the herd or not.

The equations used are explained below and the structure of the submodel is shown by the flow chart in Figure II.12. The model generates replacements within the herd; i.e., no replacement heifers are purchased. The model uses the reproductive rate (defined here as the ratio of the number of progeny surviving to slaughter to the number of females exposed), the sex ratio of offspring at birth and the fact that at least one replacement female must be produced per cow to calculate the minimum number of years a cow must remain in the herd if a stable herd is to be maintained. This is used as a check against the user specifying too short a simulation time span. The submodel obtains the average number of years a cow stays in the herd before being culled (assuming normal reproduction) from the user. It checks to ensure that this is not less than the minimum number of years the cow must remain in the herd and requests for the age at which heifers are first bred. It computes the productive life span of the cow as the difference between the age at culling and the age at first breeding and generates the number of calves produced by the cow - during her entire residence in the herd.

For purposes of this model, it is assumed that there is no crossbreeding. The model employs parameters from the synthetic breed groups of beef cattle maintained at the University ranch and these breed groups are assumed to breed true to type. The calves are then sexed and those not selected for replacements are fed for marketing. Such market animals will include culled cows and spent breeding males. The maximum age of a cow permitted in this herd by the submodel is 20 years, hence the productive years of any female can run from about 2 years of age to 20 - a maximum of 19 reproductive years. However, for purposes of the current study a maximum age of 10 years will be used. This is basically a logic submodel and the sequential derivation follows.

The number of calves (ncalves) a cow can produce in N (re)productive years is given by:

$$\text{ncalves} = N * \text{reprate} \tag{76}$$

where reprate is the reproductive rate, defined here as the number of calves raised to market as a proportion of the number of cows exposed. The number of female offspring (nfemale) in this will be:

$$\text{nfemale} = N * \text{reprate} * (1\text{-sexratio}) \tag{77}$$

where sexratio is the male to female offspring ratio. At least one female offspring must be produced if the cow is to replace herself, so that nfemale is at least 1 or:

$$N * \text{reprate} * (1\text{-sexratio}) \geq 1 \tag{78}$$

Since one female offspring must be produced as a replacement, the number of years required to produce it is the minimum (minyrs) reproductive years a cow requires to produce her own replacement, on average. Thus if N in equation 78 is replaced by minyrs, the result should equal one, i.e.,

$$\textbf{minyrs} * \text{reprate} * (1 - \text{sexratio}) = 1 \tag{79}$$

or

$$\textbf{minyrs} = 1/(\text{reprate} * (1 - \text{sexratio})) \tag{80}$$

The simulation span stipulated by the user is checked against **minyrs** to ensure that it is not less than the minimum years required to sustain herd numbers. It is also used in the calculation of minimum offspring numbers. The minimum age at which a heifer can be culled (**minage**) is the sum of her age at first breeding (**agebred**) and the minimum number of years required to produce her replacement (**minyrs**).

minage = minyrs + agebred 81

The minimum number of offspring (**nmin**) that must be produced to maintain stability in the herd structure is:

nmin = minyrs * reprate 82
={1/(reprate * (1 - sexratio))} *reprate 83
=1/(1-reprate) 84

The total number of offspring a cow can produce during her life time in the herd (ntotal) is given as per equation 76 by:

ntotal = number of reproductive years * reprate 85
= (nyears - agebred) * reprate 86

and must be greater than or equal to **nmin**. The total number of males is then computed as a product of the total number of offspring and the sexratio:

nmales = ntotal * sexratio 87

The numbers of female offspring can be calculated in a fashion similar to that of the male offspring. The only difference is that we replace "sexratio" with "(1 - sexratio)". Alternately, these could be calculated as differences between male offspring numbers and the total offspring numbers. The formulae are as follows:

$$\textbf{nfemale} = \text{ntotal} * (1 - \text{sexratio}) \tag{88}$$

$$= (\text{nyears} - \text{agebred}) * \text{reprate} * (1 - \text{sexratio}) \tag{89}$$

where **nfemale** is the total number of female calves. One of these female calves has to serve as a replacement for the dam. Hence, the number of females available for market (**mfemales**) is then:

$$\textbf{mfemale} = \text{nfemale} - 1 \tag{90}$$

$$\textbf{npfemale} = \text{nmin} * (1 - \text{sexratio}) \tag{91}$$

$$= (1/(1\text{-sexratio})) * (1 - \text{sexratio}) \tag{92}$$

$$= 1 \tag{93}$$

$$\textbf{nxfemale} = \text{nfemale} - \text{npfemale} \tag{94}$$

In the above, nfemale, npfemale, nxfemale represent the total number, the number of purebred and the number of crossbred female offspring.

2.3. The efficiency submodel

Overall efficiency was defined as the total output (in terms of lean meat production) to the total input (in terms of feed requirement in kg or Mcal ME). The computation of the total input to, and output from the herd is discussed below.

2.3.1. Total input to the herd

The total input included the initial cost of breeding stock, breeding cost (cost of maintaining a bull for service) as well as the feed consumed by all classes of animals in the herd and the extra feed for pregnancy and lactation. All costs were converted to their equivalent in feed terms. The total input was therefore computed as:

Total Input = Feed intake of slaughter female progeny from birth to slaughter
+ Feed intake of the slaughter male progeny from birth to slaughter
+ Feed intake of steers from birth to slaughter
+ Feed intake of culled breeding bulls
+ Feed intake of culled dams
+ extra feed for pregnancy
+ extra feed for lactation
+ extra feed for environmental corrections
+ breeding cost (feed equivalent)
+ initial cost of stock (feed equivalent) 95

Each of these inputs was scaled by the mature size of the breed. The total input henceforth referred to as 'equivalent feed intake'. Cumulated feed intake to any degree of maturity at slaughter was computed by the regression equations of section 2.1.2.3 (Table II.6). Feed intake corrections for the environment were cumulated separately and printed out for each degree of maturity. In the case of breeding females, the extra feed requirements for pregnancy and lactation were also cumulated separately and generated yearly until the dam was culled from the herd. The breeding cost was calculated as the total feed consumed by breeding male plus its initial cost (feed equivalent) minus its value at slaughter divided by the average number of offspring sired by him. The breeding practice of the University of Alberta beef research ranch, Kinsella, was used to estimate the number of calves produced by the bull over his lifetime in the herd. Bulls are used as yearlings and 75% of them are culled; the other 25% are used again at 2 years of age and all are then culled. The average cost of feed per bull was therefore calculated as 0.75 times the feed consumed to 1 year plus 0.25 times the feed consumed to 2 years. The value of the bull at slaughter was similarly weighted. Each bull is mated to 25 cows and hence has the potential to produce 0.75*25 (first year) plus 0.25*50 (second year) = 31.25 calves. If the reproductive rate is not unity, then the actual number of calves produced will be 31.25r where *r* is the reproductive rate. The cost carrying an additional 2 bulls per 100 cows per year as an insurance for the availability of bulls was also included. The initial cost of the stock was estimated as the cost per kg liveweight multiplied by the initial liveweight. Unfortunately, Alberta Agriculture does not report cost of breeding animals and hence the price for slaughter animals was inflated by 50% and assumed as the cost of breeding stock.

2.3.2. Output from the herd

The main output from a beef herd is lean meat from slaughter offspring, culled dams and the culled breeding males. The output from the spent male relative to the output from his slaughter offspring was, however, considered to be negligible. The total output in terms of lean meat per kg mature weight was calculated as:

Total output = lean output from slaughter male offspring
+ lean output from slaughter female offspring
+ lean output from steers
+ lean output from culled dams
+ lean output from culled breeding males.
+ extra milk available for sale (lean meat equivalent) 96

The total output was scaled by the mature size of the breed, and is hence referred to as 'equivalent lean output'. Hence, the computed efficiency has units of grams lean meat per kg feed intake or per Mcal ME intake, since weight units in the denominators of the total input and the total output cancel.

Lean meat from different slaughter offspring potentially grade differently and hence result in a net difference in value. For example, heifer carcasses are slightly discounted relative to steer carcasses while intact males have a potentially larger discount. Culled cows have the highest discount. To account for these differences, lean meat from steers was considered the standard. The value of lean meat from other types of animals were then specified relative to the value of lean from steers. The value of meat for each type of animal was obtained by computing the proportions of animals grading specific grades, multiplying such proportions by the prices obtained for the grades and then summing the results, i.e:

$$P_x = \Sigma p_i G_i \quad \ldots\ldots\ldots\ldots \quad 97$$

where P_x, is the weighted average price for a herd of animals of type x, e.g., heifers, p_i is the proportion of animals grading G_i. Hence the value of a carcass relative to that of a steer is,

$$v_x = P_x/P_s \quad \ldots\ldots\ldots\ldots \quad 98$$

where v_x is the relative value, P_x is the weighted average value of lean for a herd of animals of type x, eg culled cows, and P_s is that of a herd of steers.

There are few reports on how many animals of a specific type meet specified grades. Jones et al. (1987) reported that Canada A1/A2 carcass grades make up over 90% of the carcasses in the youthful grades. Price and Berg (1981) and Graham and Price (1982) categorized culled cows into three classes, youthful (2 - 3 years old), intermediate (4 - 5 years old) and mature, and reported the numbers of animals grading specified grades in each category. The numbers of animals involved were, however, too few to be meaningful in the current study.

Slaughter records of the University beef cattle ranch were therefore used to compute the proportions of animals of specified type grading specified grades. The proportions obtained are given in Table II.12 for steers, heifers and intact males. Those for culled cows are given in Table II.13 according to the age classification of

Price and Berg (1981) and Graham and Price (1982). The average prices of 100 lb (approx. 45 kg) of beef of differing grades reported by the Alberta Agriculture (1985 -1989) over the years 1985 to 1989 (inclusive) are given in Table II.14. The proportions of animals in Tables 12 and 13 were then used to weight these average prices to obtain the relative worth of cattle of the different types. It was assumed that the price given for bulls was for spent (breeding) males, not intact males whose original purpose was for slaughter. In this case, the prices for the various grades of steer carcasses were assumed for intact males as well. There was no price reported for grade E and so the price reported for breeding males was assumed in this case. However, only 1% of the intact males graded E and hence the last assumption had little impact on the weighted price for intact males. The derived mean (weighted) prices for 100 lb beef from various types of animals together with the worth of such animals relative to steers are given in Table II.15. The relative values were then used to weight the output of lean from each type of animal. For culled cows, for example, this is equivalent to saying that a carcass of 500 kg is equivalent to a steer carcass of 500 * 0.69 = 345 kg. Hence, the total output of lean from the herd is then given by:

$$\text{Lean\_tot} = \Sigma v_x L_x \quad \ldots\ldots \quad 99$$

where L_x is the lean content (grams) of animal type x, eg slaughter heifers. The lean content of each animal was assumed to be 33% of the live weight (Taylor et al., 1984). The lean content of the synthetic breed groups of this study could, however, be as high as 38% for the beef synthetic #1 (Shahin and Berg, 1985). Variation in lean percentage was therefore considered as a factor to be investigated, rather than assumed.

In the dairy - beef system, the price of milk relative to lean meat from steers was used to weight the excess milk over calf consumption available for sale. The mean farm value of milk (Alberta Agriculture, 1985 - 1989) was \$0.49 per kilogram of milk. Hence the value of milk relative to a kilogram of beef was computed as:

$$v_m = \text{price kg}^{-1}\text{ milk} / \text{value kg}^{-1}\text{ lean beef}$$

$$= 0.49 / (74.6/45.45) = 0.2979 \quad \text{..........} \quad 100$$

i.e., a kg of fresh milk is equivalent to approximately 300 g lean beef from a steer. At any specified herd turnover age, the efficiency was computed relative to the degree of maturity of the slaughter offspring, since as explained in section 2.1.1.1 an animal's stage of development is better represented by its degree of maturity than by its age or size.

2.4. Model validation

Most of the equations employed in this study have been independently validated (see NRC, 1981, 1984, 1987, 1989; Fox et al., 1988; George, 1984). However it was thought wise to attempt separate validation for each aspect of the model. For the growth and feed intake submodel, the critical check is on the regressions developed between cumulative feed intake (scaled by mature weight) and degree of maturity. The daily feed intake predictions from the model, that were cumulated to generate these regressions, are compared to intake predictions from the

Beef templates of Dr. Mathison in Figure II.13 to generate corroborative evidence that the computations of this model were not radically wrong. These beef templates represent an implementation of the NRC (1984) beef cattle feed intake requirements in a Lotus® spreadsheet. Only the results of the medium sized breed (Hereford) and the largest sized breed (Dairy synthetic) are presented and the body weights employed in the predictions cover the entire growth cycle. The maximum difference between any two predictions was less than 1.5 kg, and correlations between the two predictions were all greater than 0.99. The slight differences between predictions are probably due to different adjustments for different sized breeds. For example, the NRC (1984) increases feed intake by 10% for large frame steer calves and medium frame bulls, and 5% for large frame bulls. There is also a 10% reduction in intake for medium frame heifers. Fox et al. (1988) do not make similar adjustments. These results indicate that the daily predictions of feed intake from the model are computationally valid.

To evaluate the cumulative equations of feed intake generated by the model, the mean predicted feed intake (kg^{-1} mature weight) for each breed group were plotted together with those from the equations of Taylor et al. (1985) and Parks (1970, 1982). Taylor et al. (1985) and Parks (1970, 1982) assumed that a single equation would describe feed intake for each breed adequately. Figure II.14 is a plot of the scaled cumulative metabolizable energy intake in units of MJ kg^{-1} mature weight against the degree of maturity. There is an obvious and large disparity between the predictions of the current model and those from the equations of Taylor et al. (1985) and Parks (1970), when offspring are more than 40% mature. This disparity can probably be explained by differences in maturing rates between beef breed groups used in the different studies. Actual growth, maturing rates and cumulated feed intake data for the animals involved in the study of Taylor et al. (1985) have been reported by Taylor et al. (1986) and Thiessen et al. (1984). When maturing rates are compared the animals of Taylor et al. (1985) are realised to be maturing much faster than animals in the current study (Figure II.15a). The Hereford breed group was employed in the comparison because its mature size was about the same as the 550 kg mean mature weight reported for the animals of Taylor et al. (1985). By 72 weeks of age the animals of Taylor et al. (1985) were 72% mature. These animals were housed year round and fed *ad libitum* on a diet supplying 2.4 Mcal ME and hence would be expected to grow and mature very fast. In contrast, the animals of the current model are fed on range and are only 54% mature at 72 weeks. They require an extra 61 weeks to be 72% mature, i.e., an extra year and 2 months of feeding. This difference in the length of time at feed will account for the obvious disparity in Figure II.14. If, however, we compare the cumulated feed consumed to the same ages (i.e., similar times on feed) the cumulated intakes are then similar (Figures II.15b & c).

The appropriateness of equation 14 as a cumulative function for predicting the feed intake required to attain a specified degree of maturity was, however, examined. The nature of the relationship between cumulative feed intake and degree of maturity is thought to be exponential (Parks, 1970, 1982; Brody, 1945; see also figures 4 & 5), but is probably not exact. If this relation were exactly exponential, then a logarithmic transformation would linearize it. ie, if $y = ae^{bx}$, then $\log_e y = \log_e a + bx$ is linear exactly. Figure II.16a is a plot of actual cumulated (scaled) feed intake (F') against the degree of maturity (μ) and Figure II.16b is the plot of F' against

$\log_e(1-\mu)$. The latter plot represents the relationship employed by Taylor et al. (1985), since equation 13 is actually of the form $F' = a + b\log_e(1-\mu)$. Obviously Figure II.16b is not linear and hence fitting a linear regression equation will not result in a good predictor of feed intake, especially in the early stages of maturity when linearity is most affected. This is further evidenced when we include the actual fits in the plot (Figure II.17a). The relation between $\log_e F'$ and $\log_e(1-\mu)$ is even less linear (Figure II.16c) and regressions were not fitted for this relation. Figure II.16d indicates a plot of the natural logarithm of actual cumulated feed intake against the natural logarithm of the degree of maturity. This is the relation employed by the current model. It indicates that although the relation is not exactly linear, it is far more linear than any other. It therefore appears that fitting a linear regression to this transformation should provide a better predictor than the other transformations. This is also evidenced by the plot of cumulative daily intake and predicted cumulative intakes against degree of maturity (Figure II.17b). The model equation is a fairly good predictor especially in the early stages. Fitting a Taylor's type equation would underpredict intake in the early stages but predict intake accurately in the later stages. It therefore seems that equation 14 is an appropriate equation for predicting cumulative intake from degree of maturity in this model and that the predictions from it are quite valid.

The daily requirements for pregnancy in terms of metabolizable energy, generated by the equations of this model are compared to those generated by the equation of the NRC (1984). The results are shown in Figure II.18. They indicate close agreement in predictions except later in the third period of pregnancy. All correlations between the model values and those from the NRC (1984) are greater than 0.97 indicating close association. George (1984) obtained similar results when he compared the output from the current equations with those from the equations of Ferrell et al. (1976). The requirements for pregnancy generated by these equations are therefore assumed to be valid.

There are no practical figures for validating the lactation curves generated and hence the feed requirement for that lactation. However, Gleddie and Berg (1968) reported a linear decline of 0.02 kg milk day^{-1} of lactation in crossbred animals from June through October. Since it has been assumed that milk yield peaked in June, regression of yield beyond the peak on day of lactation should provide a clue to the behaviour of the predicted lactation curves. The coefficients from such regressions are shown in Table II.16. It will be realized that except for the purebred Herefords and some 2 years old heifers of some breed groups, the linear decline in milk yield beyond the peak is close to 0.02 kg day^{-1}. This suggests that the lactation curves generated are at least declining as might be expected beyond the peak and provides partial validation for using such lactation figures.

The herd submodel is based on logic rather than quantitative relationships. It is difficult to validate logic models because experiments seldom duplicate the domain of the model control variables over the entire life cycle. The model was, however, checked and verified to ensure that it is not generating unreasonable results and evaluated for robustness (see Pomar et al., 1991).

2.5. Sensitivity analysis

Sensitivity analyses were conducted by varying the parameters of the growth (Richards) function ±10% of their actual values and examining the effect on the overall efficiency. For this analysis, the reproductive rate and the mean age at herd turnover were set at 0.8 and 6 years, respectively. These values were believed to be close to those attainable under commercial conditions. In addition, the effect of varying the degree of maturity of the dam (μ_d) at turnover and the lean content (%) of each animal by ±10% were also examined.

The effect of varying the mature size (A) of each breed by ±10% while holding the other parameters constant is shown by figure II.19. An increase or decrease in A results in a change in overall efficiency of less than 3% across breeds, given that the other parameters are held constant. The model is therefore not very sensitive to changes in A and hence accuracy in the estimation of A is not critical. Similar results were observed when the inflection parameter, **m**, was varied (figure II.20). However the magnitude of the differences ranged from less than 0.1% to 3.8% in this latter case, depending on the breed and the degree of maturity of the offspring at slaughter. The model is therefore not very sensitive to changes in **m** either, and accuracy in the estimation of this parameter is also not critical. On the other hand, varying the maturing rate parameter, **k**, by ±10% results in a 3 to 6.5% change in overall efficiency (Figure II.21). It was not possible to investigate the integration constant, **b**, similarly because increasing **b** always resulted in numerical problems.

The model therefore appears not to be sensitive to the parameters of the growth function except the maturing rate parameter, **k**. It should, however, be pointed out that varying any of these growth parameters has a profound effect on the growth characteristics of the animal. For example, when A is increased by 10% while holding the other parameters constant, we are essentially forcing a bigger animal to mature within the same time frame and at the same rate as another animal 10%

smaller in size. In other words, the bigger animal is forced to grow faster to mature at the previous (fixed) maturing rate. Conversely reducing the mature size by 10% forces a smaller animal to grow slower than it would otherwise. Varying **k** has similar effects on growth, but varying **m** imposes a different shape on the growth curve and the results are not easy to predict. Hence varying the parameters of the growth curve varies other aspects of the growth characteristics of the animal as well and so the effects on overall efficiency might not be as simple as would be expected.

Figure II.22 represents the effects of varying the dams degree of maturity (μ_d) at turnover by ±10%. The change in overall efficiency ranged from about 8% to 33% for the Hereford, Beef Synthetic #2 and Dairy Synthetic breed groups and from 9 to 35% for the Beef Synthetic #1. The differences at the point of maximum overall efficiency were 29% for the SY1 and about 26% for the other breed groups irrespective of the direction of change of μ_d. It should be noted that, in contrast to the growth parameters, an increase in μ_d results in a decrease in overall efficiency while decreasing it results in an increase in overall efficiency. These changes in overall efficiency imply high sensitivity to the degree of maturity of the dam. The explanation is that as the dam ages she consumes a lot more feed than she is producing output (Taylor et al., 1985). This is particularly so here since the turnover age is not changing with the degree of maturity of the dam but is constant. In other words, when μ_d is increased, we are not allowing it to produce more offspring to help compensate, but are making it carrying a heavier maintenance load. Conversely, when μ_d is reduced she would then be producing more offspring than she normally would at that degree of maturity and she will carry less maintenance load as well since she will be younger and smaller throughout the period.

Figure II. 23 represents the effects of varying the lean content (%) ±10%. The change in overall efficiency was fairy uniform for all breeds between 4.5% to 8.7%. At the point of maximum efficiency, the change (decrease or increase) was nearly constant at 6.5%. The model is therefore fairly sensitive to changes in lean content.

In summary, varying the mature size (A) and the inflection parameter (m) while holding the others constant has little influence on overall efficiency. Increasing the maturing rate parameter, k, or the lean content, however, increases efficiency. Conversely, reducing k or the lean content would tend to reduce overall efficiency. However, increasing the degree of maturity of the dam at a specified turnover age, tends to decrease overall efficiency, but decreasing it will improve overall efficiency.

2.6. Relation to other models

This model was constructed along the lines of the model of Taylor et al. (1985). However, the treatment was not taken to the same mathematical depths of Taylor et al. (1985) and as much as possible, all parameters were estimated rather than assumed. For example, while Taylor et al. (1985) made assumptions about the degree of maturity of the dam at first and subsequent calvings, and also the decline in the value of the carcass of the dam (salvage value), such values were estimated from either the growth curves generated or from available sale prices reported for dams (Alberta Agriculture, 1985 - 1989). Furthermore, the costs of pregnancy and maintenance of each animal from year to year were predicted from available feed prediction equations. The possibility of breeds differing in feed intake and/or overall efficiency was also not discounted in the current model, and hence breeds of differing mature sizes and maturing rates can be examined. There are also extensions to include the investigation of dairy-beef production and partial sex control. While Taylor et al. (1985) provided mathematical formulations for evaluating partial sex control, such evaluations were not actually made. Other input factors such as initial herd costs not considered in the model of Taylor et al. (1985) were considered in the current model.

The model, however, has the basic limitations of that of Taylor et al. (1985), having been designed specifically for evaluating overall efficiency, especially as it relates to the time offspring are taken off the herd (degree of maturity of offspring at slaughter). Output is therefore rather specific, generated on the basis of any turnover age specified by the user, but no yearly output is generated. Hence general production systems models such the Texas A & M University (TAMU) model (Sanders and Cartwright, 1979; Cartwright and Doren, 1986) and the Winrock model (Fitzhugh, 1978) have more capability and generality. However, such models have been developed over long periods of time. The current model cannot track particular animal over its life time in the herd (such as the TAMU model) and is not capable of evaluating crossbreeding and other mating systems. It has no capability for optimizing diets for specified groups of animals, such as the Winrock model, but could evaluate the influence of cost of such diets on overall efficiency. The herd dynamics model is rather simplistic, in line with that of Taylor et al. (1985), starting with and ending with a herd in perpetual equilibrium. Such simplicity, however, confers a lot of flexibility and allows the evaluation of a complex situation rather simply. The submodels are also easy to modify and hence the entire model can easily be adjusted to account for some of the factors not currently considered. The model of Thompson and Barlow (1986) investigating the effects of changes in growth and feeding parameters on overall efficiency is perhaps more limited than the current model although it was also constructed following the methods of Taylor et al. (1985).

Table II.1. Predicted error mean squares for each growth function

Breed	Richards function	Brody function
Hereford	120.69	196.22
Beef Synthetic 1	106.36	208.46
Beef Synthetic 2	136.38	237.44
Dairy Synthetic	199.83	189.21
Holstein	199.83	189.21

Table II.2. Estimated mean growth curve parameters for females of beef and dairy breed groups[*].

Breed Group	Mature Weight (A, kg)	b	$k*10^{-3}$	m
	Richards' function[§] parameters			
Hereford	587.32 ± 12.70	0.9836	1.0239	0.68725
Beef syn. #1	610.80 ± 16.36	0.9891	1.1006	0.63739
Beef syn. #2	639.34 ± 25.22	0.9917	0.8518	0.61360
Dairy synthetic	706.64 ± 45.36	0.9979	0.5543	0.49260
Holsteins	689.21 ± 24.80	0.9319	1.6475	1.11540
	Brody's function[¶] parameters			
Hereford	567.31 ± 6.63	0.9095	1.4181	
Beef syn. #1	584.47 ± 7.63	0.9098	1.6690	
Beef syn. #2	590.98 ± 13.41	0.9085	1.4659	
Dairy synthetic	633.02 ± 18.08	0.8793	1.3408	
Holsteins	702.59 ± 16.75	0.9579	1.4899	

[*] Number of age - weight points = 14 in all cases.

[§] The Richards' function is given by: $Y = A(1-be^{-kt})^{m}$

[¶] The Brody's function is given by: $Y = A(1-be^{-kt})$

Table II.3. Multiplicative factors for adjusting body weight of growing cattle to the weight of a medium frame steer equivalent[a]

Breed	Frame size	Gender		
		Steers	Heifers	Bulls
Hereford	5	1.00	1.25	0.83
Beef syn. 1	7	0.91	1.14	0.76
Beef syn. 2	8	0.87	1.09	0.73
Dairy syn.	9	0.83	1.04	0.69

[a] From Fox et al. (1988).

Table II.4. Values of constants a and b used in the prediction of net energy content of gain (NRC, 1984)

Constant	Heifers	Steers	Bulls
		i. Medium frame	
a	0.0686	0.0557	0.0493
b	1.1190	1.0970	1.0970
		ii. Large Frame	
a	0.0608	0.0493	0.0437
b	1.1190	1.0970	1.0970

Table II.5. Values of constants used in the prediction of postweaning dry matter intake.

	Constant		
Type of animal	a	b	c
Breeding females	0.1462	0.0517	0.0074
Growing animals	0.1493	0.0460	0.0196

Table II.6. Regression constants and coefficients for "$\mathrm{Log}_e F$' = $a + b\mathrm{Log}_e \mu$" (equation 14), by breed and gender.

	Gender							
	Breeding Females		Fattening Females		Steers		Bulls	
Breed	a[c]	b[d]	a	b	a	b	a	b
	Regressions for Dry Matter Intake (kg DM kg^{-1} mature wt)							
Hereford	3.8260	3.2813	3.9256	3.3381	3.7165	3.3372	3.5370	3.3221
Beef Syn. 1	3.7170	3.4050	3.8164	3.4618	3.6029	3.4748	3.4282	3.4560
Beef Syn. 2	3.7733	3.3072	3.8751	3.3609	3.6622	3.3716	3.4902	3.3539
Dairy Syn.	3.9114	3.3946	4.0170	3.4514	3.8051	3.4663	3.6248	3.4473
	Regressions for Metabolizable Energy Intake (Mcal ME kg^{-1} mature wt)							
Hereford	4.7700	3.1200	4.8687	3.1776	4.6589	3.1715	4.4797	3.1567
Beef Syn. 1	4.6651	3.2327	4.7634	3.2908	4.5493	3.2956	4.3751	3.2785
Beef Syn. 2	4.7139	3.1431	4.8148	3.1982	4.6009	3.2015	4.4295	3.1859
Dairy Syn.	4.8451	3.2302	4.9497	3.2888	4.7364	3.2954	4.5566	3.2774

[c] Constant of the regression equation

[d] Regression coefficient

Table II.7. Mean coat depth and hide thickness in breeds of cattle used in this study[*].

	Age			
	Calves (6 - 12 month)		Adults	
Breed	Coat (cm)	Hide (cm)	Coat (cm)	Hide (cm)
Hereford	1.76		1.71	
Beef synthetic 1	1.65	0.43	1.83	
Dairy synthetic	1.51	0.40		
Holstein	1.44	0.37		

[*] Adapted from Webster et al. (1968), Young (1969) and Young and Berg (1970).

Table II.8. Internal tissue insulation (I_i, °C $Mcal^{-1}$ m^{-2} day^{-1}) factors[*]

	Flesh code		
Animal type	1	5	9
Newborn calf	2.5	2.5	2.5
1 -6 months old	6.5	6.5	6.5
6 - 12 months old	5.5	6.8	8.0
Adult	6.0	9.0	12.0

[*] From NRC (1981, 1984).

Table II.9. External tissue insulation (I_e, °C $Mcal^{-1}$ m^{-2} day^{-1}) factors*

	Coath depth, cm.			
Wind speed ($km\ h^{-1}$)	<0.5	1.0	1.5	3.0
1.6	7.0	11.0	14.0	17.0
6.4	5.0	7.5	10.0	13.5
12.8	4.0	5.5	8.0	9.0
25.8	3.0	4.0	5.0	6.5

*From NRC (1981, 1984).

Table II.10. Multiplicative factors for correcting peak mature milk yield to that of a specified age group.

	Age of dam		
Breed	2 yr	3 yr	4 or >10 yr
Hereford	0.62	0.76	0.85
Beef synthetic 1	0.77	0.83	0.95
Beef synthetic 2	0.67	0.99	0.98
Dairy synthetic	0.84	0.96	1.11
Holstein	0.60	0.825	0.925

Table II.11. Peak mature milk yields (kg) and fat contents (%) for breed groups in the study[*].

Breed group	Peak Milk yield (kg)	Milk fat content (%)
Hereford	6.9	4.9
Beef synthetic #1	7.9	4.7
Beef synthetic #2	8.3	4.8
Dairy synthetic	8.7	4.8

[*] From Butson and Berg (1984)

Table II.12. Proportions (%) of animals of specified type in specified grades.

Grade	Type of animal		
	Steers	Heifers	Bulls
A1/A2	90.5	90.6	84.9
A3/A4	6.0	5.9	4.7
B/C	3.5	2.4	9.4
D	0.0	1.2	0.0
E	0.0	0.0	1.0
Number of animals	116	85	403

Table II.13. Proportions (%) of culled cows grading specified grades.

	Age class		
Grade	Youthful	Intermediate	Mature
A1/A2	58.3	0.0	0.0
A3/A4	3.1	0.0	0.0
B/C	30.1	28.8	1.5
D1/D2	8.6	71.3	89.7
D3/D4	0.0	0.0	8.8
Number of animals	163	80	68

Table II.14. Mean price ($) in Edmonton for 100 lb beef from different types of animals (Alberta Agriculture, 1985 - 1989).

	Grade						
Type of animal	A1/A2	A3/A4	B/C	D1/D2	D3/D5	D4	
Steers	75.33	69.43	64.84				
Heifers	73.73	66.47	62.32				
Cows				52.03	46.72	43.67	
Bulls							64.34

Table II.15. Mean weighted and relative prices of meat from different types of animals, and milk used in the model.

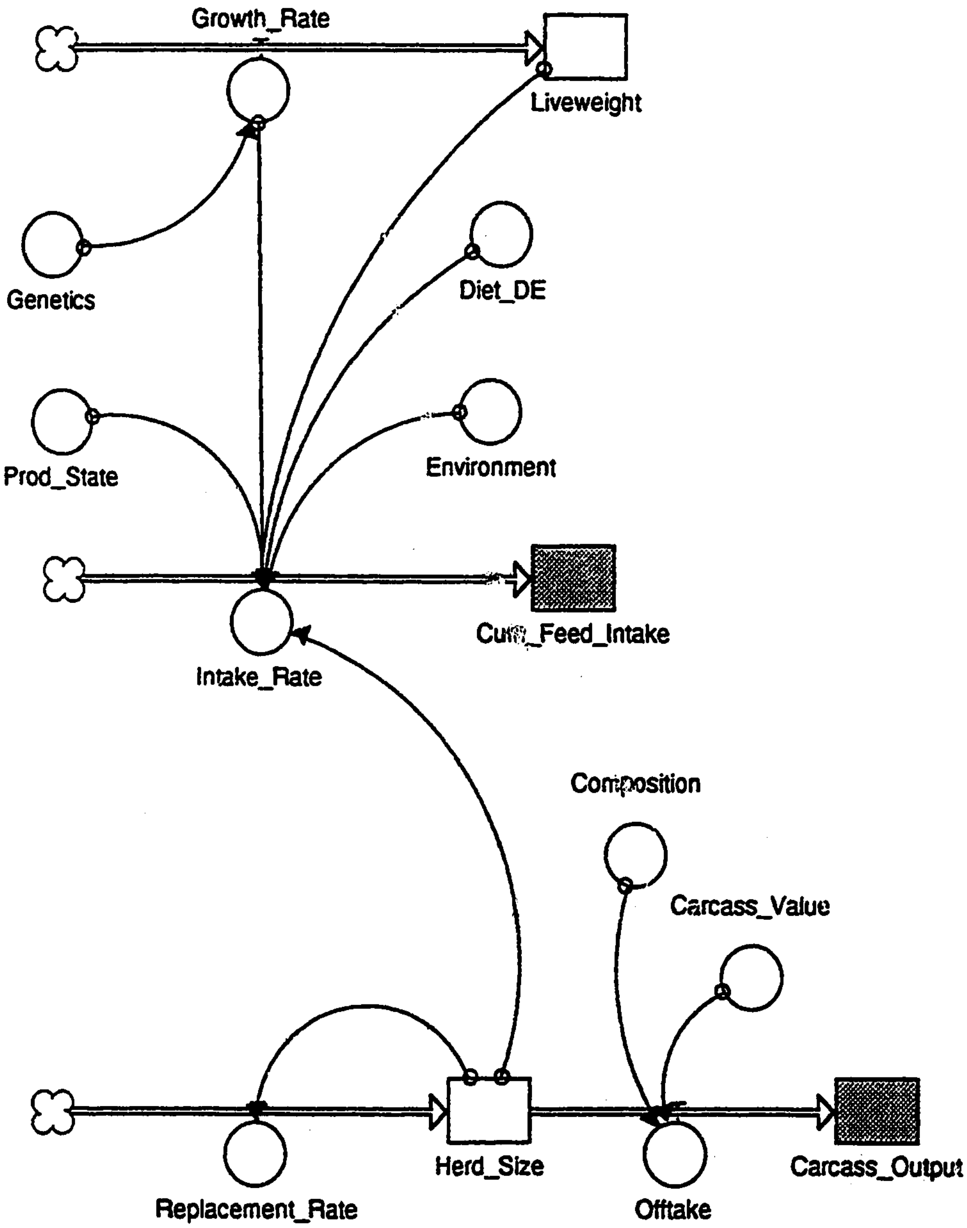
Item	Mean price ($) /100lb	Relative price
Steer	74.60	1.00
Heifer	72.96	0.97
Intact male	73.82	0.99
Cows, youthful	68.28	0.92
Cows, intermediate	55.05	0.74
Cows, mature	51.58	0.69
Milk	22.27	0.30

Table II.16. Regression coefficients of milk yield beyond the peak on day of lactation[§]

Age	Hereford	Beef Syn. 1	Beef Syn. 2	Dairy Syn.
2 yr old Heifers	-0.0065	-0.0130	-0.0119	-0.0187
3 yr old cows	-0.0081	-0.0147	-0.0228	-0.0247
4 & >10 yr olds	-0.0109	-0.0189	-0.0225	-0.0306
Mature	-0.0139	-0.0197	-0.0222	-0.0252

[§] All r^2s >0.98

Figure II.1. Schematic representation of the Beef Efficiency Model (BEM)


Growth_Rate
Liveweight
Genetics
Diet_DE
Prod_State
Environment
Cum_Feed_Intake
Intake_Rate
Composition
Carcass_Value
Replacement_Rate
Herd_Size
Offtake
Carcass_Output

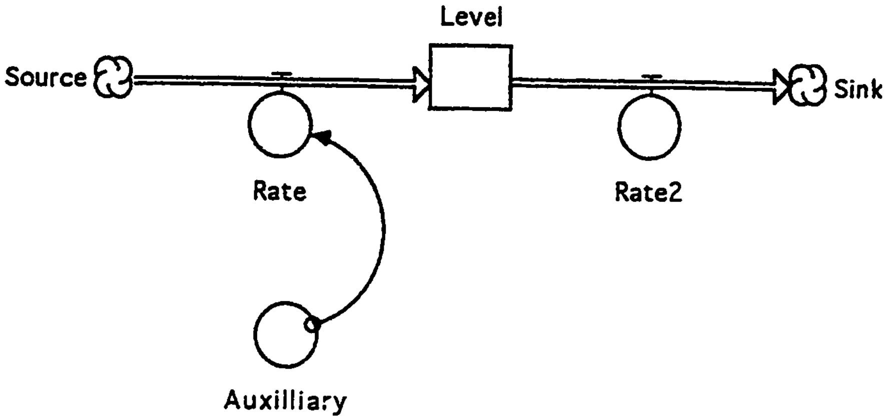
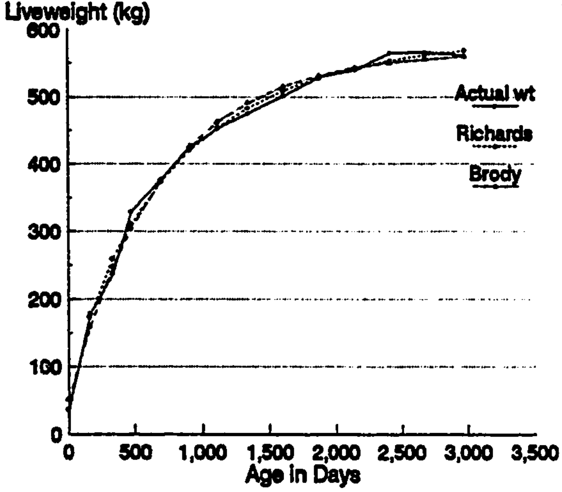


Figure II.2. Explanation of symbols used in BEM diagram (figure 1). Each term is defined below.

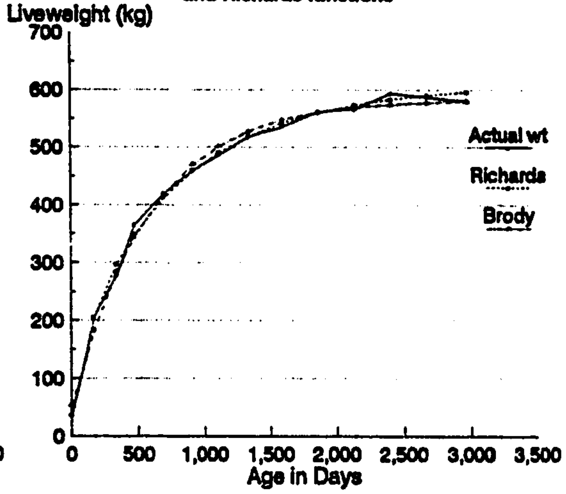
i. Source.	A source is a point of origin or a beginning condition: e.g., for growth, the starting point is birth weight.
ii. Rate.	Rates represent material transfers per unit of time, e.g. growth rate.
iii. Auxiliary.	Auxiliary variables influence calculations of rates of material transfers: e.g. the breed or gender influences the growth rate.
iv. Level.	These are state variables and represent points of accumulation of material within the system: e.g. weight is the cumulation of growth rate.
v. Sink.	These represent end (termination) points or final conditions.

Figure II.3. Growth curves of the breed groups in this study, fitted by the Richards and Brody functions employing the parameters reported in Table II.2.

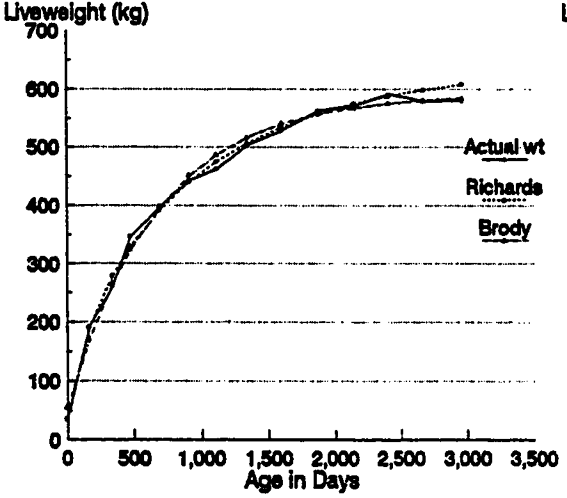
Growth curves of Herefords fitted by the Brody and Richards functions



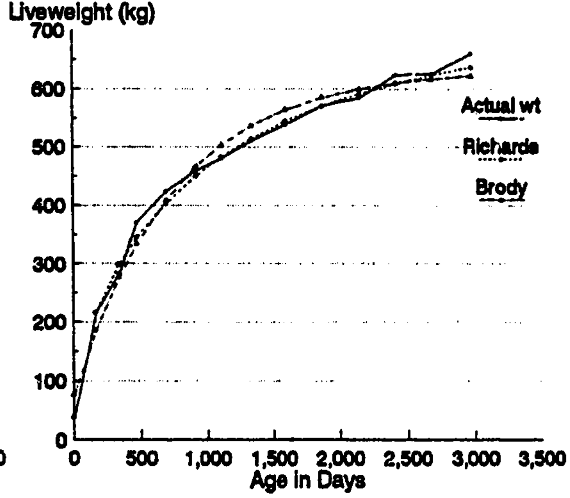
Growth curves of Beef Syn. #1 fitted by the Brody and Richards functions



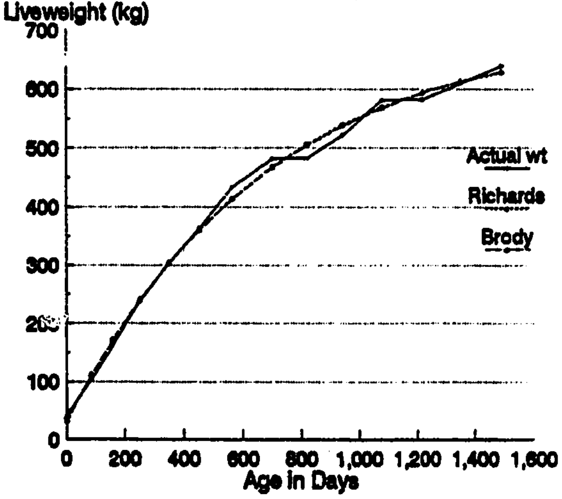
Growth curves of Beef Syn. #2 fitted by the Brody and Richards functions



Growth curves of Dairy Syn. fitted by the Brody and Richards functions



Growth curves of Holsteins fitted by the Brody and Richards functions



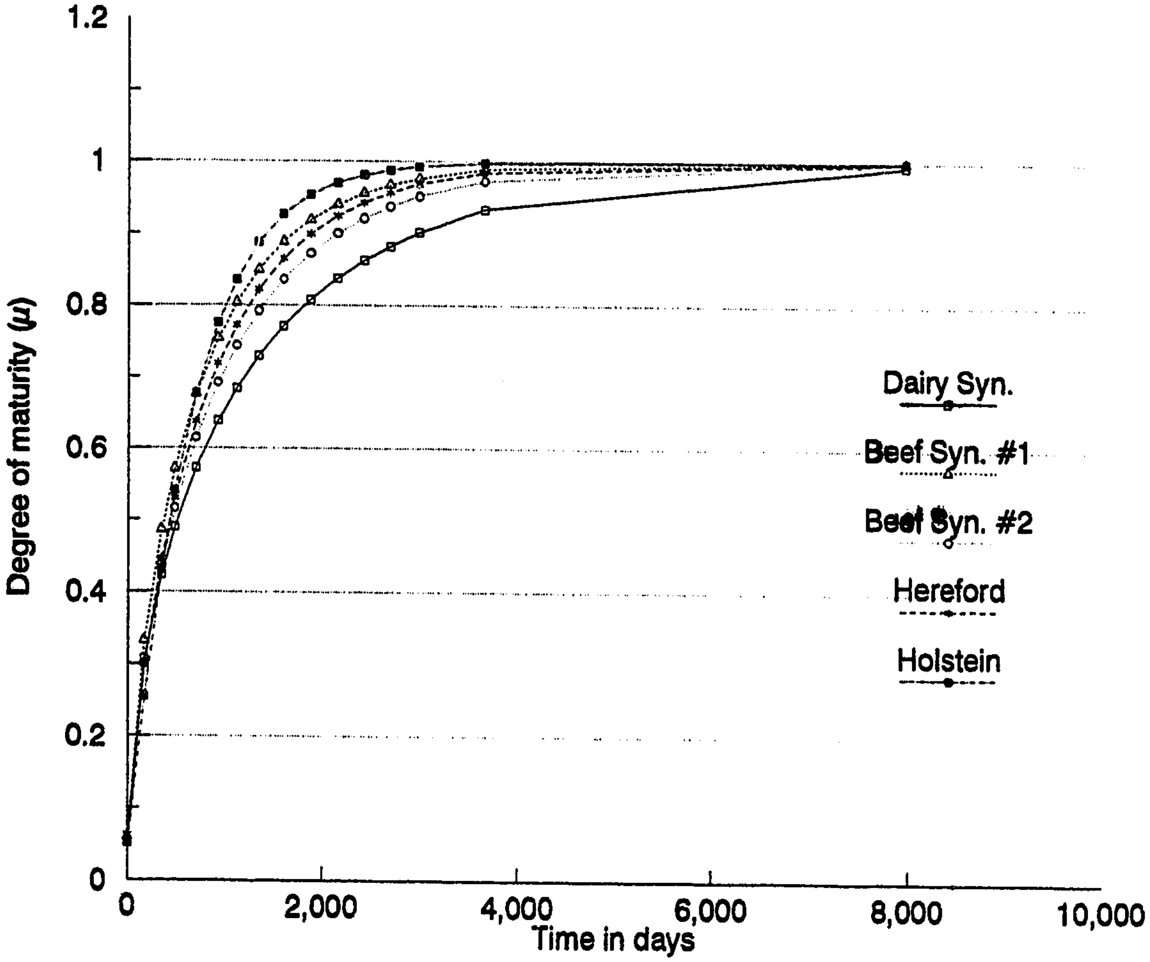


Figure II.4. Degree of maturity of five breed groups plotted against age in days.

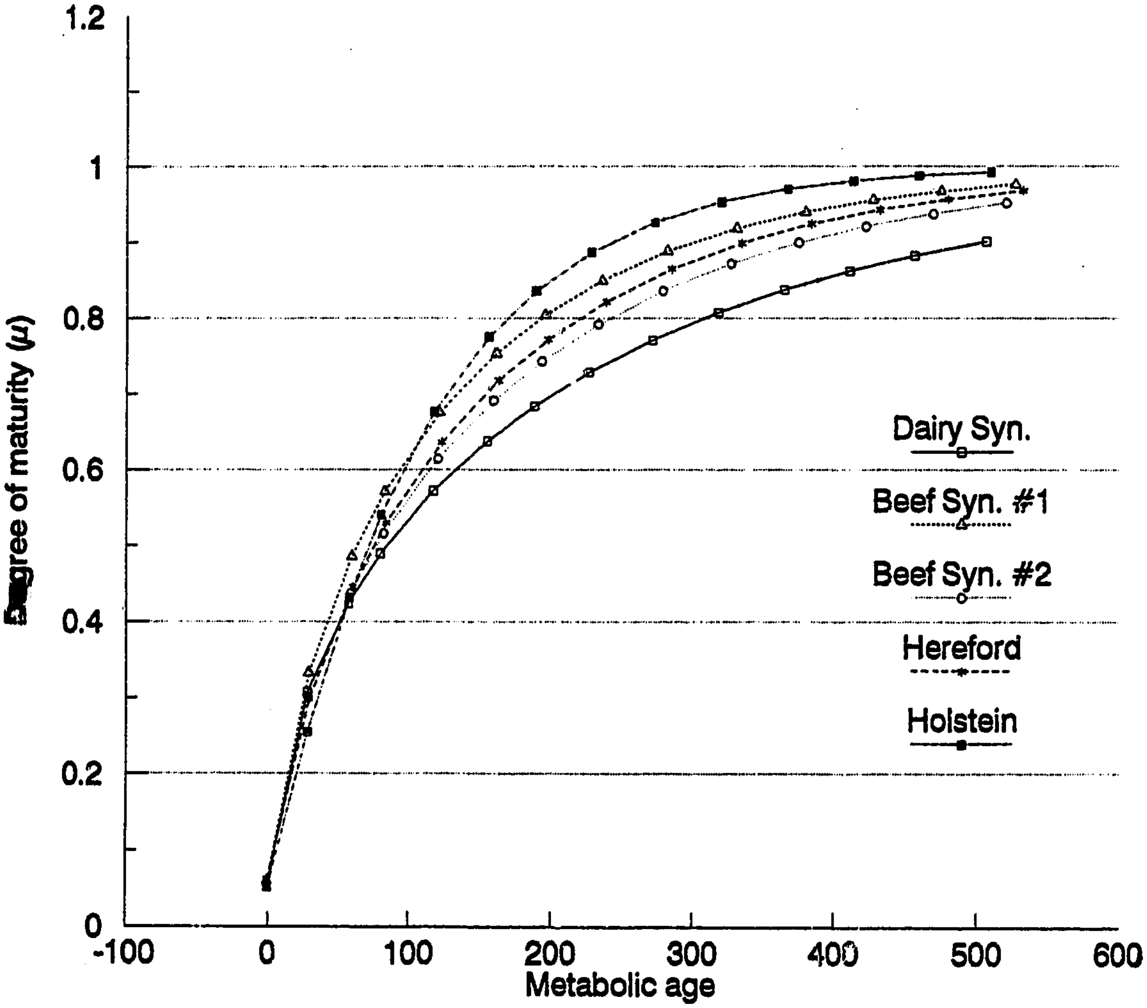
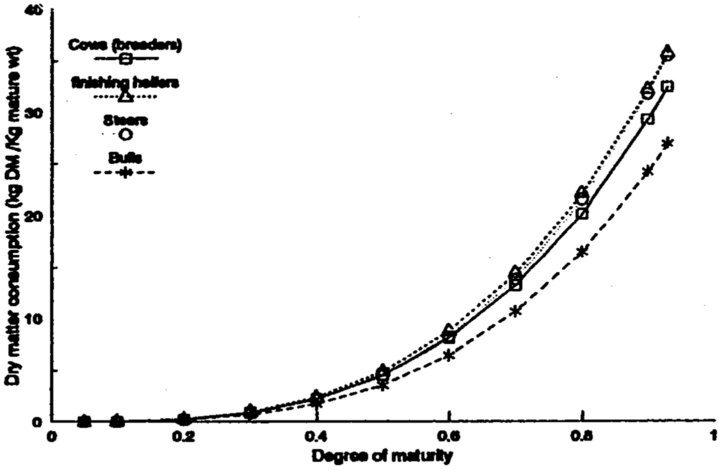
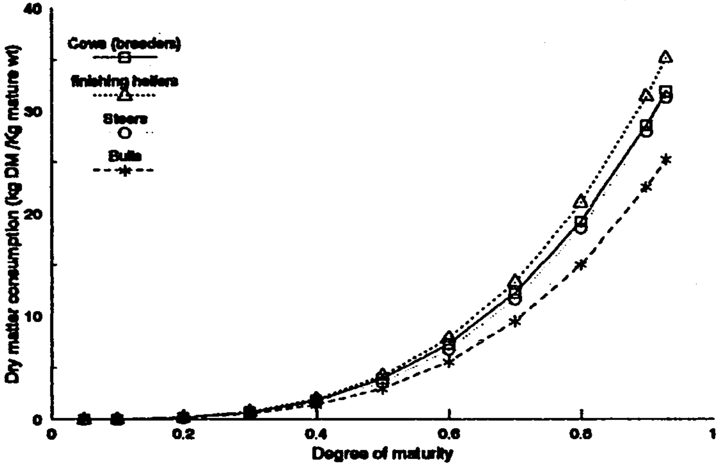
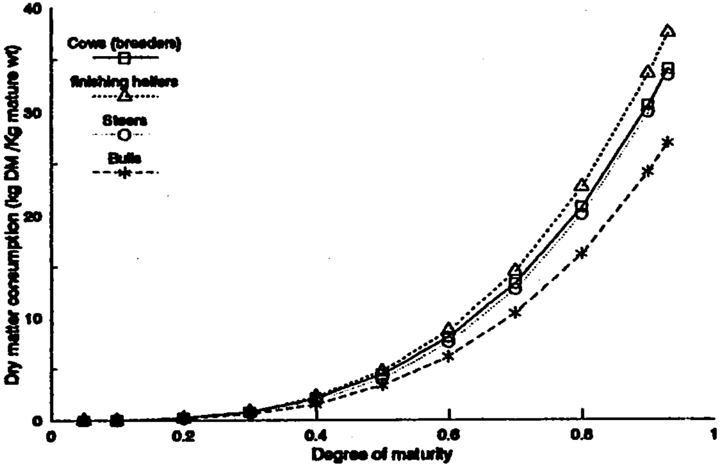


Figure II.5. Degree of maturity of five breed groups plotted against metabolic age.

Figure II.6. Predicted cumulative dry matter intakes (kg DM kg^{-1} mature weight) by degree of maturity and breed


Dry matter Intake by gender (Hereford)


Dry matter Intake by gender (Beef Synthetic 1)


Dry matter Intake by gender (Beef Synthetic 2)

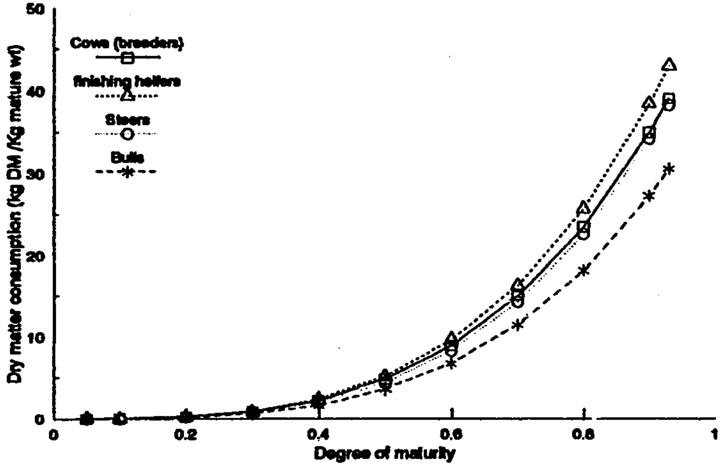
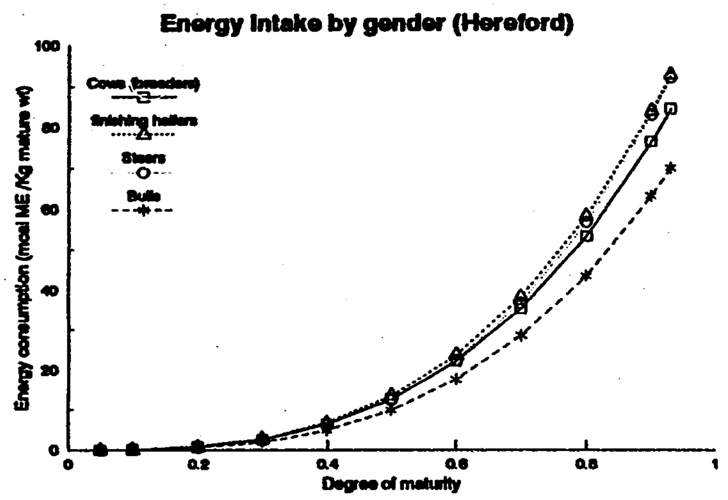
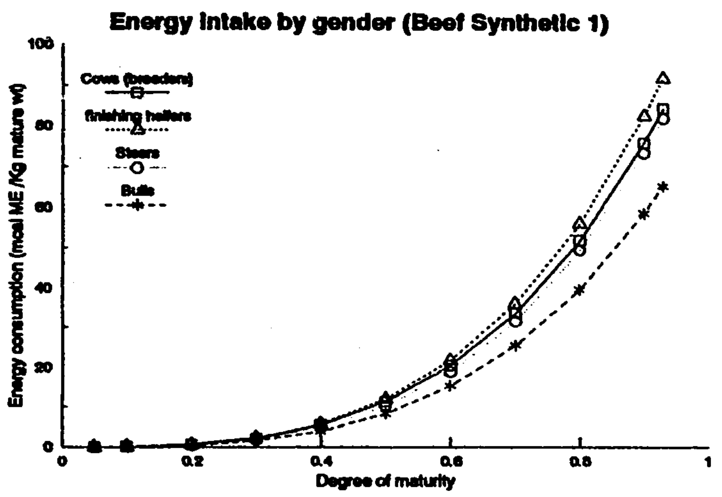
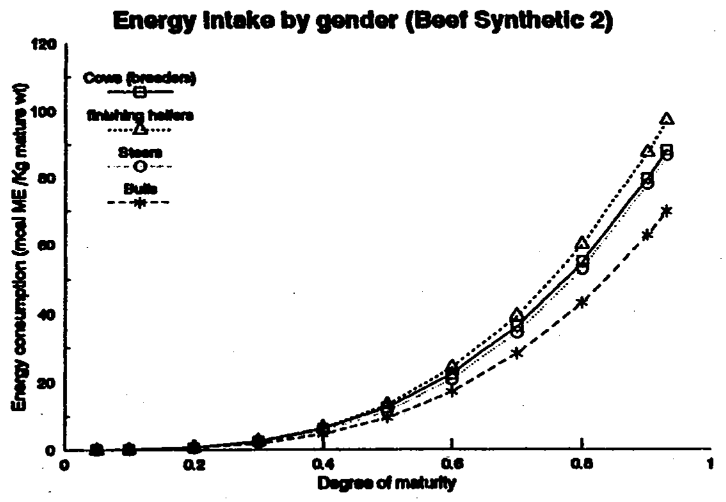
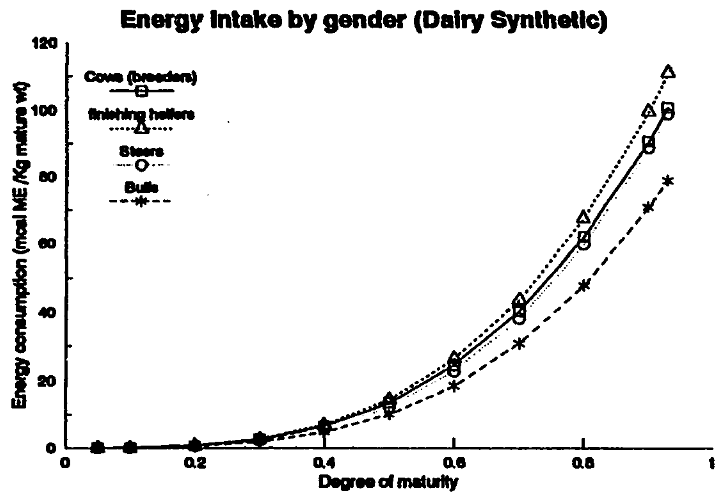

Dry matter Intake by gender (Dairy Synthetic)

Figure II.7. Predicted cumulative metabolizable energy intakes (Mcal ME kg^{-1} mature weight) by degree of maturity and breed.


Energy intake by gender (Hereford)


Energy intake by gender (Beef Synthetic 1)


Energy intake by gender (Beef Synthetic 2)


Energy intake by gender (Dairy Synthetic)

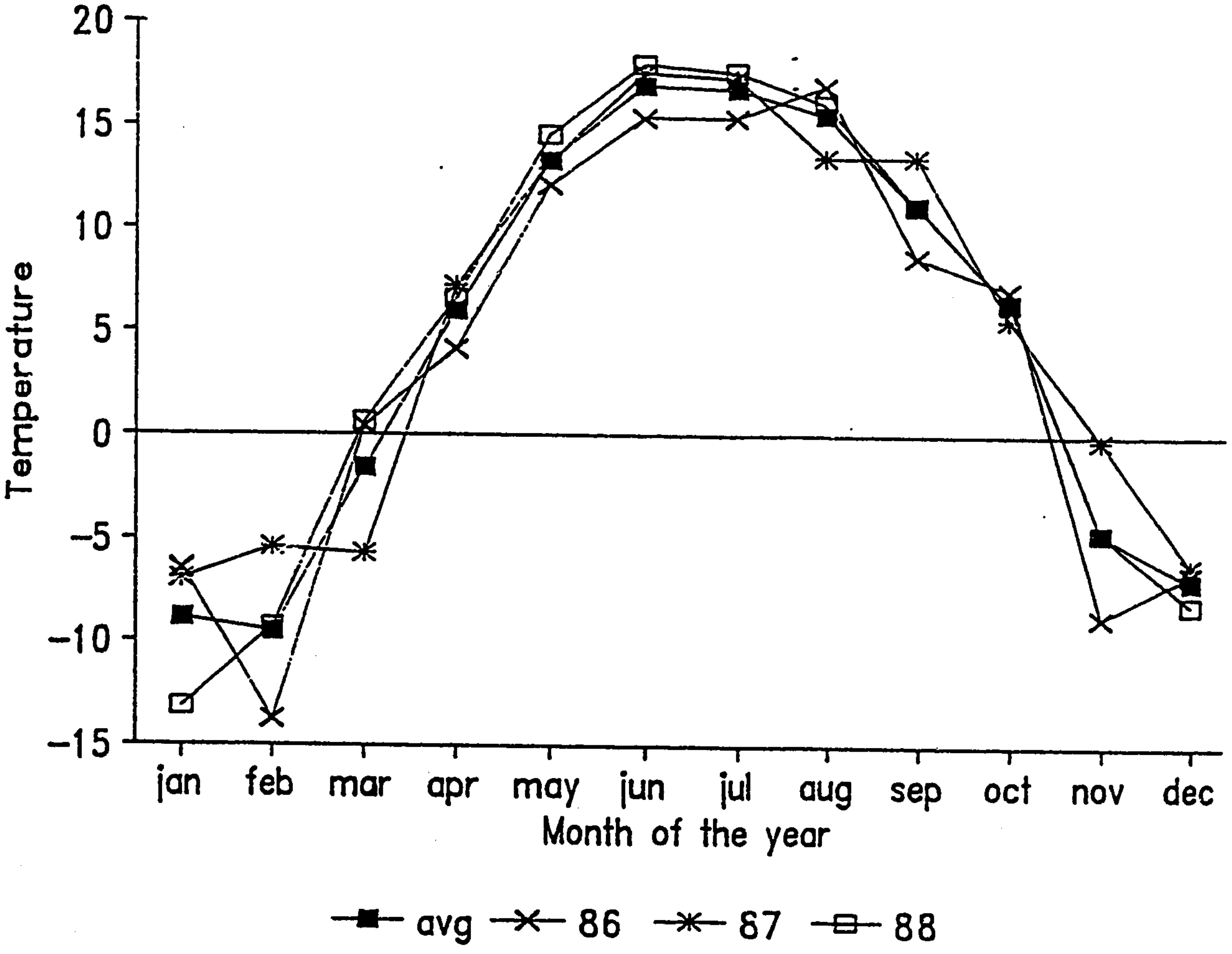


Figure II.8. Mean monthly temperatures at the University of Alberta beef research ranch, 1986 - 1988.

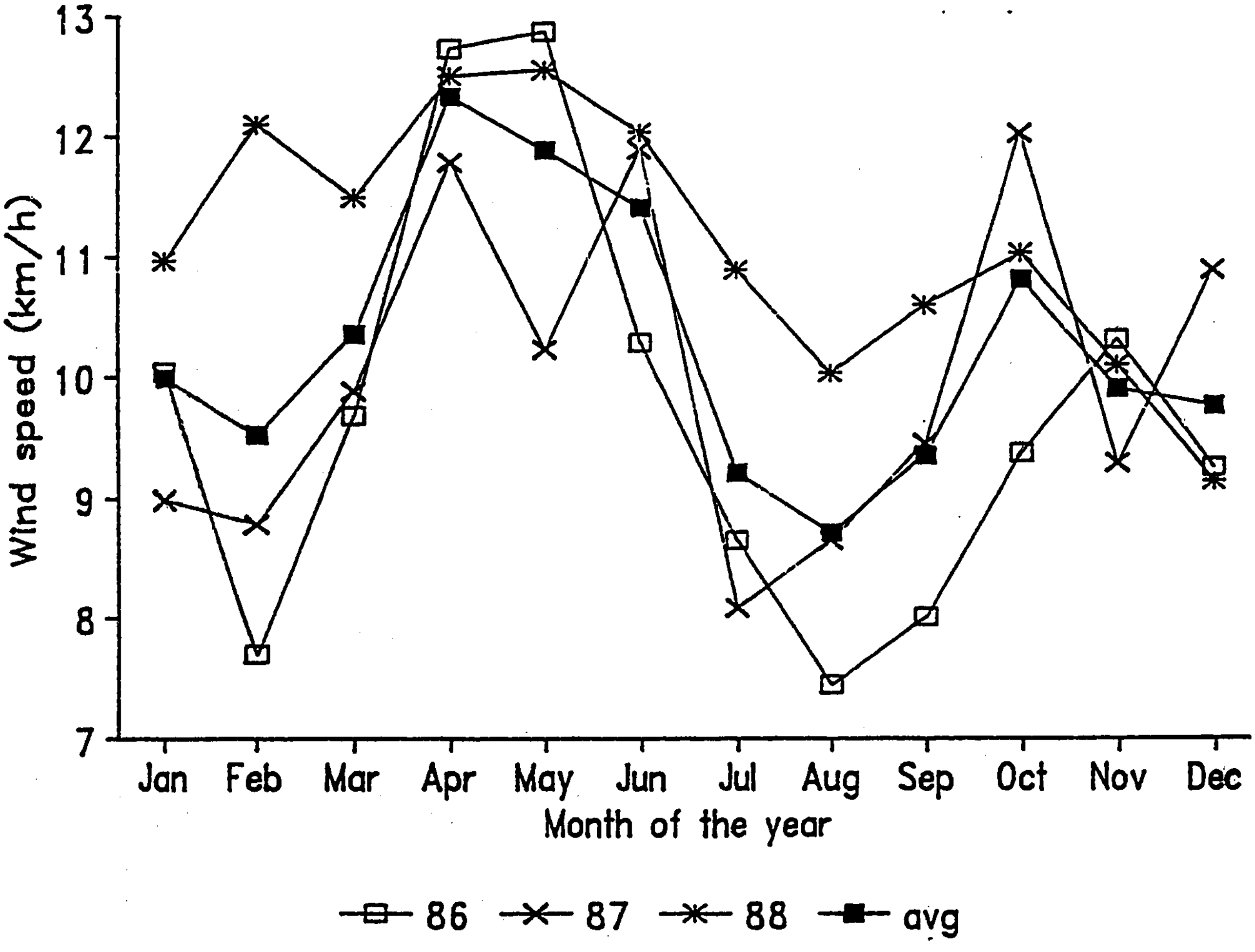
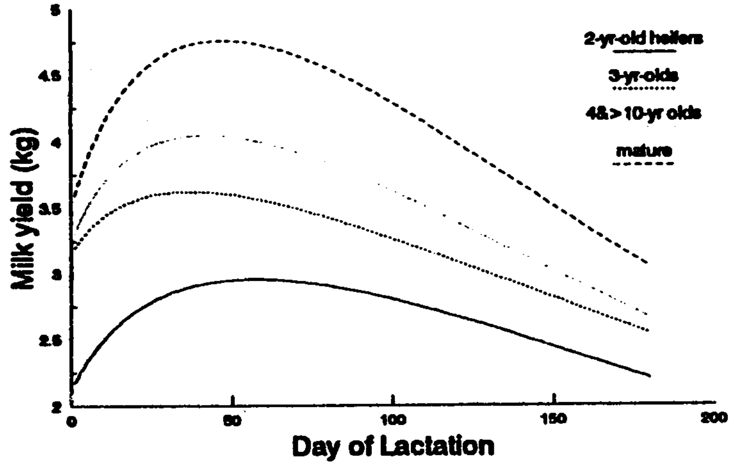
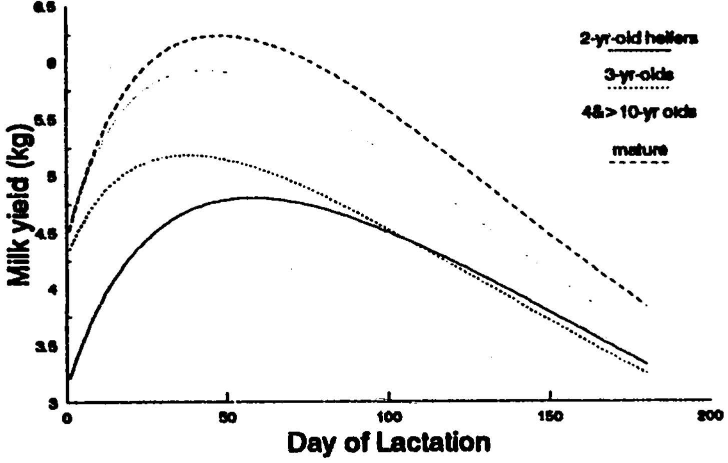


Figure II.9. Mean monthly wind speeds at the University of Alberta beef research ranch, 1986 - 1988.

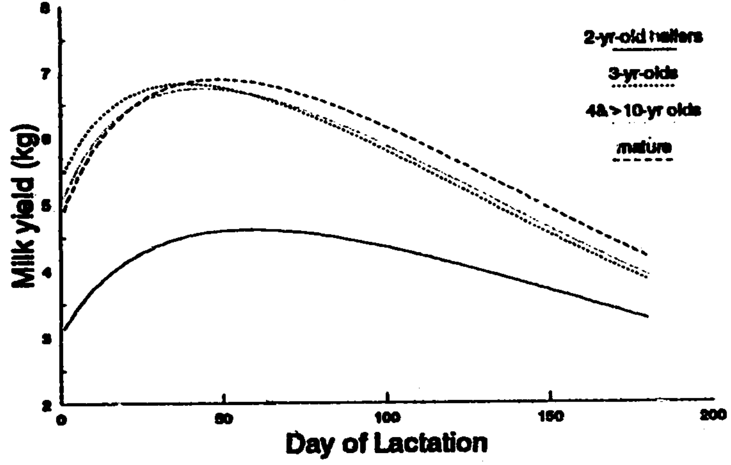
Figure II.10. Predicted lactation curves of 4 breed groups of beef cattle by age at lactation.



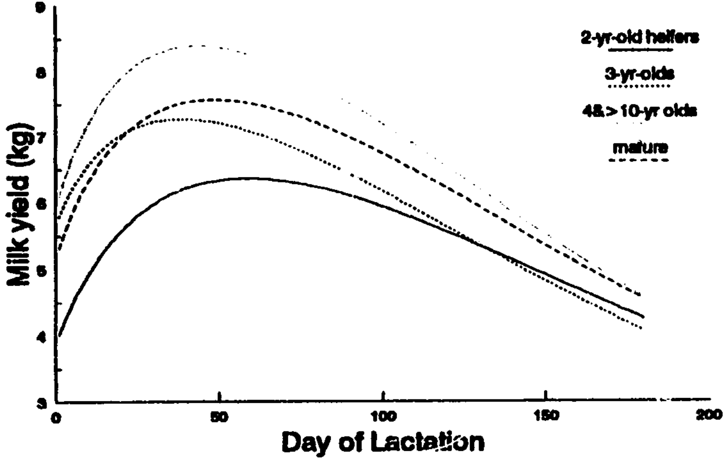
Herefords



Beef Synthetic 1



Beef Synthetic 2



Dairy Synthetic

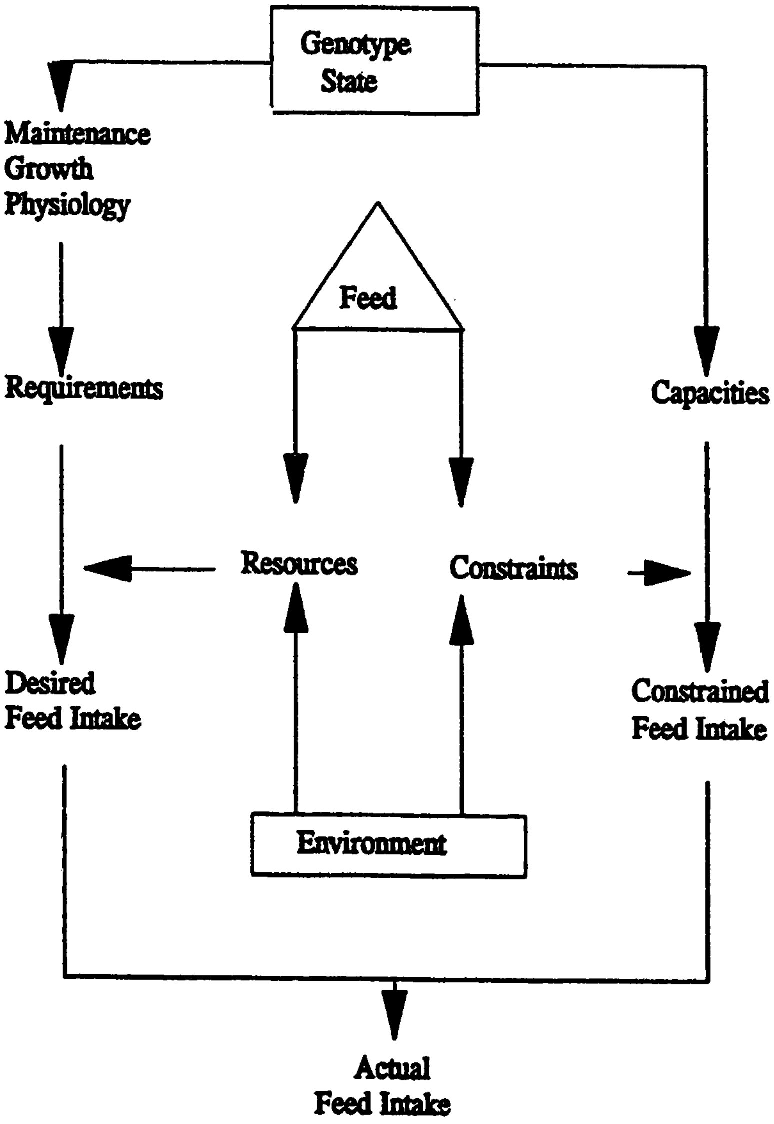


Figure II.11. A scheme for predicting growth and feed intake (adapted from Emmans and Oldham, 1988)

Figure II.12. Flow diagram of the herd submodel. It indicates that, for any cow, the number of calves produced depends on the entire productive life, the reproductive rate and the breed (genetics). The number of calves becoming cows or bulls depends on the sex ratio and the numbers of animals sold or slaughtered depends on the culling rate. 'F recr' and 'M recr' are the female and male recruitment rates.

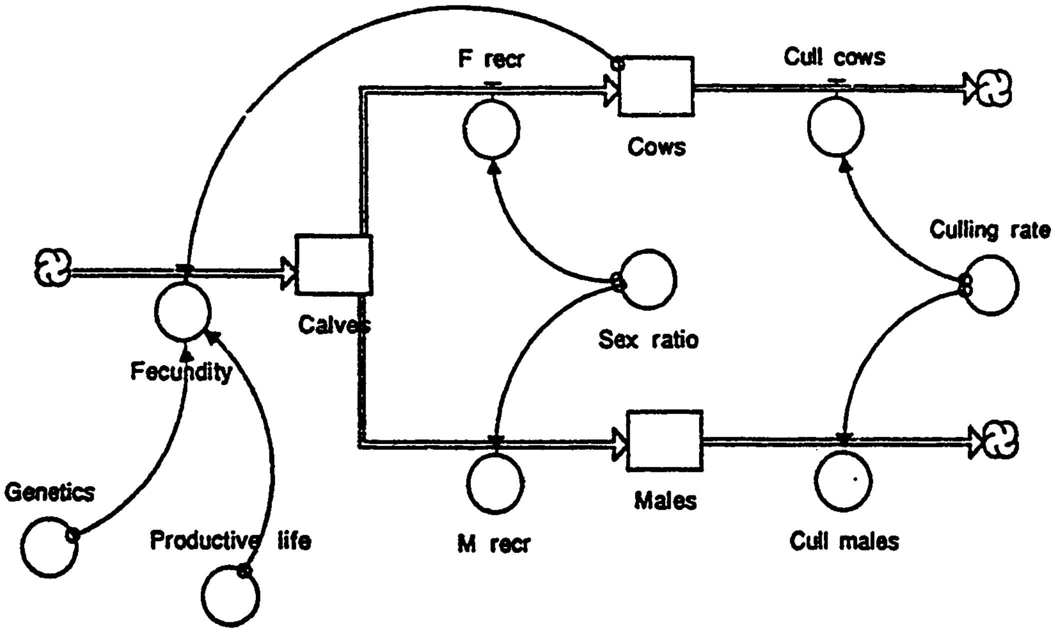
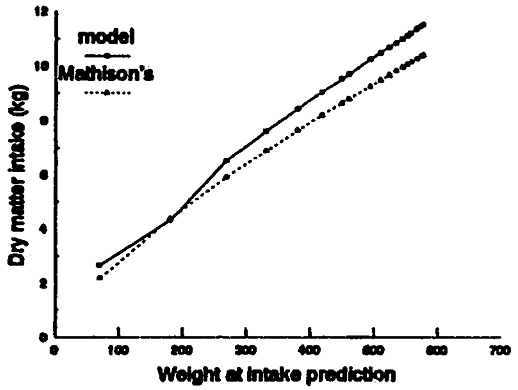
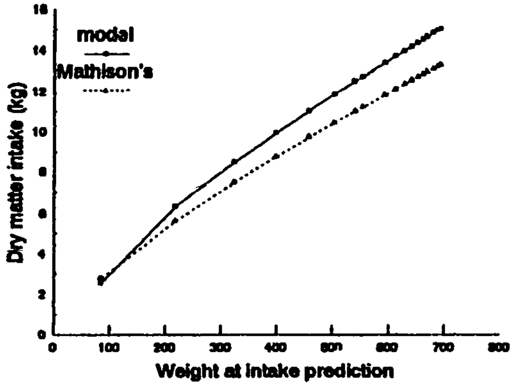
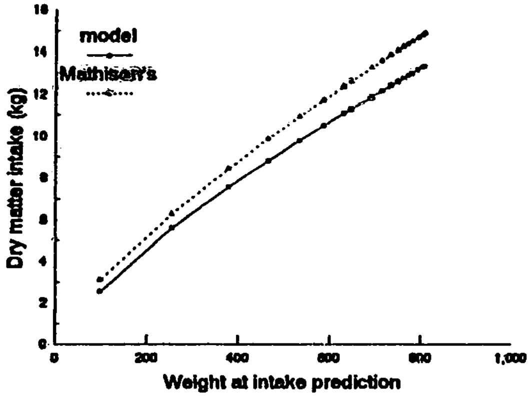
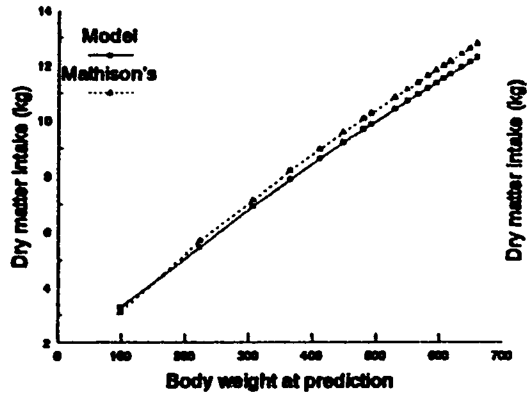

F recr
Cull cows
Cows
Culling rate
Calves
Sex ratio
Fecundity
Genetics
Productive life
Males
M recr
Cull males

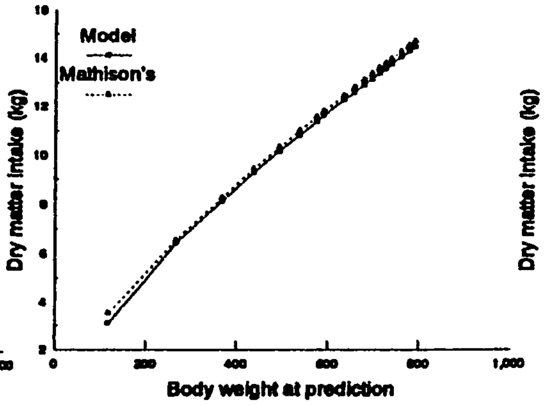
Figure II.13. Comparison of daily feed intake predictions from the model with those from the Beef feed intake templates of Dr. Mathison (University of Alberta, Dept of Animal Science).


Hereford, Breeding females


Hereford, Steers


Hereford, Bulls


Dairy Synthetic, Breeding females


Dairy Synthetic, Steers

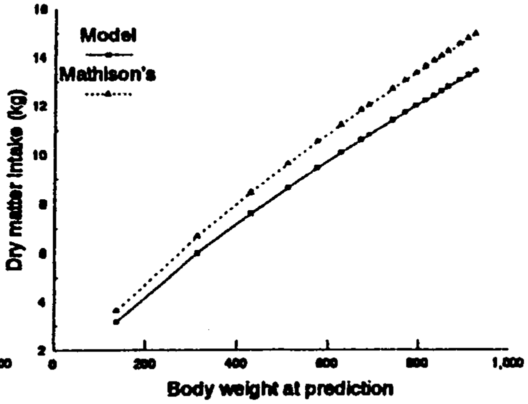
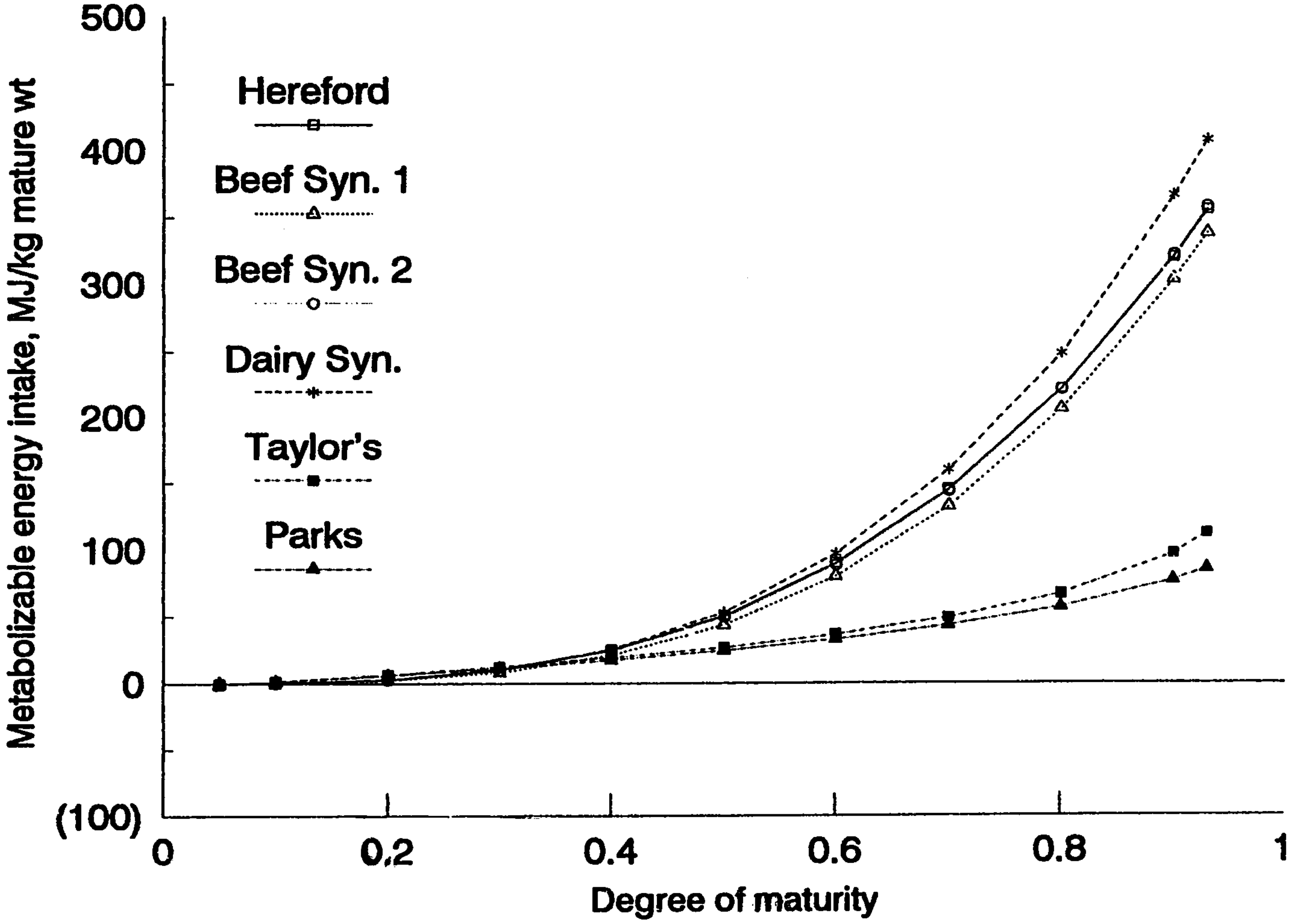

Dairy Synthetic, Bulls

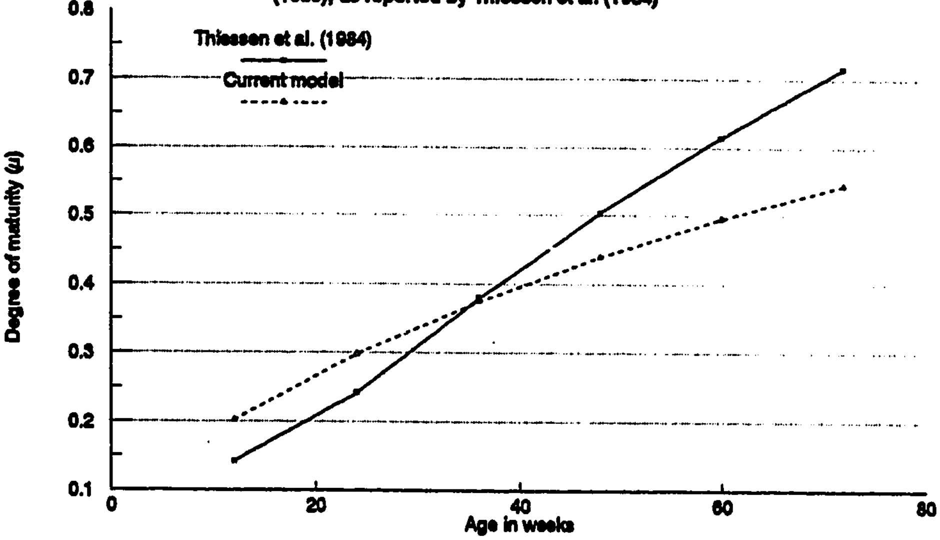
Figure II.14. Comparison of predicted cumulative metabolizable energy intake from the model and those of Parks (1970, 1982) and Taylor et al., (1985) (all units in MJ kg^{-1} mature weight)



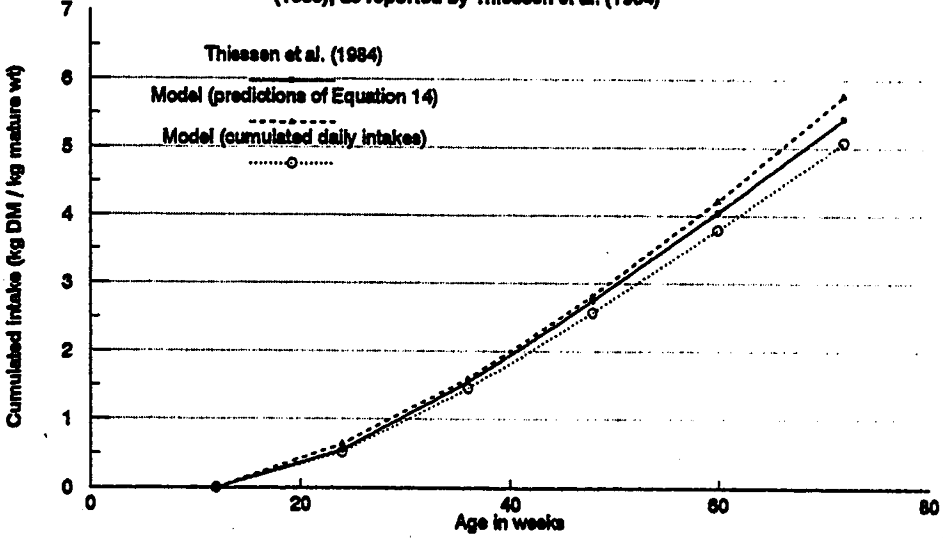
Metabolizable energy intake, MJ/kg mature wt
500
400
300
200
100
0
(100)
0
0,2
0.4
0.6
0.8
1
Degree of maturity
Hereford
Beef Syn. 1
Beef Syn. 2
Dairy Syn.
Taylor's
Parks

Figure II.15. Comparison of maturing rates and cumulated feed intake (kg or MJ ME) to specific age points between animals of this study and those of Taylor et al. (1985).

Rate of maturing of animals in model (Herefords) compared to those in study of Taylor et al. (1985), as reported by Thiessen et al. (1984)



Comparison of cumulated feed intake (kg / kg mature wt) to specified ages with those from study of Taylor et al. (1985), as reported by Thiessen et al. (1984)



Comparison of cumulated feed intake (Mcal ME / kg mature wt) to specified ages with those from study of Taylor et al. (1985), as reported by Thiessen et al. (1984)

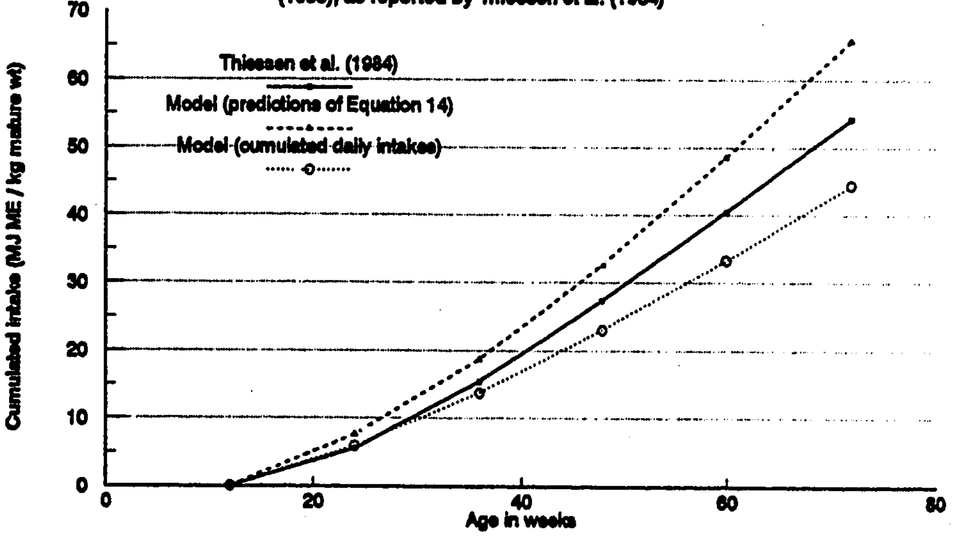
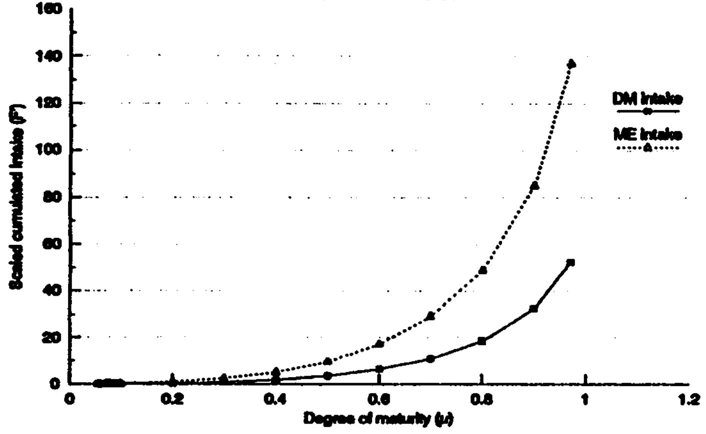
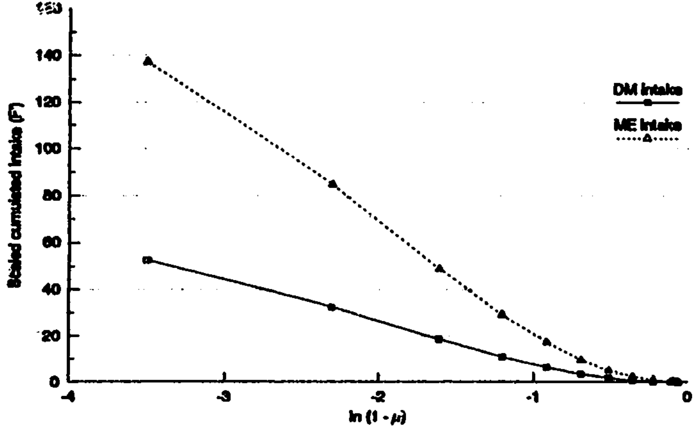


Figure II.16. Behaviour of cumulative feed intake: a. predicted cumulated feed intake (F', Mcal kg^{-1} mature weight) against degree of maturity (μ). b. predicted cumulated feed intake against ln(1-μ). c. natural logarithm of predicted cumulated feed intake (lnF') against ln(1-μ). d. lnF' against ln(μ).

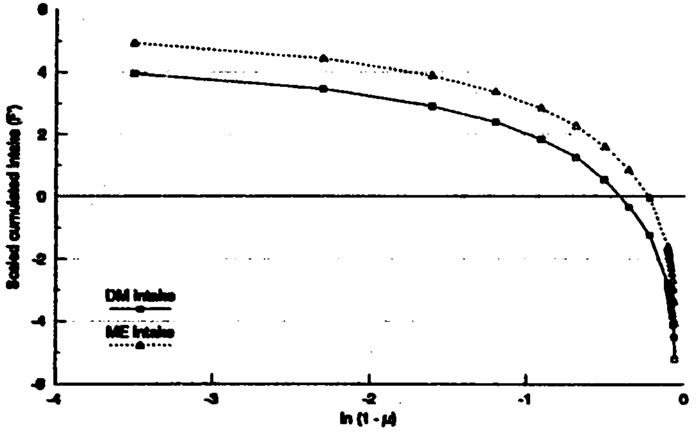
Plot of scaled cumulated feed (F^*) intake against degree of maturity (μ)



Plot of scaled cumulated feed (F^*) intake against ln(1 - μ)



Plot of the log of scaled cumulated feed (lnF^*) against ln(1 - μ)



Plot of the log of scaled cumulated feed (lnF^*) against ln(μ)

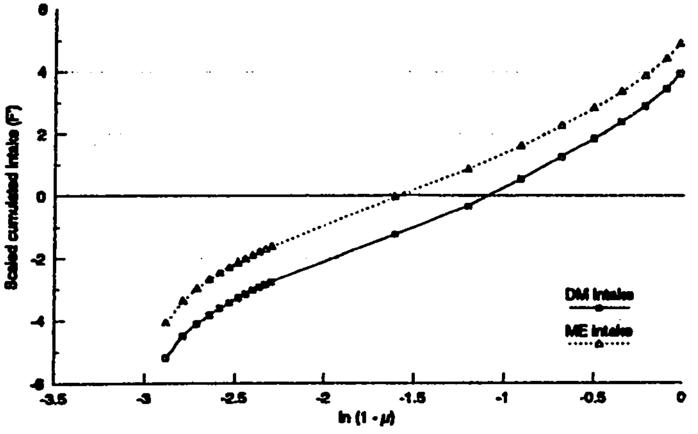
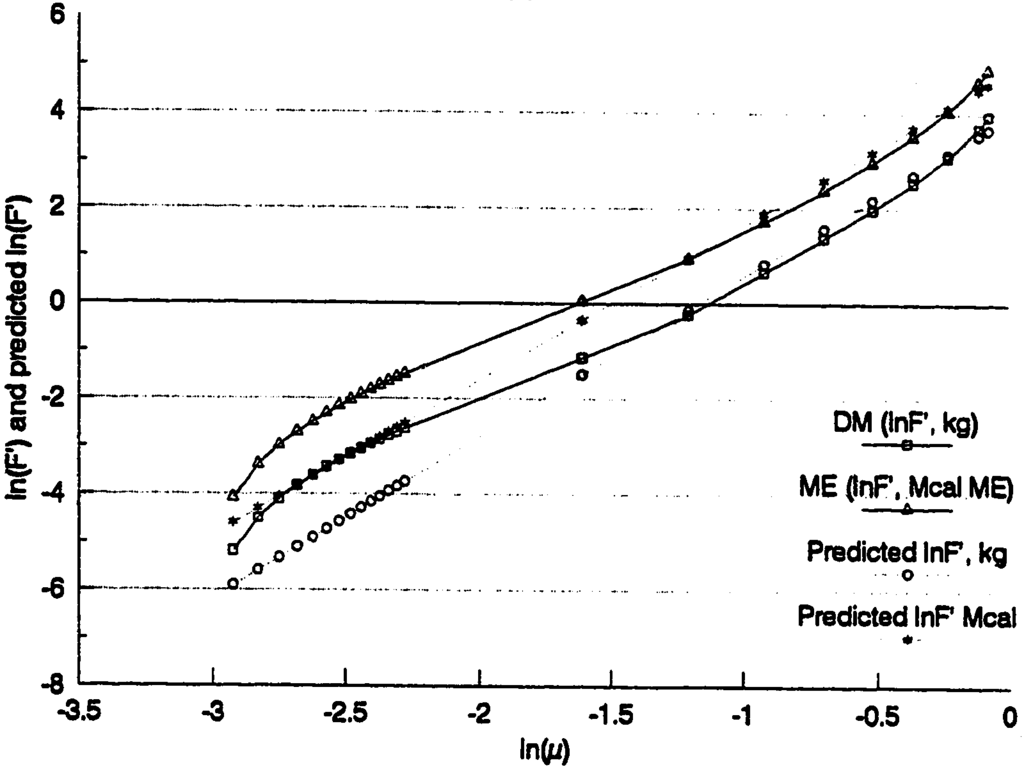


Figure II.17. Plots of (a). F' against $\ln(1-\mu)$ and (b). lnF' against $\ln(\mu)$ together with the fitted regression equations.


Plot of the lnF' and predicted lnF' against ln(μ)

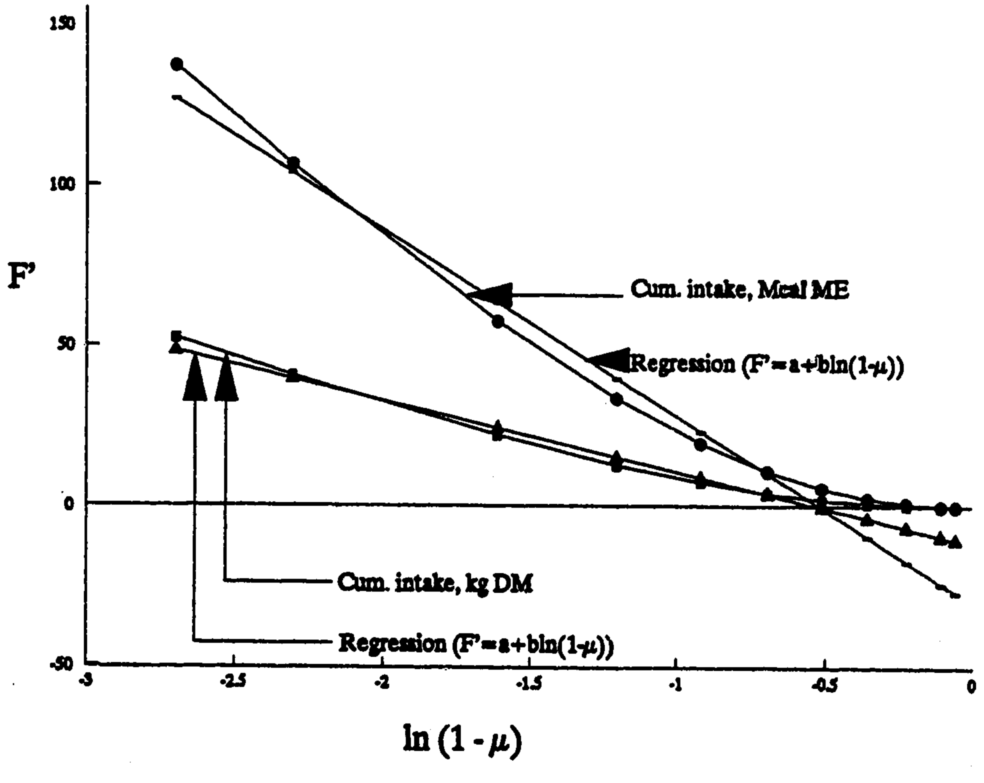
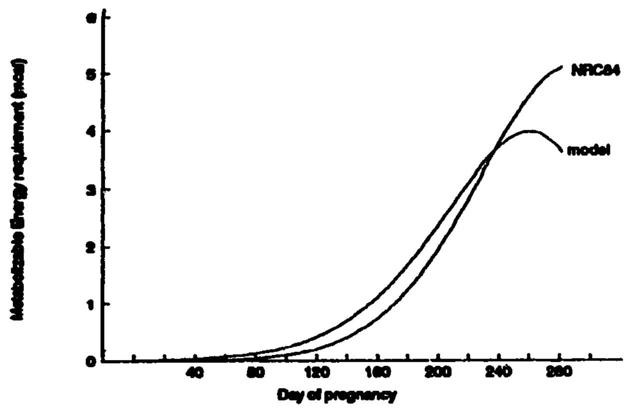
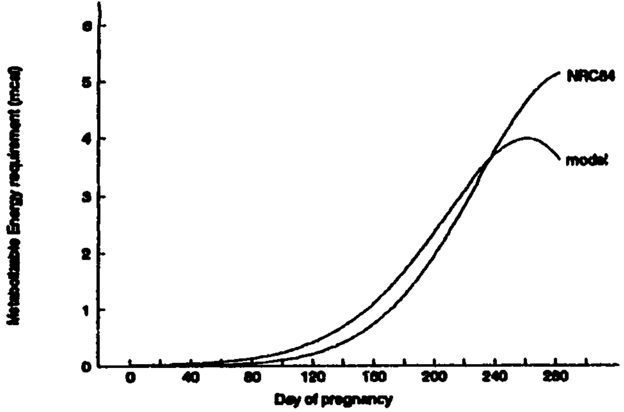

Plot of Scaled feed intake (F') and Predicted F' against ln(1 - μ)

Figure II.18. Comparison of daily metabolizable energy requirements for pregnancy as estimated by the model and by the NRC (1984).

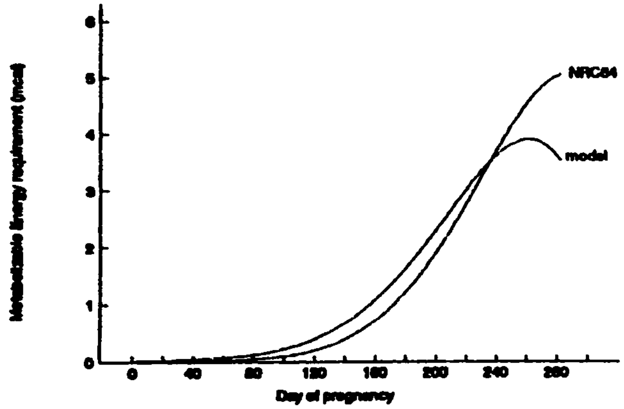
Daily pregnancy requirements, Hereford



Daily pregnancy requirements, Beef Synthethic 1



Daily pregnancy requirements, Beef Synthetic 2



Daily requirements for pregnancy, Dairy Synthetic

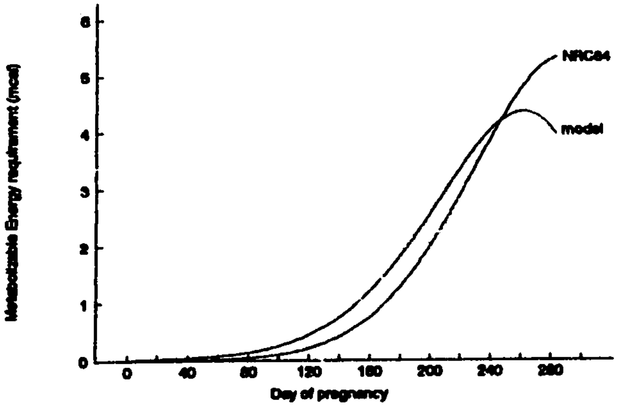
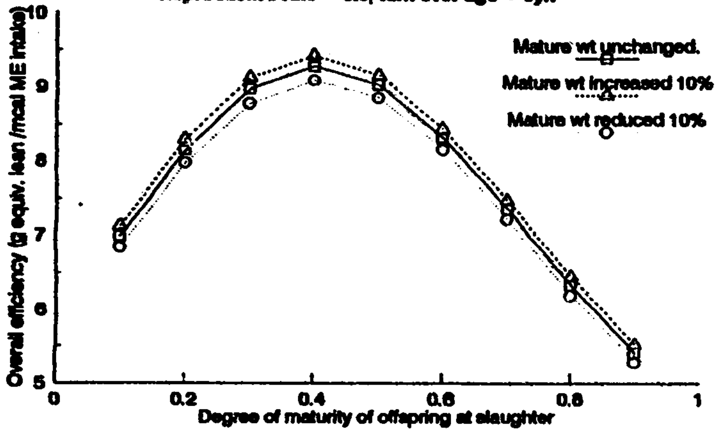
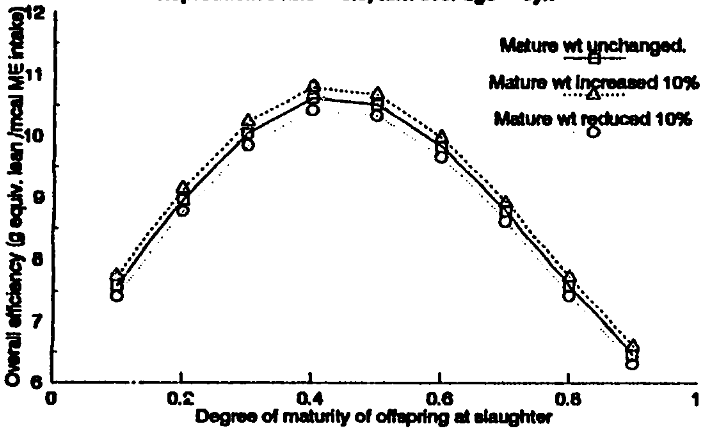


Figure II.19. Effect of increasing or reducing the mature size of the breed (A) by 10% on the overall efficiency.

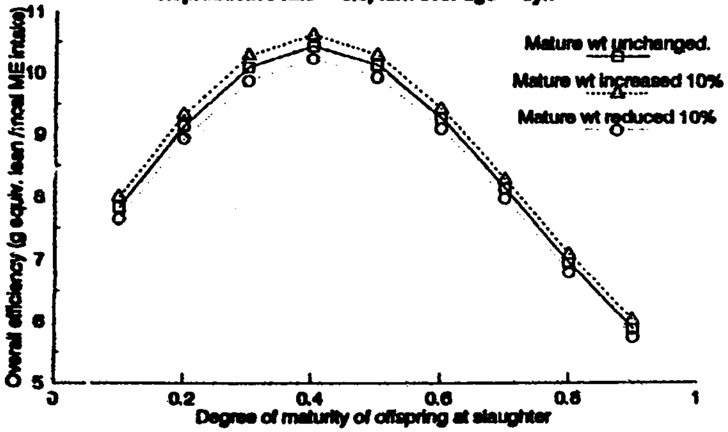
Effect of increasing or reducing mature weight by 10% on the overall efficiency in Herefords. Reproductive rate = 0.8, turn over age = 6yr.



Effect of increasing or reducing mature weight by 10% on the overall efficiency in Beef Syn. #1 Reproductive rate = 0.8, turn over age = 6yr.



Effect of increasing or reducing mature weight by 10% on the overall efficiency in Beef Syn. #2 Reproductive rate = 0.8, turn over age = 6yr.



Effect of increasing or reducing mature weight by 10% on the overall efficiency in Dairy Syn. Reproductive rate = 0.8, turn over age = 6yr.

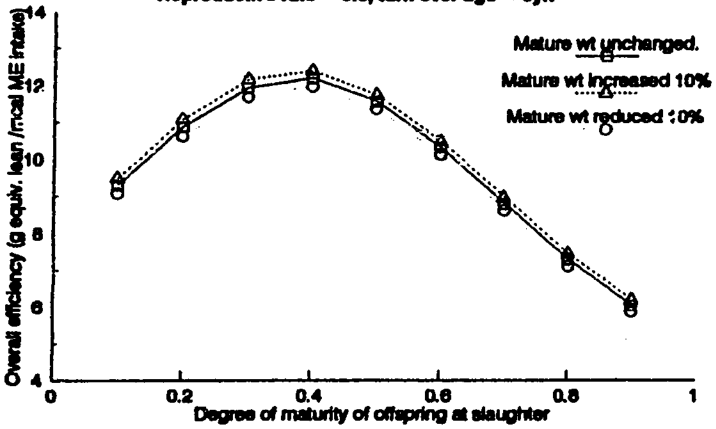
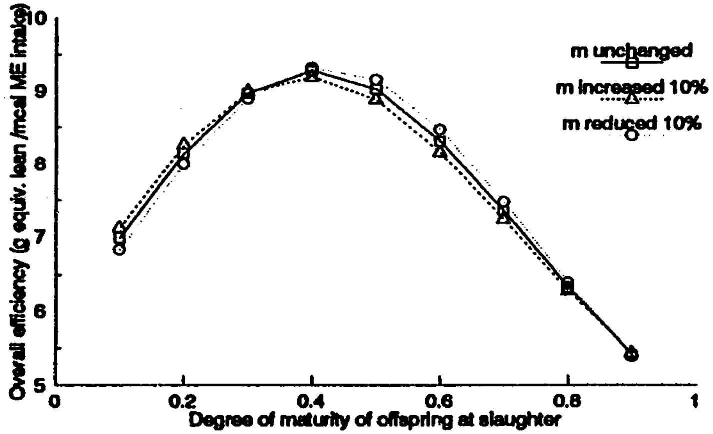
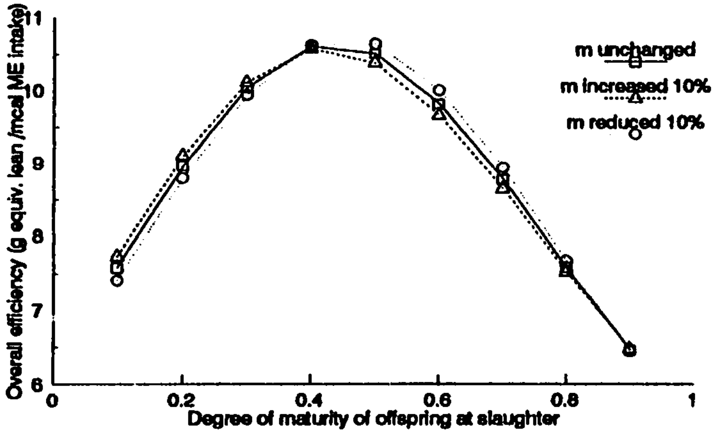


Figure II.20. Effect of increasing or reducing the inflection parameter (**m**) of the breed by 10% on the overall efficiency.

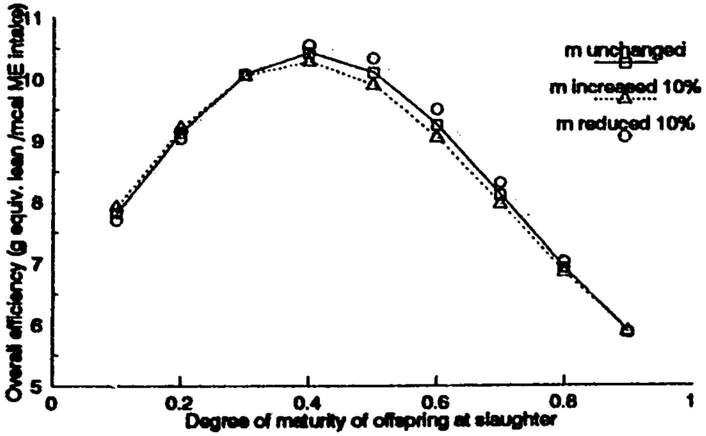
Herefords



Beef Synthetic 1



Beef Synthetic #2



Dairy Synthetic

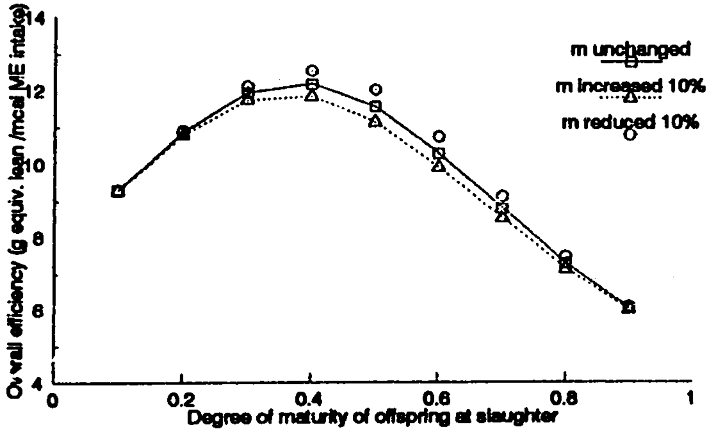
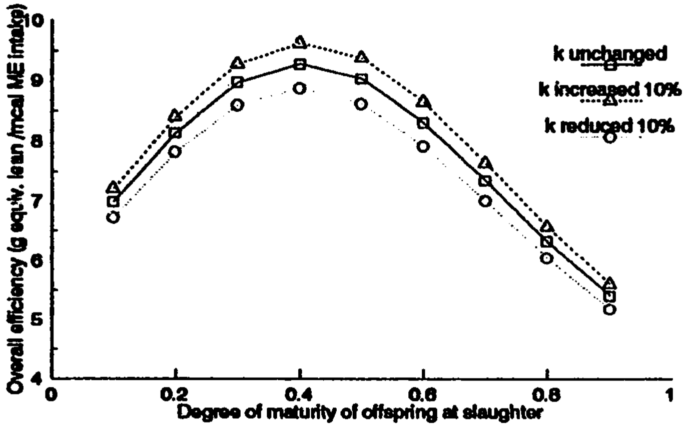
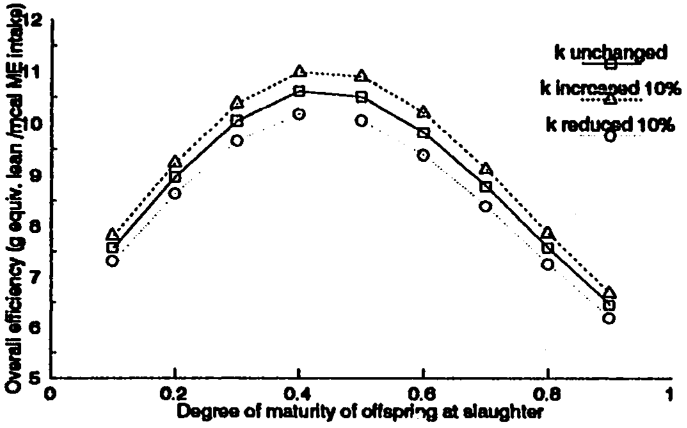


Figure II.21. Effect of increasing or reducing the maturing rate parameter (k) of the breed by 10% on the overall efficiency.

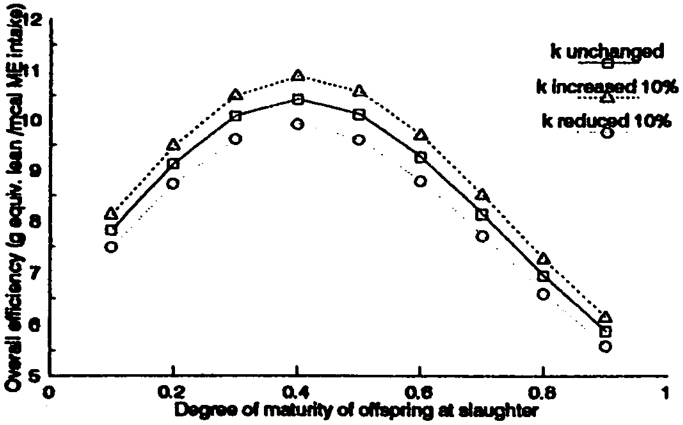
Herefords



Beef Synthetic 1



Beef Synthetic 2



Dairy Synthetic

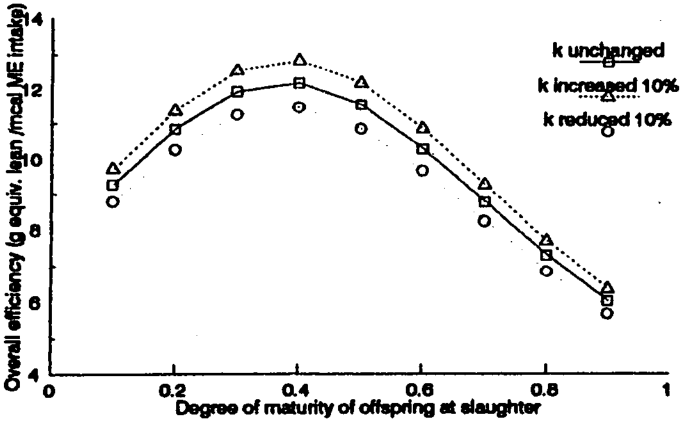
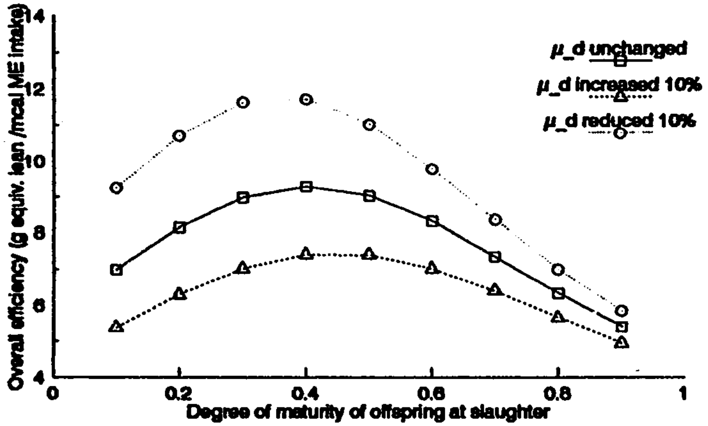
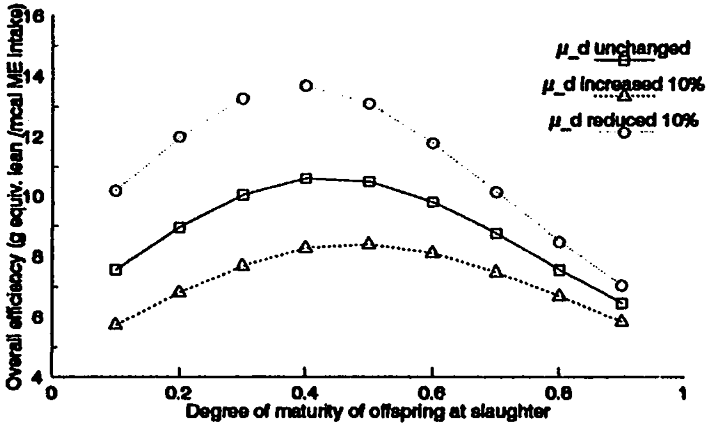


Figure II.22. Effect of increasing or reducing the dam's degree of maturity (μ_d) at turnover of each breed by 10% on the overall efficiency.

Hereford.



Beef Synthetic 1



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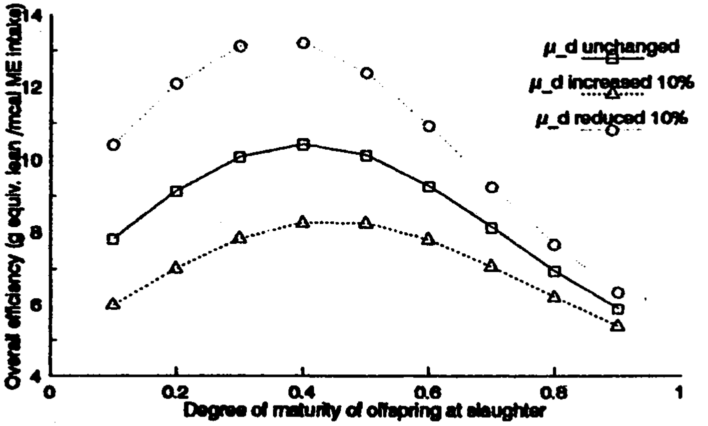


Dairy Synthetic

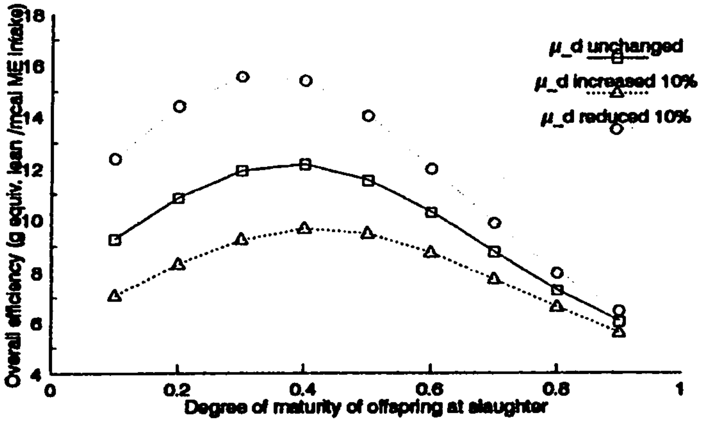
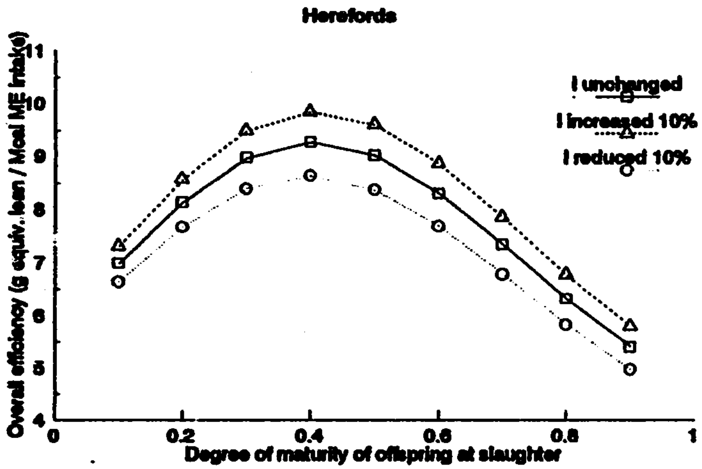
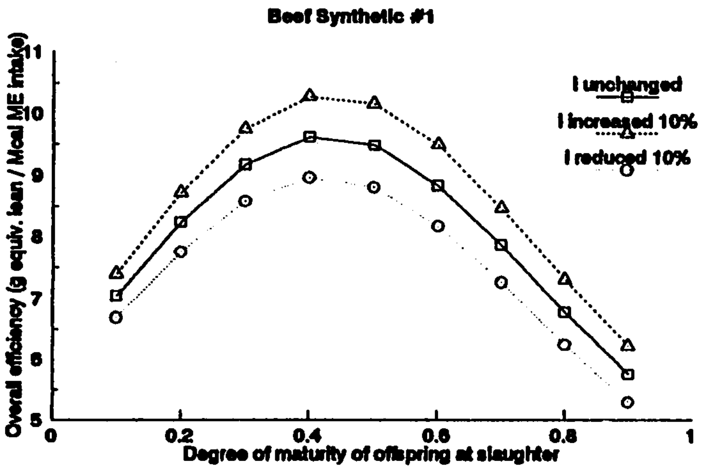


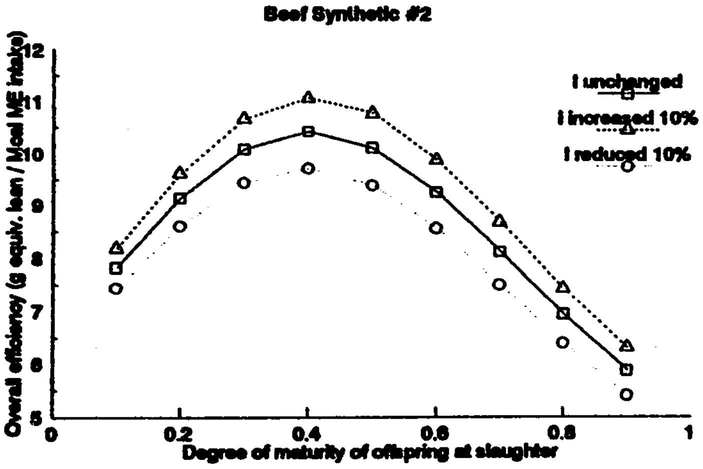
Figure II.23. Effect of increasing or reducing the lean content of each animal from each breed by 10% on the overall efficiency.



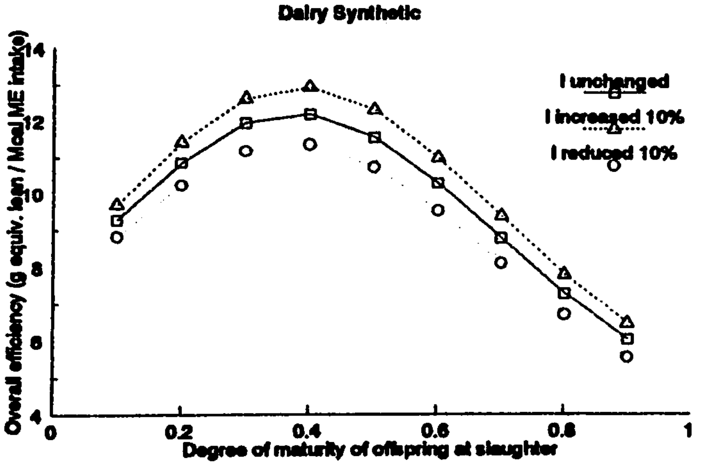
Herefords



Beef Synthetic #1



Beef Synthetic #2



Dairy Synthetic

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3. Efficiency in Traditional Beef Production Systems.

3.1. Introduction

A traditional system of beef production is taken as a production system in which the male : female offspring ratio is 1 : 1, a cow is allowed to remain in the herd, as long as she produces a calf annually. The logic in such a system is to spread the cost of maintaining the dam over as large a number of calves as she can possibly produce, thus minimizing this cost. Overall efficiency in such a system could be influenced by the breed of cow (Morris and Wilton, 1976), the reproductive rate in the herd, the number of offspring she is allowed to produce (mean age at turnover, Taylor et al., 1985) and probably the month of calving. A review by Morris and Wilton (1976) indicates that small cows are superior in biological efficiency if only combined cow and calf feed requirements and calf weights were considered. However, when the feed requirements for replacements to the breeding herd were included, with extra salvage weight of saleable beef from the breeding herd as cow weight increased, biological efficiency was little affected by cow size, unless reproductive performance also changed. They concluded that little variation is expected in biological efficiency due to differences in size of cows, though considerable changes in outputs and requirements per animal may be introduced by changing mature size.

Energy intake influences reproduction (Wiltbank et al., 1962, 1964; Dunn et al., 1969). Hence, there is a belief that there is an optimum reproductive rate for each breed of cow under normal feeding, and that exceeding such a reproductive rate in the herd could be the result of excessive feeding (feed wastage), leading to increased (probably excessive) dam feed costs (Berg, personal communication). Alternately, if the reproductive rate falls below the optimum, then the herd is probably being underfed. This suggests that studies of herd reproduction in which the reproductive rate varies should be accompanied by varying dam feed costs. The results of Taylor et al. (1985) contradict traditional logic that dam maintenance costs are reduced with the increase in the number of offspring she is allowed to get. They suggest that the dam be culled as soon she produces her replacement.

This study was conducted to investigate the behaviour of overall efficiency in a traditional beef production system, as it is influenced by the breed group, the turnover age of the herd, and the reproductive rate of the herd. Overall efficiency was evaluated with respect to the degree of maturity at which slaughter offspring are taken off the herd. Studies of the reproductive performance of the herd also investigated the level to which the cow herd can be overfed without efficiency dropping unacceptably, given that the reproduction is changing as well.

3.2. Materials and Methods

The model (BEM) described in chapter 2, was employed in simulation studies to evaluate the influence of breed group, reproductive rate, turnover age and month of calving on the overall efficiency in traditional beef production systems. To investigate the breed effect, the mean age at culling and the mean reproductive rates reported by Berg et al. (1990) and Arthur et al. (1991) were employed to simulate base overall efficiencies. The mean reproductive rates (calf crop weaned) reported by Berg et al. (1990) were 0.75 for the Hereford, and the Beef synthetics 1 and 2, and 0.77 for the Dairy synthetic. The mean ages at culling were 3.7, 4.5, and 5.2 years respectively for the Herefords, Beef synthetic #1 and the Dairy synthetics (Arthur et al., 1991). The mean age at culling for all three was 4.2 years and was assumed for the Beef synthetic #2 as well. The breeds were also compared at the same reproductive rate (0.8, assumed to be the reproductive rate attainable under 'normal conditions', see Arthur et al., 1991) and age at culling (6 years, assumed to be the industry average). In both cases, the sizes of the synthetic breed groups relative to the Herefords were considered in computing the outputs. It was also assumed that all breeds had the same lean content of 33% of live weight. However, the SY1 could have as much as 38% lean (Shahin and Berg, 1985). Therefore, the effect of changing the SY1 lean content to 38% was also examined.

To investigate the effect of turnover age on overall efficiency, reproductive rates reported by Arthur et al. (1991) were rounded to 0.8 and assumed to be the rate attainable under 'normal feeding'. The age at culling (age at turnover) was then varied from the minimum (see chapter 2) to a maximum of 10 years. The 10 years maximum was thought to be reasonable because a maximum age at culling of 16 years was reported by Arthur et al. (1991). To investigate the influence of reproductive rate, a mean culling age of 6 years was assumed and reproductive rate was varied from 0.5 to 1.0. The effects of concomitant changes in feed intake were evaluated by assuming that increasing the normal reproductive rate from 0.8 to 1.0 was associated with extra feed costs for the dam. Hence by maintaining r at 1.0 and increasing additional dam feed costs from 0 to 10% in increments of 5%, the extra level of feeding could be investigated and the behaviour of overall efficiency compared with those for r = 0.8 (the "normal" reproductive rate). To investigate the month of calving effect, reproductive rate was kept constant at 0.8 and the age at turnover at 6 years and the month of calving varied.

3.3. Results and Discussion

3.3.1. Breed effects on overall efficiency.

Results of overall efficiency expressed in terms of grams lean per kg dry matter (DM) intake or per megacalorie (Mcal) metabolizable energy (ME) intake were similar in trend and hence only those on a $Mcal^{-1}$ ME basis are reported. Figure III.1 indicates the mean ME intake (Mcal, scaled by mature weight) for the four beef breeds. The Beef Synthetic #1 (SY1) had the lowest energy consumption kg^{-1} mature size at any degree of maturity, whereas the Dairy Synthetic (SD) had the highest. On that basis, one would expect the SY1 to be the best breed group in terms of overall efficiency and the SD the worst breed group.

The breed group comparisons for overall efficiency are shown by Figure III.2 for the base efficiencies, employing the reproductive rates (r) and turnover ages reported by Berg et al. (1990) and Arthur et al. (1991). Differences in overall efficiency between some of these breed groups were substantial. These differences range from a minimum of less than 1% to a maximum of 25% and the difference between the best and the poorest breed group at the point of maximum efficiency (degree of maturity of offspring at slaughter, $\mu = 0.4$) was 24%. The SY1 breed group had the lowest efficiency when offspring are slaughtered before 20% maturity, but thereafter the Hereford was the worst, up to 80% maturity. The SD breed group was the most efficient followed by the SY2. At the point of maximum efficiency the SD breed group was 24, 20, and 12% more efficient than the Hereford, SY1 and SY2 respectively. It is surprising that the SD group was most efficient, as it had the highest feed intake (Figure III.1) and was culled latest (at 5.2 years). These differences can, however, be interpreted in the light of the sensitivity analysis (section 2.5). It will be recalled that the degree of maturity of the dam was the parameter to which the model was most sensitive and that an increase in the degree of maturity of the dam results in lowered overall efficiency. Though the SD breed was culled (turned over) latest in life, the dams of this group were still relatively the youngest (80% mature). By contrast the SY1 group were culled on average at the age of 4.5 years and had dams 89% mature, whereas the Herefords (culled at 3.5 years) and the SY2 (culled at 4.2 years) were 82 and 83% mature respectively.

Hence, the SD breed group had a longer productive life relative to the other breed groups and its dams were still younger. These two factors account for nearly all the differences between the SD and the other breed groups. By contrast, the SY1 which was most mature at culling would be disadvantaged, since more maturity implies lowered efficiency, but also because it had a shorter productive life (i.e., fewer offspring relative to its maturity) than the SD. The fact that the SD breed becomes least efficient when its offspring are allowed to remain in the herd too long is probably a reflection on its relatively higher feed intake and its absolute size. This breed group is so large that as it matures its overall efficiency declines faster. Though the differences displayed in Figure III.2 are not easy to interpret, if it could be assumed that the reproductive rates and turnover ages reported by Berg et al. (1990) and Arthur et al. (1991) are similar to the industry averages (i.e., if one raised these breeds, he would on average achieve these production characteristics), then it could be argued that the relative differences in Figure III.2 represent the differences between these breeds that could be expected in the industry.

The breed group comparisons at the same turnover age and reproductive rate are shown by Figure III.3 ($r = 0.8$). The trends were similar for other reproductive rates. The Hereford breed group was consistently the poorest breed group in overall efficiency, followed by SY1 group especially when the age at turn over was less than 10 years. The SD breed group was still the most efficient. The differences in overall efficiency ranged from less than 1% to 33% depending on the age at culling and the degree of maturity of the offspring at slaughter. The SD, SY2 and the SY1 were 31, 12 and 4% respectively more efficient than the Herefords at the point of maximum efficiency ($\mu = 0.4$) when the age at culling was 6 years. The respective differences were 17, 8 and 7% at a culling age of 10 years implying that the differences declined with age at culling for the SD and SY2 breed groups but increased slightly for the SY1 and by 10 years of age there is virtually no difference between the SY1 and SY2. The differences between breed groups reported here are substantial, and differ from the preponderance of research in this area. Brody (1945) and Kleiber (1947) believed that differences in mature size were unlikely to be associated with differences in productive efficiency and this appears to be supported by the sensitivity analysis on mature size (section 2.5). Since then, a review by Morris and Wilton (1976) concluded that little difference exists among breeds when the cost of replacement, and the salvage value of the culled cow are considered. Dickerson (1978) suggested that factors associated with size such as longer gestation and lactation, dystocia and post weaning rate of gain preclude size *per se* from having a major effect on life-cycle production efficiency. Experimental work comparing cattle of different sizes at the same finish (% fat, Smith et al., 1976; Barber et al., 1981; Kempster et al., 1982; Stewart and Martin 1983) seem to confirm these opinions.

However, most of the experimental studies compare efficiency over some portion of the life of the slaughter offspring without examining the entire production system and most usually impose some resource constraint (either feed or space). If significant differences in management costs exit between the breed groups, this could influence the overall efficiency, but such differences were assumed to be minimal in the current study. There are also differing opinions in this area. Blaxter (1968) and Taylor and Young (1966) argue that individual differences in rate of maturing are likely to be associated with differences in production efficiency. In experimental studies, Cundiff et al. (1981, 1984) reported significant differences in efficiency between large and small breed groups compared at the same marbling or fat trim points. They reported that breed groups reaching these end points faster were more efficient because of lower energy for maintenance. It appears likely that while the mature size *per se* will not influence breed differences, the overall effect of small differences in maturing rates, mature sizes and feed intake do have an effect on breed differences in overall feed efficiency.

The unexpectedly low overall efficiency of the SY1 can be explained by its faster growth and maturing rates (as suggested by Taylor and Young (1966) and Blaxter (1968)) and are in line with the results of the sensitivity analysis (section 2.5). It should be recalled that increasing the dam's degree of maturity by 10% resulted in a reduction in overall efficiency. It should also be recalled that the SY1 was the fastest maturing breed (see Figures II.3 & II.4, chapter 2) and that dams are culled on an age basis, not on a "same maturity" basis. Therefore, at any age of herd turnover, the SY1 dams are bigger, more mature and carry a relatively larger maintenance load. Since the dam's intake is by far the larger proportion of the input to the herd, the large and more mature dams of the SY1 at any turnover age would make this breed less efficient. By contrast, the SD which was the slowest maturing would be the least mature at any turnover age and therefore more efficient.

If we change the lean content of SY1 to 38%, it is still not as efficient as SY2 or SD at early turnover ages and early degrees of maturity of the offspring at slaughter (Figure III.4a) but becomes the most efficient breed group when the turnover age is 10 years (Figure III.4c) and offspring are retained in the herd beyond 40% maturity. Increasing the lean content of SY1 therefore does not confer dramatic advantages in overall efficiency, because the model is not very sensitive to this parameter. The improvement in overall efficiency shown, however, should not be surprising since changing the lean content did not include a corresponding rise in feed requirement, i.e., the output has been increased while input remains the same.

Therefore, a faster maturing large-sized breed is probably not the most advantageous in terms of overall efficiency in a cow-calf system unless such a breed has other qualities.

This is mainly because the dams of such a breed mature quickly and hence carry a large maintenance load for the rest of their life in the herd. In a feedlot, the offspring of such a breed would reach market weight and condition quickly, saving the operator a lot of feed, and hence improving his efficiency. This suggests that such offspring ought to command a premium price, a condition not considered in the current analysis.

3.3.2. Effect of reproductive rate

The effect of changing the reproductive rate (r) from 0.5 to 1.0 on the overall efficiency is shown by Figure III.5 for an average turnover age of 6 years. The effects of changing r were similar in trend for all breeds but varied slightly in magnitude and stage of occurrence from breed to breed. In any breed, improving r improved overall efficiency as long as the offspring were marketed or slaughtered early enough. For the Hereford and SY2 breed groups, this implies not retaining offspring beyond 70% maturity in the herd. For the SY1, offspring should not be retained beyond 75% maturity and for the SD breed group, the offspring should not be retained beyond 65% maturity. This implies that for all four breed groups, offspring must be slaughtered before 4 years of age. This is of course not a limitation since most beef animals are slaughtered before 2 years of age. Beyond the switch-over points the decline in overall efficiency is rapid at higher values of r. Before the switch over in overall efficiency, the SY1 breed group was most sensitive to changes in r, followed by the SY2 and the Herefords. The maximum differences in overall efficiency before the switch (between $r = 1.0$ and $r = 0.5$) for all breed groups were 28.7%, 24.9%, 25.3% and 23.8% for the SY1, SY2, Hereford and the SD respectively.

These differences are of course very substantial especially for breed groups such as the SY1. In the SY1 breed group, $r = 1.0$ was 8.8% more efficient than $r = 0.8$ at the point of maximum efficiency. This difference is of practical significance since a reproductive rate of 0.8 approximates what is obtained under field conditions. The values for other breed groups were 6.6, 7.2 and 7.5% for the SD, SY2 and Hereford respectively. These compare very well with the conclusion of Dickerson (1978) that 10% or 8% improvement in biological efficiency could be expected in lamb or beef from a 20% genetic increase in the number of offspring produced (by an increased reproductive rate). The results obtained in this study are in most respects similar to those of Taylor et al. (1985) although they did not find as rapid a decline in overall efficiency beyond the peak. Their results indicated an increase of 4% to 5% at the point of maximum efficiency for a proportionate increase of 0.1 in r and efficiency curves did not cross over. The differences obtained in the current study range from 3.9 to 6.5% for a 10% increase in the reproductive rate. Fennessy and Thompson (1989), working with farmed red deer obtained 5 - 9% improvement in efficiency for a 10% increase in r. The current results therefore agree reasonably well with the few estimates published.

The switch-over in efficiency is rather puzzling. However, cumulative feed intake is exponential in nature. Hence the longer the offspring are maintained in the herd the more rapid the cumulative feed intake increases. On the other hand, total lean output probably increases linearly. The larger the number of offspring (higher r), the more pronounced will the increase in feed intake be with advancing maturity and hence the switch over.

The above discussion did not consider concomitant changes in feed intake (feed costs) as r increases. Figure III.6 compares the overall efficiency for $r = 0.8$ and $r = 1.0$ with the feed cost required to achieve $r = 1.0$ increased in steps of 5% over that required to achieve $r = 0.8$. The efficiency for $r = 1.0$, when the cost of achieving both reproductive rates are assumed to be equal is also given for comparison. It will be realized that increasing the dam feed costs by 10% reduces the overall efficiency of r = 1.0 to that of r = 0.8 at the 6 and 8 year turnover ages. At a turnover age of 10 years, the difference in efficiency might justify the extra feed costs. However, increasing the dam feed cost by 15% lowered overall efficiency irrespective of age at turnover. Taylor et al. (1985), investigating the effects of reducing dam feed costs, also reported marked influences on overall efficiency. This suggests that it is probably unwise to overfeed stock (especially beyond 10% of normal levels) to achieve better reproduction. This of course does not consider the possibility that overfeeding could lead to excessive fattening and poorer reproduction. Thus, if for the same level of feeding the reproduction can be improved, some amount of improvement in overall efficiency is possible.

3.3.3. Effect of age at turnover on overall efficiency

The influence of age at turnover (culling) is shown by Figure III.7 for each breed group. These values were evaluated for a reproductive rate of 0.8. In general, the overall efficiency declines the longer cows are maintained in the herd. However, beyond 6 years of age the decline in overall efficiency is minimal and indeed in some breed groups (Hereford and SY1) the overall efficiency begins to recover, depending on when the offspring are slaughtered. In general, maximum efficiency was obtained if offspring were slaughtered between 30 to 60% mature, usually at 40% maturity. At the latter degree of maturity, the SY1 breed group has recovered in efficiency enough to make culling at 10 years of age 4 - 9% more efficient than culling at 4 years of age. Hence, for this breed group these results suggest it might be worthwhile retaining cows as long as possible, though offspring must be slaughtered before they are 60% mature. The differences in overall efficiency ranged from less than 1% to 53% depending on the breed group and the degree of maturity of the offspring at slaughter. At the point of maximum efficiency, $\mu = 0.4$, turning over the herd at 4 years of age was 5.4%, 3.1%, 7.3% and 9.5% more efficient than at 5 years of age. Relative to turnover at 6 years of age, 5 years was 2.8%, 1.1%, 4.3% and 6.4% more efficient at the point of maximum efficiency for the respective breeds listed above. However, culling at 6 years of age was only -0.8%, -1.5%, 0.4% and 2.5% more efficient than culling at 7 indicating that the trend in overall efficiency was reversing for most of the breeds by this turn over age. These results are similar in some respects to those of Taylor et al. (1985), who reported a maximum difference of 15% at the point of maximum efficiency and 8% between overall efficiency at 5 and 7 years of age at turnover. In the present study, maximal differences at the point of maximum efficiency ($\mu = 0.4$) were 8.5%, 13%, 12% and 19% for the Hereford, SY1, SY2 and SD breed groups respectively. However, the efficiency curves derived by Taylor et al. (1985) were relatively unchanging at the maximum (very platykurtic) and overall efficiency continuously declined with increasing age at turn over. Results similar to those of Taylor et al. (1985) were also reported by Fennessy and Thompson (1989) for red deer but the changes in overall efficiency with the length of residence in the herd were smaller in their study. They attributed this to the fact that the red hind was much more mature at first calving than cattle and hence the efficiency at first calving would be smaller than that for cattle. Subsequent changes in overall efficiencies would then be expected to be smaller as well.

The decline in overall efficiency from year to year (in the first 6 years of this study) is probably attributable to the dam aging, eating a lot more but contributing a lot less to the output. As explained by Taylor et al. (1985), when a dam is young she uses her feed consumption both for reproduction and productive growth, since her carcass is still of prime value. However, as she ages, her carcass is less valuable and she is consuming a lot more feed, that is not being used for productive growth. Hence she consumes more feed than she is producing output (both from her salvage value and the offspring she is producing). The reversal of the trend in overall efficiency beyond 6 years of age at culling differs noticeably from the results of Taylor et al. (1985). This is probably the result of a difference in the treatment of the price of cull cow (dam) meat. Taylor et al. (1985) employed a function ($P_{d(n)} = 1.02 - 0.02n$, where $P_{d(n)}$ is the price of dam meat at her n^{th} calving) that decreases with age (number of calvings) to predict the value of cull cow meat. As the value of the culled cow declined her contribution to the total output declined fairly constantly as the age at which she was culled increased. In the current study, however, the value of culled cow meat remained constant over some age ranges, 2 - 3 years, 4-5 years and 6 years or older. Beyond 6 years of age, no more penalty is incurred in the value of lean from a culled cow and hence the contribution of the dam to the output will tend to stabilize a bit and not decline as fast as in the case of Taylor et al. (1985). This effect is illustrated by Figure III.8 and is evaluated at offspring degree of maturity of 0.4. It indicates the contribution of the dam to both input and output (%), depending on her age at culling (values were evaluated at offspring degree of maturity = 0.4). It can be seen that while the proportion of output due to the dam is decreasing fairly constantly for each breed group, the decline in the contribution of the dam to output is less rapid beyond 6 years of age. This improvement in the dam's contribution to output together with the increased number of offspring probably made the dam's maintenance cost less important, and hence the improvement in overall efficiency beyond 6 years of age.

3.3.4. Effect of month of calving on overall efficiency

The cumulative intake of feed to satisfy environmental corrections are shown for the

SY1 breed for different months of calving in Figure III.9. It is obvious that there are some differences in the cumulated scaled energy intake (Mcal ME kg^{-1} mature size), depending on the degree of maturity considered. These differences are independent of differences in the cost of management of the calves between months of calving. It should, however, be noted that beyond one year of age (when animals are more than 40% mature), no further corrections are computed because the calculated lower critical temperatures for all animals at this stage are far lower than the environmental temperatures used in this study. Indeed for calving in the month of May, no corrections are computed at all. All the cumulated corrections for feed intake for any month of calving are therefore less than 1 Mcal ME kg^{-1} mature size. These cumulated corrected feed intakes are low and hence will not be expected to result in large changes in overall efficiency. The resultant overall efficiencies are plotted in Figure III.10. The largest difference in overall efficiency was only 2.6% (between May and November, when $\mu = 0.3$). November and December were the least efficient months of calving while May and June were the most efficient. Hence unless calves from November and December calving attract premium prices for some reason, these months will probably be the worst months of calving since calf rearing at this time will also be expensive.

3.4. Summary and Conclusions

A deterministic Beef Efficiency Model (BEM) was used to evaluate overall efficiency in traditional beef production systems using four breed groups of beef cattle available at the University of Alberta beef research ranch, Kinsella. The breed groups were the Beef Synthetic #1 (SY1), Beef Synthetic #2 (SY2), the Dairy Synthetic (SD) and purebred Hereford (H). When the average turnover ages and reproductive rates reported for each breed group were employed in the simulation, the Hereford and SY1 breed groups were less efficient than the SY2 and SD breed groups, mainly because of differences in the maturity of their dams and the lengths of their productive life. When breeds were compared at the same reproductive rate and turnover age, the Hereford breed group was least efficient, followed by the SY1. In the latter breed group, this was thought to be because the dams of this breed group were more mature at any turnover age since this breed group was the fastest maturing. There was improvement in overall efficiency with increase in reproductive rate but this improvement declined rapidly if offspring were not slaughtered early enough. There was a dramatic decline in overall efficiency as the age at turnover increased from 4 to 6 years. However, beyond 6 years of age most breed groups began to recover in overall efficiency and any decline in efficiency was marginal. Calving during the months of May and June resulted in the most efficiency though differences between months were marginal overall. This comparison, however, did not take into consideration any differences in the value of calves depending on the month of calving.

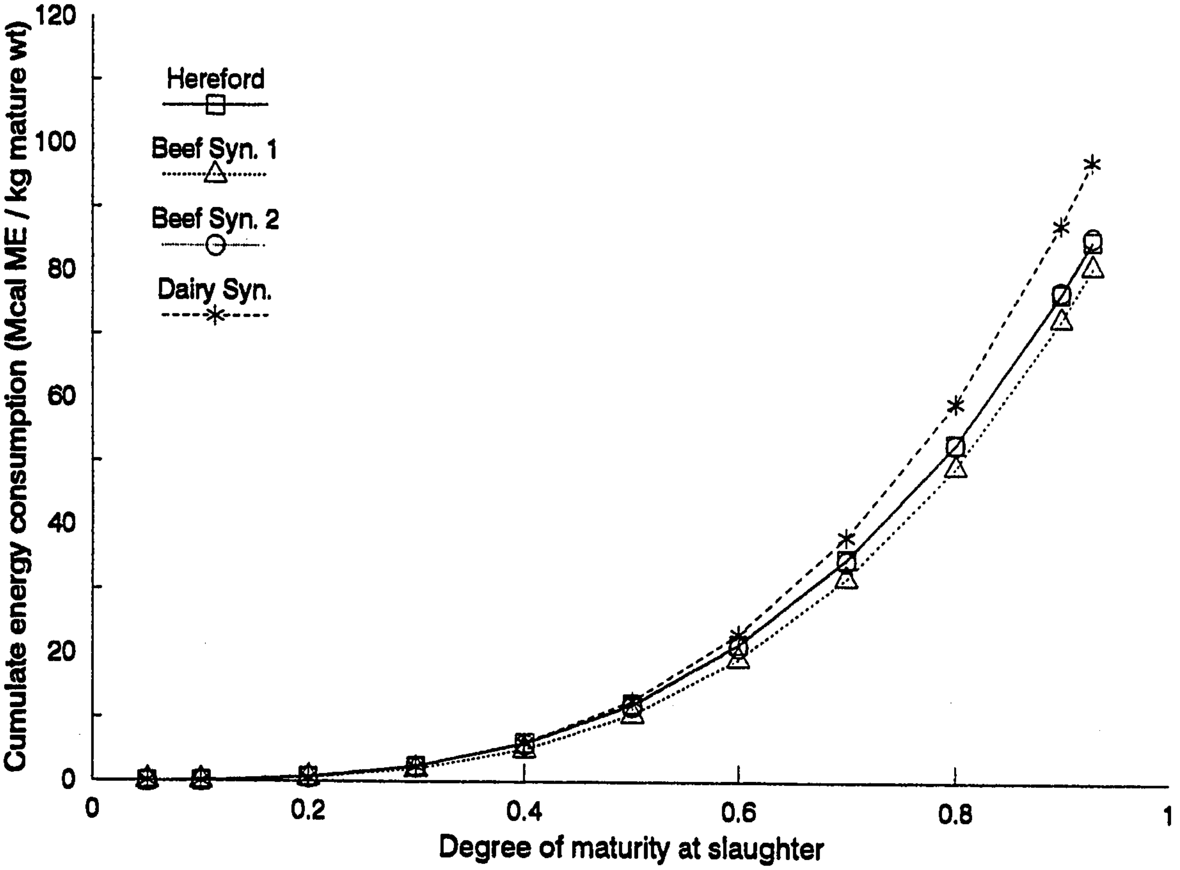
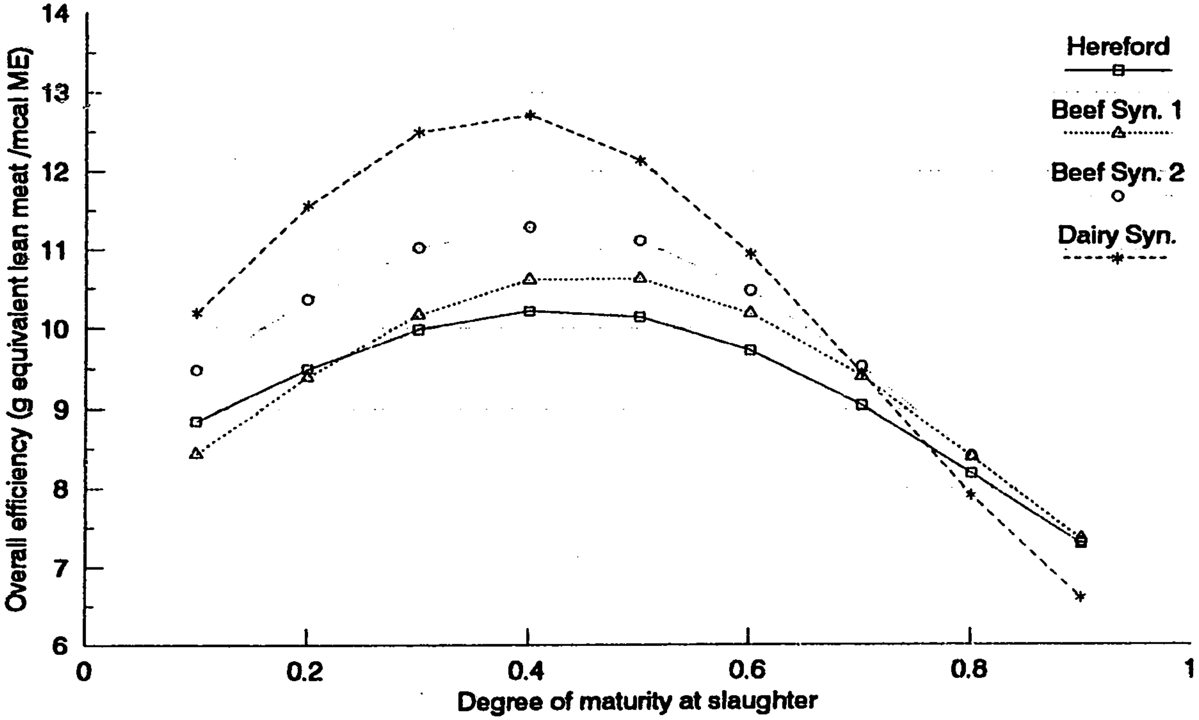


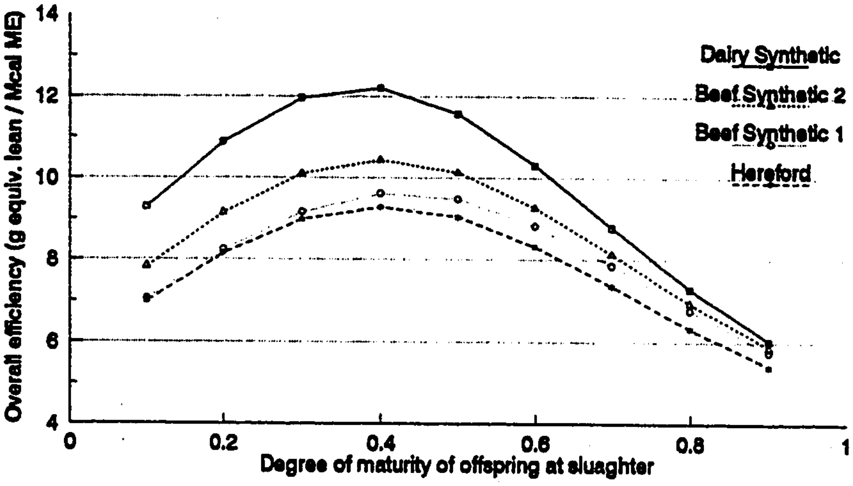
Figure III.1. Breed mean cumulative energy consumptions (Mcal kg^{-1} mature wt) to specific degrees of maturity.

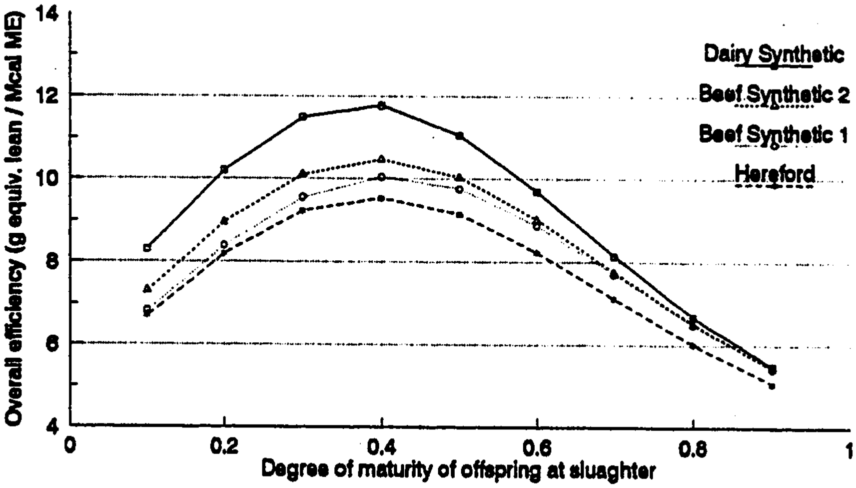
Figure III.2. Base overall efficiency (g equivalent lean Mcal^{-1} ME) values for the four beef breed groups, simulated using the longevity values (years) and reproductive rates reported by Berg et al. (1990) and Arthur et al. (1991)



Base overall efficiencies for all breeds using default reproductive rates and turn over ages reported by Berg et al. 1990 and Arthur et al. 1991

Figure III.3.Overall efficiency (g equivalent lean $Mcal^{-1}$ ME) in four beef breed groups simulated at the reproductive rate (0.8) and turnover age (6 years).


Age at turn over = 6yr


Age at turn over = 8yr

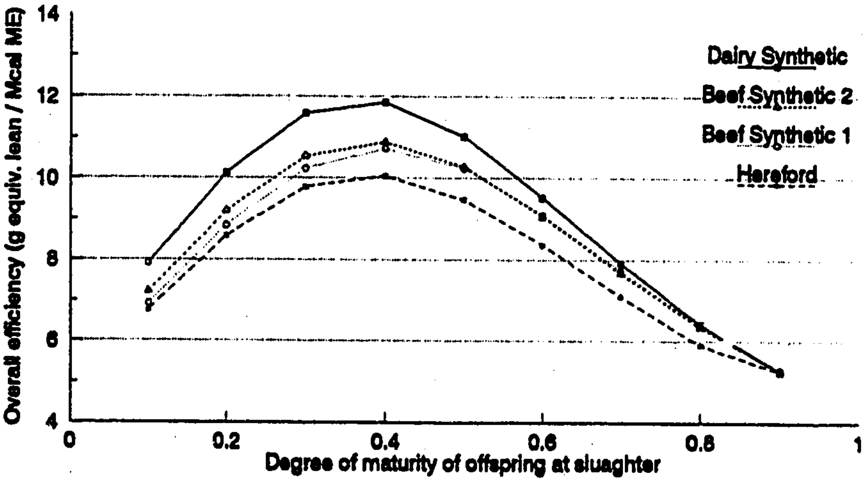
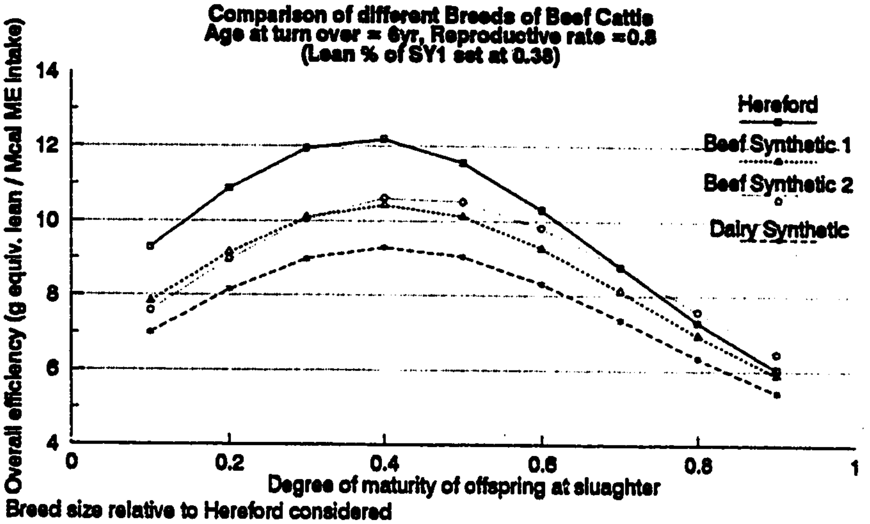
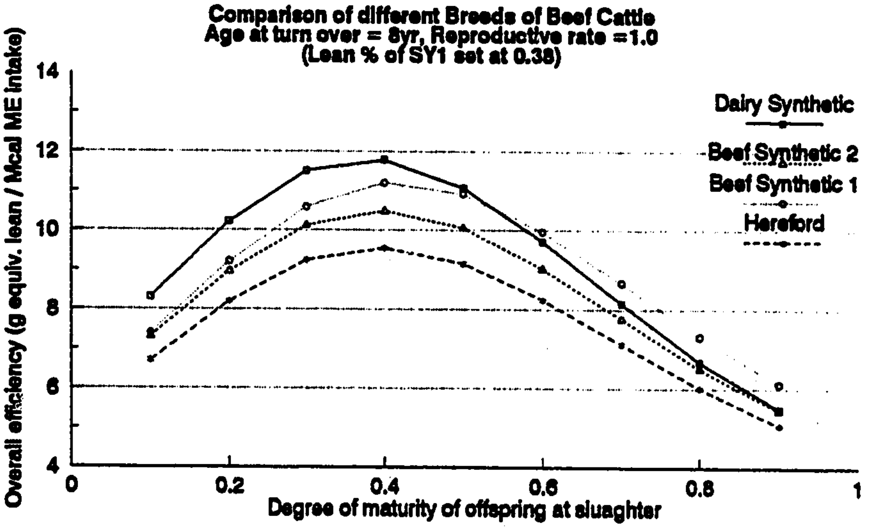

Age at turn over = 10yr

Figure III.4. Effect of changing the lean content (%) of the SY1 breed group to 38% while maintaining the other breed groups at 33% lean content on overall efficiency (g equivalent lean $Mcal^{-1}$ ME).



Breed size relative to Hereford considered



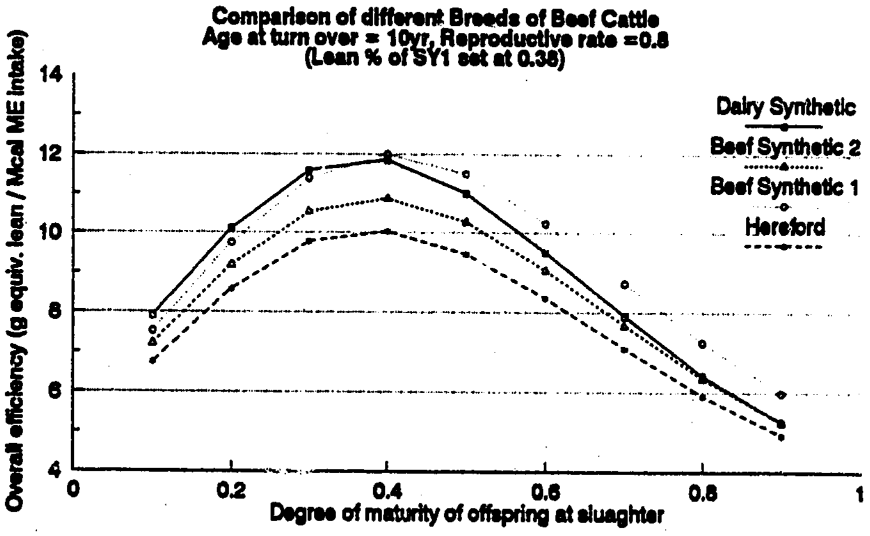
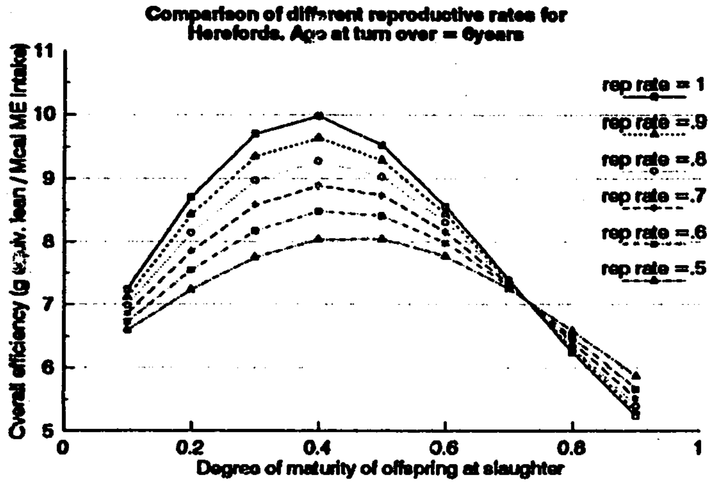
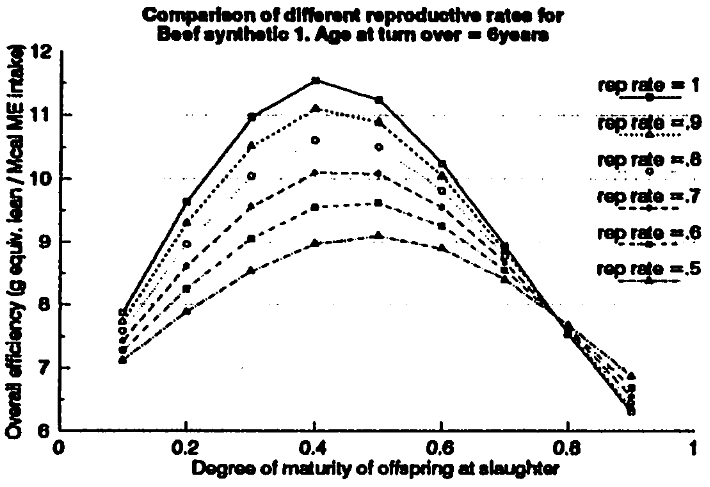
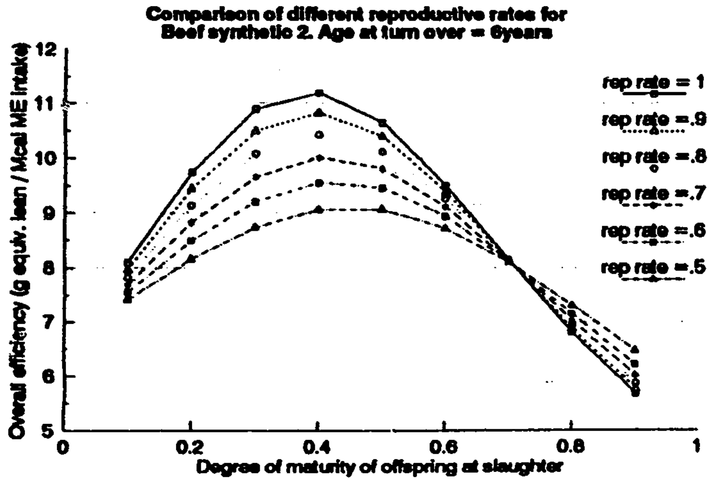


Figure III.5. Effect of varying the reproductive rate on the overall efficiency (g equivalent lean $Mcal^{-1}$ ME) in the four beef breeds.


Comparison of different reproductive rates for Herefords. Age at turn over = 6years


Comparison of different reproductive rates for Beef synthetic 1. Age at turn over = 6years


Comparison of different reproductive rates for Beef synthetic 2. Age at turn over = 6years

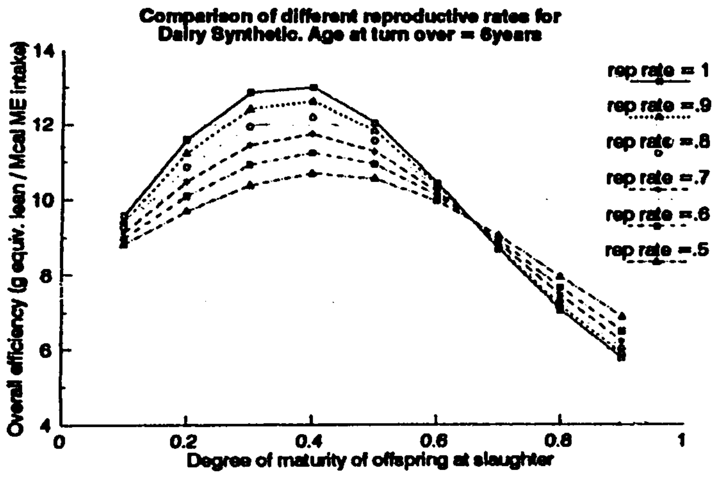
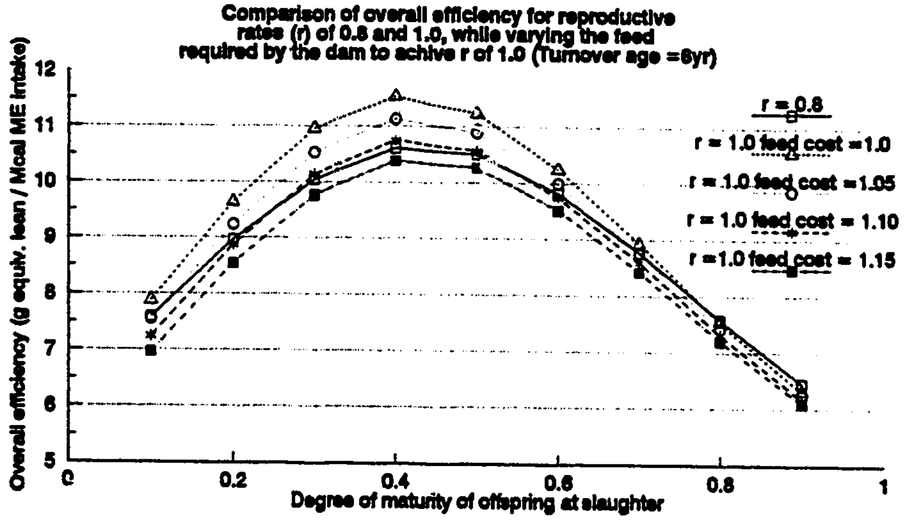
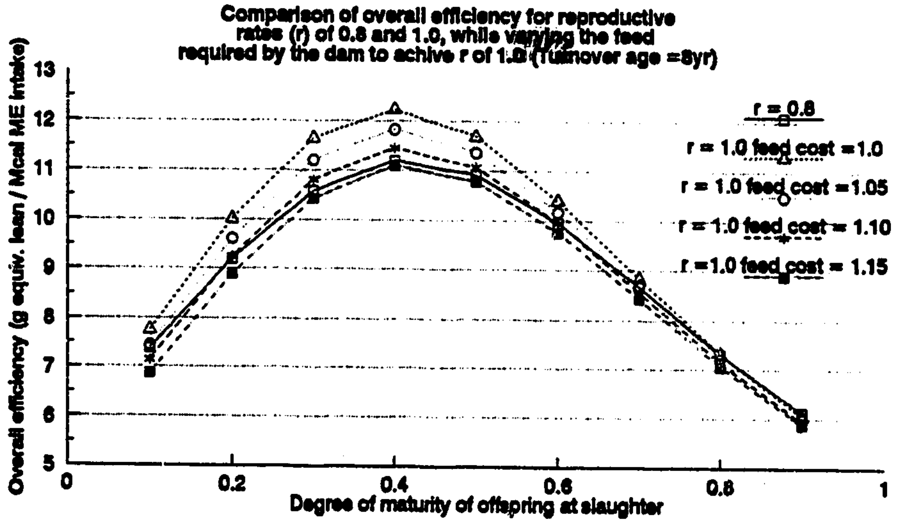

Comparison of different reproductive rates for Dairy Synthetic. Age at turn over = 6years

Figure III.6. Comparison of the overall efficiency (g equivalent lean $Mcal^{-1}$ ME) for reproductive rates of 0.8 and 1.0, while varying the feed required by the dam to achieve the reproductive rate of 1.0.


Comparison of overall efficiency for reproductive rates (r) of 0.8 and 1.0, while varying the feed required by the dam to achive r of 1.0 (Turnover age =8yr)


Comparison of overall efficiency for reproductive rates (r) of 0.8 and 1.0, while varying the feed required by the dam to achive r of 1.0 (Turnover age =8yr)

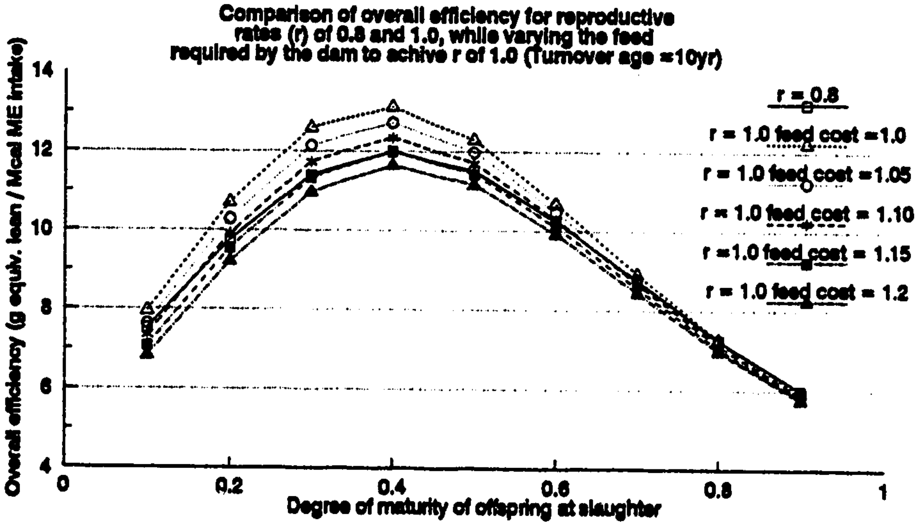
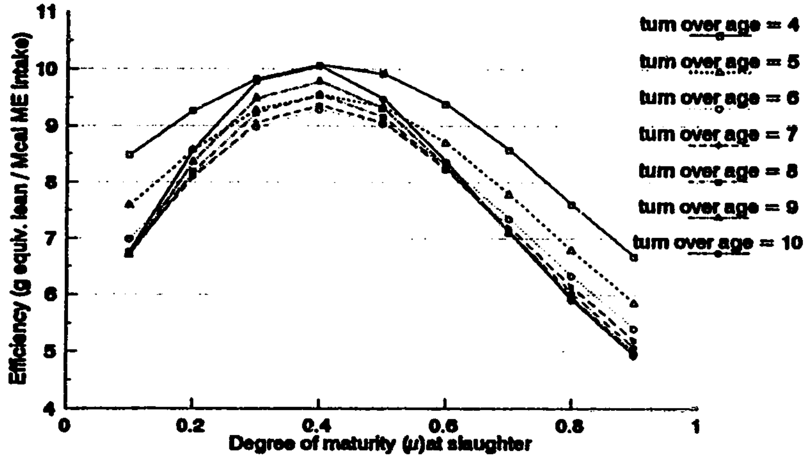
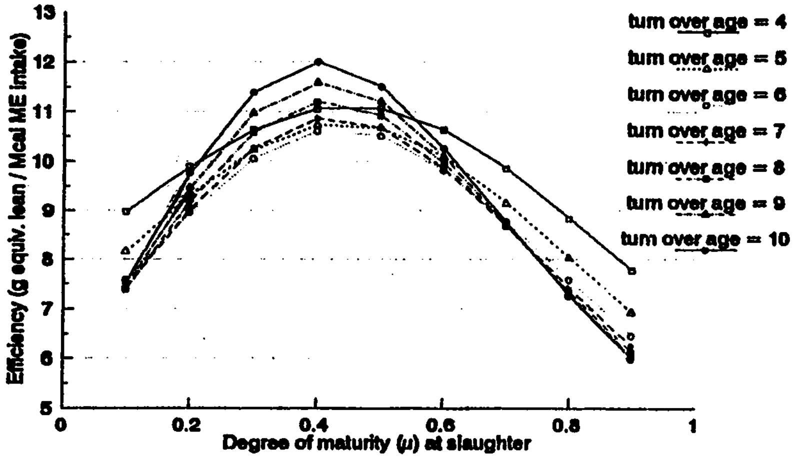
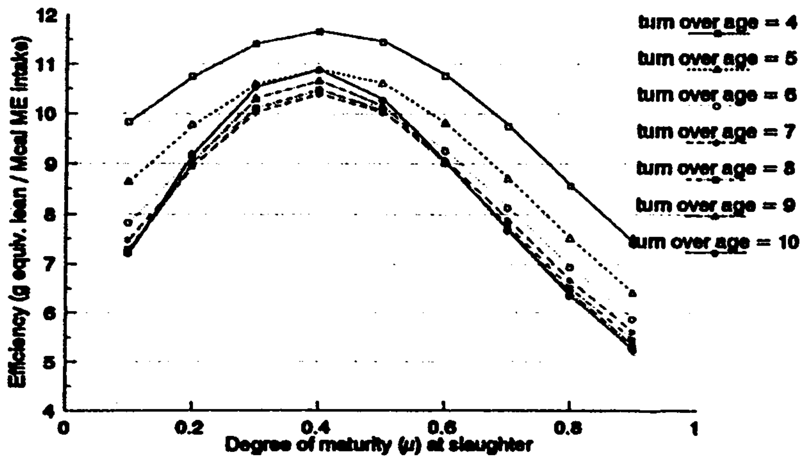

Comparison of overall efficiency for reproductive rates (r) of 0.8 and 1.0, while varying the feed required by the dam to achive r of 1.0 (Turnover age =10yr)

Figure III.7. Effect of varying the age at turnover on the overall efficiency (g equivalent lean Mcal^{-1} ME), reproductive rate = 1.0.


Hereford


Beef Synthetic 1


Beef Synthetic 2

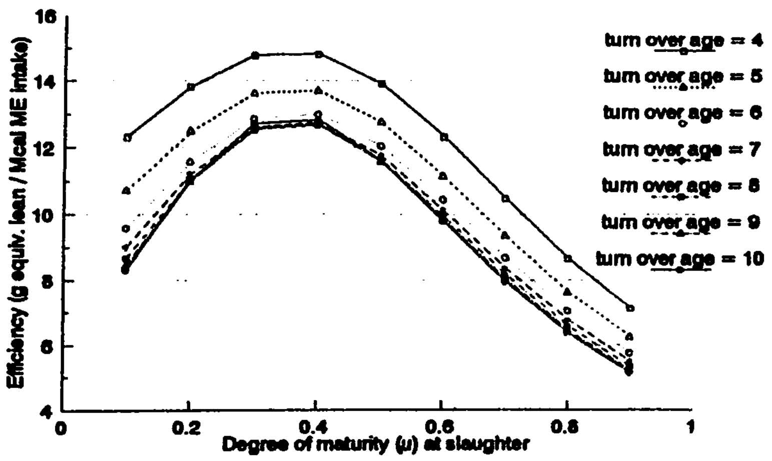
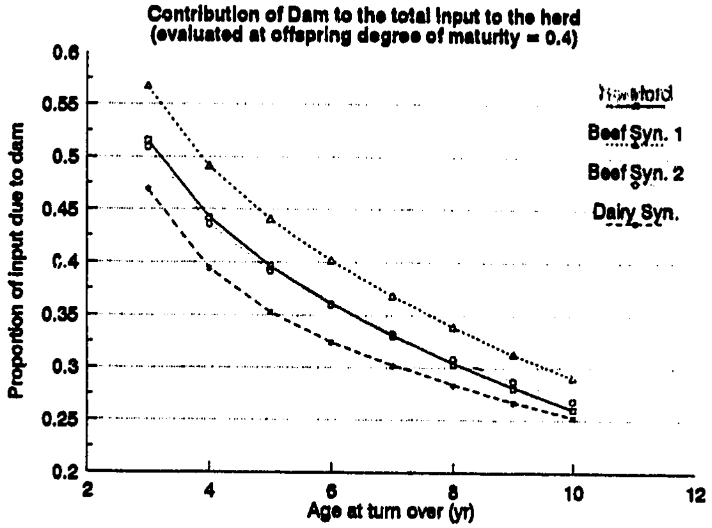
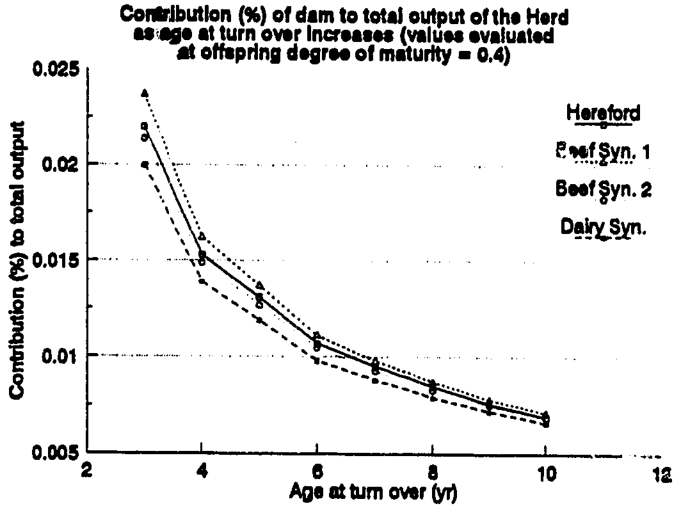

Dairy Synthetic

Figure III.8. Proportionate contribution of the dam to the input to, and the output (%) from the herd and the degree of maturity of the dam at culling (herd turnover).


Contribution of Dam to the total input to the herd (evaluated at offspring degree of maturity = 0.4)


Contribution (%) of dam to total output of the Herd as age at turn over increases (values evaluated at offspring degree of maturity = 0.4)

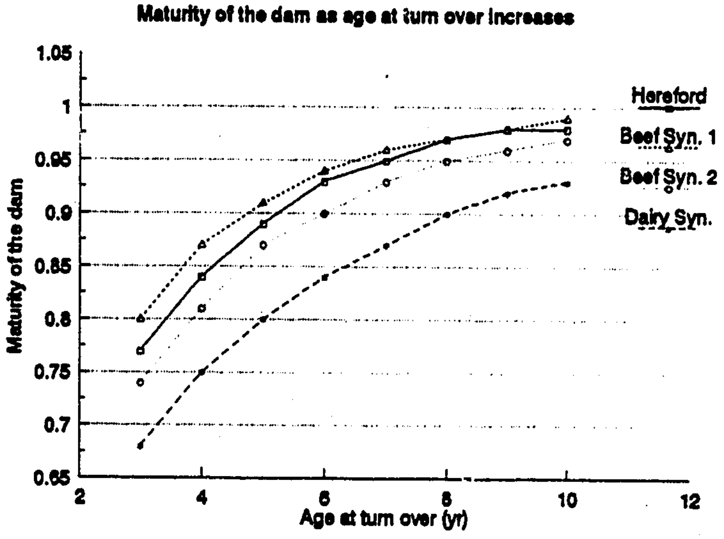

Maturity of the dam as age at turn over increases

Figure III.9 Cumulated environmental corrections (Mcal ME kg^{-1} mature size) by month of calving.

Cumulated ME intake /kg mature size for environmental corrections, depending on month of calving (SY1)

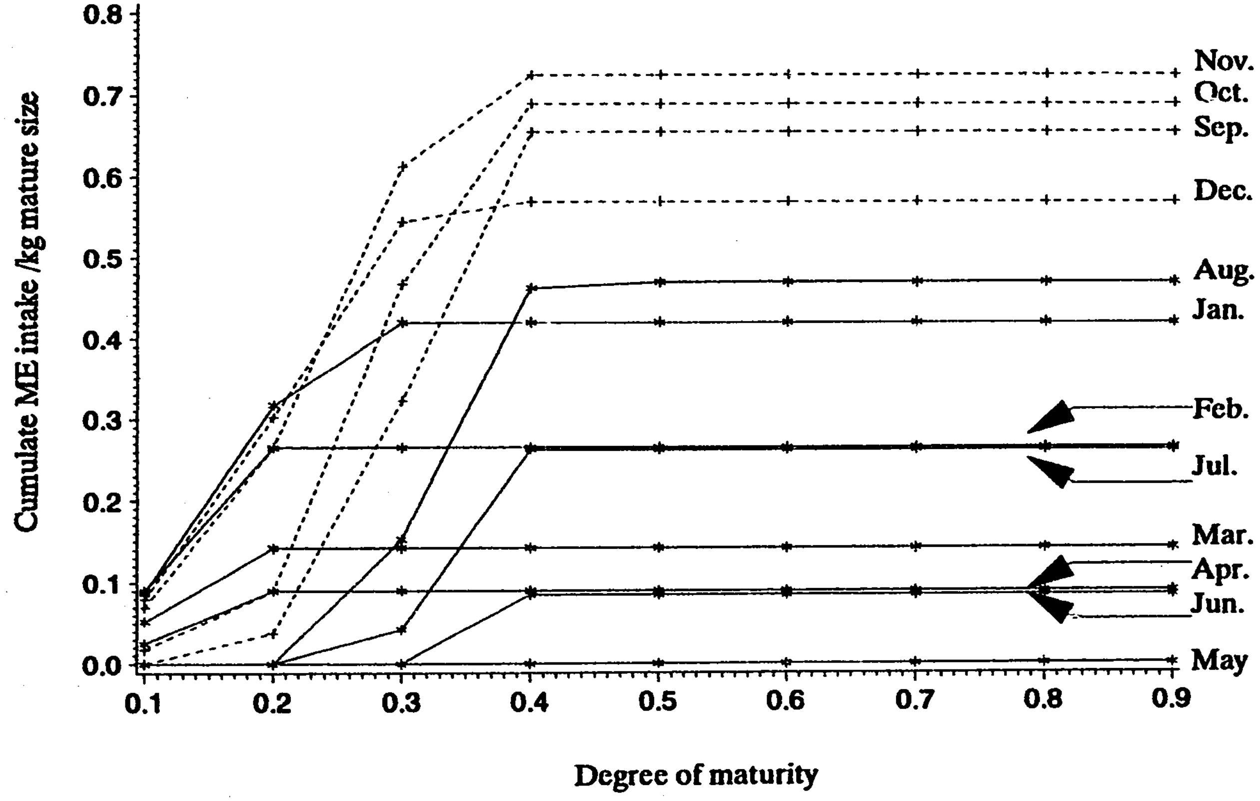
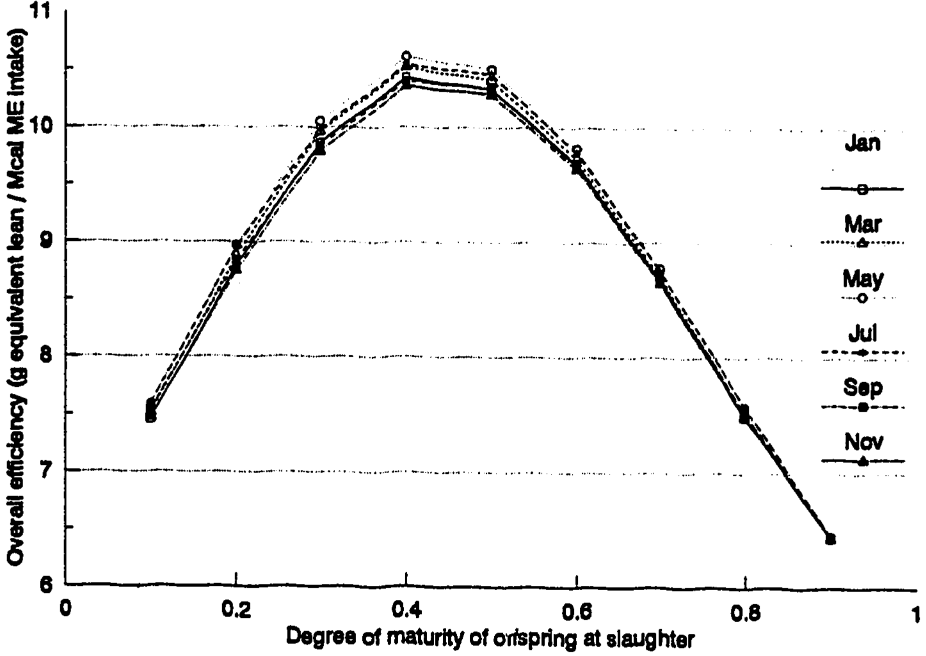
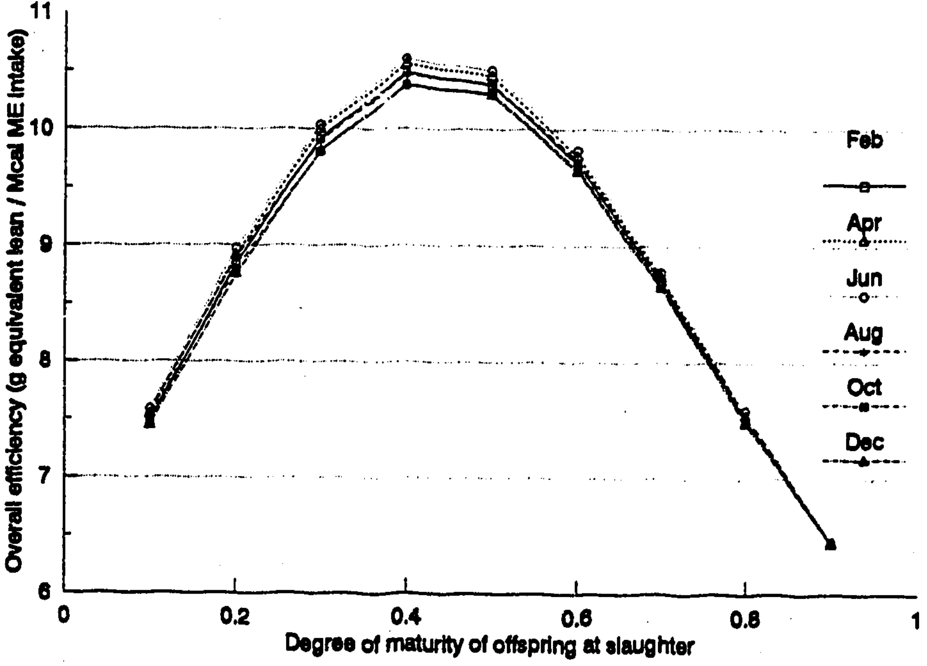


Figure III.10. Influence of month of calving on overall efficiency (g equivalent lean $Mcal^{-1}$ ME) in Beef Synthetic #1

Influence of month of calving on Overall Efficiency



Influence of month of calving on Overall Efficiency



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4. Efficiency in sex-ratio controlled and dairy-beef production systems

4.1. Introduction

Advances in biological technology has made complete sex ratio control in farm animals feasible. Although success in the sexing of semen has been reported (Shapley, 1983), the accuracy of such procedures is still in doubt (Van Vleck, 1986) and therefore this method of sexing is not yet practical (Church et al., 1986; Nicholas, 1989). Altered sex ratios resulting from subjecting semen to various treatments (Nicholas, 1989) have however been reported and since there is a difference between the X and Y male gametes, one can speculate that it is only a matter of time before a procedure to separate or selectively inactivate the sperm types from a semen sample is developed (Nicholas, 1989).

Successful sexing of embryos at early stages of development has also been reported (Betteridge et al., 1981; White et al., 1984) and more progress has been noted in this area (Nicholas, 1989). Splitting embryos into two identicals is now a relatively common commercial practice (Baker and Shea, 1985), though regular production of larger numbers of identicals from a single embryo appears to be less practical (Nicholas, 1989) and perhaps also less desirable from the stand point of increased inbreeding. Techniques such as multiple ovulation and embryo transfer (MOET) are already in use especially in dairy cattle (Seidel, 1984; Roberts, 1986). Hence multiple sexed-embryo transfer is practical even though this will require a lot of technological input. In Canada, the cost of producing sexed embryos appears to be declining while the success rate (in terms of successful sexing and pregnancy rate on transfer) appears to be increasing (Davidson, 1985, 1989, 1991) and some farmers are already employing embryo freezing and transfer in their operations (Davidson, 1991).

The technology to control the sex of animals born is therefore available. Whether the cost of achieving such control is justified is a moot point and hence studies to evaluate the usefulness of sex control, be it achieved by semen sexing or embryo sexing and splitting, appears warranted.

In Europe, beef is produced mainly as a by-product of dairying. Zarnecki and Stolzman (1986), and Freeman (1988) estimate that 80% of the beef in Western Europe is derived from dairy and dual purpose cattle whereas Eastern Europe and the Soviet Union derive probably more than 90% of their beef from the same source (Zarnecki and Stolzman, 1986). Only about 20% of the beef originates from dairy herds in North America (Freeman, 1988). In a dairy herd, a cow is often required to conceive only as means of getting her to milk. The resultant calf (unless when required for replacement) is of no significance to the dairy industry. It makes intuitive sense to use such calves for beef production. Therefore, unless when a replacement is required, crossing dairy cows to beef bulls and using the resulting calves for beef ought to be a more efficient system, relative to the traditional cow/calf system. Andersen (1978) claims that from a biological point of view, this is the most efficient production form, as the maintenance requirement of the breeding cow simultaneously forms the basis for milk production, calf production and the cow's own growth till the age of 4 years. It will therefore be interesting to compare the efficiency of such a system and that of the traditional as well as the sex-controlled systems of beef production.

The objectives of this study were therefore:

i. To investigate the effect of complete and partial sex ratio control on the overall efficiency of beef production, taking into consideration the cost of achieving such control.

ii. To evaluate the efficiency of beef production from a dairy herd with an average milk production.

In both cases the system will be compared to the traditional system of beef production.

4.2. Materials and methods

The model, BEM, (chapter 2) was used to simulate overall efficiency under various sex-controlled scenarios. It was first assumed that sex-control was complete. An 'all male' and an 'all female' system were then evaluated. In the all male system, it was assumed that except for dam replacement, all offspring produced were male. The cost of breeding (cost required to attain given levels of reproduction and sex control) was then successively increased by 10% relative to the original cost of achieving pregnancy in a traditional system. A case of incomplete sex control was also considered. In traditional systems, the sex ratio is 1:1. Instances where one sex has 80% or 90% probability of occurring (ie sex ratios of 4 : 1 or 9 : 1) were also considered. In all cases, the age at turn over was varied from the minimum possible to 10 years. A reproductive rate of 0.8 and 1.0 were investigated in all cases.

The all female system was then modified to evaluate the theory of Taylor et al., (1985) that if a cow could be slaughtered soon after her replacement is produced, the system would be more efficient. This is the 'single sex bred heifer' system (SSBH, Taylor et al., 1985). In such a system, the possibility of the herd becoming rapidly extinct is high (Taylor et al., 1985) unless sex control is complete (100%) and accompanied by a reproductive rate of at least 1.0. Conversely, if sex control is not complete the herd would still become rapidly extinct even with a reproductive rate of 1.0. Such a system will therefore require a lot of technological input and so the breeding cost is likely to be extremely high relative to that of a traditional system. Hence the cost of breeding, relative to that in a traditional system, was also increased successively to investigate the effect of the high cost of achieving and maintaining such a system. The breeding cost in traditional systems was computed as the cost of maintaining a breeding male minus his salvage value at slaughter divided by the number of offspring sired by him (see chapter II, section 2.3.1).

Taylor et al. (1985) assumed a breeding cost of 1 MJ kg^{-1} mature weight in traditional systems. Under the current calculations (chapter II), the breeding cost for all breed groups (converted from Mcal kg^{-1} mature weight to MJ kg^{-1} mature weight) ranged from 0.5 to 0.62. These values are therefore about half the value assumed by Taylor et al. (1985). However the breeding cost figures used here are fairly conservative since in the industry bulls are not turned over as rapidly as at the University research station.

For dairy-beef systems, mature milk production was assumed to average 5000 kg milk (3.5% fat) per cow per year. This was intended to be a conservative estimate as the average milk production reported for dairy cows in Canada for the years 1988 and 1989 were 5,689 and 5,806 kg cow^{-1} $year^{-1}$ respectively (Dairy Farmers of Canada, 1990). A reproductive rate of 0.8 was assumed and the effect of age at culling was also investigated. The results were then compared to the traditional and sex controlled system under the same reproductive rate and age at turn over. The dairy breed was assumed to be crossed with the Beef synthetic #1 as the terminal sire breed group. Since growth parameters of offspring from such a cross were not available, the mean values of the parent breed groups (Table II.2) were assumed.

In all cases, modelling experiments were intended to compare a sex-ratio controlled system with the same reproductive rate and turnover age, a traditional system with identical reproductive rate and operated at maximum efficiency (turned over as soon as the dam replacement is produced) and a traditional system turned over at 4 years of age with the dairy-beef system.

4.3. Results and discussion

4.3.1. 'All male', 'all female' and the 'single sex bred heifer' production systems

The results of overall efficiency in the mainly male and all female systems are shown by Figure IV.I, for a reproductive rate of 1.0 and complete (100%) sex control. The values reported are for only the SY1 and SD breed groups, representing the fastest and slowest maturing breed groups. The mainly male system was generally more efficient than the all female system, and the difference between the two tended to increase with increase in the degree of maturity of the offspring at slaughter and also with increase in the age at turnover. In the SY1 breed group the difference between the male and female systems ranged from 4% to 52% (depending on the degree of maturity of offspring at slaughter) when the culling age is 4 years but increased to 12 - 77% when the culling age is 10 years. In the SD breed group the differences were 3.5 - 58% and 12 - 79% at 4 and 10 years of age at culling. The male system also tended to attain its maximum efficiency at a later degree of maturity than the female system.

The differences between male and female production systems reported here are large. The trend is in agreement with the fact that males are more efficient than females in the feedlot. Foote and Miller (1971) estimated an increase in efficiency of 10% in male systems of beef production and an economic advantage of $20.00 for each male offspring replacing a female. Fennessy and Thompson (1989) reported a similar trend in efficiency in favour of male red deer compared to females. The difference between sexes were however small in their study (1% - 3.5%). In contrast, Taylor et al., (1985) predicted little difference between male and female systems. They attributed this to the fact that the dam's maintenance cost was indeed the largest cost and that maintaining either male or female offspring did not significantly influence this cost and hence the lack of difference in overall efficiency. Taylor et al. (1985) however used one equation of intake for all genders and breeds. Hence males and females had identical scaled feed intakes. This would minimize male and female differences in overall efficiency. In the current study, all males were assumed to be intact and from the cumulative feed intake curves (chapter 2, figures II.5 and II.6) it would appear there is a large enough gender difference in intake (less intake for males per unit mature size) to account for a difference in efficiency. Besides, the males were assumed to be 1.4 times the size of the female at each degree of maturity. Hence the males would produce 1.4 times more lean meat but consume less feed.

Comparisons of males and females were similar to the above under partial sex control or reproductive rates less than unity, though the actual differences tended to be less than those reported above.

For comparison, the results for the single sex bred heifer (SSBH) system and the maximum overall efficiency possible in a traditional system with reproductive rate of 1.0 and a similar traditional system turned over every 4 years are included and presented in Figure IV.2. The SSBH was clearly the best system exceeding all others in efficiency by at least 21% (Beef synthetic #1) or 30% (Dairy synthetic). The 'all male' system turned over at 3 years of age was the next best system, but this system was at most 5% more efficient than a traditional system operating at maximum efficiency (incidentally this traditional system is turned over at 3 years as well). The traditional system the SSBH was 27 - 77% (Beef synthetic #1) and 37 - 140% (Dairy synthetic) more efficient than the traditional system operating at maximum efficiency, depending on the degree of maturity of offspring at slaughter. The all female system was less efficient than either the all male system or the traditional system at maximum efficiency, but all systems were more efficient than the traditional systems turned over at 4 years. If however the sex controlled systems are turned over at 4 years of age instead of 3 years, the traditional system at maximum efficiency is 7% (Beef Synthetic #1) or 12% (Dairy synthetic) more efficient than the all male system.

In comparison, Taylor et al. (1985) reported that the SSBH was 50% more efficient than their best traditional system. This though is not directly comparable to the current results since the reproductive rate for the traditional system was set at 0.85 and their dams were crossed to terminal sire breeds 1.8 times larger. However, they did not find any difference between all male systems and traditional systems but their all female system was more efficient than the traditional system. The reverse is true here as under current conditions there is a fairly large difference in intake between males and females to precipitate a difference in efficiency. The reason for the high efficiency of the SSBH system is the feed cost of the dam. In this system, the dam is culled at 2 years, shortly after her first calf. Her carcass is still of prime value (92% of the value of a steer carcass, Table II.15). Indeed under practical conditions most of such cows would produce carcasses that grade A1/A2. This makes the production of her replacement almost incidental, as if the calf was produced in the process of fattening the dam for market. Hence the efficiency would tend to be very high, approaching that of an individual animal.

The implication is that if a sex-ratio controlled system of production is to be considered, the best option would be the single sex bred heifer system. If however a male system is considered, then it is best to turn it over as quickly as possible (every 3 years) since only then will it out-perform the most efficient traditional system. There appears to be no point in adopting an all female system beyond the SSBH stage since the best traditional system would do better.

4.3.2. Cost of sex-ratio control

The effect of increasing the breeding cost (cost required to maintain a specified reproductive rate and level of sex control) in a complete (100%) sex-ratio controlled system in multiples of 10, relative to that in a traditional system, is shown by Figure IV.3 for a reproductive rate of 1.0, and turned over at 2 years of age (SSBH). As the breeding cost is increased, the overall efficiency declines as would be expected, and when this cost is 80 times the cost in a traditional system, the system is no longer more efficient than the traditional system of production operated at maximum efficiency, for all breed groups. If, however, the system is turned over every 4 years instead of 2 years, breeding costs exceeding 30 times that of the traditional system would make the traditional system, operated at maximum efficiency, as efficient as the sex-ratio controlled system (Figure IV. 4). Furthermore, if the reproductive rate is 0.8, breeding costs exceeding 30 times the traditional system also makes the system less efficient (Figure IV. 5). In dollar terms under the current calculations, the breeding cost in the traditional system is about $3.85 - $5.00 per calf (compare with the estimate of Taylor et al., 1985, of £5.00, equivalent to about $10.00). Hence in the case of a SSBH system, the cost of sex control must exceed $300.00 - $400.00 for it not to be profitable. This is a large sum, and implies that for this system not to be efficient, the technology of sex control must be really inefficient, and hence costly. However, if the system is turned over at 4 years, or if the reproductive rate is 0.8, then the cost of technology need only exceed $115.00 - $150.00 for the system not to be efficient; i.e., sex control should be highly efficient and therefore cheap for such systems to be efficient. In addition, the longer such systems are maintained before turnover, the higher the efficiency in sex control technique will have to be and hence cheaper, for such systems to be profitable.

The conclusion from this is that, whatever type of sex control operation is adopted, as rapid a turnover as possible provides the best chance for success, even if the cost of the sex control is high; i.e., even if the technology is not efficient.

4.3.3. Level of sex control

Figure IV.6 is a comparison of 3 levels of sex-ratio control, 100%, 90%, and 80% and the turnover ages for each system is the earliest possible for each, 2, 2.11 and 2.25 years respectively, all represented here as 2+ years. The levels of sex-ratio control indicated here represent the proportion of male offspring in the herd, and rises by 10% each time to 100%. The results indicate that higher levels of sex-ratio control result in more efficiency than lower levels, as might be expected. Differences between sex-ratio control levels increased with the degree of maturity of the offspring at slaughter, but declined with age at turnover (compare Figures IV.6 and IV.7). The differences were largest in the SD breed group and smallest in SY1 breed group. In the former group, the difference ranged from 6% to 27% from one level to the other at 2+ years of age at culling but declined to <1% to 5% by 4 years of age at culling. In SY1, the respective differences were 2% to 13% and <1% to 4% at 2+ and 4 years of age at culling. Beyond 4 years of age at turnover however there were no obvious further declines in the differences in efficiency from one level to the other up to 10 years of age at culling. Fennessy and Thompson (1989) reported increases in efficiency from about 1% at 23 weeks of age slaughter to 3.5% at 63 weeks in red deer, with each 10% increase in the proportion of male offspring. However, they did not investigate the effect of age at turnover in this case. Their results are therefore similar to those reported here, at least in trend. By contrast, Taylor et al (1985) reported less than 1% differences even at 100% sex-ratio control.

It should be noted that under practical conditions, differences in level of sex-ratio control will be associated with differences in cost, possibly negating the differences in overall efficiency. It is however likely that in the case of the SSBH system, the cost differences will have to be substantial to make it less efficient. These results also imply that under partial sex control, the cost of sex control should be really cheap for the systems to be efficient. For example, in the SD breed group, 80% partial sex control turned over at 2.25 years is still 25 - 59% more efficient than the traditional system at maximum efficiency. If however this system is maintained for 4 years instead of 2.25, then it will be 16 - 35% less efficient than the traditional system at maximum efficiency, so that if the cost of sex control is not cheap, the efficiency will be far worst in this situation.

4.3.4. Other trends

The influence of age at turnover in sex-ratio controlled systems was similar in trend to that in traditional systems. Overall efficiency declined with increase in age at turnover up to 6 years. Beyond 6 years turnover age there was some recovery in overall efficiency, though this was marginal in the case of the all female system. These results are shown in Figures IV.7 (all males) and IV.8 (all females). The declines in overall efficiency from 2 years to 3 years of age at culling and from 3 years to 4 years at culling were large, but beyond 4 years were marginal up to 6 years. At the point of maximum efficiency (offspring degree of maturity at slaughter, μ, = 0.4), the reduction in efficiency between culling at 2 years and other ages ranged from 26.4% to 48% for Hereford, 19% to 43% for Beef synthetic #1, 30% to 66% for Beef synthetic #2 and 30% to 74% for Dairy synthetic in the all male system. This is probably a function of the decline in dam carcass value over the years (see Table II.15) and the corresponding rise in her maintenance cost with increasing maturity.

Breed differences under sex controlled systems were also similar to those under traditional systems. Differences between breed groups in the mainly male system ranged from 1% to 42% (depending on the degree of maturity of offspring at slaughter) when the culling age was 4 years, but declined to <1% to 20% when the culling age was 10 years. Differences between breed groups at the point of maximum efficiency ranged from 3 - 40% at 4 years and declined to 2 - 20% at 10 years of age at culling (Figure IV.9). As in the traditional system, the SY1 breed group tended to maintain its efficiency better than the other breed groups with increasing age at culling. The all-female system followed a similar pattern as the male system but differences were less and the decline in efficiency beyond the peak was more rapid.

4.3.5 The dairy-beef system

Overall efficiency curves for the dairy-beef system with a reproductive rate of 0.8 are presented in Figure IV.10. Overall efficiency increases with increase in age at turnover. This contrasts with the traditional and sex-ratio controlled systems in which efficiency declined with increasing turnover age. In further contrast to the traditional and sex-ratio controlled systems of beef production, the maxima are generally obtained when the offspring are slaughtered within the early stages of maturity (i.e., 10% to 30% mature). This implies that to obtain maximum benefit at each turnover age offspring should be sold before they are 40% mature i.e., within their first year of life (at weaning, since this is most practical).

Differences between consecutive turnover ages ranged from a low of 1% to 8% to a high of 1% to 17% depending on the offspring degree of maturity at slaughter. The difference between the overall efficiency when turnover age is 10 years and that when it is 4 years (best and worst turnover ages in the study) ranged from 1% - 95%. Differences between turnover ages were generally largest during the early stages of maturity of the offspring. However as the turnover age increases, the decline in efficiency is more rapid with advancing maturity of the offspring and by the time offspring are slaughtered at 90% maturity, differences are 1% or less. Of course, there is no reason to maintain offspring in the herd till they are 90% mature before slaughter.

The explanation for this trend is found in Figure IV.11. The dam's feed intake is still the largest proportion of the total input but it is decreasing with increase in turnover age (Figure IV.11a). There is however an opposing and probably larger effect; milk output is increasing with age at turnover and is a far larger proportion of the total output than the dam's feed intake is of total input (compare Figures IV.11a & c). This tends to offset the declining dam's feed cost and hence the increase in overall efficiency with increase in age at turnover. Although the extra feed required to produce the milk also rises with age, its contribution to total input is not as large as the contribution of milk to output, nor the contribution of the dam's feed intake to input. The effect of the extra and increasing amount of feed required for milk production can therefore be considered marginal.

Comparisons between the dairy-beef system, the traditional and sex-controlled systems are presented in Figure IV.12. The intention was to compare systems with the same reproductive rate and turnover age. However, the efficiency figures obtained for the dairy-beef system were so large that it did not make sense comparing them to far less efficient systems. Hence for this comparison, the most efficient system in the current studies (the single sex bred heifer (SSBH) system, reproductive rate = 1.0 and sex control = 100%, breed group = Dairy synthetic) and the most efficient traditional system (reproductive rate = 1.0, and age at turnover = 3, breed group = Dairy synthetic) were used. Of course such systems are not available and will require some technological investment to implement, whereas dairy-beef system as described here requires no new technology or investment to achieve. Hence the comparisons ought to be biased in their favour and any superiority of the dairy-beef system over these systems should be considered very conservative. It should also be noted that such comparisons are confounded by environmental influences because the beef and dairy breed groups were raised in different environments.

It is obvious from the figure that the worst dairy-beef system (4 years of age at turnover) is still more efficient than either of the best sex-ratio controlled and traditional systems. Differences between the dairy-beef system at 4 years of age at turnover and the single sex bred heifer (SSBH) system ranged from 9% - 87%, whereas at 10 years of age at turnover the dairy beef systems were 10% - 265% more efficient than the SSBH (i.e., 1.1 to 3.65 times more efficient). However, relative to the best traditional system, the lowest difference from the dairy-beef system was 160%. These differences are significant and indicate that a dairy-beef system will be more efficient than a sophisticated, high technology beef system. Although it is likely, that beef from dairy herds will be discounted, the current results suggest that even with a large discount, such systems are unlikely to be less economical than pure beef herds.

There are virtually no reports comparing a dairy-beef system with either pure beef or dairy systems. In Europe, where dairy-beef systems are operating, the focus appears to be on evaluating different terminal (beef) sire breeds (e.g. Liboriussen, 1982; Southgate, 1982; Southgate et al., 1982, 1987; Langholz, 1986) or investigating scenarios for the most profitable dairy-beef production (e.g. Doyle et al., 1985). However, Rozzi et al. (1984) used a linear programming approach to compare dairy-beef production systems with pure dairy systems. They found that producing beef from the dairy system made it 30% more efficient. However, the focus in the current study was on comparing beef production systems hence pure dairy systems were not considered.

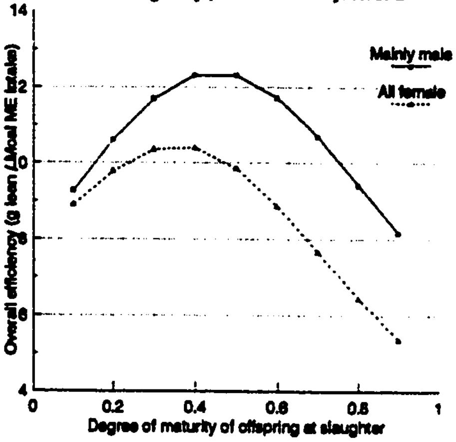
4.4. Summary

A deterministic beef efficiency model (BEM, Chapter II) was used to evaluate and compare system efficiency in sex-ratio controlled and dairy-beef production systems. The results indicated that the 'mainly male' system was 4% - 79% more efficient than the 'all female' system, as the degree of maturity of offspring at slaughter varied. The male system was about 5% more efficient than a comparable traditional system operated at maximum efficiency. However, all the above systems were far less efficient than the single sex bred heifer system (SSBH), the latter being 27% - 140% more efficient. The results also indicated that the cost of achieving the sex control would have to be at least 80 times the breeding cost in a traditional system for the SSBH to be less efficient than the best traditional system. Increasing the proportion of male offspring in the herd by 10% results in about 5% improvement in overall efficiency beyond 3 years age at turnover. At 2 and 3 years turnover age, the differences were larger. Efficiency in a dairy beef system tended to increase with age at culling in contrast to the other systems, because of increasing total milk output. This system was by far the most efficient system. The least difference between it and any other system was 9% (this occurring only if offspring were retained in the herd till they were 90% mature before slaughter) and the least difference between it and the best tradition system was

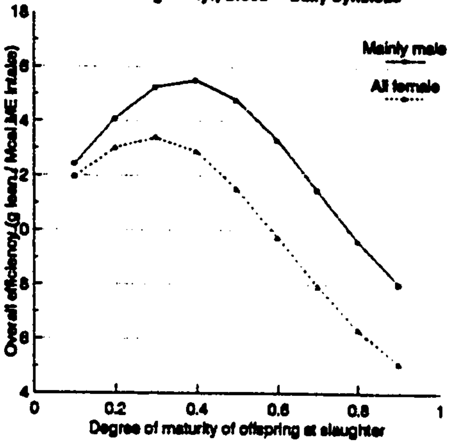
160%. It was thought unlikely that discounting beef from the dairy-beef system would make the system less efficient than the pure beef systems.

Figure IV.1. Comparison of 'all male' and 'all female' systems of beef production for different ages at turnover.

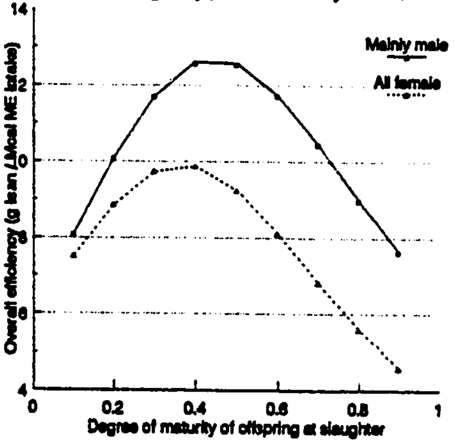
Comparison of mainly male and female systems in a sex-controlled system with reproductive rate =1.0 and turn over age =4yr; Breed = Beef Synthetic 2



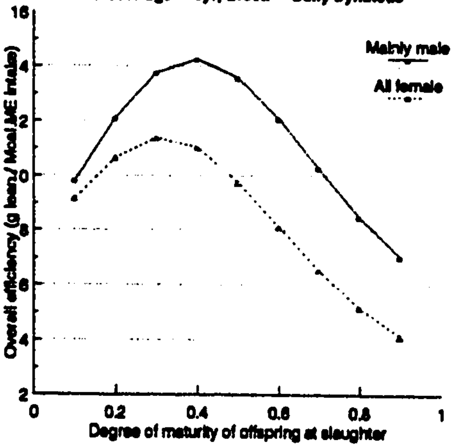
Comparison of mainly male and female systems in a sex-controlled system with reproductive rate =1.0 and turn over age = 4yr; Breed = Dairy Synthetic



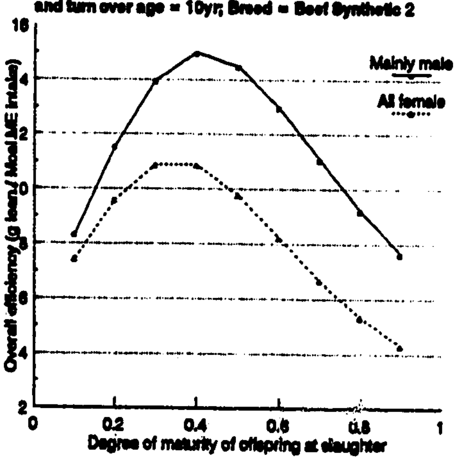
Comparison of mainly male and female systems in a sex-controlled system with reproductive rate =1.0 and turn over age =8yr; Breed = Beef Synthetic 2



Comparison of mainly male and female systems in a sex-controlled system with reproductive rate =1.0 and turn over age = 8yr; Breed = Dairy Synthetic



Comparison of mainly male and female systems in a sex-controlled system with reproductive rate =1.0 and turn over age = 10yr; Breed = Beef Synthetic 2



Comparison of mainly male and female systems in a sex-controlled system with reproductive rate =1.0 and turn over age =10yr; Breed = Dairy Synthetic

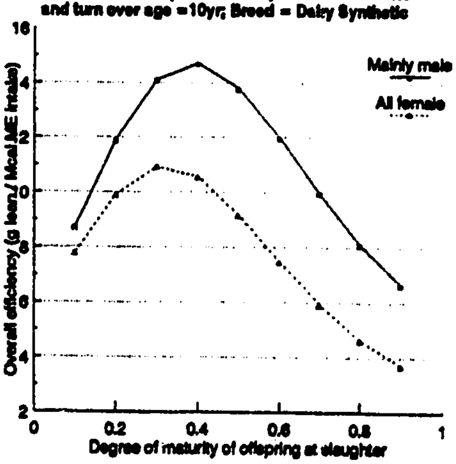
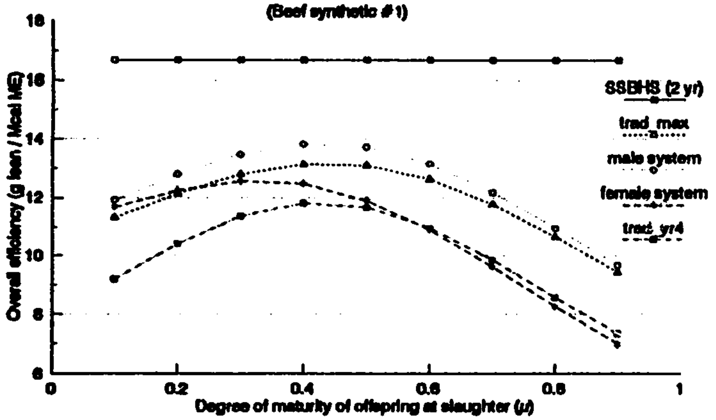
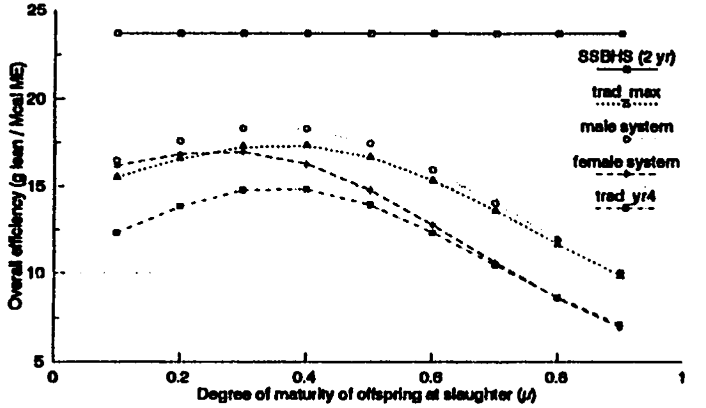


Figure IV.2. Comparison of some sex-ratio controlled systems of beef production with the traditional systems.

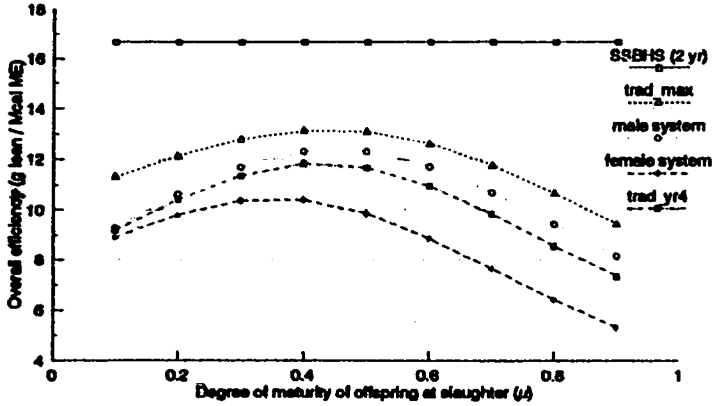
Efficiency in 'mainly male' and 'all female' systems at 3yr of age at culling. The maximum in a traditional system is added for comparison. (Beef synthetic #1)



Efficiency in 'mainly male' and 'all female' systems at 3yr of age at culling. The maximum in a traditional system is added for comparison. (Dairy synthetic)



Efficiency in 'mainly male' and 'all female' systems at 4yr of age at culling. The maximum in a traditional system is added for comparison. (Beef synthetic #1)



Efficiency in 'mainly male' and 'all female' systems at 4yr of age at culling. The maximum in a traditional system is added for comparison. (Dairy Synthetic)

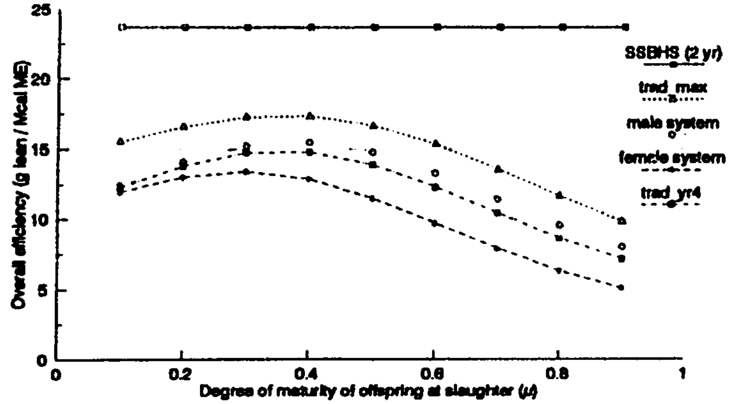
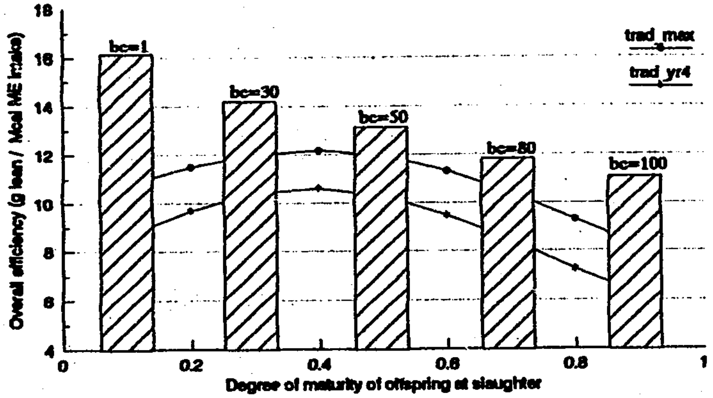


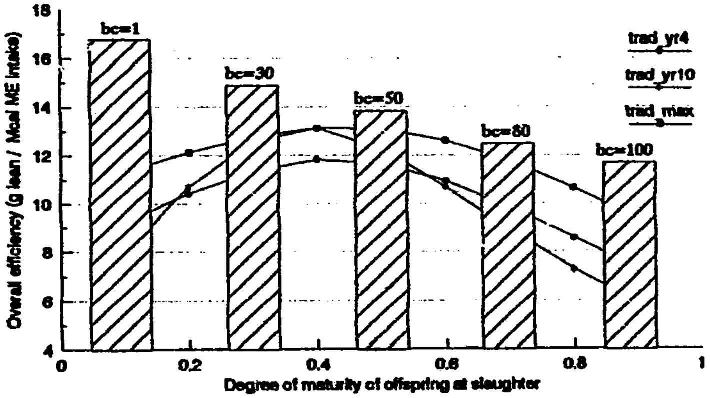
Figure IV.3. Effect of increasing the breeding cost in a single sex bred heifer system by multiples of that in the traditional system: a comparison with the traditional system.

Effect of increasing breeding cost (bc) of a sex controlled system in multiples of that of a traditional system; breed = Hereford, r = 1.0, s= 100%.



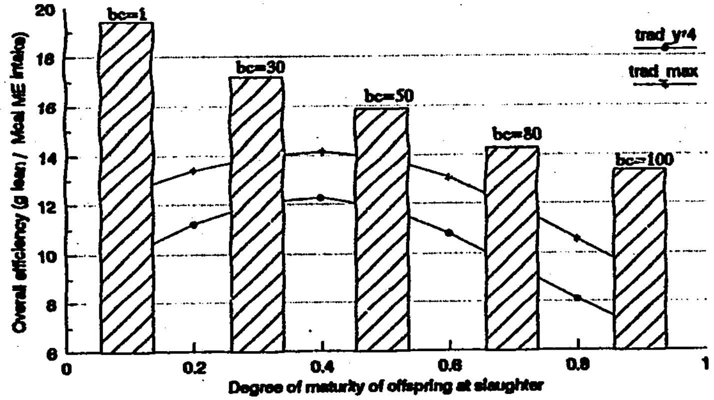
Single sex bred heifer system.

Effect of increasing breeding cost (bc) of a sex controlled system in multiples of that of a traditional system; breed = Beef Syn. #1, r = 1.0, s= 100%.



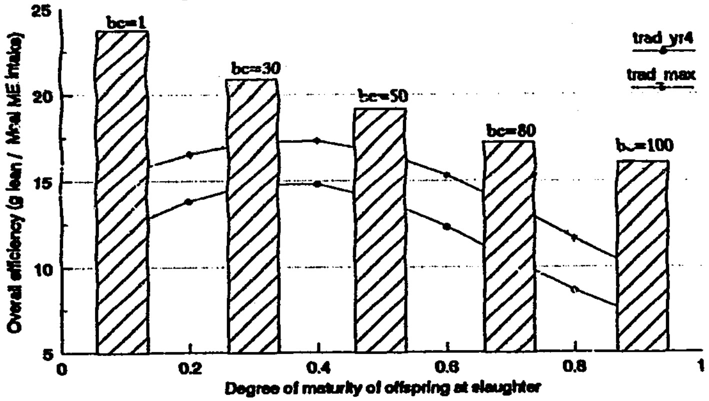
Single sex bred heifer system.

Effect of increasing breeding cost (bc) of a sex controlled system in multiples of that of a traditional system; breed = Beef Syn. #2, r = 1.0, s= 100%.



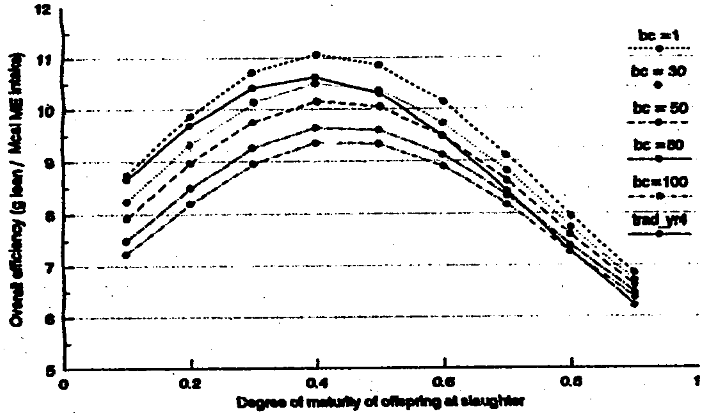
Single sex bred heifer system.

Effect of increasing breeding cost (bc) of a sex controlled system in multiples of that of a traditional system; breed = Dairy Syn., r = 1.0, s= 100%.

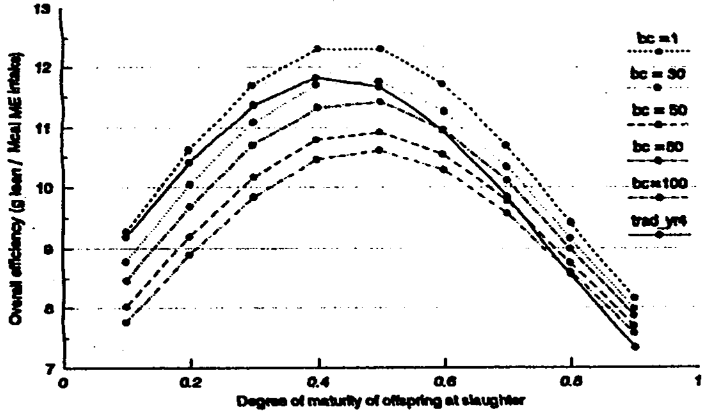


Single sex bred heifer system.

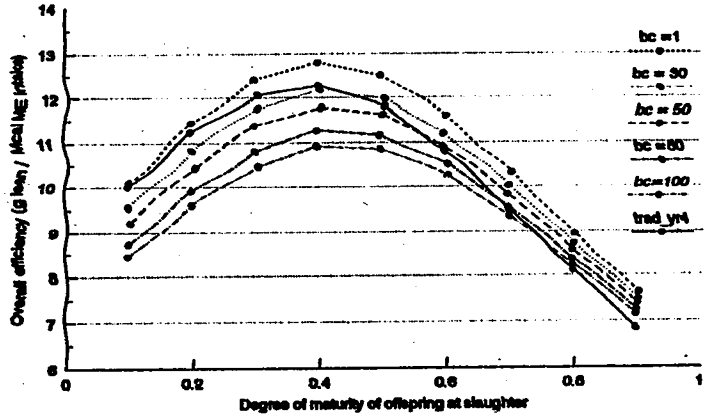
Figure IV.4. Effect of increasing the breeding cost in a sex--ratio controlled system with a reproductive rate of 1.0 and turned over at 4 years of age on the overall efficiency (g equivalent lean $Mcal^{-1}$ ME) relative to that in a traditional system.



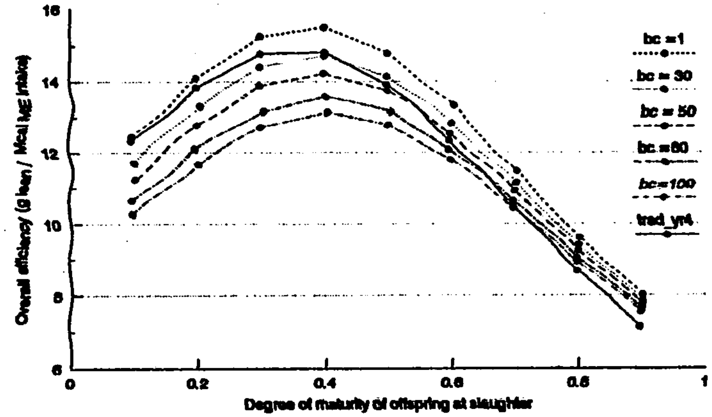
Effect of increasing breeding cost (bc) of a sex controlled
system in multiples of that of a traditinal system.
Breed = Hereford, Age at turnover = 4 yr, r = 1.0, s= 100%.



Effect of increasing breeding cost (bc) of a sex controlled
system in multiples of that of a traditional system.
Breed = Beef Syn. #1, Age at turnover = 4 yr, r = 1.0, s= 100%.



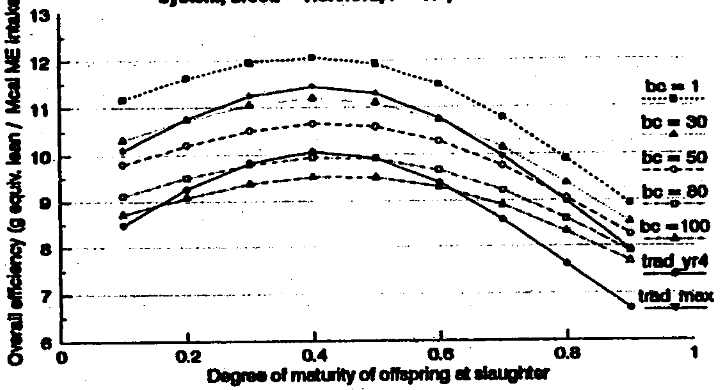
Effect of increasing breeding cost (bc) of a sex controlled
system in multiples of that of a traditional system
Breed = Beef Syn. #2, Age at turnover = 4 yr, r = 1.0, s= 100%.



Effect of increasing breeding cost (bc) of a sex controlled
system in multiples of that of a traditional system.
Breed = Dairy Syn., Age at turnover = 4yr, r = 1.0, s= 100%.

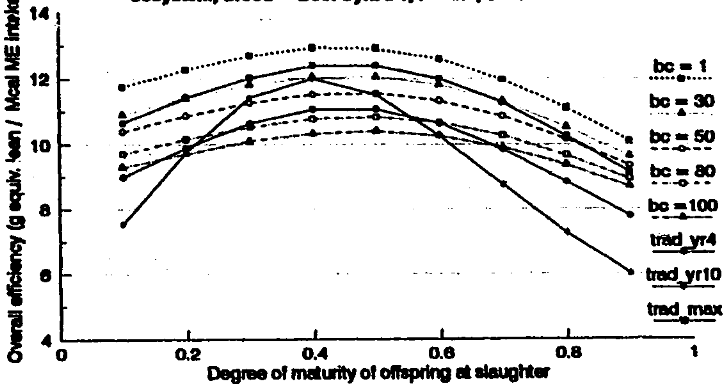
Figure IV.5. Effect of increasing the breeding cost in a sex-ratio controlled system with reproductive rate = 0.8 and turned over at 3 years on the overall efficiency (g equivalent lean Mcal^{-1} ME) relative to that in the traditional system.

Effect of increasing breeding cost (bc) of a sex controlled system: relative to that of a traditional system; breed = Hereford, r = 0.8, s= 100%.



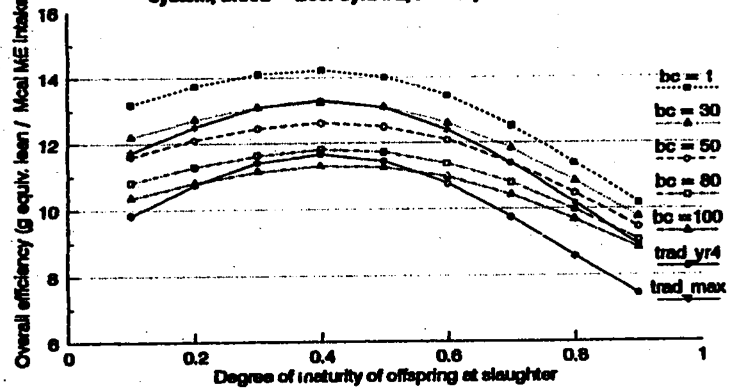
Age at culling = 3yr

Effect of increasing breeding cost (bc) of a sex controlled system relative to that of a traditional system; breed = Beef Syn. #1, r = 0.8, s= 100%.



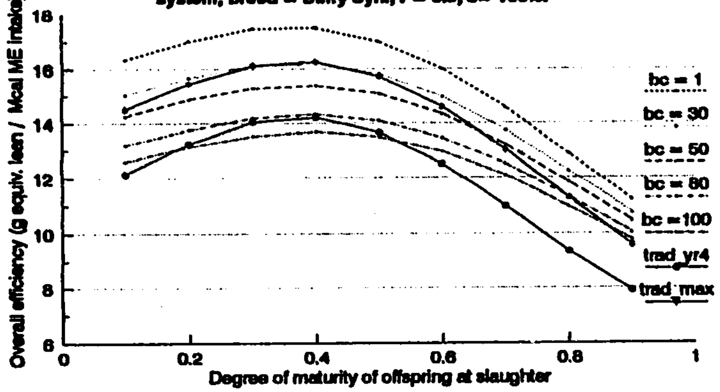
Age at culling = 3yr

Effect of increasing breeding cost (bc) of a sex controlled system relative to that of a traditional system; breed = Beef Syn. #2, r = 0.8, s= 100%.



Age at culling = 3yr

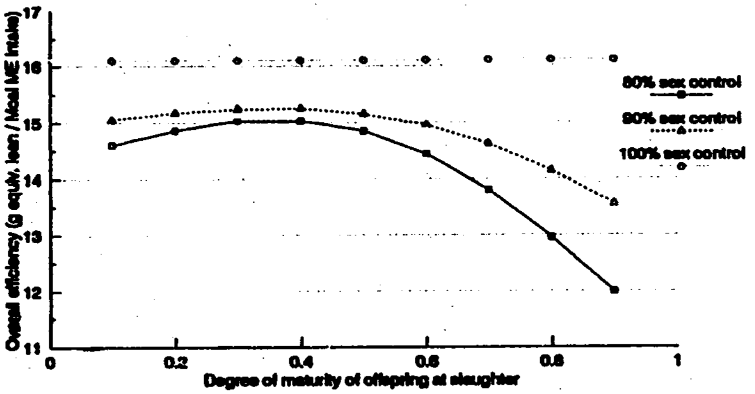
Effect of increasing breeding cost (bc) of a sex controlled system relative to that of a traditional system; breed = Dairy Syn., r = 0.8, s= 100%.



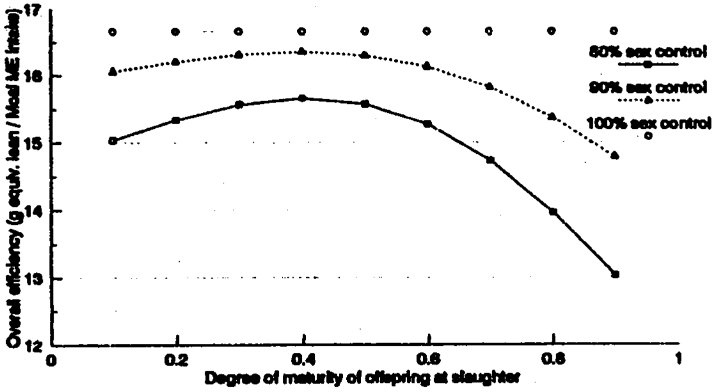
Age at culling = 3yr

Figure IV.6. Effect of level of sex-ratio control (proportion of male offspring) on overall efficiency (g equivalent lean $Mcal^{-1}$ ME).

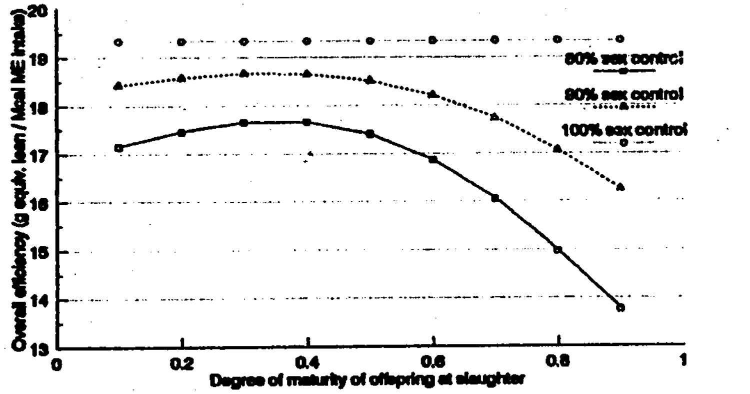
Comparison of efficiency due differing levels of sex control. Breed = Hereford, r = 1.0, Age at culling = 2+ years



Comparison of efficiency due differing levels of sex control. Breed = Beef Syn. #1 r = 1.0, Age at culling = 2+ years



Comparison of efficiency due differing levels of sex control. Breed = Beef Syn. #2 r = 1.0, Age at culling = 2+ years



Comparison of efficiency due differing levels of sex control. Breed = Dairy Syn., r = 1.0, Age at culling = 2+ years

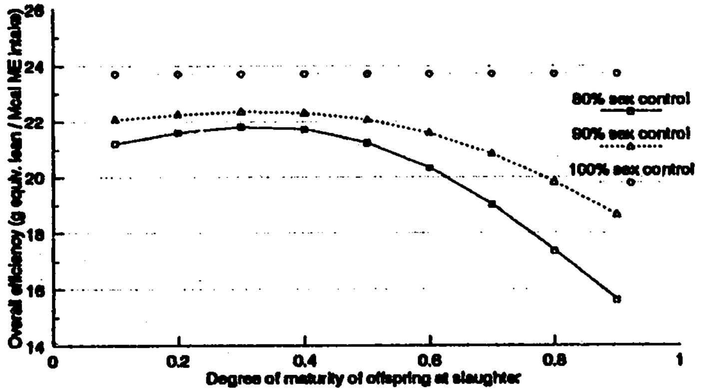
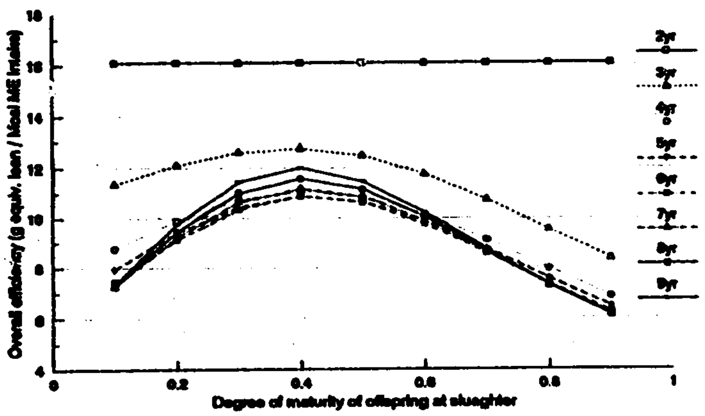
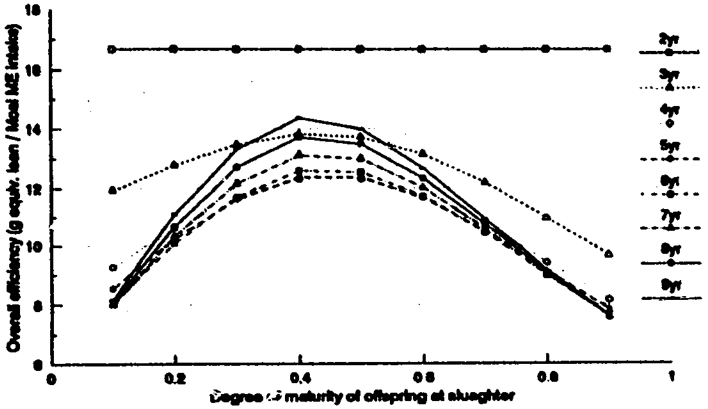


Figure IV.7. Effect of age at turnover on the efficiency (g equivalent lean $Mcal^{-1}$ ME) in 'all male' systems of beef production

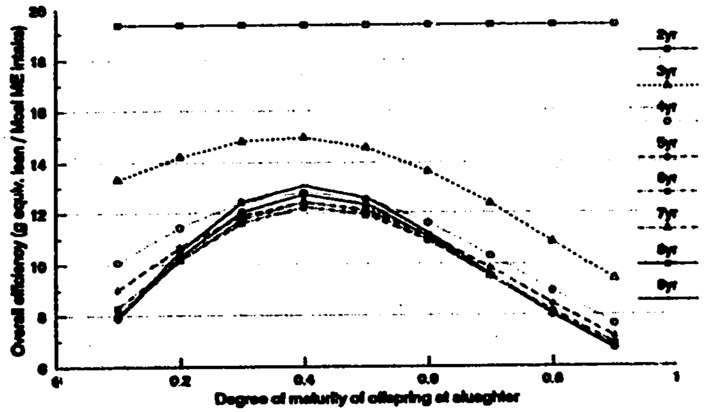
Effect of age at turn over on overall efficiency in sex controlled systems. Sex control = 100% (male) reproductive rate =1.0 and Breed = Hereford



Effect of age at turn over on overall efficiency in sex controlled systems. Sex control = 100% Reproductive rate = 1.0 and Breed = Beef Syn. #1



Effect of age at turn over on overall efficiency in sex controlled systems. Sex control = 100% Reproductive rate = 1.0 and Breed = Beef Syn. #2



Effect of age at turn over on overall efficiency in sex controlled systems. Sex control = 100% Reproductive rate = 1.0 and Breed = Dairy Syn.

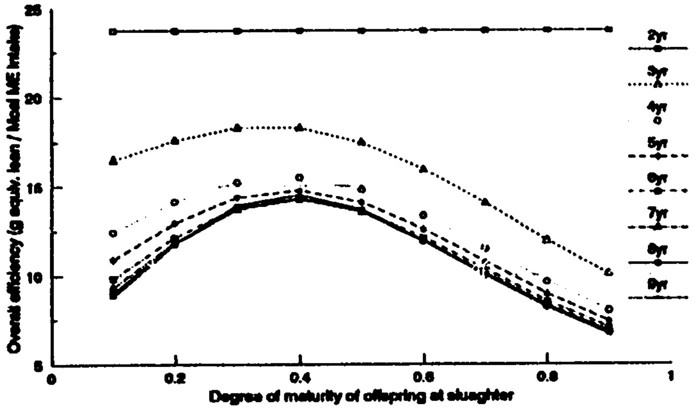
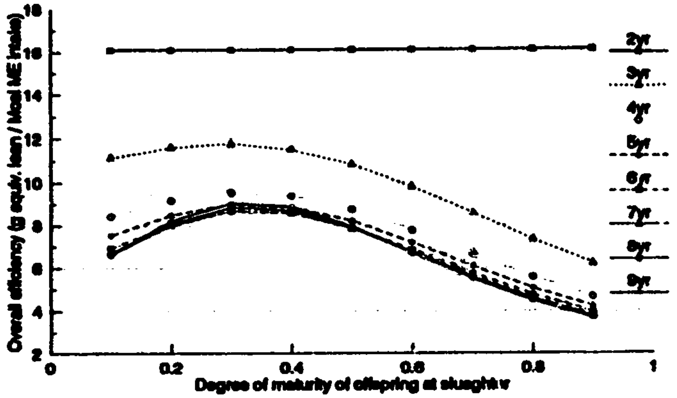
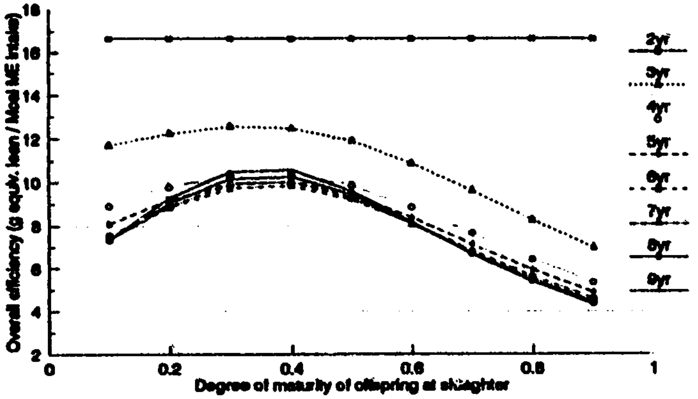


Figure IV.8. Effect of age at turnover on efficiency (g equivalent lean $Mcal^{-1}$ ME) in 'all female' systems of beef production

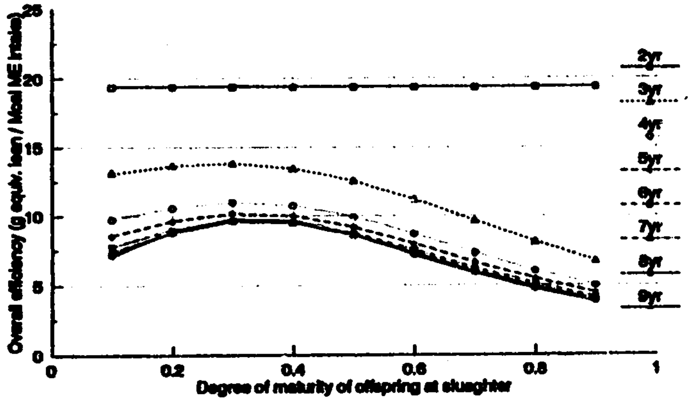
Effect of age at turn over on overall efficiency
In sex controlled systems. Sex control = 100%
Reproductive rate = 1.0 and Breed = Hereford
All female



Effect of age at turn over on overall efficiency
In sex controlled systems. Sex control = 100%
Reproductive rate = 1.0 and Breed = Beef Syn. #1
All female



Effect of age at turn over on overall efficiency
In sex controlled systems. Sex control = 100%
Reproductive rate = 1.0 and Breed = Beef Syn. #2
All female



Effect of age at turn over on overall efficiency
In sex controlled systems. Sex control = 100%
Reproductive rate = 1.0 and Breed = Dairy Syn.
All female

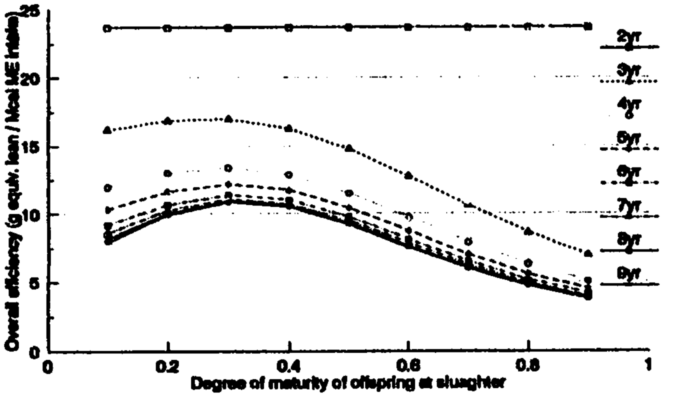
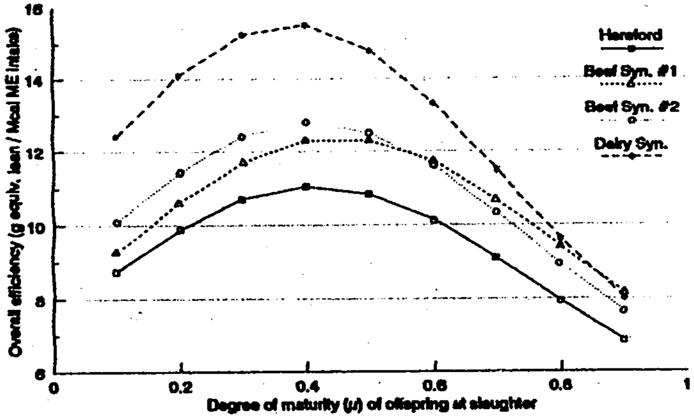
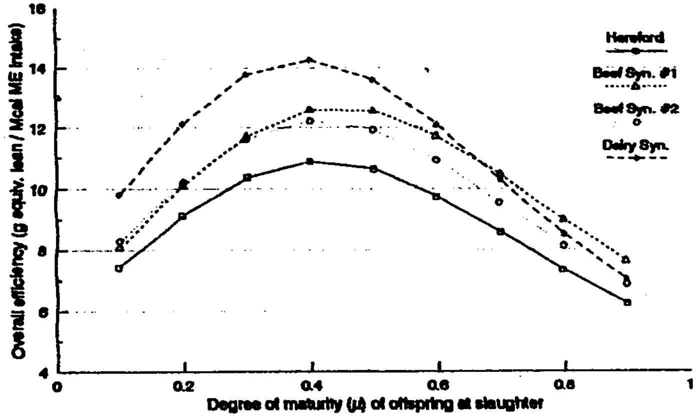


Figure IV.9. Breed effect on the efficiency (g equivalent lean $Mcal^{-1}$ ME) in sex controlled (all male) systems of beef production.

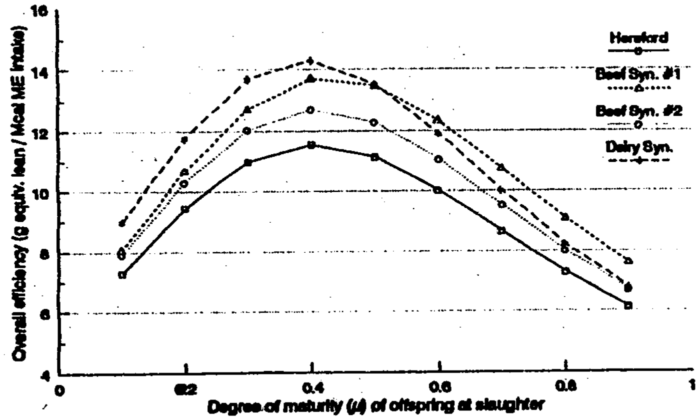
Comparison of breed groups in overall efficiency
(Mainly male production systems with r=1.0 and
complete sex control. Age at culling = 4yr)



Comparison of breed groups in overall efficiency
(Mainly male production systems with r=1.0 and
complete sex control. Age at culling = 6yr)



Comparison of breed groups in overall efficiency
(Mainly male production systems with r=1.0 and
complete sex control. Age at culling = 8yr)



Comparison of breed groups in overall efficiency
(Mainly male production systems with r=1.0 and
complete sex control. Age at culling = 10yr)

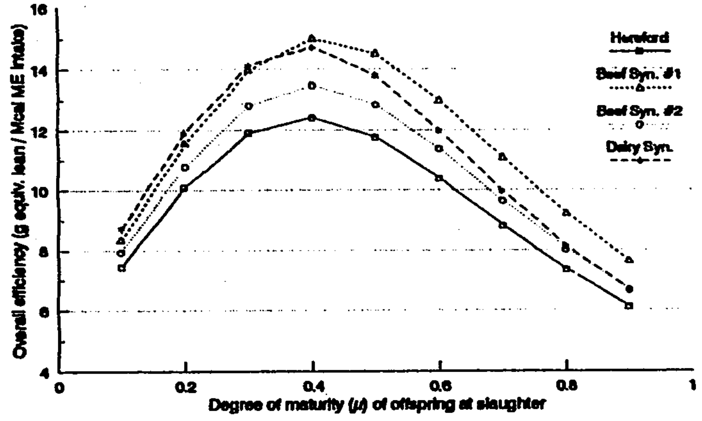


Figure IV.10. Effect of age at turnover on efficiency (g equivalent lean $Mcal^{-1}$ ME) in a dairy-beef system of production

Influence of age at turnover on efficiency in a Dairy-beef system: reproductive rate = 0.8.

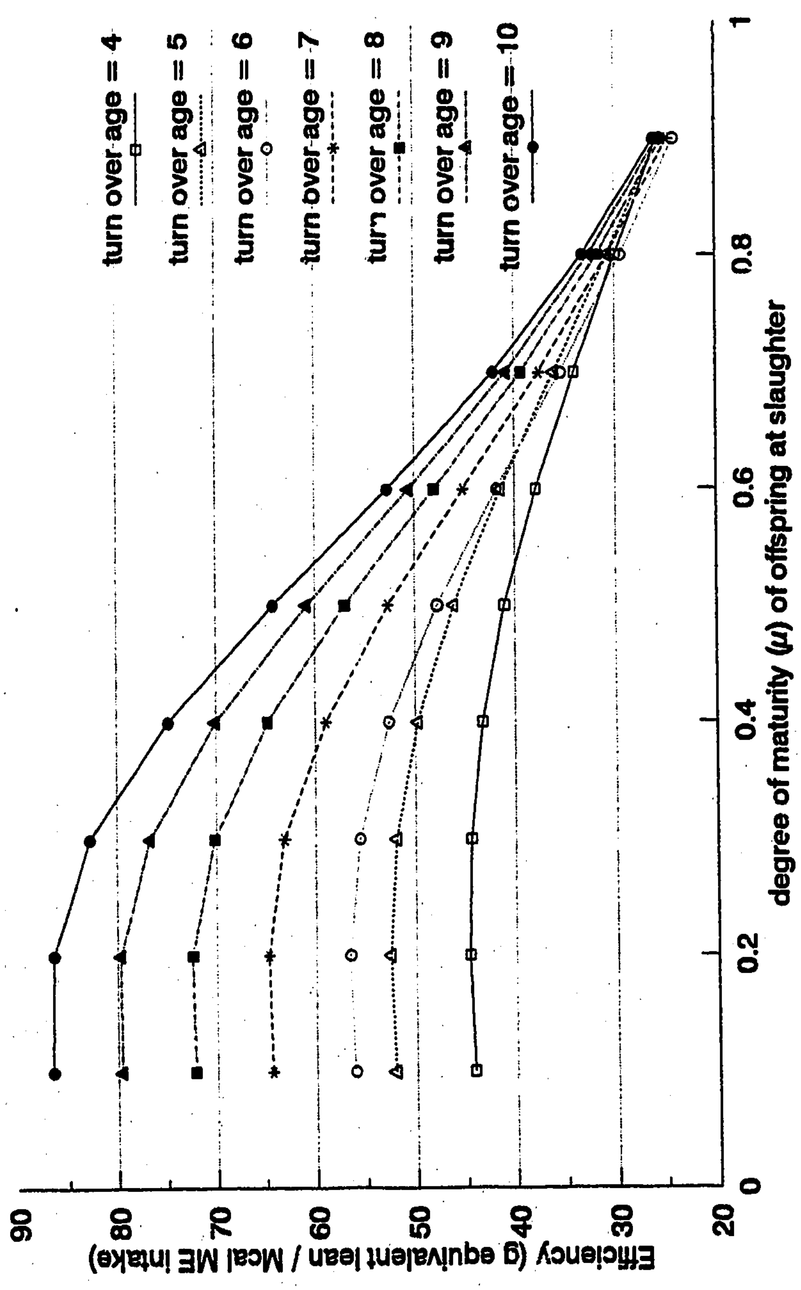
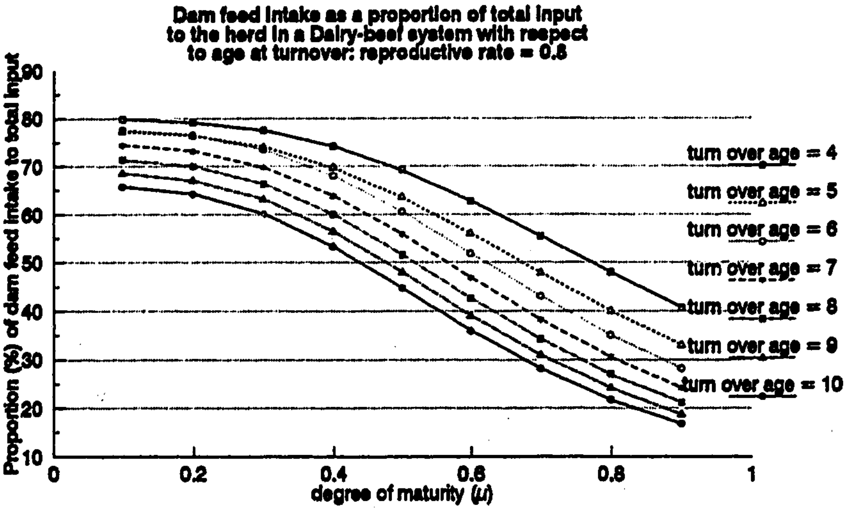
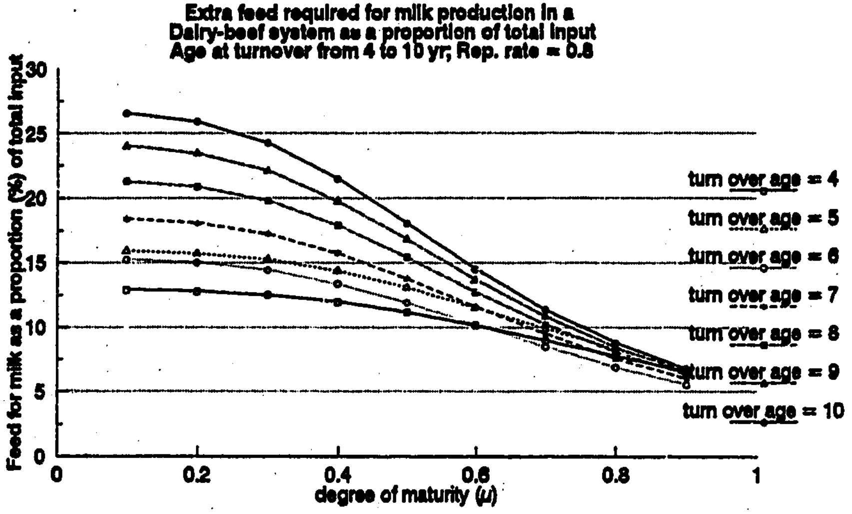


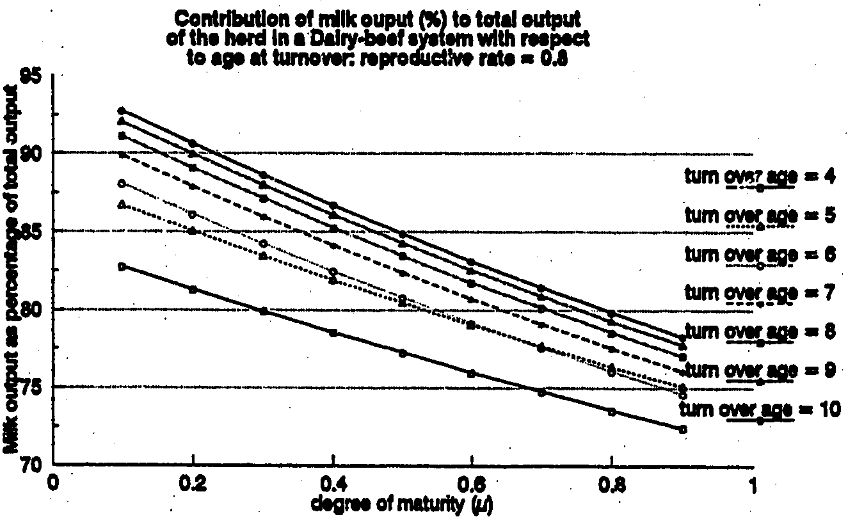
Figure IV.11. Contribution of the dam and milk output to the total inputs and outputs in a dairy-beef production system.



Dam feed intake as a proportion of total input to the herd in a Dairy-beef system with respect to age at turnover: reproductive rate = 0.8



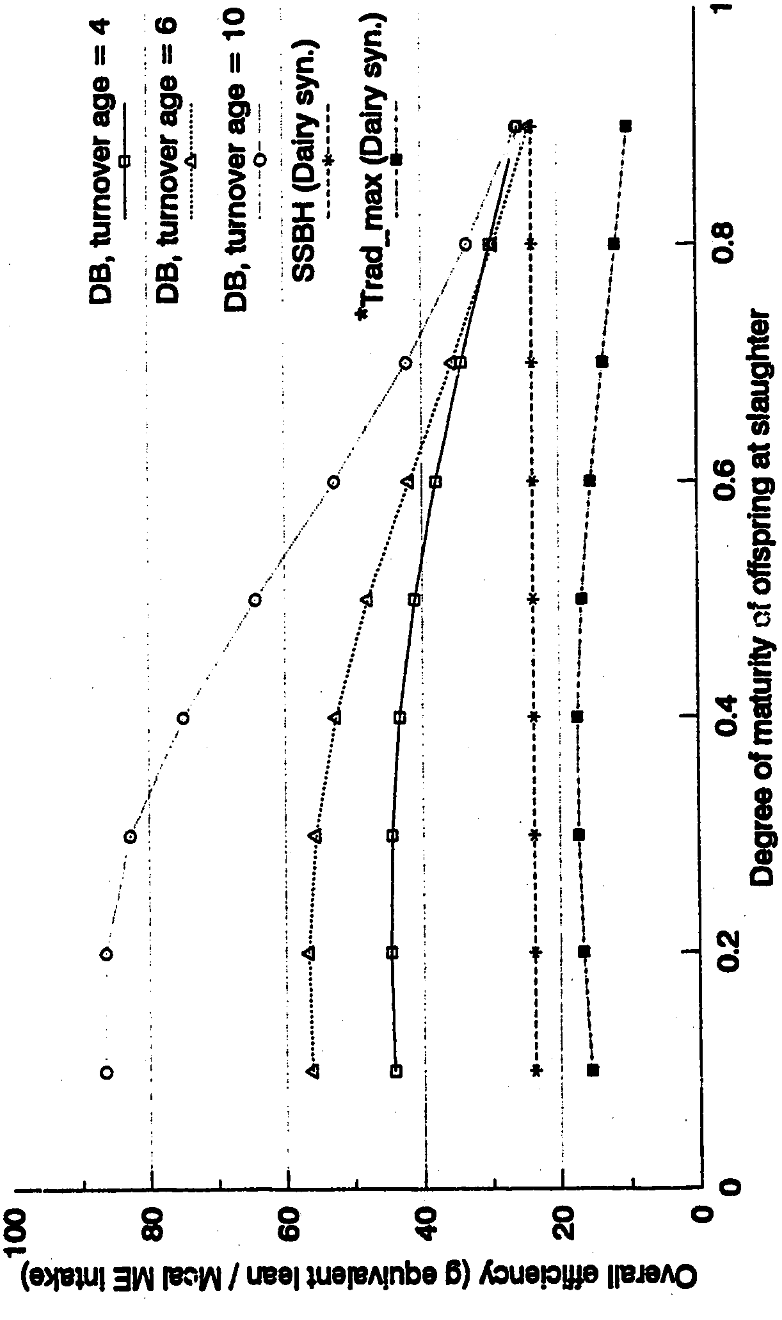
Extra feed required for milk production in a Dairy-beef system as a proportion of total input Age at turnover from 4 to 10 yr; Rep. rate = 0.8



Contribution of milk ouput (%) to total output of the herd in a Dairy-beef system with respect to age at turnover: reproductive rate = 0.8

Figure IV.12. Comparison of the dairy-beef, single sex bred heifer and traditional beef production systems in overall efficiency (g equivalent lean $\mathrm{Mcal^{-1}}$ ME).

Comparing the Dairy-beef (DB) system with the best sex-ratio controlled and traditional systems (Dairy synthetic with r = 1.0)



*Traditional system operated at maximum efficiency

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5. General Discussion

In Agricultural research as in other fields of study, some problems are either impossible to investigate experimentally or too expensive both in time and material to conduct. Measuring the efficiency of an entire beef herd or production system is one such problem that is too expensive to evaluate experimentally. The development of immense computing power and its increased availability and accessibility in recent years has stimulated interest in the use of computers to model and simulate such problems, at least to identify focal points for actual experimentation.

The model described in Chapter II was developed in light of the above, to enable the investigation of trends in overall efficiency in an entire beef herd, and to enable comparisons of such systems. Total (feed equivalent) input included the feed intake of the entire herd, the initial costs of the herd and breeding costs. Total (steer lean equivalent) output included the total lean meat produced by the herd up to turnover and any excess saleable milk. Growth was predicted by a Richards' function (Richards, 1959) and used to predict daily feed consumption using standard equations (NRC, 1984, 1987, 1989; Fox et al., 1988). Cumulated feed consumption and body weight were then scaled by mature weight and a relation between the two developed. Herd production was simulated by the performance of a conceptual 'average cow' similar to Taylor et al. (1985) and efficiency was evaluated with respect to the degree of maturity of offspring at slaughter.

While efficiency in a herd can be influenced by a number of factors, the results in traditional beef production systems (Chapter III) suggest that the average age at which the herd is turned over should be carefully considered. Overall efficiency tended to decline with increasing turnover age up to 6 years, and then increased marginally in most breed groups thereafter. The decline in efficiency with increase in age was first reported by Taylor et al. (1985) and has subsequently been shown for red deer as well (Fennessy and Thompson, 1989). The implication here is that females be culled as soon as their replacement is produced. Hence in a herd with a reproductive rate of 0.8 and sex ratio of 0.5, it should be possible to cull 40% of the cows shortly after their first calf (at 2 years). This of course would also tend to reduce the generation interval and make genetic selection more effective. Unfortunately it does not appear that this concept has received any commercial attention.

Increasing the reproductive rate increased efficiency as expected. However, if such an increase were assumed to result from increases in feed consumption by the cow herd (i.e, over-feeding), then a 10% excess in feed intake results in less efficiency (Chapter III). This seems to suggest that as long as costs to the herd are not substantially increased in the process of achieving improved reproduction, the overall efficiency will improve accordingly. However, increases in overall costs could impinge on any improvement in efficiency. For example, if improvement in the reproductive rate is the result of improved management without increased input, that would improve overall efficiency more than the case in which improvement in reproduction is the result of higher level of nutrition. The level of improvement in efficiency (3.9% to 6.5% for each 10% improvement in the reproductive rate) is similar to those of Taylor et al. (1985) and Fennessy and Thompson (1989).

There were also substantial breed differences in overall efficiency explainable by differences in maturing rates of the breed groups. Since dams are culled on the basis of age, faster maturing breed groups like the Beef synthetic #1, were always more mature and hence carrying a larger maintenance load at each age at culling. Such breed groups, contrary to expectation, were always less efficient at each turnover age. This is because the maturity of the dam was the most sensitive parameter in the model and it was negatively related to overall efficiency (Chapter II). The model was not sensitive to factors such as mature size and hence mature size could not be a major reason for breed group differences. These results imply that some thought be given to breed selection in the beef enterprise. For example, if there is a premium for faster growth, then the early maturing breeds might not be less efficient than the later maturing breed groups.

In systems where sex of offspring is controlled, those in which mainly male calves are produced were more efficient than systems producing only female calves (Chapter IV). This contrasts with the results of Taylor et al. (1985) but is similar to that of Fennessy and Thompson (1989). At the same turnover age however, a traditional system operated at maximum efficiency is only 5% less efficient than the mainly male system, implying that there might be a definite limit on how much sex-ratio control can cost before such systems are not efficient. However, a female system operated as a single sex bred heifer system (reproductive rate = 1.0, sex-ratio control is 100% and herd is turned over every 2 years) was far more efficient than either mainly male or traditional system operated at maximum efficiency. This result agrees with the earlier findings of Taylor et al. (1985) and Fennessy and Thompson (1989). It is a reflection of the importance of the dam's feed intake as a proportion of the total input. In a single sex bred heifer system dams are culled at 2 years, shortly after weaning their first calves, and hence yield a carcass of prime value and their own replacement. The feed cost of the dam then serves the dual function of productive growth as well calf production (Taylor et al., 1985). The cost of sex-ratio control would have to be at least 80 times that in the traditional system for this system not to be efficient.

This implies that unless cost of achieving 100% sex control and a reproductive rate of 1.0 exceeds about $350.00 per cow, this system is the most efficient. In other words this system is efficient enough to withstand high costs in sex-ratio control.

The dairy-beef system has been described as the most efficient production form (Andersen, 1978). The results of the current study although conservative in every respect seem to support this notion (Chapter IV). The difference between this system and a traditional system with higher reproduction and operated at maximum efficiency was at least 160%. The minimum difference between this system and a single sex bred heifer system was 9%. However, this occurs only when offspring are slaughtered at 90% mature. This is unlikely to happen in practice hence the difference will usually be larger than 9%. The maximum difference between the dairy-beef and any other system ranged from 87% to 265%, depending on the offspring degree of maturity at slaughter. Comparison of efficiency in the dairy-beef system with pure beef production systems has hardly been done, probably because of the difficulty of measuring such efficiencies to start with. However differences as large as those reported here ought to stimulate some thoughts. In sharp contrast to the traditional and sex-ratio controlled systems, efficiency in this system incre. with turnover age, because milk production is such a large proportion of the total output and milk production increases with turnover age.

The model built and used in the current studies has its limitations, developed along that of Taylor et al. (1985). As pointed out in Chapter II, it will not identify individual animals and is not as general as other beef models such as the Texas A & M Beef model (Sanders and Cartwright, 1979; Cartwright and Doren, 1986). It only treats the case of *ad libitum* feeding without consideration for other feeding schemes, and is not capable of evaluating crossbreeding. However, it emphasizes the influence of the degree of maturity of offspring at slaughter, indicating optimum times to market the offspring and traces trends in efficiency with respect to single variables such as age at turnover. The influence of simultaneous changes in two variables were not evaluated in the current study mainly because of lack of a three dimensional graphics presentation system. It should be an interesting consideration in future studies. Development of a more realistic herd model and including some stochastic elements in model could also be considered in the future. The current efficiency values are also basically biological and will not necessarily agree with economic evaluations. However as suggested by Thompson and Barlow (1986), "although economic efficiency is perhaps the more relevant figure for producers, biological efficiency is a stable measure across national boundaries and over time, around which the economics can be built".

The use of computers in modelling livestock systems is still new. Cartwright (1982) suggests that it has captured the imagination of some as a progressive addition to livestock production science, but appears to others as a useless diversion. He contends that the truth probably lies somewhere between, and that solutions to real world problems ultimately have to be found in the real world. Whatever opinion we might have of this method of investigation, as pointed out above, the magnitude of some of the differences reported here ought to generate some amount of empiricism.

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Appendix. Listing of program statements

Three programs, feed.c, herd.c and eff.c were written and combined into a project file, BEM.PRJ. This is a listing of the program statements.

Feed.c

```
#include <ctype.h>
#include <math.h>
#include <conio.h>
#include <stdio.h>
#include "b:\modeld.h"

                                          /*   Main program    */
main()

{
char op_type;                             /* operation type */
int sex_cont;                              /* type of sex control i.e, ali male or all female */

float nyears=10.0;
start (&op_type, &sex_cont);
dynamics(nyears);
over_eff(op_type, sex_cont);
return (0);
}
/******************* end of main func. *******************************/


float richards(int time, float mrate, float beta, float inflex, float matwt)
{
  float X2, X3, X4, X5, X6, T;

   T = time;
  X2 = mrate * T *(-1.0);                 /* -kt */
  X3 = exp (X2);                          /*exp(-kt)*/
  X4 =beta * X3;                          /*Bexp(-kt) */
  X5 = 1.0 - X4;                          /* 1 - B(exp(-kt)) */
  X6 = pow (X5, inflex);                  /*   (1 - B(exp(-kt))^M */

  return(matwt * X6);                     /*A(1-B(exp(-kt))^M */
}

/******************* end of function Richards **********************************/

```

```
                                        /* function for computing regressinons */

void regress(float num, float cumX, float cumY, float crossP, float squareX,
        float squareY, float *bee, float *ea, float *rsq)
{
float meanX,
     meanY;

meanX = cumX / num;
meanY = cumY / num;

*bee = (crossP - (num * meanX * meanY))/ (squareX -(num * meanX * meanX));
*ea  = meanY - (*bee * meanX);
*rsq = *bee * (crossP - (num * meanX * meanY)) / (squareY - (num *meanY
                                                          *meanY));
}
/*******************************end of regress function **********************/


void calf_intake(float cor_wt, float gain, float milk, float Matwt,
              float MEd, float NEGd, float NEMd, int brd_size,
               int sex, float *dmi, float *ei, float *NEga)

{
float
     M_dm_kg=0.12,              /*milk dry matter and energy values*/
     M_NEM=3.34,                /*milk net energy for maintenance/kg */
     M_NEG=2.16,                /*milk net energy for gain/kg */
     M_ME=5.29,                 /*milk metabolizable energy/kg */
     shrt=0.0,
     NEMr,
     NEG,
     NEP,                       /* net enegry of production required */
     NEPM,                      /* net energy of prod. content of milk, per kg */
     TNEPM,                     /* total net energy of production from milk */
     NEPD,                      /* net energy of prod. content of diet, per kg */
     MR,                        /* amount of milk required to satisfy NEP */
     DDMR,                      /* amount of diet required to satisfy NEP */
     cor_brd,
     Diet_MEI,
     Diet_DM,
     Milk_MEI,                  /*total milk net energy for maintenance */
     A,
     Milk_DMI,
     Milk_DM;

Milk_DM = milk * M_dm_kg;

A = Matwt;
cor_brd = (brd_size < 5) ? 1.0 : 1.12;
NEG = gain_neg(brd_size, cor_wt, gain, sex);
NEMr =cor_brd * 0.077 * (pow(cor_wt, 0.75));
```

```
*NEga = NEG;


NEP = NEG + NEMr;
MR = (NEMr / M_NEM) + (NEG / M_NEG);

NEPM = NEP / MR;
TNEPM = Milk_DM * NEPM;      /* total net energy of production from milk */

if (TNEPM >= NEP)
    {
     Milk_DMI = NEP / NEPM;         /* milk dry matter actually consumed */
     Milk_MEI = Milk_DMI * M_ME;
     *dmi = Milk_DM / A;            /* A is mature wt - scaling */
     *ei  = Milk_MEI /  A;
    }
else
    {
      shrt = NEP - TNEPM;
      Milk_DMI = Milk_DM;
      Milk_MEI = Milk_DMI * M_ME;
      DDMR = (NEMr / NEMd) + (NEG / NEGd);
      NEPD = NEP / DDMR;
      Diet_DM = shrt / NEPD;
      Diet_MEI = Diet_DM * MEd;
      *dmi = (Diet_DM + Milk_DM) / A;
      *ei  = (Diet_MEI + Milk_MEI) / A;
    }
}

/************** end of calf_intake function ******************************/


/*          This function computes cummulated weights and cummulated log_wts for regression
            using my 'reg' 124 function       */

void totals_wt(float wt,  float ln_wt, float *cum_wt, float *log_wt,
               float *wt_sq, float *log_wtsq)
     {
     *cum_wt += wt;
     *log_wt += ln_wt;
     *wt_sq  += wt * wt;
     *log_wtsq += ln_wt * ln_wt;
     }
/********************** end of totals_wt function ***********************/



/* This function cummulates energy, log energy and their crossproducts with
   weigth and log weight for regression
*/

```

```
void totals(float dm, float wt, float ln_wt, float E, float *cum, float
          *cum_e, float *log_cum, float *cum_sq, float *log_cumsq,
          float *xpdt_E, float *xpdts, float *log_xpdts, float *lnxpdt_E,
          float *ln_Esq, float *ln_E, float *Esq)
    {
    float log_dm,
          log_E;

    log_E       =log(E);
    log_dm      = log(dm);
    *cum_e      += E;
    *Esq        += E * E;
    *ln_E       += log_E;
    *ln_Esq     += log_E * log_E;
    *xpdt_E     += E * wt;
    *lnxpdt_E   += log_E * ln_wt;
    *cum        += dm;
    *log_cum    += log_dm;
    *cum_sq     += dm * dm;
    *log_cumsq  += log_dm * log_dm;
    *xpdts      += wt * dm;
    *log_xpdts  += ln_wt * log_dm;
     }
/**************** end of totals function *****************************/

/* This function centers a string on screen at the specific row    */


void center(char *S, int row)
{
clrscr();
gotoxy(40 -strlen(S) /2, row);
cprintf("%s",S);
}

/************** end of centering function *************************/

/*This function computes predicted feed intakes by sex/function.
  sex 1 = breeding females, sex 2 = fattening heifers, sex 3 = steers
  and sex 4 = bulls
*/

void feed(int sex, float NEM, float ME, float wt, float breed, float mwt,
          int brd_size, float *dmi, float *ei, float *NEga, float NEGd)

{
float intake, size;
float size_eff[3][2] = {{0.90, 1.00},
                        {1.10, 1.10},
                        {1.00, 1.05}};
int index1, index2;

```

```
index1 = (brd_size > 1) ? 1 : 0;
index2 = (sex <=2) ? 0 : (sex-2);

size = size_eff[index2][index1];


switch(sex)
   {
    case 1:                         /* breeding females */

          intake = pow(wt, .75) *((0.1462*NEM) - (0.0517*NEM*NEM) - 0.0074)
                   * breed * size;
    break;
    case 2:                         /* heifers */
    case 3:                         /* steers */
    case 4:                         /* bulls  */
           intake = pow(wt, .75) * ((0.1493*NEM) -(0.0460*NEM*NEM) - 0.0196)
                    * breed * size;
    break;
    }
*NEga = (intake - (0.077 * pow(wt, 0.75)/ NEM)) * NEGd; /*net E for
                                                  gain available*/
*dmi = (intake/mwt);
*ei  = (intake*ME/mwt);

}
/*************************end of feed function   ****************************/

/* This function obtains the factor for correcting weight to a medium frame
   steer equivalent.
*/

float equiv_wt(int breed, int sex)
 {
 int b;
 extern float matrixEQ[4][3];
 b = (breed == 5) ? 4 : breed;     /* This assumes the dairys breeds are of */
 return(matrixEQ[b-1][sex-1]);     /* frame size 9, same as the SD */
 }

/*************** end of equivalent weight function ***************************/

/* This function computes the net energy required for specified gain, sex
   and breed
*/

float gain_neg(int brd, float wt, float adg, int sex)
{
extern float matrixX[2][3],         /* coefs for NEG equation */
             matrixP[3];
float NEG;
int breed;
```

```
breed = ((brd >1) ? 1 : 0);          /* decisions based on medium or large frame size */

NEG = matrixX[breed][sex-1] *(pow(wt,0.75)) * (pow(adg, matrixP[sex-1]));
return(NEG);
}
/**************** end of net energy for gain function ******************/

/********* breed correction fo maintenance requirement ******************
This function returns the correction for breed size, mainly dairy breed
*/

float breed_cor(int breed, float actual_wt, int gender)
{
 float value;
 if(breed < 5 || gender == 4)
   value = 1.0;
 if(breed == 5)
     value = (actual_wt > 318.0) ? 1.08 : 1.0;

 return (value);

}
/**************** end of breed correction function **********************/


/* This function reads growth parameters from the external matrixGP    */


void growth_parms(float *x1, float *x2, float *x3, float *x4, int brd_size)
{
extern float matrixGP[5][4];
int b;
    b = brd_size;
    *x1 = matrixGP[b-1][0];
    *x2 = matrixGP[b-1][2];
    *x3 = matrixGP[b-1][1];
    *x4 = matrixGP[b-1][3];
}
/* * * * * * * * * * * end of growt_parms function * * * * * * * * * * * * * * */


/* This function obtains the temperature of the month and the correction for [illegible] */

void Temp(int mth, int season, float *tmp1, float *cor_t, float *wnd)
{
extern float tmp[2][12];
extern float wind[2][12];
float cur_tmp,
      cor_tmp;
char ans = 'x';

*tmp1 = cur_tmp = tmp[season-1][mth-1];
```

```
*wnd = wind[season-1][mth-1];

if(cur_tmp > 35.0 && ans == 'Y')
   cor_tmp = 0.9;
if(cur_tmp >35.0 && ans =='N')
   cor_tmp = 0.65;
else if(cur_tmp >35.0)
   {
    printf("Is there night time cooling ?(Y/N)\n");
    scanf("%c", ans);
    while(toupper(ans) != 'Y' || toupper(ans) != 'N')
        {
         BEEP;
         scanf("%c", ans);
        }
    cor_tmp = (toupper(ans) == 'Y') ? 0.9 : 0.65;
   }
if(cur_tmp >= 25.0 && cur_tmp <= 35.0)

   cor_tmp = 0.90;
if(cur_tmp >= 15.0 && cur_tmp < 25.0)
   cor_tmp = 1.0;
if(cur_tmp >= 5.0 && cur_tmp < 15.0)
   cor_tmp = 1.03;
if(cur_tmp > -5.0 && cur_tmp < 5.0)
    cor_tmp = 1.05;
if(cur_tmp >= -15.0 && cur_tmp <= -5.0)
    cor_tmp = 1.07;
if(cur_tmp < -15.0)
    cor_tmp= 1.16;
*cor_t = cor_tmp;
}
/*********************** end of Temp function ******************************/


/* Beginning of month of yr program. It returns the month of the year by using 2 'for loops' to
   reduce any moment in the simulation to a point in a 365 day cycle and determine
   the month from there.
*/

void mthofyr(int time, int Cal_p, int *yr, int *mnth)
{

int i, j, k, days;
extern float tmp[2][12];
extern int cum_days[2][12], yr_days[20];
for(j=0; j<20; j++)
 {                                   /* first 'for loop' */
  i = j + 1;
  if(time <= yr_days[0])             /*This loop ensures days !> 365 so that month */
    {                                /*is always decided on 365 day cycle */
    days = time;
```

```
      *yr = 1;
      break;
      }
   else if(time > yr_days[j] && time <= yr_days[i])
      {
      days = time - (365 * i);
      *yr = i + 1;
      break;
      }

 }
                                          /* second 'for loop' */
for(k=1; k<=12; k++)                             /* decides month of year*/
 {
  if(days <= cum_days[Cal_p-1][0])
      {
      *mnth = 1;
      break;
      }
   else if(days > cum_days[Cal_p-1][k-1] && days <=cum_days[Cal_p-1][k])
      {
      *mnth = k+1;
      break;
      }
 }
}

/*****************************end of month of year program ******************************/

void totals_c(float cdmi, float cei, float ln_wt, float *cum_cdmi, float
              *cum_cei, float *cdmi_sq, float *cei_sq, float *xpdcmi,
              float *xpdcei)
      {
      *cum_cdmi += cdmi;
      *cum_cei += cei;
      *cdmi_sq  += cdmi * cdmi;
      *cei_sq += cei * cei;
      *xpdcmi += cdmi * ln_wt;
      *xpdcei += cei * ln_wt;
      }
/********************** end of totals_wt function ************************/

void preg(int day, int year, int brd, float *preg_e, float bwt)
{
 double ff,
        fp,
        fe,
        cw,
        ce,
        nw,
        uw,
        ne,
```

```
      ct,
      ue,
      q = 0.0;
static float qc[3][4] = {{5.0, 2.9, 1.2, -0.8}, {5.2, 2.9, 1.5, -0.3},
                         {3.6, 2.3, 0.9, 1.4}};
if(brd > 2)
   brd -= 1;

if(year <= 4)
   q = qc[brd-1][year-2];
if (year > 9)
   q = qc[brd-1][3];

ff=(0.00006811 -(0.000000197*day))*(exp((0.0885 -(0.0001281*day))*day));
fp = (0.03452 -(0.0001094*day))*(exp((0.0589 -(0.00009334*day))*day));
cw = (0.084042 -(0.0003087*day))*(exp((0.05614 -(0.0001031*day))*day));
nw = (0.2685 -(0.0009322*day))*(exp((0.04378 -(0.000076*day))*day));
uw = (1.3664 -(0.0038414*day))*(exp((0.02475 -(0.0000348*day))*day));

fe = ((5.505 * fp) + (9.527 * ff));
ce = 0.539 * cw;
ne = 0.539 * nw;
ue = 0.952 * uw;
fe += (ce + ne + ue + 0.006877);

*preg_e = fe * ((bwt - q)/36.4)/(1000.0 * 0.125);
                                   /*mcal ME /day for pregnancy, assumes 12.5% efficiency of
                                        ME use for preg. */
}
/******************************end of preg function ******************************/


void e_lact(float *tot_e, float *daily_milk, float *fat, int day_lact,
          int breed, int year)
 {
static float BAP[5]={6.9, 7.9, 8.3, 8.7, 30.0};
static float BAF[5]={4.9, 4.7, 4.8, 4.8, 3.5};
static float age_coef[3][5]={{0.62, 0.77, 0.67, 0.84, 0.60},
                             {0.76, 0.83, 0.99, 0.96, 0.825},
                             {0.85, 0.95, 0.98, 1.11, 0.925}};



float PYm,                         /* Peak milk yield for mature and other ages */
      PY4,
      PY3,
      PY2,
      DPYm,                        /*day of peak lactation */
      DPY4,
      DPY3,
      DPY2,
      Wam,                         /* Wood's equation, 'a' coefficient */
```

```
      Wa4,
      Wa3,
      Wa2,
      Wbm,                              /* Wood's equation, 'b' coefficient */
      Wb4,
      Wb3,
      Wb2,
      Wcm,                              /* Wood's equation, 'c' coefficient */
      Wc4,
      Wc3,
      Wc2,
      DYm,                              /*daily milk yield */
      DY4,
      DY3,
      DY2,
      DMF,                              /* daily milk fat % */
      PMF,                              /* peak milk fat %  */
      LE;                               /* metabolizable energy for lactation mcal / day */

float bap, day1, brdadj = 5.0;         /*breed adjustment */
int yr, day;
if (breed == 5)
  {
   *daily_milk = 5.0;
   *fat = 3.5;
  }

else
  {
  bap = BAP[breed - 1];
  PMF = BAF[breed - 1];

  PYm = ((0.125 * brdadj) + 0.375) * bap;
  PY2 = age_coef[0][breed-1] * PYm;        /*age coefs correct mature milk yield*/
  PY3 = age_coef[1][breed-1] * PYm;         /*to age specific basis */
  PY4 = age_coef[2][breed-1] * PYm;

  DPYm = PYm + 40;
  DPY2 = DPYm + 10;
  DPY3 = DPYm - 10;
  DPY4 = DPYm - 5;

  Wam = 5.30 - (0.075 * DPYm);
  Wa2 = 4.00 - (0.05 * DPY2);
  Wa3 = 6.65 - (0.11 * DPY3);
  Wa4 = 5.85 - (0.09 * DPY4);

  Wbm = (log(PYm) - log(Wam))/(log(DPYm + 14) -1);
  Wb2 = (log(PY2) - log(Wa2))/(log(DPY2 + 14) -1);
  Wb3 = (log(PY3) - log(Wa3))/(log(DPY3 + 14) -1);
  Wb4 = (log(PY4) - log(Wa4))/(log(DPY4 + 14) -1);

```

```
Wcm = Wbm / (DPYm + 14);
Wc2 = Wb2 / (DPY2 + 14);
Wc3 = Wb3 / (DPY3 + 14);
Wc4 = Wb4 / (DPY4 + 14);
day = day_lact + 14;
day1 = (day_lact + 1.0)/7.0;


if (year > 1 && year < 4)
  yr = year;
else if(year == 4 || year > 10)
  yr = 4;
else
  yr =5;

switch(yr)
   {
    case 1:
         *daily_milk = 0.0;
         break;

    case 2:
         *daily_milk = Wa2 * pow(day, Wb2)*exp(-Wc2*day)*(PY2 /
                    (age_coef[0][breed-1] *10.0));
         break;

    case 3:
         *daily_milk = Wa3 * pow(day, Wb3)*exp(-Wc3*day)*(PY3 /
                    (age_coef[1][breed-1] *10.0));
         break;

    case 4:
         *daily_milk = Wa4 * pow(day, Wb4)*exp(-Wc4*day)*(PY4 /
                   (age_coef[2][breed-1] *10.0));
         break;

    case 5:
         *daily_milk = Wam * pow(day, Wbm)*exp(-Wcm*day)*(PYm /10.0);
         break;
   }

DMF = 1.01 * PMF * pow(day1, -0.13) * exp(0.02 * day1);
*tot_e = (0.3512 + (0.0962*DMF)) * (*daily_milk)/0.6510;
                                        /*0.651 eff. of conversion of ME to NEl */
*fat = DMF;
}
}
/**************************************end of lactation function      ******************/

/* This function computes enviromental corrections by proceedure of Fox et al 1988)*********/

void enviro(float cei, float NEG, float pe, float le, int age,
```

```
            float tmp, float wt,  float wind, float *MEc)

{
static float TI[4][3] = {{2.5, 2.5, 2.5},  /* tissue insulation values */
                         {6.5, 6.5, 6.5},
                         {5.5, 6.8, 8.0},
                         {6.0, 9.0, 12.0}};

static float EI[4][4] = {{7.0, 11.0, 14.0, 17.0}, /*external insulation */
                         {5.0, 7.5, 10.0, 13.5},
                         {4.0, 5.5, 8.0, 9.0},
                         {3.0, 4.0, 6.5, 6.5}};

static float skin[4] = {1.0, 0.8, 0.5, 0.2}; /*skin condition */
                                        /*clean & dry =1.0 etc */
static float hide[3] = {0.8, 1.0, 1.2};      /*thickness of the hide */

int age1, flesh = 1, wnd, coat;
float ins1,
    ins2,
    ins,
    sa,                              /* surface area */
    dm_maint,
    dm_gain,
    ME_gain,
    NEFP,
    HP,
    MECS,
    LCT;

/***************** get age factor for reading TI & EI *****************/

if (age <= 30)
   {
   age1 = 1;                         /*new born*/
   coat = 1;                         /* hair <0.5*/
   }
else if (age > 30 && age <= 180)
   {
   age1 = 2;
   coat = 2;                         /* hair = 1 cm */
   }
else if (age > 180 && age <= 365)
   {
   age1 = 3;
   coat = 3;                         /*hair = 1.5cm */
   }
else
   {
   age1 = 4;
   coat = 4;                         /* hair = 3.0 cm */
   }
```

```

/******************** get wind factor for reading EI *********************/


if (wind <= 1.6)
    wnd = 1;
else if (wind >1.6 && wind <= 6.4)
    wnd = 2;
else if ( wind >6.4 && wind <= 12.8)
    wnd = 3;
else
    wnd = 4;

/********* obtain TI & EI and compute total insulation *****************/

ins1 = TI[age1-1][flesh];
ins2 = EI[wnd-1][coat-1] * skin[0] * hide[1]; /*clean skin moderate hide */

/************ compute total insulation **********************************/

ins = ins1 + ins2;

/********************compute surface area ************************************/

sa = 0.09 * pow(wt, 0.67);

/*************** compute net energy for production **********************/


NEFP = (0.65 * le) + (0.125 * pe) + NEG;

/*********** compute heat production ************************************/

HP = (cei - NEFP)/sa;
/************** compute lower critical temp *****************************/

LCT = 39 - (ins * HP);

/************ compute ME for cold stress *********************************/
MECS = sa * (LCT - tmp) / ins;

if (MECS < 0.0)
    MECS = 0.0;
*MEc = MECS;
}


/******** THis function computes the effect of previous temperature */

void pre_tmp(int mnth, int sea, int yr, float *pretmp_eff)
  {
   extern float tmp[2][12]; /* monthly tmps by season of calving */
```

```
    float pretmp;

/******* assign 0.0 to pretmp effect in first month of simulation. *****/

    if ( yr == 1 && mnth ==1)
        *pretmp_eff = 0.0;

/***** compute effect of pretmp by NRC 1981 equation in other cases *****/

    else if (mnth == 1)
        {
        pretmp = tmp[sea-1][11];
        *pretmp_eff = 0.0007 * (20.0 - pretmp)/0.65; /* divide by .65 to
                                                     convert to ME */
        }
    else
        {
        pretmp = tmp[sea-1][mnth-2];
        *pretmp_eff = 0.0007 * (20 - pretmp)/0.65;
        }
    }


/******************-------------end of previous temp function -----------*/

void dynamics(float years)
{
 float len,
       wind,
       temp,
       time,
       breed_f,                    /*breed correction factor */
       Cor_dm,
       Cor_E,
       cor_e,                      /* enviro. energy, not weight by metabolic wt */
       temp_cor,                   /* temperature correction for feed intake */
       Mwt_f,
       matwt,
       mrate,
       inflex,
       beta,
       wt_now,
       met_wt,
       wt_eq,
       cor_wt,
       scaled_wt,
       log_wt,
       PADG,
       MEd = 2.60,
       NEGd,
       NEMd,
       milk,
```

```
      cumwt,
      logwt,
      NEGa,                     /*net E for gain consumed (available)*/
      DMI,                      /* total intake to age i,  Y1i for regression purposes*/
      EI,                       /* total energy intake to age i */
      cumfeed,                  /* sum Y1i by previous terminology */
      logfeed,                  /* sum log Y1i */
      xpdts,                    /* sum XiY1i */
      wtsq,                     /* sum Xsq */
      cum_E,                    /* sum Y2i, energy */
      log_E,                    /* sum log Y2i */
      xpdt_E,                   /* sum XiY2i crossproducts energy and wt */
      Esq,                      /* sum Y2sq */
      lnxpdt_E,                 /* crossproducts in log form, energy and wt */
      lnEsq,                    /* sum log Y2sq */
      feedsq,                   /* sum Y1sq */
      logxpdts,                 /* crossproducts in log, dm intake and wt */
      logwtsq,
      logfeedsq,
      cum_dm_p,                 /*cum dm for pregnancy */
      cum_dm_l,                 /*cum dm for lactation */
      cum_e_p,                  /* cum energy for preg. */
      cum_e_l,                  /* cum energy for lact. */
      dm_p,                     /*daily dm for pregnancy */
      dm_l,                     /*daily dm for lactation */
      le,                       /* daily lactation energy */
      pe,                       /* daily preg. energy */
      mfat,                     /* milk fat - not used in this function */
      bwt,                      /* birth weight */
      tei,                      /*total daily energy intake, include pe & le */
      cum_cdmi,                 /*total corrected dm intake to age i */
      cum_cei,                  /*total corrected energy intake to age i */
      dmi,                      /* daily dm intake without preg. or lact. */
      ei,                       /* daily energy intake , no preg or lact. */
      pretmp,                   /* previous temp. effect */
      pretmpeff,                /* prevoius tmp effect weight by metabolic weight */
      logB, logA,logrsq,        /* regression parameters  */

      logB1, logA1, logR1_sq;

float chk_pretmp[12];           /*temp. mat. used to ensure previous tmp eff is not
                                computed unless there was environmental corrections in the
                                last month */
int i, j, limit, k, m,
    gender, sex,
    month, year, day, day2,
    calving_mth, array_index,
    breedsize;

extern int matrixAGE[5][10], min_age[7]; /*age at specific mieu & minimum */
                              /*age at culling for dams       */
                                /* variables for passing value  to other models  */
```

```

extern float eq_coefs[2][5][8],      /* regression coefficients */
             e_off_dm[5][4][10],     /* enviro. cor. to specific mieus */
             e_off_e[5][4][10],
             e_dam_min_dm[5][7],     /* enviro cor. dm to specified min ages, dams */
             e_dam_min_e[5][7],      /* enviro cor. E. to specified min ages, dams */
             e_dam_e[5][10],         /* enviro cor. E. to each yr end, dams */
             e_dam_dm[5][10];        /* enviro cor. dm to each yr end, dams */

len = DAYSINYEAR * years;            /* number of iterations, days */
limit = len;                         /*converts len to an integer */
array_index = 2;
cprintf("Input month of calving from 1 (Jan) to 12 (Dec)\n");
scanf("%d", &calving_mth);

shift_cum_days(calving_mth-1);       /*rearrange cum. days to appropriate month */
shift_tmp(calving_mth-1);            /*rearrange temperature to appropriate month */
shift_wind(calving_mth-1);           /*rearrange wind speed to appropriate month */

NEMd = (1.37 * MEd) - (0.138 * MEd * MEd) + (0.0105 *(pow(MEd,3))) - 1.12;
NEGd = (1.42 * MEd) - (0.174 * MEd * MEd) + (0.0122 *(pow(MEd,3))) - 1.65;



for(breedsize=5; breedsize<=5; breedsize++)
  {
   growth_parms(&Mwt_f, &mrate, &beta, &inflex, breedsize);  /* obtain growth*/
   for(gender = 1; gender<=4; gender++)                      /*parameters*/
     {
     cumwt=0.0;
     logwt=0.0;
     DMI = 0.0;
     EI  = 0.0;
     Cor_dm = 0.0;
     Cor_E  = 0.0;
     cor_e  =0.0;
     cum_cdmi=0.0;
     cum_cei=0.0;
     cumfeed=0.0;
     logfeed=0.0;
     xpdts=0.0;
     wtsq=0.0;
     cum_dm_p=0.0;
     cum_dm_l=0.0;
     cum_e_p =0.0;
     cum_e_l =0.0;
     le = 0.0;
     pe = 0.0;
     cum_E=0.0;
     log_E=0.0;
     xpdt_E=0.0;
     Esq=0.0;
```

```
lnxpdt_E=0.0;
lnEsq=0.0;
feedsq=0.0;
logxpdts=0.0;
logwtsq=0.0;
pretmpeff =0.0;
logfeedsq=0.0;

if (breedsize == 5 && gender >1)
    {
      beta = 0.9605;
      mrate =0.00137405;
      inflex =0.8764;
    }

adult_wt (&matwt, Mwt_f, gender, breedsize);

sex = (gender <= 2) ? 1 : gender-1; /* assigns breeders & heifers same*/

wt_eq = equiv_wt(breedsize, sex);   /* equivalent weight */

center(MES,12);

for(i=1; i <=limit; i++)
  {
  time = i;
  if(i == 1)
    {
    BWT (sex, mrate, beta, inflex, matwt, &bwt);  /* birth wt */
    if (gender == 1)
      bwts[breedsize-1][0] = bwt; /* females */
    else if (gender == 4)
      bwts[breedsize-1][1] = bwt;  /* males */
    }
  wt_now =richards(time, mrate, beta, inflex, matwt); /* current wt */


  PADG   = (richards(++time, mrate, beta, inflex, matwt) - wt_now);/*
                               predicted daily gain */

  cor_wt = wt_now * wt_eq;    /* wt corrected to medium frame steer equiv.*/
  met_wt = pow(wt_now, 0.75); /* metabolic weight */
  scaled_wt = wt_now/matwt;
  log_wt    =log(scaled_wt);  /* remember return to "scaled_wt */
  breed_f = breed_cor(breedsize, wt_now, gender);
  mthofyr(i, array_index, &year, &month); /* obtain month of year */
  Temp(month, array_index, &temp, &temp_cor, &wind);

                                        /* requirements for p & l */
  Preg_lact (i, &le, &milk, &mfat, &pe, bwt, breedsize, year);

  if(i< 180 || wt_now < 200.0)
```

```
                                   /* preweaning feed intake */
      calf_intake(cor_wt, PADG, milk, matwt, MEd, NEGd,
               NEMd, breedsize, sex, &dmi, &ei, &NEGa);

    else
                                   /*post weaning feed intake */
       feed(gender, NEMd, MEd, cor_wt,  breed_f, matwt,
           breedsize, &dmi, &ei, &NEGa, NEGd);

                                  /* compute cumulated values */
   cum_all (&tei, &EI, &DMI, &cum_e_p, &cum_dm_p, &cum_e_l, &cum_dm_l,
          pe, le, ei, MEd, dmi, matwt);

                    /* obtain eviromental correction - energy only */

  enviro(tei, NEGa, pe, le, i, temp, cor_wt, wind, &cor_e);
  chk_pretmp[month-1] = cor_e; /* assign corrections for current month */
  pre_tmp(month, array_index, year, &pretmp);

  if ((month == 1 && year == 1) || chk_pretmp[month-2] == 0.0)
      pretmp = 0.0;
  pretmpeff = pretmp * met_wt;

  Cor_E = cor_e + pretmpeff;
  Cor_dm = Cor_E / MEd;
  cum_cdmi += Cor_dm / matwt;
  cum_cei  += Cor_E / matwt;
  totals_wt(scaled_wt, log_wt, &cumwt, &logwt, &wtsq, &logwtsq);
  totals(DMI, scaled_wt, log_wt, EI, &cumfeed, &cum_E, &logfeed,
  &feedsq, &logfeedsq, &xpdt_E, &xpdts, &logxpdts, &lnxpdt_E,
  &lnEsq, &log_E, &Esq);
  get_cum_vals(cum_cdmi, cum_cei, breedsize, year, gender, i);
  }                             /* end of for loop */
  regress(len, logwt, logfeed, logxpdts, logwtsq, logfeedsq, &logB1,
      &logA1, &logR1_sq);  /* dm regressions */
  regress(len, logwt, log_E, lnxpdt_E, logwtsq, lnEsq, &logB,
         &logA, &logrsq);       /* energy regression */

  get_coef(logA, logB, logA1, logB1, breedsize, gender);

  get_preg_lact(gender, breedsize, years, cum_e_p, cum_dm_p,
             cum_e_l, cum_dm_l);
  printf("\nFor sex %d, the regressions are\n", gender);
  printf("The relation between log feed and log maturity is\n");
  printf("Log Feed Intake = %.4f + (%.4fLogwt)\n",logA, logB);
  printf("The relation between log energy and log maturity is\n");
  printf("Log Energy Intake = %.4f + (%.4fLog_mat.)\n",logA1, logB1);
  printf("The R-sq for the DM relation is %.4f\n",logR1_sq);
  printf("The R-sq for the Energy relation is %.4f\n",logrsq);
  }                             /* end of gender loop */
}                               /* end of breed loop */

```

```
}
/************************ end dynamic aspects ************************************/

void adult_wt(float *matwt, float mwt_f, int gender, int b) /* mature_wt by sex */
{
 if (b == 5)
   {
    switch (gender)
     {
     case 1:
     *matwt = mwt_f;
     break;
     case 2:
     *matwt = 649.895;
     break;
     case 3:
     *matwt = 779.982;
     case 4:
     *matwt = 909.979;
     break;
     }
   }
 else if(gender==3)                /*steers assumed to 1.2 times mature wt of females */
    *matwt = mwt_f*1.2;
 else if(gender==4)                /*bulls*/
    *matwt = mwt_f*1.4;
 else
    *matwt = mwt_f;                /*female mature wt, breeders and fatteners */
}
/************* end of mature weight function *********************************/


void BWT (int gender, float k, float b, float m, float a, float *bwt)
{
 switch(gender)
     {                             /* compute birth weights */
       case 1:
              *bwt = richards(1.0, k, b, m, a);
              break;
       case 2:
       case 3:
              *bwt = richards(1.0, k, b, m, a * 1.4);
              break;
     }
 }
/************************ end of BWT function ********************************/

void Preg_lact (int time, float *le, float *milk, float *mfat,
                float *pe, float bwt, int breed, int yr)
{
 static int day, day2=300;
float milk_e, mlk, mlk_fat, preg_e;
```

```


  if (time == ((yr-1) *365)+1)
    day=1;
  if (day > 180)
   {
   *milk = 0.0;
   *le = 0.0;
   }
  else
   {
   e_lact(&milk_e, &mlk, &mlk_fat, day, breed, yr);
   *le = milk_e;
   *milk = mlk;
   *mfat = mlk_fat;
   day++;
   }

  if (time == ((yr-1) *365)+95)  /*        if (day == 95) */
    day2 = 1;
  if (day2 <= 282)
    {
    preg(day2, yr, breed, &preg_e, bwt);
    *pe=preg_e;
    day2++;
    }
 else
   *pe =0.0;

  if (yr == 1)
      {
      *pe=0.0;
      *le=0.0;
      }
}
/************** end of preg_lact function ********************************/

void cum_all (float *tei, float *EI, float *DMI, float *cum_e_p,
              float *cum_dm_p, float *cum_e_l, float *cum_dm_l,
              float pe, float le, float ei, float MEd, float dmi,
              float matwt)
{
 float dm_p, dm_l;
dm_p = pe/MEd;
dm_l = le/MEd;
*cum_e_p  += pe/matwt;          /* scaled cummulated p & l requirements */
*cum_dm_p += dm_p/matwt;        /* by mature size */
*cum_e_l  += le/matwt;
*cum_dm_l += dm_l/matwt;
*DMI += dmi;
*EI  += ei;
*tei  = (ei*matwt) + le + pe;
```

```
}
/********************** end of function cum_all ***********************/


void get_cum_vals(float cum_cdmi, float cum_cei, int brd, int yr,
                  int sex, int time)
{
extern float e_off_dm[5][4][10], e_off_e[5][4][10],
             e_dam_e[5][10], e_dam_dm[5][10],
             e_dam_min_dm[5][7], e_dam_min_e[5][7];

extern int matrixAGE[5][10], min_age[7];
int k;



     for (k = 1; k <11; k++)
        {
         if (time == matrixAGE[brd-1][k-1])
           {
            e_off_dm[brd-1][sex-1][k-1] = cum_cdmi; /* environmental cor. */
            e_off_e[brd-1][sex-1][k-1] = cum_cei;   /* to specified mieus */
           }
        }
     for (k=0; k < 7; k++)
        {
         if (sex == 1 && time == min_age[k])
           {
            e_dam_min_dm[brd-1][k] = cum_cdmi;     /* enviro. cor. for minimum */
            e_dam_min_e[brd-1][k] = cum_cei;       /* ages at culling */
           }
        }
    if (time == yr * 365 && sex == 1)
       {
        e_dam_dm[brd-1][yr-1] = cum_cdmi;           /* yrly e cor. for dams */
        e_dam_e[brd-1][yr-1] = cum_cei;
       }
}
/******************* end of get cum vals function *************************/


void get_coef(float constt, float bee, float log_const, float log_bee,
                  int brd, int gender)

{
 extern float eq_coefs[2][5][8];

switch (gender)
 {
   case 1: eq_coefs[0][brd-1][0] = constt;
           eq_coefs[0][brd-1][1] = bee;
           eq_coefs[1][brd-1][0] = log_const;
```

```
            eq_coefs[1][brd-1][1] = log_bee;
            break;
    case 2:
            eq_coefs[0][brd-1][2] = constt;
            eq_coefs[0][brd-1][3] = bee;
            eq_coefs[1][brd-1][2] = log_const;
            eq_coefs[1][brd-1][3] = log_bee;
            break;
    case 3:
            eq_coefs[0][brd-1][4] = constt;
            eq_coefs[0][brd-1][5] = bee;
            eq_coefs[1][brd-1][4] = log_const;
            eq_coefs[1][brd-1][5] = log_bee;
            break;
    case 4:
            eq_coefs[0][brd-1][6] = constt;
            eq_coefs[0][brd-1][7] = bee;
            eq_coefs[1][brd-1][6] = log_const;
            eq_coefs[1][brd-1][7] = log_bee;
            break;
    }
}
/***************** end of get_coef function ************************************/


void get_preg_lact(int sex, int brd, float yr, float e_p, float dm_p,
                   float e_l, float dm_l)
{
extern float p_cum_e[5][2],          /* breed by type of calf */
             p_cum_d[5][2],
             lact_cum[2][5];

if (sex == 1)                         /* female calves */
    {
     p_cum_e[brd-1][0] = e_p / (yr-1); /* mean preg. req'ts over simulation span*/
     p_cum_d[brd-1][0] = dm_p / (yr-1);
    }

else if (sex==4)                      /* male calves */
    {
     p_cum_e[brd-1][1] = e_p / (yr-1);  /* mean preg. req'ts over simulation span*/
     p_cum_d[brd-1][1] = dm_p / (yr-1);
    }
lact_cum[0][brd-1] = e_l / (yr-1);
lact_cum[1][brd-1] = dm_l / (yr-1);
}




void
shift_cum_days(int monthno)
```

```
                                        /* monthno - starting month of the second season */

{
int i;                                  /* cursor for arrays */
int prev_cum;                           /*cumulative amount to previous month in the second season*/
                              /* this routine offsets the cumulative days so that the second season starts
                               * with a month other than January
                               * this algorithm works by calculating the length of each month from the
                               * first cum_days , i.e. length of month[i] = cum_days[0][i] - cum_days [0][i-1]
                               * these are cumulated to calculate the new cum_days into cum_days[1][i].
                               * The December to January transition is handled by a special case
                               */

prev_cum=0;
if (monthno == 0)
    {
    for (i=0; i < 12; i++)
        {
        cum_days[1][i] = cum_days[0][i];
        }
    }
else
    {
    for  (i=0; i < 12; i++)
        {
        cum_days[1][i] = cum_days[0][(i+monthno)%12]
                       - cum_days[0][(i+monthno -1)%12] + prev_cum;
        if ( (i+monthno)%12 == 0 )  cum_days[1][i] += 365;  /* handle year end */
        prev_cum = cum_days[1][i];
        }
    }
}
/******************************end of shift_cum_days routine ************/

void
shift_tmp(int monthno)
/* monthno  - month that is to be the starting month of 2nd season */
/* this routine shifts the temperatures so that the 2nd season
 * starts with a month other than January
 */

{
int i;                                  /* cursor for passing through months */

for (i=0; i < 12; i++)
    {
    tmp[1][i] = tmp[0][(i+monthno) % 12 ];
    }
}
/******************************end of shift_tmp routine ************/
void
shift_wind(int monthno)
```

```
/* monthno - month that is to be the starting month of 2nd season */

                              /* this routine shifts the wind values so that the 2nd season
                               * starts with a month other than January
                               */
{
int i;                        /* cursor for passing through months */

for (i=0; i < 12; i++)
   {
   wind[1][i] = wind[0][(i+monthno) % 12 ];
   }
}
/*******************************end of shift_wind routine ************/
```

Herd.c

```
/* This module generates the numbers of animals of different
 classes in the herd on the basis of the performance of the
conceptual 'average' female.
*/

#include "b:\herd.h"
void start(char *type, int *cont)

/* - *type returns  the type of operation and
     *cont returns the type of sex control
                                        */
{
char ans[2];
/*****************************************************************************
 *    nmales[MAXYEARS],   number of male offspring per dam             *
 *    nfemale[MAXYEARS],  number of female offspring per dam            *
 *    npmales,            number of pure bred male progeny per dam     *
 *    nxmales[MAXYEARS],  number of cross bred male progeny per dam     *
 *    npfemale,           number of pure bred female progeny per dam  *
 *    nxfemale[MAXYEARS], cross bred female progeny per dam             *
*****************************************************************************/
float nyears,
      nmin,
      ntotal,
      miniage,
      miniyrs,
      sexratio,
      reprate,
      agebred,
      nxmales[MAXYEARS],
      nxfemale[MAXYEARS],
      nmales[MAXYEARS],
```

```
     nfemale[MAXYEARS],
     npfemale,
     npmales;

int  i,
     arraysize;


  clrscr();
  heading();
  menu();
  cprintf("\n\nMake a choice, eg 1 , 2 , etc.\n");

gets(ans);
*type = ans[0];

switch(ans[0])
   {
    case '1':
    case '3':
    break;

          getherdinput(&reprate, &sexratio, &agebred, &nyears);
          numbers(&nmin, &ntotal, reprate, sexratio, agebred, nyears);
          minyrs(&miniyrs, reprate, sexratio);
          miniage = miniyrs + agebred;        *minimum age at which a cow*
                                              *can be culled from the herd*
          validinput(nyears, miniage, nmin, ntotal, &reprate,
                      &sexratio, &agebred, &nyears);

          herd(nxmales, nxfemale, nmales, nfemale, &npmales, &npfemale,
              &arraysize, sexratio, agebred, nyears, reprate);

          printf("the reproductive rate is    %.2f\n",reprate);
          printf("the male to female ratio is %.2f\n",sexratio);
          printf("the age at first breeding is %.2f\n",agebred);
          printf("the mean age at culling is   %.2f\n",nyears);
          get_key();
          clrscr();
          break;

    case '2':
          cprintf("Is this an all male or mainly male system? (Y/N)\n");
          gets(ans);
          if (toupper(ans[0]) == 'Y')
             *cont = 1;
          else if (toupper(ans[0]) == 'N')
             *cont = 2;
          break;
    case '4':
          exit();
    }
```

```
}

/*********************************end of main*************************************/
void heading(void)
{
tab(20);
cprintf("BEEF EFFICIENCY MODEL \n");
tab(26);cprintf("Version 1.    \n");
tab(20);
cprintf("-------------------------\n\n\n");
}

/********************end of heading *******************************************/
void menu(void)
{
tab(9);
cprintf("1 - Simulate efficiency in traditinal systems\n\n");
tab(9);
cprintf("2 - Simulate efficiency in Sex controlled systems\n\n");
tab(9);
cprintf("3 - Simulate efficiency in Dairy beef systems\n\n");
cprintf("4 - Quit \n");
}
/*********************************end of menu**********************************/

void tab(int end)
{
int col = 1;
do
   {
    putchar(' ');
    col++;
   }while(col <= end);
}

/********************* end of tab function ********************************/

void getherdinput(float *p1, float *p2, float *p3, float *p4)
                    /* obtains herd parameters from user */
{

   puts(MSREPRATE);
   scanf("%f",p1);
   puts(MSSEXRATIO);
   scanf("%f",p2);
   puts(MSAGEBRED);
   scanf("%f",p3);
   puts(MSYEARS);                /******************************************/
   scanf("%f", p4);             /* user input of number of years a cow */

}                    /* getherdinput */

```

```
/*****************end of obtaining herd parameters function******************/
int validherdinput(float min, float total)
{
 if (total< min)   /*if (y2-y1)*r < 1/(1-r), r = reprate, y2 = nyears,
                     y1=agebred */
    {
    puts(MSNMIN);
    return(FALSE);
    }
 return(TRUE);
}
/***********end herd input validation ************************************ ***/

void numbers(float *x1, float *x2, float m1, float m2,
                 float m3, float m4)   /* calculates total and minimum */
                                       /*numbers of offspring per cow */

{
      *x2 = (m4 - m3) * m1;    /* (y2 -y1) * r , see previous function */
      *x1 = (1.0 / (1.0 - m2));  /* 1/(1-sexratio) */
}
/********************* end of numbers function ******************************/
/*void minage(float *x3, float x4)  calculates minimum age at culling i
{                                   not detrimental

float minyears;

      minyrs(&minyears);
      *x3 = minyears + x4;
} */
/********************* end of minimum age function *********************/
void minyrs(float *yrs, float y1, float y2)
{
 float chk1;

 chk1 = y2;
 if (chk1 == 1.0)
      *yrs = 1.0/y1;    /* # of yr required for a replacement in complete
                        sex control. This is essentially the # of yr for
                        one offspring */
 else
      *yrs = 1.0 /(y1 * (1.0 - y2)); /* y1 = reprate, y2 =sexratio */
}
/**************************end of minyrs function*********************/
int get_key(void)
/* Uses the BIOS to read the next keyboard character */
{
 int key, lo, hi;

 key = bioskey(0);
 lo = key & 0X00FF;
 hi = (key & 0XFF00) >> 8;
```

```
 return((lo == 0) ? hi + 256 : lo);
}                                    /* getkey */
/****************************end of getkey ***********************************/
int validyrs(float yr1, float yr2)
    /* checks that the number of year is within valid bounds: minyrs - 20 */
{

    if (yr1 > MAXYEARS) /* yr1 = nyears = age at culling */
      {
       puts(ERRMAXYEARS);
       printf("%4d\n" ,MAXYEARS);
       return(FALSE);
       }

    if (yr1 < yr2)/* yr2 = minyrs = minimum yrs of residence in herd b4 cull */
       {
       puts(MSMINYRS);
       return(FALSE);
       }
return(TRUE);
}                                    /* validyrs() */


/*********************** end of years validation function **********************/

void validinput(float k1, float k2, float k3, float k4,
                float *rep, float *sex, float *age, float *nyrs)

/*k1 = nyears, k2 = miniage, k3 = nmin, k4 = ntotal;
  rep = reprate
  sex = sex_ratio
  age = age at first breeding (agebred)
  nyrs = age at culling.
*/

{
int yrs = TRUE,
    input =TRUE;

 yrs = validyrs(k1, k2);
 input = validherdinput(k3, k4);

 if (yrs == FALSE)
       {
       puts(MSTRYAGAIN);
           if (get_key() == ESC)
               exit();
           else
               {
               printf("input age at culling again\n");
               scanf("%f", nyrs);
               }
```

```
    }


if (input == FALSE)
    {
     puts(MSTRYAGAIN);
     if (get_key() == ESC)
         exit();
     else
        {
         printf("input reproductive rate, sex ratio and age at first\n");
         printf("breeding again, on the same line with spaces between\n");
         scanf("%f %f %f", rep, sex, age);
         }
     }
}
/**************** end of validinput function *********************************/

/* herd dynamics module:
*   This is function is set up for computing numbers .
*   of different classes of animals for a stable herd
*   structure
*************************************************************/

void herd(float nxm[], float nxf[], float nma[], float nfe[], float *npm,
          float *npf, int *index, float x1, float x2, float x3, float x4)

{
float years, nmin;
           /* minimum # of yrs to maitain herd equilibrim */
int i, j;
int temp;      /*temporary var. - least (non - fractional) # of yrs > minyrs*/

nmin = 1.0/(1.0 - x1); /*least # of offspring per cow */
nma[0] = nmin * x1;            /*x1 = sexratio */
nfe[0] = nmin * (1.0 - x1);
*npm = nma[0];
*npf = nfe[0];
nxm[0] = nma[0] - *npm;
nxf[0] = nfe[0] - *npf;

minyrs(&years, x4, x1); /* x4 = rep. rate, x1 - sexratio) */
temp = years + x2 + 1;  /*minimum age (minyrs + agebred) truncated and
                        *incremented                      */

for (j =temp - x2, i = 1; j <= x3 - x2; j++, i++)   /* x2 = agebred,
                                                     * x3 = nyears  */
 {
    nma[i] = j * x4 * x1;
    nfe[i] = j * x4 * (1 - x1);
    nxm[i] = nma[i] - *npm;
    nxf[i] = nfe[i] - *npf;
```

```
    }
*index = i ; /* number of elements calculated in this loop */

}

/********************************** end of herd dynamics function *********/
```

Eff.c

```
#include <stdio.h>
#include <math.h>
#include <conio.h>
#include "b:\eff.h"


void over_eff(void)
{

float b1, b2, b3, b4, /*regression coefficients for heifers, steers & bulls */
                      /* and dams */
      c1, c2, c3, c4, /*constants           "    "      "     "    */

      mieu_d,         /* degree of maturity of dam at culling           */
      cor_d;          /* enviromental corection for dam                 */

int breed,
    reprate,
    energydm,
    years,
    season,
    i, j;

cprintf("Input the breed number from 1 to 5\n");
scanf("%d", &breed);


season = 1;
for (breed = 1; breed < = 4; breed+ +)
    {
    printf("The results for breed %d are\n", breed);
    for(energydm = 1; energydm < =1; energydm+ +)
      {
       printf("Energy or dry matter level is %d\n", energydm);
       eq_parms(breed, &c1, &b1, &c2, &b2, &c3, &b3, &c4, &b4, energydm);

     printf("The intake equations are\n\n");
     printf("%f %f %f %f %f %f %f %f\n", c1, b1, c2, b2, c3, b3, c4, b4);

   for(reprate = 1; reprate < =7; reprate+ +)
```

```

    {
    get_rep_yr(reprate, &i);
     printf("For rep. rate %d\n", reprate);
     for(years=i; years< =10; years+ +)

         {
          if (reprate= = 1)              /* j is the index to the */
            j = years -2;              /* array holding herd numbers*/
          else if (reprate > 1  && reprate <6)
            j = years - 3;
          else if (reprate = = 6)
            j = years - 4;
          else
            j = years - 5;
      printf("Year %d\n", years);
            eff(c2, c3, c4, c1, b2, b3, b4, b1, breed,
                reprate, years, j, season, energydm);

            }    /* end years loop */
         }       /* end of rep. rate loop */
     }          /* end of energy or dm loop */
 }             /* end of breed loop */
}             /* end of function */

/*
|  This is the efficiency module.
|  It receives regression parameters on
| the relationship between feed intake(cummulative)
|  and degree of maturity  and computes the efficiencies
|   at various degrees of maturity of the slaughter offspring.
*/







void eff(float c_h, float c_s, float c_b, float c_d, float b_h, float b_s,
        float b_b, float b_d, int brd, int rep, int yrs, int index,
        int season, int eordm)
{
float lean_h,                  /* lean from heifers */
     lean_s,                   /* "     "  steers */
     lean_b,                   /*  "    "   bulls */
     lean_d,                   /*  "    "  culled dams */
     milk=0.0,                    /* milk available for sale */
     feed_h,                   /* cummulative feed from heifers */
     feed_s,                   /* "     "  steers */
     feed_b,                   /*  "    "   bulls */
     feed_d,                   /*  "    "  culled dams */
```

```
        feed_l,                 /* feed for lactation       */
        feed_m,                     /*feed for total milk accounts for
                                    number of lactations */
        feed_p,                     /* total pregnancy requirements */
        feed_pf,                /* feed per female pregnancy */
        feed_pm,                  /* feed per male pregnancy */
        b_cost,                 /* relative breeding cost */
        qual_h = 0.97,                  /*meat quality from heifers */
        qual_s = 1.00,                  /*meat quality from steers */
        qual_b = 0.99,                    /*meat quality from bulls */
        qual_d = 0.92,                   /*meat quality from culled dams */
        value_m=0.3,                    /*value of milk relative to meat */
        num_h,
        num_s,
        num_b,
        num_d =1.0,
        wt_h,
        wt_s,
        wt_b,
        wt_d,
        pcent_h = 0.33,
        pcent_s = 0.33,
        pcent_b = 0.33,
        pcent_d = 0.33,
        output,
        input,
        efficiency,
        cor_h,  /*environmental corrections for heifers, steers etc */
        cor_s,
        cor_b,
        cor_d,
        tot_num, /* total number of offspring - to correct lactations and
                        pregnancies */
        lean_bb = 0.33, /* lean from breeding bulls */
        icost_b,   /* initial cost of bulls */
        icost_c,   /* initial cost of cows */
        init_cost, /* total initial costs */
        m,          /* relative breed size - relative to herefords */
        r,          /* rep rate */
        mieu_d,
        mieu = 0.1;

extern float D_ME,
                lact_cum[2][5],
                p_cum_e[5][2],
                p_cum_d[5][2],
                brd_val[3][4],
                e_off_dm[5][4][10], /*enviromental corrections, 5 breeds, 10 mieus */
                e_off_e[5][4][10]; /*and 4 genders, mieu == degree of maturity */

extern float U_d_yr[10][4],
               e_dam_e[5][10],/* yrly envir. cor for dams */
```

```
          e_dam_dm[5][10];


int  i;
  if (yrs == 4 || yrs == 5)
      qual_d = 0.7386;
   else if ( yrs > 5)
      qual_d = 0.6902;

  if (brd == 2)
    pcent_h = pcent_s = pcent_b = pcent_d = 0.38;

feed_l = lact_cum[eordm-1][brd-1];

feed_pf = (eordm == 1) ? p_cum_e[brd-1][0] : p_cum_d[brd-1][0];
feed_pm = (eordm == 1) ? p_cum_e[brd-1][1] : p_cum_d[brd-1][1];

b_cost = brd_val[season][brd-1];
get_init_cost (brd, &icost_c, &icost_b);

init_cost = (eordm == 1) ? (icost_c + icost_b) * D_ME : (icost_c +icost_b);

if (brd == 1)
        m = 1.0;
else if (brd == 2)
        m = 1.04;
else if (brd == 3)
        m = 1.09;
else if (brd == 4)
        m =1.20;
else
  m = 1.17;

if (rep == 1) r =2.0; else if (rep == 2) r = 1.0; else if (rep == 3) r = 0.9;
else if (rep == 4) r = 0.8; else if (rep == 5) r = 0.7; else if (rep == 6)
r = 0.6; else r = 0.5;

nums(&num_h, &num_s, &num_b, rep, index);
/*
num_h =0.617;
num_s =0.0;
num_b =1.617;
*/
tot_num = num_h + num_s + num_b;
feed_m = tot_num * feed_l;              /* total feed for lactation */
feed_p = ((num_s +num_b) * feed_pm) + (num_h * feed_pf);      /* total feed preg. */

for(i=1; i<10; i++, mieu +=0.1)
  {
   switch(eordm)
      {
       case 1:
```

```
                cor_h = e_off_e[brd-1][1][i];
                cor_s = e_off_e[brd-1][2][i];
                cor_b = e_off_e[brd-1][3][i];
                cor_d = e_dam_e[brd-1][yrs-1];
                break;
        case 2:
                cor_h = e_off_dm[brd-1][1][i];
                cor_s = e_off_dm[brd-1][2][i];
                cor_b = e_off_dm[brd-1][3][i];
                cor_d = e_dam_dm[brd-1][yrs-1];
                break;
        }
    wt_h = wt_s = wt_b =mieu;
    wt_d = U_d_yr[yrs-1][brd-1]; /* mieu_d - degree of maturity of the dam */
    mieu_d =wt_d;

    lean_h = num_h * wt_h * qual_h * pcent_h;
    lean_s = num_s * (wt_s * 1.2) * qual_s * pcent_s;
    lean_b = num_b * (wt_b * 1.4) * qual_b * pcent_b;
    lean_d = num_d * wt_d * qual_d * pcent_d;

    output = ((lean_h + lean_s + lean_b + lean_d + lean_bb) * m
                + (milk * value_m)) * 1000;

    feed_h = (exp(c_h + (b_h * mieu)) + cor_h) * num_h;
    feed_s = (exp(c_s + (b_s * mieu)) + cor_s) * num_s;
    feed_b = (exp(c_b + (b_b * mieu)) + cor_b) * num_b;
    feed_d = (exp(c_d + (b_d * mieu_d)) + cor_d) * 1.05;

    input = feed_h + feed_s + feed_b + feed_d + b_cost
            + feed_p + feed_m + init_cost;

    efficiency = output/input;

    printf("%.1f    %.2f    %.4f\n", r, mieu, efficiency);
/*   printf("%d  %.2f  %.2f  %.4f  %.4f\n", yrs, mieu, mieu_d,
              (lean_d * m/output)*100,  feed_d/input); */


    }
}


void eq_parms(int brd, float *c1, float *b1, float *c2, float *b2,
                float *c3, float *b3, float *c4, float *b4, int E_or_dm)

{
 extern float eq_coefs[2][5][8];

*c1 = eq_coefs[E_or_dm-1][brd-1][0];
*b1 = eq_coefs[E_or_dm-1][brd-1][1];
*c2 = eq_coefs[E_or_dm-1][brd-1][2];
```

```
*b2 = eq_coefs[E_or_dm-1][brd-1][3];
*c3 = eq_coefs[E_or_dm-1][brd-1][4];
*b3 = eq_coefs[E_or_dm-1][brd-1][5];
*c4 = eq_coefs[E_or_dm-1][brd-1][6];
*b4 = eq_coefs[E_or_dm-1][brd-1][7];
}

void nums(float *h, float *s, float *b, int rep, int yr)
{
 extern float numsr[7][4][9];

 *h = numsr[rep-1][0][yr];
 *s = numsr[rep-1][1][yr];
 *b = numsr[rep-1][2][yr];
}

void get_rep_yr(int rep, int *yr) /* get yr immediately after the min #yr a */
{                                 /* cow must stay in the herd */

switch(rep)
    {
    case 1:
         *yr = 3;
         break;
    case 2:
    case 3:
    case 4:
    case 5:
        *yr = 4;
        break;
    case 6:
        *yr = 5;
        break;
    case 7:
        *yr = 6;
        break;
    }

}
/************************ end of get mieu_d function ************************/

void get_init_cos  (int brd, float *cost_c, float *cost_b)

/* obtain the initial cost of the breeding stock. Assuming 1 bull per 25cows
   and 1 reserved bull for 100 cows, the cost of bulls per cow is the sum of
   (cost of bull/25) and (cost of bull/100). Each converted to a feed equivalent

*/
{
  extern float bwts[5][2], matrixGP[5][4];
  float cost_kg_b,
        cost_kg_c,
```

```
        feed_cost_kg,
        tot_cost_b,
        tot_cost_c,
        bwt_b,
        mwt_c,
        bwt_c;

cost_kg_b = 348;
cost_kg_c = 327;
feed_cost_kg = 15;

bwt_c = bwts[brd-1][0];
bwt_b = bwts[brd-1][1];

mwt_c = matrixGP[brd-1][0];

tot_cost_b = (bwt_b *cost_kg_b / 25) + (bwt_b *cost_kg_b / 100);

tot_cost_c = bwt_c *cost_kg_c;

*cost_b = (tot_cost_b / feed_cost_kg) / (mwt_c * 1.4);
*cost_c = (tot_cost_c / feed_cost_kg) / (mwt_c);
}
```