Economic values of performance traits in maternal and paternal strains of beef cattle
by Bradley Welding Kolstad

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Animal Science
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Abstract:
A computer simulation model was used to measure economic performance of five strains of composite cattle from Beefbooster Cattle Alberta Ltd. There were three maternal strains (Ml, M2, and M4) , an easy-calving sire strain (M3) and a terminal cross strain (Tx). All strains were evaluated in purebred systems. Three rotational crossbreeding systems were simulated: three-way rotation using maternal strains (ROT), ROT used with an easy calving sire (M3) on yearling replacement heifers (ROT3), and ROT3 used with Tx bred to mature cows (ROT3X). Economic effects of changing genetic potential of individual traits within each of the strains using ROT3X were also measured. These economic estimates were used to determine economic weightings of each trait within each strain and selection indexes were calculated for each strain. Traits examined were mature weight, weaning weight, birth weight, probability of conception, age at first estrus (puberty), and milk production. Only weaning weight and birth weight were studied in M3 and Tx. All three rotational mating systems were more profitable than any purebred system. Maternal strains had similar estimated profits followed by Tx and M3. Tx was close in profit to maternal strains, however, M3 was considerably lower. Changes in mature weight, weaning weight, and probability of conception were shown to be important for all maternal strains. Changes in milk production and age at first estrus did not prove to be very important in these strains at current levels of performance. Weaning weight and birth weight were both important in M3 while only weaning weight was important in Tx. Changes in birth weight and probability of conception both caused a shift in age distribution of the herd. A younger age distribution proved to be the most profitable. (KEY WORDS: Beef cattle, Mating systems, Selection)

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ABSTRACT

A computer simulation model was used to measure economic performance of five strains of composite cattle from Beefbooster Cattle Alberta Ltd. There were three maternal strains (M1, M2, and M4), an easy-calving sire strain (M3) and a terminal cross strain (Tx). All strains were evaluated in purebred systems. Three rotational crossbreeding systems were simulated: three-way rotation using maternal strains (ROT), ROT used with an easy calving sire (M3) on yearling replacement heifers (ROT3), and ROT3 used with Tx bred to mature cows (ROT3X). Economic effects of changing genetic potential of individual traits within each of the strains using ROT3X were also measured. These economic estimates were used to determine economic weightings of each trait within each strain and selection indexes were calculated for each strain. Traits examined were mature weight, weaning weight, birth weight, probability of conception, age at first estrus (puberty), and milk production. Only weaning weight and birth weight were studied in M3 and Tx. All three rotational mating systems were more profitable than any purebred system. Maternal strains had similar estimated profits followed by Tx and M3. Tx was close in profit to maternal strains, however, M3 was considerably lower. Changes in mature weight, weaning weight, and probability of conception were shown to be important for all maternal strains. Changes in milk production and age at first estrus did not prove to be very important in these strains at current levels of performance. Weaning weight and birth weight were both important in M3 while only weaning weight was important in Tx. Changes in birth weight and probability of conception both caused a shift in age distribution of the herd. A younger age distribution proved to be the most profitable. (KEY WORDS: Beef cattle, Mating systems, Selection)

INTRODUCTION

Efficient use of resources in beef cattle production is critical, as in any business, if maximum efficiency is to be obtained. There are many options which producers may utilize when attempting to maximize efficiency. Genetic improvement of livestock is one method which can be used. There are two primary tools which can be used for genetic improvement: selection and mating systems (crossbreeding).

Selection allows one to select cattle to be maintained in the herd based on the merits of individual cows. Many factors affect success of selection with two primary ones being heritability of the trait or traits being selected and amount of selection pressure being applied. Many times selection pressure is placed on more than one trait. As well, there are often correlated responses in traits not selected for directly, which can be either positive or negative. Thus, it is important to have a method of applying proper selection pressures on relevant traits to maximize potential benefits of selection. One powerful tool is a selection index which allows traits to be weighted according to amount of change desired, heritability of that trait and correlated responses with other traits.

Mating systems can produce genetic improvement of cattle in two ways. Mating of animals from unrelated breeds exploits heterosis which results from dominance properties of genes allowing offspring to be better than either parent. Using specific breeds in paternal and maternal roles exploits breed complimentarity. Complimentarity is due to additive gene effects. It is possible to breed two types of cattle differing in expression of traits to produce offspring suited to a particular function. An example of this is breeding a small breed type sire to first calf yearling replacement heifers to minimize dystocia.

LITERATURE REVIEW

One of the primary research goals relative to beef production is to increase efficiency. There are many areas in which efficiency can be improved. One is through genetic improvement by use of selection and mating systems (Koch et al., 1982; Clarke et al., 1984). Long (1980) stated that two primary methods are selection within breed to enhance specific characteristics (traits) and selection among breeds and combinations of breeds. In a review on crossbreeding systems, Gregory and Cundiff (1980) stated that crossbreeding systems allow optimization of both additive and nonadditive effects of genes of economic importance. Thus, two powerful tools are available for improvement of beef cattle production and efficiency; selection and crossbreeding.

Livestock Improvement

Crossbreeding

Utilizing different mating systems allows for crossbreeding, resulting in heterosis which is generally considered to be beneficial. Notter et al. (1979a) state that many areas of beef production can be improved through heterosis including beef production per cow exposed, beef production per calf weaned, and economic efficiency. Gregory and Cundiff (1980) reported that heterosis from continuous crossbreeding can increase calf weaned per cow exposed to breeding by over 20%.

Crossbreeding cattle with the goal of increasing efficiency and production is now fairly widely used and recommended (Belcher and Frahm, 1979; Long, 1980). The large variety of cattle breeds presently available give excellent opportunities to mix breeds to match crossbred cattle to environmental and management factors. As well, Setshwaelo et al. (1990) also stated that breed differences in performance characteristics are important genetic resources for improving beef production efficiency. Nunez-Dominguez et al. (1992) were able to show that economic efficiency of crossbred cattle was higher than contemporary straightbreds. It was determined that individual and maternal heterosis decreased the costs per unit of output production by 6% and 6%, respectively.

Kress et al. (1990) studied 264 contemporary two-year-old straightbred and crossbred dams from 1978 to 1981. Breed groups studied were Hereford, Angus-Hereford, 25% Simmental-75% Hereford, 50% Simmental-50% Hereford and 75% Simmental-25% Hereford. They found no significant differences for length of gestation, calving difficulty, and late milk production. Traits which were found to be important ($P < .01$) were calf weights (birth, early and late milking periods, and weaning), calf average daily gains, early milk production and other calf traits at weaning. Maternal heterosis for calf weights were estimated at 6.3, 12.9, 9.0 and 7.6% for calf weights at birth, 40 days, 130 days and weaning, respectively. As well, estimated maternal heterosis for proportion calving and actual calf weight weaned per cow exposed were 41.3 and 34.6%, respectively. In a related study, Kress (1992) estimated maternal heterosis of the same breed types previously discussed for three- to eight-year-old dams. Maternal heterosis for calf weaning weight and for calf weaning weight per cow exposed were estimated at 5.2 and 17.9%, respectively.

In a series of related papers Gregory et al. (1991a,b,c) and Gregory et al. (1992a,b,c) discussed composite breeds and retained heterosis. If all breeds which are in a composite breed are bred randomly and contribute equally, heterosis of the herd is maintained at (n-1)/n times the maximum F_1 where n is number of breeds (Gregory et al., 1991a). Thus, with composite breeds, it is theoretically possible to maintain a large amount of heterozygosity.

The papers by Gregory et al. (1991a,b,c) and Gregory et al. (1992a,b,c) showed that heterosis has an effect on many traits which are considered to be important to production. These traits were separated into three categories by Dickerson (1970), being female production, female reproduction and growth of young animals. Furthermore, it was shown that heterosis for many of these traits still had a significant influence in F_2 and F_3 dams, thus it appears that there is retained heterozygosity.

Gregory et al. (1992c) found that 12 hour milk production was .689 kg (14.5%) higher in composite breeds than in straightbreds. Gregory et al. (1992a) claimed that heterosis for F_1 dams was significant for reproductive and maternal traits and the F_2 and F_3 retained the expected heterozygosity for two of three composite populations. Traits examined by Gregory et al. (1991c) were birth weight, average daily gain from birth to weaning, 200 day weight, average daily gain from weaning to 368 days, 368 day weight, 368 day height, 368 day condition score, and 368 day muscling score (male calves). It was shown that heterosis was significant for most traits examined with F_1, F_2, and combined F_3 and F_4 generations for two of the three composite populations studied.

Specialized Sire and Dam Strains

Crossbreeding systems allow for improvement of productivity of beef cattle other than just heterosis. One effective tool is the use of specialized sire and dam strains. Use of these strains allows for additive effects of genes to be employed within a system to help maximize productivity. Selection for different traits within strains allows for complimentarity when strains are crossed.

Dam strains should generally be selected for number of offspring produced (reproductive and productive efficiency), and sire strains should be selected for growth and carcass traits (Smith, 1964; Moav, 1966a,b,c). Typically, a systematic roto-terminal system will breed younger dams to sires of similar genotype allowing for adequate replacement heifers to maintain herd population. Progeny of specialized sires are generally sold (male and female), as sires are generally selected for growth which is not a desired trait within female replacements. Because of this, specialized sires are commonly called terminal sires.

One aspect of terminal sires which Smith (1964) failed to discuss was that of sires chosen for low birth weight. These sires are intended for use with first calf yearling heifers (primiparous), to minimize incidence of dystocia (MacNeil et al., submitted). By decreasing dystocia, associated labor costs and incidence of neonatal mortality are kept at a minimum.

Data analyzed by Smith (1976a et al.) looked at effects of sire breed on economic efficiency within terminal crossbreeding mating systems. Sire breeds examined were Hereford, Angus, Jersey, South Devon, Limousin, Charolais and Simmental. Dam breeds used were Hereford and Angus. Traits examined in progeny were level of calving difficulty, preweaning survival, growth rate, feed efficiency, carcass composition and quality grade. Smith (1976) concluded that despite the increased dystocia costs associated with use of larger terminal breeds, gain in efficiency and growth of the calves from larger terminal breeds (Limousin, Charolais and Simmental), more than justified these costs.

Having a systematic, well managed roto-terminal mating system, it is possible to increase productivity and efficiency of beef cattle. Use of crossbred dams will exploit maternal heterosis for production and reproduction. Breeding the dam to a sire of a different breed (or composite breed type), will allow for individual heterosis in progeny for growth, efficiency and survivability. As well, if appropriate terminal cross bulls are used, minimum losses can be incurred with an easy calving bull for primiparous females, and high growth rate sires used on mature cows will maximize calf growth and gain.

Selection

Selection is the main tool which can be used for genetic improvement of animals to optimize productivity and maximize efficiency (Buchanan et al., 1982a; Koch et al., 1982; Clarke et al., 1984; Frahm et al., 1985a,b; Irgang et al., 1985a,b,c) by altering gene frequencies of traits being selected for or against. Frahm et al. (1985a) used Lush's (1945) explanation of selection as: "a process of differential reproduction whereby certain individuals are permitted to contribute more offspring to the next generation than others."

One strong advantage to combining selection with crossbreeding is that traits which have a lower response to selection tend to exhibit larger amounts of heterosis. The opposite is also true. The reason behind this is that selection works on the additive properties of genes while heterosis is due to dominance (nonadditive interactions of genes; Legates and Warwick, 1990).

Selection for one trait is a fairly simple process especially if the phenotypic expression of that trait is relatively easy to measure and consequently easily selected for. As well, response to selection for a single trait can be predicted by multiplying heritability of that trait by the observed selection differential (Buchanan et al., 1982a). However, when selection pressure on more than one trait is desired, it can get much more complex, requiring an indexing system (Koch et al., 1974; Buchanan et al., 1982a,b).

Not only is selection for one trait accomplished fairly easily, it can also show significant results in a relatively short period of time. Irgang et al. (1985a,b) analyzed data from two strains of Hereford cattle in which sires were selected for either weaning weight or postweaning gain over 12 years equalling an average of about 1.85 generations of selection. Selection for weaning weight resulted in a selection differential of 54.4 kg and postweaning gain had a selection differential of 37.8 kg. Using a control to estimate environmental effects, it was found that estimated genetic gains in weaning weight and postweaning growth were 1.07 ± .36 kg/yr in bulls and .62 ± .36 kg/yr in heifers and .85 ± .40 in bulls kg/yr and .30 ± .28 kg/yr respectively.

When utilizing selection, one must realize that there are often correlated trait responses between traits being selected for and other traits (Miller and Pearson, 1979). This correlated response can often be undesirable. Selection for performance traits (i.e. weaning weight, yearling weight, gain) leads to an undesirable increase in birth weight. Koch et al. (1974) found that selection for weaning weight, yearling weight or an index of yearling weight and muscling score led to a positively correlated response in birth weight. They also stated that birth weight increases could be decreased by 30% if all selection was for post-natal growth instead of weaning or yearling weights. Buchanan et al. (1982a,b), using data from a longer period of time for the same herds as Koch et al. (1974), also found that birth weight increased with all strains. It was suggested that to help minimize increases in birth weight an index should be used which includes emphasis against birth weight.

In a similar study by Frahm et al. (1985a,b) two strains of Hereford cattle were selected for either weaning weight or yearling for a period of 15 years which equated to 3.22 generations of selection. Average selection differentials in standard measure per generation interval for weaning weight and yearling weight for birth weight were .44 and .51 respectively and .0 for the control line. Estimated genetic responses/generation (in standard deviation units) of birth weight in the weaning weight and yearling weight strains were .29 and .26 respectively. Results indicate that it is important to consider all traits when developing selection goals. Selecting for production traits (i.e. weaning weight or yearling weight), often leads to undesirable effects on birth weight.

Optimizing productivity and efficiency of beef cattle requires selection for several traits. However, selecting for one trait can often lead to unwanted correlated responses in other traits. A way to minimize this is to develop a multi-trait selection index.

Bioeconomic Breeding Objectives

It is widely agreed that the first and most important decision in any animal improvement plan is to determine bioeconomic breeding objectives (Cartwright, 1970; Harris, 1970; Vesely and Robison, 1972; James, 1978; Miller and Pearson, 1979; James, 1982; Newman et al., 1985a,b; Ollivier, 1986; Ponzoni, 1986; Tess, 1986; Ponzoni, 1987; Newman et al., 1992; MacNeil and Newman, submitted). This quantifies specific goals in terms of measurable traits and helps determine methods for obtaining them. When formulating a bioeconomic goal, one must take into account both the genetic and economic aspects of animal production.

Generally, the primary goal of any producer is to make a profit. Developing comprehensive animal breeding programs enables a producer to maximize the most efficient opportunities available. Newman et al. (1985a) listed the nine steps outlined by Harris et al. (1984) involved in developing a breeding program to maximize efficiency: (1) describe the production system, (2) formulate the bioeconomic objective of the system, (3) choose the breeding system and breeds, (4) estimate selection parameters and economic weights, (5) design the animal evaluation system, (6) develop selection criteria, (7) design matings for selected animals, (8) design a system for expansion (multiplication) and, (9) compare alternative combined programs. In deciding upon overall production objectives, biological or economic efficiencies may be used in the definition.

Ponzoni (1987) and Ponzoni and Newman (1989) broke down the process of defining breeding objectives into the following four categories: (1) specification of production and marketing system, (2) identification of sources of income and expense in commercial populations, (3) determination of traits influencing income and expense and, (4) calculation of economic value of each trait.

When determining traits to include in the breeding objective, it is important to include all traits which are economically important (Fowler et al., 1976; Newman et al., 1985a,b). Miller and Pearson (1979) state that, "failure to provide an economic assessment of genetic alternatives may lead to recommendations of industry actions that are not the most profitable available".

It has been shown that moderate errors in the estimation of economic weightings have relatively minor effects on the correlation of genetic merit with selection indexes; but this is not always the case (Tess, 1986). However, not including important traits can lead to errors in developing selection indexes. Reasons for not including potentially important traits are that they are either difficult to measure or are mistakenly thought to have less importance than what they actually have. One example of a trait which can be difficult to quantify is feed costs in grazing ruminants. Ponzoni and Newman (1989) were able to show that by not including feed costs in the economic evaluation of beef cattle, emphasis within the system was shifted from reproduction to production. There was an 18% loss in efficiency of the selection index by not including feed costs.

Furthermore, it is important that breeding objectives be long term and will prevail for several generations (Cartwright, 1970; Tess, 1986). It is pointless and a waste of money to select for a trait which will be undesirable in one or two generations. James (1982) pointed out that swine producers in the early part of the century did not "read the signs" right and selected for the "lard type" pig.

Hazel (1943) stated that "the relative economic value for each trait depends upon the amount by which profit may be expected to increase for each unit of improvement in that trait." Thus, by determining the effect on profit of changes in traits, we are able to develop economic weightings for traits.

Once bioeconomical breeding objectives have been determined, it is necessary to have a tool to implement these objectives. A selection index can be calculated which will allow different selection pressures to be put on different traits to attempt to meet the defined goals.

A simplified selection index (I) as defined by Falconer (1989) is:

$$I=b_1P_1+b_2P_2+...+b_nP_n$$

where: b = standard regression coefficients

P = phenotypic values (ie. P_1=$Trait_1$-$Trait_x$)

n = number of traits included.

Economic weights can be added into the index allowing for economic efficiency to be a function of selection. Vesely and Robison (1972) state that "with consideration of the relative economic importance and the genetic parameters, breeding plans can be developed". Hazel (1943) as shown by Tess (1981) defined breeding merit (H) as:

$$H = a_1G_1+a_2G_2+...+a_nG_n$$

where: a's = economic weights for each trait

G's = breeding values for the traits

There has been controversy in recent years concerning methods used to develop economic weights. Hazel (1946) first introduced economics into selection indexes with the previously discussed breeding merit equation. Hazel (1946) stated that "relative economic value for each trait depends upon the amount by which profit may be expected to increase for each unit of improvement in that trait." This is still the basis for determining economic weights for livestock improvement.

Harris (1970) claimed that genetic improvement of livestock should be based on economics through one of three measurements: (1) profit, (2) return on investment, or (3) cost per unit production. All three of these measurements are concerned with income relative to expenses and are defined as (Harris, 1970):

$$\text{Profit} = \text{Income} - \text{Expenses}$$

$$\text{Return on Investment} = \frac{\text{Income}}{\text{Expenses}}$$

$$\text{Cost per Unit Production} = \frac{\text{Expenses}}{\text{Product}} \approx \frac{\text{Expenses}}{\text{Income}}$$

When determining expenses, Tess (1986) states that both variable and fixed costs must be taken into account as economic efficiency is maximized when average total costs are minimized. Average total costs are the sum of fixed and variable costs whereas marginal costs only account for variable costs. Including fixed costs is more realistic because if production is increased, then fixed cost are spread out over more product and thus has an effect of efficiency of a total production system.

Dickerson (1978) states that profit should not be used as they do not give a true measurement of efficiency since "real prices received for animal products tend to fluctuate around cost of production plus a margin sufficient to encourage continued production of the product." He claims that biological effects on economic efficiency should be measured which he defines by using return on investment. Harris (1970) said that profit should not be used as it does not accurately reflect individual contributions to overall profit. James (1982) reasons that profit is the measurement which should be used, and competition between producers causes profit to determine what producers do and thus economic weights should be based on this.

Brascamp et al. (1985) set about determining the most adequate base for evaluating economic efficiencies. They were able to show that if profit is zero or is set to zero, then all bases give the same economic weights. The rationale was that average profit over an extended period of time will not change. This average profit is called 'normal profit' in economic theory and is "the profit required for the producer to stay in business in the long term." In a free-market system which has unrestricted entry and production, economics of a market will control that market. This results in an equilibrium where if profit is larger than 'normal profit' there will be incentive to increase production. This occurs through either more producers entering the system or by current producers increasing production. Increased supply causes a decrease in demand resulting in profit once again moving toward equilibrium at 'normal profit'. The opposite is true if profit decreases below 'normal profit'. Due to the principals of 'normal profit', it can then be considered a cost of production as it is required to maintain a business.

'Normal profit' always works toward equilibrium and thus has an average of zero (Brascamp et al., 1985).

Bourdan and Brinks (1987a) used a computer simulation model to determine effects of changing genotypic potential of traits on biological and economic efficiency. Economic weights for live weight of animals when sold at weaning for birth weight, yearling weight, mature weight and milk production were .63, .21, .03, and .83 $/kg change respectively.

Amer (1992) claimed that present methods used to calculate economic weights are not adequate. Many parts of conventional economic theory are not properly addressed when calculating economic weights. Amer (1992) states that to have a true economic weighting system, all aspects of production must be taken into account in order to optimize production. Optimum size of the production system must be determined and the effects of rescaling this system must be considered when deriving economic weights. Methods used by many such as Brascamp et al. (1985) do not account for different levels of production and in fact by setting profit to zero, they cancel out the effects of optimizing the production unit (Amer, 1992). A problem with attempting to optimize all levels is that this can be a very complex problem. Individual enterprises would need to all be determined separately as well as indexes within enterprises. Furthermore, applying these theories to different sized units also presents difficulties.

More work is needed on combining classical economic theory with livestock economics before it will be applicable on an industry basis.

Developing a selection index for specialized strains of cattle in a crossbreeding system can be even more important. For instance, in a system where both maternal and terminal strains are used, there will be different selection pressures applied on different strains. The main selection on maternal strains will be on reproductive traits while terminal strains will be on growth traits. If different mating systems are to be considered as well, it becomes evident that selection indexes and economic weightings become even more important.

It is often difficult or impossible to collect all of the data required to develop truly efficient economic weights. Traits are either hard to measure or it is not possible within the living system to change what is required to test something. Fortunately, there is a powerful tool available now, the computer simulation model.

Simulation Modeling

There is often a desire by researchers to have data on certain things which are not possible to obtain through conventional research methods. Animal breeding research is often hampered by a low number of offspring per animal per year resulting in a long generation interval. An example of this is cattle which have an average of less than one calf per year and generally do not produce first offspring until two years of age. This can lead to constraints on research which would be too costly and time consuming or at least delays results from such research for several years. It is often possible to use a model of one thing to depict some other thing.

The term 'model' can be used for many different things. People often think of things which are a small representation of the larger object, such as dolls, when discussing models (Dent and Blackie, 1979). Another example of this might be a blueprint of a house which is a model of that house. However, other types of models exist. Graphing concentration of a substance over time is a conceptual model of what is actually happening. Sheep can be used as models for cattle as they are cheaper and easier to use with shorter generation intervals. Newman et al. (1985a,b) used mice to model a swine breeding system to evaluate alternatives in a production system. Mice are used as models in some research relating to humans and livestock.

According to Forbes and Oltjen (1985) the most widespread models in use are statistical such as analysis of variance and regression analysis. With the advent of the computer, these models are much more readily evaluated than in the past. This is because a computer is able to do multiple complex equations without risk of error (errors that do occur are the result of either an error in program or input). Thus, what may have taken weeks to calculate in the past can now be accomplished in seconds with a much reduced risk of error (Forbes and Oltjen, 1985). With this in mind, a model can simply be defined as "an equation or set of equations which represents the behavior of a system" (Spedding, 1988). The definition can get much more complex depending on what type of model is being discussed. A computer simulation model describing an entire herd for its lifetime is an example of this. However, computer simulation models are just another way of looking at things.

Any system is a collection of subsystems. Spedding (1988) stated, "a system consists of a group of inter-related components that interact for a common purpose and react as a whole to external or internal stimuli." Spedding goes on to say that, "the ultimate purpose of the study of agriculture is, directly or indirectly, the improvement of an agricultural system." Changing any part of a system can only be considered an improvement if the net result for the entire system is an improvement.

Computer simulation modeling allows any number of subsystems to be examined. It is possible to alter a subsystem and see the results on the whole system. This takes a relatively shorter time and is less costly than actually attempting the research with the true biological system. As well, modeling allows changes to be made to a system which may not even be possible with present technology or research facilities allowing for some decisions to be made on the future direction of research.

Constructing computer simulation models

Constructing models requires a well defined approach with a logical sequence of steps to be followed. Steps involved in constructing and use of a model, according to Dent and Black (1979) are: (1)Definition of system and objectives for modelling, (2)Analysis of data relevant to the model, (3)Construct model, (4)Validate model, (5)Sensitivity analysis, (6)Use of model in decision-support.

After each of these steps it may be necessary to go back and redefine the system and objectives. This can be a result of thinking of new things which were not previously assumed or available. Or possibly, the model was constructed and did not perform in the desired manner. If this happened the person would need to redefine and change the model in whatever ways deemed necessary.

As stated, one must first determine and define many things in advance when constructing a model. Some of these include; what is the purpose of the model and what is it trying to show and what are the boundaries of the model. Boundary of a model is the limit of what is being simulated in the model. There are no interactions possible across the boundary, the only data that crosses the boundary are inputs and outputs. Thus, inputs and outputs of model have to be defined prior to building model. Type of model which is going to be constructed must also be defined before beginning. Will it be stochastic or deterministic or a combination of both? Will it be empirical or deductive or a combination of both. These different types of models are discussed below.

After the model is constructed, one must then validate it. This is a testing of the model to see if it is working correctly. To validate a model, data from a model is compared to data from real life. The actual data which is compared must not have been used in construction of the model as this will bias the comparison. Often this presents a problem. As a modeler, you want to use all available information in order to try and get the most accurate depiction of a situation, and yet, you must be able to compare your output to other data which was not used in construction.

After validation, a sensitivity analysis is done to the model. A sensitivity analysis is performed by changing variables or parameters within the model by small amounts. This allows one to determine how sensitive the model is to changes for each parameter or subsystem. Often, one of the purposes of a model is to perform sensitivity analyses. When doing a sensitivity analysis, you are essentially determining weighing factors for each variable tested. Thus, if a change in a variable has a large effect on the system, then this variable will be given a large weighting factor.

Finally, if it already hasn't been done in the previous step, the model is used for its intended purpose. Depending on output at this point, data will either be used or else the model may be modified again to get desired performance.

Deterministic vs. Stochastic

The difference between deterministic and stochastic models is whether or not the model simulates random events. A deterministic model has no probability distributions associated with it and it generally has a definite predictive nature to it (Forbes and Oltjen, 1985). That is, there are no random variables involved with the model and if you enter same parameters twice in a row, you will get same results. Thus, comparison of means is the only statistical analysis which can be done on output from a deterministic model (Dent and Blackie, 1979).

Bourdan and Brinks (1987a,b,c) modified the Texas A&M University Beef Cattle Production Model (Sanders, 1977; Sanders and Cartwright, 1979) which had previously been modified by Notter (1977). The model was completely deterministic. Classifications of animals within the model were by age, sex, month of calving, lactation status, calving difficulty and month of gestation. The objectives of the study were to determine the effects of the major production traits (growth and milk production) on biological and economic efficiency with different management systems and economic conditions within a northern plains environment. They also wanted to generate weighting factors for certain traits and look at interactions of genotype, environments, management and economic variables. This research was done using a simulation model because there is "only a limited number of genotype-management-economic combinations which can be studied in the field" (Bourdan and Brinks, 1987a,b,c).

Using their model, Bourdan and Brinks (1987a) were able to show that keeping calves to one year of age was biologically less efficient but economically more efficient than selling calves at weaning. Herd efficiency increased when birth weight decreased and when yearling weight increased. Efficiency did not change when mature weight was altered while holding all other traits constant. Changing feed costs caused different cow sizes to be more efficient under different circumstances.

In developing a deterministic simulation model, Long et al. (1975) stated that using a simulation model allows a method of simultaneous consideration of many more traits than could be studied in one research trial. Their model took into account nutritional costs, fixed costs, cow size and correlated progeny growth, attrition rates, milk yield for cows of different ages and other considerations. They were able to show that large cattle were more efficient in a drylot system while in a pasture system small cattle were more efficient.

In stochastic models one or more variables have probability distributions and are randomly generated. This allows the model to have different outputs every time even if input is the same. Having random variables gives the model itself some variation. Due to randomness and variability of the model it is possible to do many replications and compare results for variation (i.e. ANOVA's). Variability in the model is meant to simulate true variability found in biological systems which are being modelled (Forbes and Oltjen, 1985).

According to Dent and Blackie (1979) stochastic models (or variables) are used "to describe both unexplained events (as far as the model is concerned) and events which are truly random. The reason they include unexplained events is that because we have chosen our boundaries, we can not explain everything. By choosing our boundaries, we are saying that we are only interested in characterizing a system with a certain number of variables. Variables outside this boundary still occur in the true system but are not accounted for within the model (Dent and Blackie, 1979). Thus we might build a stochastic model to take into account this 'unexplained' variation. Within a stochastic model, animals are generally treated as individuals.

Lamb and Tess (1989a,b) used stochastic computer simulation models to evaluate different breeding systems in small beef herds. Herds consisted of one bull, 30 cows and 10 replacements. Crossbreeding systems considered were purebred, two- and three-breed rotation using either natural service or artificial insemination and a four-breed composite. Small beef herds are sensitive to age of dam effects as well as random variation of sex ratio of calves which can have large effects on quantity and quality of replacement heifers. Because of the sensitivity that these herds have to this random variation, to properly evaluate effects of this randomness, it is important to use stochastic determination of sex of calf.

Lamb and Tess (1989a) found that culling cows for age before 12 years resulted in not being able to maintain the herd and within 21 years the system was not able to recover. Furthermore, even though the composite and three-breed rotations ranked above the two-breed rotation, the difference was not significant. As most producers of small herds raise cattle as a secondary enterprise, the authors did not feel that the extra management involved with the more comprehensive mating systems was justified. In a companion paper, Lamb and Tess (1989b) analyzed herds of 50 dams and two sires. They found results similar to the 30 dam herd in that the two-breed rotation was an adequate mating system for the same reasons as a 30 dam system.

It is possible to have a model that is a combination of deterministic and stochastic variables. For instance, if a model had deterministic variables for most of it, but there was no way to adequately account for variability of one or more variables, these variables may need to be stochastic. Thus one would have a model which was largely deterministic with a small amount of stochastic variation. An example of this might be a model which predicted life cycle efficiency of a herd of cattle. Most variables might be based on means, however, in order to determine sex of calves there would need to be a random function involved.

Empirical vs. Deductive

There are two different ways to construct a model. A model may be constructed through either empirical or deductive methods. A combination of the two can also be used.

Empirical construction deals with using data which has been statistically analyzed and results are used to determine mathematical equations. These equations will tell how variables are related but may not tell why, as they are generally statistical relationships that do not necessarily identify cause and effect relationships. Thus, equations are statistically accurate but one is not always able to interpret results biologically.

Empirical relationships which truly describe the variables with which they are dealing with tend to be accurate and show close to a true picture of what is desired. If it is possible to use actual data in mathematical equations which meet the objective of the model, empirical relationships will show the results of inputing different variables in a model.

Jarrige et al. (1986) developed a totally empirical model to predict voluntary dry matter intake of roughages in ruminant animals. The authors developed a "fill unit" to describe different forages. The fill unit was used to determine the intake capacity for each forage regardless of the category of animal or the diet the animal is being fed. The authors used results from 2331 forages fed to Texel sheep and 137 different feeding trials in cattle.

A substitution method was devised when using some concentrates in the higher producing animals. As determination of intake capacity was based strictly on physical limitations on distension of the reticulo-rumen, it is not possible to predict intake of diets which utilize a high percentage of concentrates or pelleted forages. Diets such as these have a high metabolic control of intake which was not considered in determination of intake capacities. Another limitation of this simulation was that as all equations are empirical, it is not possible to estimate the "fill unit" for forages which do not have a specific "fill unit" already determined for them.

Construction of a model with a deductive approach can differ markedly. Often, data is not available or what is available does not adequately explain relationships between variables. In cases such as this, a researcher will often need to use personal knowledge and experience to try to deduce what a relationship is. This often involves interpolation or extrapolation of available data or just using one's intuition. This allows a development of a cause and effect relationship between variables which might not be possible with empirical data. Whittemore (1986) summed up deductive relationships by saying that as there is always a lack of knowledge for the relationships of variables they "invariably include a mixture of hard fact, soft fact, hypothesis and inspired guesses".

Mertens (1987) developed a model which was almost totally deductive. He reasoned that current methods used to estimate feed intake and digestibility did not adequately explain the true situation. Among other factors, he felt that there was a psychogenic factor involved with feed consumption. This social relationship is not possible to describe with empirical equations so a deductive approach had to be used. Furthermore, he wanted to be able to predict intakes and digestibilities without having specific data for the actual situation. As previously stated, empirical equations do not allow estimates to be made outside the scope of the actual data to be used to construct the equation. With this in mind, Mertens developed a series of deductive equations to predict feed intake and digestibilities of feeds.

Both empirical and deductive approaches have weaknesses. As stated previously, empirical equations do not necessarily explain biological relationships between variables. Deductive equations are generally the opinion of one or a few researchers and this opinion may not always be correct or agree with popular opinion. It is possible to develop a model which utilizes both empirical and deductive equations. This has the advantage of being able to explain relationships statistically and to include biological meaning to them.

Forbes (1977) attempted to explain voluntary feed intake and energy balance in lactating cows. To do this he developed a model which was largely empirical but also used some deductive reasoning. He attempted to explain intake with the interactions between physical and metabolic limitations of the animal. Many of these interactions have not been fully explained so he had to use deductive approaches to try to estimate them. He was especially interested in attempting to predict intake during early lactation when intake lags behind the productive energy requirements of the animal.

One of the problems with research on animals attempting to determine economic weights of different traits is that it can be very time consuming. As well, it is not always possible to measure everything required. Computer simulation modeling offers a very powerful tool to enable the simulation of a herd life cycle. This allows traits to be manipulated individually to enable the determination of economic weights of different traits.

OBJECTIVES

This project was completed in cooperation with Beefbooster Cattle Alberta Ltd. There are presently five synthetic strains of Beefbooster cattle. The five strains are three maternal strains (M1, M2 and M4), an easy-calving strain (M3) and a terminal cross strain (Tx). The maternal strains have had primary emphasis placed on reproductive traits with M1 and M2 being selected for weaning weight and M4 being selected for weaning weight. The easy-calving strain (M3) has been selected primarily for small birth weight with the primary purpose of being bred to first calf yearling heifers to minimize dystocia. The terminal cross strain (Tx) has been selected for increased post-weaning average daily gain with the purpose of being used on mature cows to produce calves with superior genetic potential for growth.

The first objective was to determine the relative profitability of the five strains of beefbooster cattle in both purebred mating systems and rotational mating systems. The second objective was to determine economic weights of performance traits in each of the strains within a rotational-terminal mating system (described in materials and methods), and to calculate selection indexes. Traits considered were mature weight, preweaning growth rate, birth weight, milk production, conception rate and age at puberty. Net profit was used as the primary measure of economic performance.

MATERIALS AND METHODS

Simulation Model

A computer simulation model written by M.W. Tess was modified to suit the purposes of this project. The model was deterministic with a limited amount of stochastic functions, mostly relating to reproduction. The model simulated life-cycle performance for an entire beef herd. The model took into account many different physiological aspects in the growth and production of beef cattle including growth, feed intake, body composition, reproduction and lactation.

Simulation strategy was based on simulating individual cows in one day stages for the number of years set at the beginning of the model. Performance of the cattle was determined by many different interactions. These included genetic potential, physiological state, and feed availability and quality.

Different feed types were available depending on age of the animal and preset feeding regimens. Replacement heifers and brood cows were fed forages and supplements. Calves receive milk and creep feed if set into the model. Intake of feeds was determined by physiological demand of the cow (or calf) and by capacity of the cow for neutral detergent fiber (NDF), which is a measurement of bulk of the diet. Chemical composition of feed (i.e. metabolizable energy, crude protein, rumen degradable protein), was another factor which affects intake of feeds.

The physiological state of each animal was determined by many components including age, weight, body composition, stage of gestation, and state of lactation if a cow is producing milk. Growth and body composition of an animal are a function of genetic potential nutrient intake and age. Phenotypic values of these traits were determined by the growth curve, physiological state and by nutritive intake of the animal, both in the past and at present time.

Factors involved with reproduction were puberty, anestrus, postpartum interval, body composition and weight of the cow. Conception was determined stochastically, and calculated as a probability given the presence of a bull. Conception had a random component through use of a pseudorandom number generator and the probability of conception.

Lactation curve was another aspect of production which was determined by genetic potential of the cow. Priority of nutrient partitioning was determined by physiological state of the cow and by nutrient intake. These conditions controlled the maximum amount of milk production for each cow.

There were two different types of inputs in this model; external inputs and simulated (or internal) inputs. External inputs were mating system, genotype, feeds and limitations, chemical composition of feeds, market price for animals sold and production and management decisions including replacement rate, management groups, day of weaning and number of years to simulate. Simulated inputs were feed consumption, feed costs and non-feed costs which include veterinary and labor associated costs such as dystocia.

Simulated outputs of the model were weight, lean and fat composition for each class of cattle. Classes of outputs were cull cows, steer calves and non-replacement heifer calves.

Model Applications

As previously stated, the model was modified to simulate genetic strains and mating systems used by Beefbooster Cattle Alberta Ltd. There are presently five synthetic strains of Beefbooster cattle. The five strains are three maternal strains (M1, M2 and M4), the easy-calving strain (M3) and the terminal cross strain (Tx). Traits examined were birth weight, preweaning gain, mature weight, milk yield, age at puberty, and conception rate. Mating systems simulated were straight breeding (PURE), three-way rotational crossbreeding (ROT), rotational crossbreeding with first-calf heifers being bred to easy-calving bulls (ROT3), and rotational crossbreeding with easy-calving bulls as well as a terminal cross strain for mature cows aged six years and older (ROT3X).

In the rotational-terminal system (ROT3X) total number of maternal genotypes considered were eleven and total number of calf genotypes is twenty three. Table 1 shows all of the different genotypes. The first number corresponds to the most recent sire breed, the second number to the next most recent, etc... For instance, an animal with genotype 124 would have an M1 sire and a 241 dam. With the rotational crossbreeding system, dam genotype is used to determine the sire breed to which she will be bred. Thus, a cow with genotype 241 will be bred to the sire which is least related which is M1, producing a 124 calf. When using either terminal cross strain (M3 or Tx), the last number of the genotype designation is left off for simplicity. In this manner, a 421 cow bred to an M3 sire will produce a 342 calf. It should be noted that the full genotype of this offspring would be 3421, however, a three digit designation is used for all genotypes.

Genotypes entering the system were considered to have as close to equal composition of breeds as was possible using an ROT system. The 124 calf illustrated above would have a composition of 57.14% M1, 28.57% M2 and 14.29% M4. If this was a female and bred to an M4 the 412 offspring would then be 57.14% M4, 28.57% M1 and 14.29% M2. A 512 calf from the ROT3X system would be 50.0% Tx, 28.57 M1, 14.29% M2 and 7.14% M4. Heterosis of calves within the ROT system were considered to maintain 86% of maximum heterosis. Terminal sire calves had 100% individual heterosis.

Table 1. Individual genotypes used in model.

		Breed of dam				
		M1	M2	M3	M4	Tx
Breed of sire	M1	111	124		142	
	M2	214	222		241	
	M3	312 314	321 324	333	341 342	
	M4	412	421		444	
	Tx	512 514	521 524		541 542	555

Economic Inputs and Outputs

During a cycle of the program there were different procedures which were called and performed at different times. On the first day of the year, or on the first day of simulation if it didn't start on day one, non-feed costs were assessed based on total number of cattle present at that time. On the first day of the breeding season, all cows which were currently in the herd were counted in order to determine total number of cows exposed. At this time average weight and fat percentage of the cows were determined, stored and later output.

Health prevention and treatment costs used are shown in Table 2. Treatments were typical of a Northern Great Plains environment and more specifically Montana. The prices shown were obtained in the Bozeman, Montana area from veterinary and farm supply store in the fall of 1992 (Davis, 1992).

Table 2. Health costs.

Livestock class	Service/Supply	$/head
Cow costs	Labor/Dystocia	15.00
	Preg. Test	1.25
	IBR/BVD	1.00
	Vibrio/Lepto	.50
	E-Coli	.90
	Warbex	.70
	Wormer	2.50
	Fly Tags	2.00
	Pink Eye	.09

		8.94
Yrling costs	Preg. Test	1.25
	IBR/BVD	1.00
	Vibrio/Lepto	.75
	Clostridial	.25
	Wormer (Ivormec)	6.00
	Bangs	2.00
	Fly Tag	2.00
	Pink Eye	.09

		13.34
Calf costs	Clostridial	.25
	Implants	.90
	Pink Eye	.09
	Scours	.50
	Pneumonia	.10

		1.84

When animals were sold marketing costs were computed. These costs can be divided into two different categories, an increase in expenses and a decrease in income. Increases in expenses are non-feed costs and were added onto the previously calculated non-feed cost. These costs include trucking, checkoff and other fees. Checkoff and fees were

$1.55 per animal sold while trucking costs were based on a 50 mile trip at $275 and 50,000 pounds of live weight, costing $0.0055 per pound sold.

Costs which were a decrease in income were not considered to be non-feed costs, however they were calculated at the same time as costs which increase expenses which was during marketing and so will be described now. These costs were shrink and commission. Shrink was calculated at 3% of live weight (weight*.97). Commission was calculated for all classes except for calves as it was assumed that calves were sold by forward contract. Commission for sale of cattle was charged at a rate of 2.5% of amount received.

Labor and bull costs were also added to non-feed costs. These were calculated using total number of cows exposed throughout the simulation run. Labor was equal to $15 per cow exposed. The formula for determining bull costs was: Total number of cows exposed * (((375.0+87.5)/25)+2.16). Bull cost was determined by adding depreciation cost of bulls to winter feed costs. This was then divided by 25 which was total number of cows bred per bull per year and then $2.16 was added on which is veterinary costs. The total of this was multiplied by total number of cows exposed to determine cost of bulls.

A further cost which could be added onto non-feed costs was related to dystocia (described below). Any cow which experienced dystocia had associated costs. A cost of fifteen dollars, due to extra labor, was added to every cow which experienced dystocia. The next major set of events which transpired were at weaning. Many different functions occurred at this time of year. Weights of all calves were added up as well as total age in days (to determine average age at weaning).

Each year the weights of all heifer calves which had either M1, M2 or M4 sires were stored. During the last year of the simulation all heifers were sorted on the basis of breed and weight. Heaviest calves of each breed were kept for replacement heifers and all others were sold. Number kept for each breed was equal to the number of cows of that breed type originally entering the simulation to maintain equal populations of each breed type.

Cattle Management

Cows were culled for several reasons. If cows reached the preset maximum age or if the simulation was in its final year, then all remaining cows were sold. Cows were culled if they lost calves or failed to conceive. Approximately one third of cattle which experienced dystocia, those of which had a hard pull, were culled. All cull cows were sold at weaning.

At weaning, number of calves weaned per cow exposed was calculated as well as calf weight weaned per cow exposed.

This was calculated using number of cows exposed which were permitted to continue on to produce the next calf. Thus, even though cows were exposed in the final year of the simulation , they were not included in these calculations as the simulation ended before cows can produce. Total number of exposures was used in some calculations to be discussed later.

Mortality

Probability of a calf dying on any particular day was determined at two different times. The first time was on the day that the calf was born and the second time was when the calf was four days of age. Probability of the calf dying was based on results by Patterson et al. (1987). They found a death loss of 4.6% in the first three days of a calf's life and 2.1% from the fourth day to weaning. Of the total calves which died, 68.66% died within the first three days and 31.34% died in the remaining days to weaning. Each of the different genotypes had a survival rate which was read into the program at the beginning. This survival rate was then used to determine probability of death on each day. Up until the fourth day probability equaled genotypic survival rate multiplied by percentage probability (.6866) and divided by four (number of days). For the rest of the year, since day of weaning was known, it was possible to determine how many days there were between the fourth day of the calf's life and day it was weaned. Probability of death was then determined similar to before except it was multiplied by .3134 and the divisor was the number of days just discussed. It was then determined by the pseudorandom number generator whether or not a calf dies on any particular day.

Probability of death for cows was set at 0.9% per year. However, due to simplifying the program to avoid dealing with orphan calves, only dry cows had a probability of death. Thus probability of death on any particular day was determined by calculating number of days that a cow was dry per year and using this as a divisor of yearly probability. Number of days dry was determined by adding number of days from day one to parturition to number of days from weaning to end of the year. Once the cow was bred, gestation length was deterministic so date of parturition is easily calculated.

Simulation Strategy

The simulation model was set up to first run on a per cow basis. Originally 102 cows were started in the model and allowed to run for 12 years. Reasoning behind the choice of 102 was that it was initially intended to start with 100 head. All cattle entering system were weanling heifer calves and were kept until age 12. This allowed one full run of the model to simulate a hierarchial system of simulating an entire herd of all ages for one year. Herd size being simulated was approximately 500 and thus needed about 100 replacement heifers per year. In the full crossbreeding mating system there were combinations of maternal strains and in order to be able to have an equal number of cattle starting from each strain, it was determined to use 102 giving seventeen cows per strain. With runs for purebred strains, 102 was used to keep simulations consistent. Resulting data gathered from this were then used to determine productivity and efficiency on a per cow basis for the model.

Profit for Fixed Resource Base

Profit was calculated on a cow basis ($ per cow exposed per year) and on the basis of a ranch utilizing a fixed forage resource base. Adjustment factors for variable inputs and outputs were obtained by using M1 cows as a base herd. The simulation was repeated 100 times and results were used to determine adjustment factors. Mean kilograms of range forage consumed was divided by 304.4 kg/AUM to determine mean AUM's of the base herd which resulted in a fixed feed resource base of 4200 AUM's. The adjustment factor was determined by dividing the actual number of AUM's consumed for that run into land base level of 4200. Thus, in all simulation runs it was possible to adjust inputs and outputs to a fixed feed resource base. This worked with different replications of M1 cows as well as all other strains. Other strains were adjusted to the M1 base.

With the fixed feed resource base it was assumed that all range forage consumed was raised on the ranch and the ranch was able to produce its own hay (or most of it). This means that variable feed costs drop significantly; however, operating costs of the ranch were then taken into account. With the fixed ranch size there were numerous operating costs involved which are given in Table 3.

Table 3. Overhead calculations.

	Individual Cost	Units	Total Cost
Vehicles	$9,000.00	1	$9,000.00
Insurance			
House	$50,000.00	0.0068	$340.00
Working Fac.	$30,000.00	0.0068	$204.00
Barns	$60,000.00	0.0068	$408.00
Misc. Equip.	$10,000.00	0.0068	$68.00
Repairs			
Improvements	$150,000.00	0.02	$3,000.00
Fence	$77,777.78	0.02	$1,555.56
Utilities	$2,000.00	1	$2,000.00
Supplies	$2,333.33	1	$2,333.33
Property Taxes	$7,466.67	1	$7,466.67
Interest on land	$777,777.78	0.05	$38,888.89
Hay expense	$30.00	650	$19,500.00
Labor	$2,000.00	6	$12,000.00
		Total	$96,764.44

Amount of hay consumed was also adjusted. On the same runs that were analyzed for range forage consumption, hay consumption (alfalfa and grass hay) was also analyzed. From this level of hay, production was set for the ranch. Thus, on the fixed feed resource base, the ranch was able to produce 225 and 425 metric tons of grass hay and alfalfa hay, respectively. Levels were set slightly below minimum consumption for each of these. By doing this there was never a negative hay consumption and some will always need to be purchased. This prevented confounding factors from entering into determination of breakeven prices and other economic analysis.

Once the adjustment factor was determined, the different total feed consumptions were then adjusted to fit the fixed feed resource base. Then, alfalfa and grass hay total consumptions had the amount which is produced on the land subtracted from these and this gave total amount of hay which was purchased. Cost per unit of all purchased feed is shown in Table 4. It should be noted that range AUM's consumption was only a cost in the per cow basis as land was owned in the fixed feed resource base scenario. As well, labor was only included with per cow basis as it was taken into account in overhead costs in the fixed feed resource base.

Table 4. Feed costs.

Feed	Cost per Unit
Alfalfa Hay	$75/ton
Grass Hay	$40/ton
Barley	$100/ton
Range	$10/AUM

Interest on all non-feed costs at six percent per annum was added as well. Total expenses were then calculated by adding feed and non-feed costs.

Prices received for all livestock were obtained by using September through November issues of Cattle Fax from 1990 and 1991 for Montana and Wyoming. For heifer and steer calves a price slide was used to adjust price received according to how much the calf weighed. Formulas used for determining prices obtained for calves were:

Steer price received = 2.231-0.002839*(weight-181.4)

Heifer price received = 2.080-0.001977*(weight-181.4).

These formulas were simple regressions to predict change in price due to change in weight. Difference in calf weight from the base level of 181.4 kg (400 lbs) was determined and then multiplied by the adjustment (0.002839 for steers), and this was then subtracted from the mean price per kilogram received for the 181.4 kilogram calf. Thus, every kilogram increase in a steer calf's weight above 181.4 kilograms resulted in a decrease of $0.002839/kg of live weight sold. The inverse was true if weight was less than 181.4 kilograms in that price received for the calf was increased by the same proportion.

Simulation of Dystocia

Dystocia was determined differently for different age classes of animals and was determined stochastically. Heifers were given a probability for dystocia which was calculated using cow size and calf birth weight. The rest of the age groups were assigned a probability dependent on age. Smith et al. (1976b) broke down incidence of dystocia by age within different breed groups. Results from Angus dams were used to assign probabilities of dystocia for different age groups (not heifers). Three year old cows (second calf), had an 11% probability of dystocia, four year olds a 3% probability and five years and older a 5% probability. A random number was then used to determine whether or not a cow experienced dystocia. With any of the classes of cows, probability of the calf dying within the first three days was five times higher if dystocia occurred (Azzam et al., 1993).

As mentioned, cow size and calf birth weight were used to predict probability of dystocia. As with other age groups, actual incidence of dystocia was determined stochastically. Pelvic area was not actually known within the model and must therefore be predicted for heifers at parturition. Using results from Bellows et al. (1971) it was calculated that pelvic area was equal to 0.63 of body weight in moderate body condition (body condition score equalling 5). Lean body mass was used to predict pelvic area regardless of body condition. A condition score of five was considered to be an animal with sixteen percent body fat and live weight of a cow was assumed to have fifteen percent body fill. Thus, by dividing lean mass by .69, live body weight at body condition score five was estimated for an animal at any body condition score (fat percentage), from lean mass.

The ratio of pelvic area to birth weight (RATIO = PA/BWT) was used to determine probability of dystocia (PDYST). Cook (1991) formulated a prediction equation from data taken from Short et al. (1979), which was:

$$PDYST = 1.796-(0.1175*RATIO)-(0.003886*RATIO^2).$$

This equation actually produced a higher level of dystocia in heifers than was expected. In order to lower occurrence of dystocia to a rate comparable with the actual cattle being simulated, the intercept was decreased by 0.1 (from 1.796 to 1.696). This caused dystocia to generally occur in 25 to 30% of heifers.

Model Refinement

There was a problem in the original model in that cows which already had a relatively high percentage of fat for body composition continue to have the same intake as those with a low fat percentage. By having the same capacity (or more if animal weighed more), than thinner cows, this allowed higher fat percentage cows to continue putting on weight (mostly fat), as fast as their thinner counterparts. This was a somewhat unrealistic result because it has been shown that cows with higher fat percentages have a decreased ruminal capacity (Forbes, 1977).

Ruminal capacity was lower for cows which have higher body fat percentages. This adjustment was made for both dry and lactating cattle. Maximum fat percentage for cattle in this simulation was set at 36%. The formula used in determining reduction in capacity assumed that a cow did not have any reduction at fat percentages below twenty percent. The formula used to determine decrease in capacity was:

CAPACITY = CAPACITY*(.8+(.2*(.36-FAT PERCENT))/.16).

This formula was only applicable if fat percentage was greater than twenty percent. Capacity was adjusted linearly to a maximum of a twenty percent decrease in capacity. Thus, if fat percent equaled twenty, capacity was one hundred percent of its potential, however at twenty eight percent fat capacity was decreased to ninety percent. Use of this formula prevented cattle which were on free choice feed from continually gaining weight, at the same rate, until maximum fat percent was reached.

Another adjustment which was not present in the original model was change in milk production corresponding to dam age. Lamb (1991) summarized data regarding milk production for different age groups of cattle. Milk production was set at seventy eight, eighty eight, ninety six, one hundred and ninety eight percent of maximum genetic potential for two, three, four, five to nine, and ten and older years of age, respectively.

Model Outputs

The final addition to the model was a subroutine which summed up outputs from the simulation and printed out desired information. The output listed a yearly summary of both calves and cows. For each sex, weaning weight and average age at weaning for calves were summarized. Data output for cows was number exposed each year, number dead, number sold and number which experienced dystocia. Average weight and average fat percentage of cows at breeding were summarized. A sample output from a ROT3X simulation is shown in Appendix A.

Some of the measures of productivity were then shown. These were total number of calves born and total number weaned. Total number of cows exposed were also shown. There are two numbers given with either the final year included or not. The reason why the final year was not always used was that cows bred in the final year do not have opportunity to wean calves in the following year. Total calf weight weaned per cow exposed and number of calves weaned per cow exposed were calculated and shown here.

Biological and cash inputs were divided by the weights of the different classes of animals sold. Perhaps the most important measurement was cash inputs for steer weight equivalent. Steer weight equivalent was determined by adding up amount of money received for each class of animal and then dividing this by price received per kilogram for steer calves. Thus, steer weight equivalent was number of kilograms of steer calf weight needed to be sold at the steer calf price to equal the same amount of money which all classes made. Taking total cash inputs, which was feed and non-feed costs added together and dividing this by steer weight equivalent, it was possible to determine how much it cost to produce every kilogram of steer weight equivalent. This also could be considered as breakeven steer price of the operation.

Net income was determined by simply using the difference between total income and total expenses. Net income per cow exposed was then determined as another measure of productivity.

The adjustment factor was then determined and some of the previous calculations were again done on the fixed feed resource base data.

Experimentation

Base input parameters for genotypes are shown in Table 5, Table 6 and Table 7. Table 5 is a list of parameters which are common to all genotypes. Table 6 shows those parameters which are relevant to dams and Table 7 are the parameters important to all genotypes.

Table 5. Common input parameters.

TRAIT	
AGE (DAYS)	202
DEATH RATE PERCENT	5
MATURE FAT PERCENT	36
POSTPARTUM INTERVAL (DAYS)	50
AGE AT CULL (YEARS)	10

Table 6. Dam input parameters.

	Traits				
Genotype	Start weight	Start fat percent	Daily peak milk production	Age at first estrus	Probability of conception
111	209.95	0.0762	11.4067	379	0.9409
222	216.25	0.0764	11.5463	373	0.9409
333	195.51	0.0775	11.2672	371	0.9120
444	214.14	0.0763	11.2672	373	0.9120
555	222.58	0.0747	10.2902	373	0.9216
124	223.51	0.0778	12.1145	362	0.9609
142	223.09	0.0777	12.0723	362	0.9567
214	225.62	0.0778	12.1568	361	0.9609
241	226.25	0.0778	12.1357	360	0.9567
412	224.35	0.0778	12.0300	361	0.9482
421	225.40	0.0778	12.0511	360	0.9482

Input parameters for pure strains are taken from MacNeil et al. (submitted). Input parameters for crossbred genotypes were determined using percentage of each parental genotype and amount of heterosis present in each. A three-breed genotype will contain 57.14%, 28.57% and 14.29% of each genotype and will exhibit 86% of maximum heterosis for each trait with terminal-sired calves having 100% individual heterosis. Table 8 gives individual heterosis values for traits taken from Long

(1980) and MacNeil and Newman (1993). Any value which could be used from MacNeil and Newman (1993) was used because they were studying the same strains of cattle and many of the genetic parameters used in the model were taken from them. Values used were the low estimates of literature values. This was because the cows simulated were already crossbreds and would not have expression of full heterosis.

Table 7. Calf input parameters.

	Traits		
Genotype	Birth weight	Yearling weight	Mature weight
111	37.01	410.10	516.00
222	37.57	424.46	551.00
333	31.17	385.28	476.00
444	37.39	418.65	572.00
555	43.46	430.43	606.00
124	38.50	436.86	547.78
142	38.48	435.99	550.85
214	38.67	441.18	558.04
241	38.73	442.46	566.24
312	35.67	427.19	529.42
314	35.65	426.31	532.51
321	35.55	423.93	521.70
324	35.61	425.22	529.93
341	35.56	424.37	520.15
342	35.65	426.55	525.30
412	38.59	438.55	567.27
421	38.67	440.71	572.40
512	42.05	451.13	596.37
514	42.04	450.25	599.46
521	41.94	447.86	588.65
524	42.00	449.16	596.88
541	41.96	448.30	587.10
542	42.04	450.48	592.25

Table 8. Estimates of heterosis.

TRAIT	% Heterosis
Mature Weight	3
Birth Weight	4
Weaning Weight	6
Milk Production	7
Probability of conception	1

Experimentation predicting economic weights for selected traits involved manipulation of genotypic input parameters using the ROT3X mating system. Most traits were either increased or decreased by 20%, however, weaning weight had a 22% change and probability of conception was altered by only 6%, as even a 10% increase would result in a probability greater than 1.0. Each trait was altered on each base genotype individually. Thus, when determining a 20% increase in birth weight, the M1 genotypic value for birth weight was increased by 20%. Using the new value, birth weights were then recalculated for each of the genotypes using the previously discussed formula. This resulted in a large number of runs. For instance, when testing the economic sensitivity of a change in each non-maternal input parameters, there were a total of ten different scenarios to test (five for an increase and five when decreased). Each scenario was replicated 20 times with a resulting 200 runs required to test sensitivity of changing each trait in all genotypes.

Due to the stochastic nature of the model, it was possible to analyze results using one-way analysis of variance

(SAS, 1985). From the comparison of mating systems, means were compared using Duncan's multiple range test. To evaluate the effects of genetic changes in single traits, "treatment" means were compared to the base system using t-tests.

Economic weights were computed as simple linear regressions of profit on genetic changes in each of the various traits using the GLM procedure of SAS (1985). For example, change in adjusted net income (dollars) per kilogram increase in mature weight was determined.

Selection indexes were computed using regression estimates of economic weights, phenotypic variances-covariances and genotypic variances-covariances. The software used to compute the indexes was obtained from Dr. Scott Newman (Kuenzi, 1975) Only regression estimates of economic weights which were significant (P<.05) were included.

RESULTS AND DISCUSSION

Comparison of Breeding Systems

Comparisons of strains and mating systems based on net income per cow exposed and adjusted profit are presented in Table 9. Supplementary tables are presented in Appendix B showing some effects of the different systems. Net income was adjusted to a fixed feed resource which adjusted herd size to meet available feed level. Results are based on 20 replications. Both comparisons given below are from the same sets of simulations.

Table 9. Net income per cow exposed and adjusted net income.

Strain/mating system	Net income /cow exposed, $	Adjusted net income, $
ROT3X	104.81[a]	56,254[a]
ROT3	100.41[b]	50,354[b]
ROT	99.28[b]	49,906[b]
M2	91.87[c]	47,856[c]
M4	89.53[c]	46,756[cd]
Tx	89.46[c]	45,516[d]
M1	85.20[d]	47,037[cd]
M3	70.74[e]	43,746[e]

[abcde] Means within columns with different subscripts differ significantly (P<.05).

As expected, for both measures of profit, all three rotational systems had significantly (P<.05) higher net incomes than any of the purebred systems. The ROT3X had a higher income than any other system for both net income per cow exposed and adjusted net income. These results agree with Cartwright et al. (1975), Fitzhugh et al. (1975), Smith (1976), Notter et al. (1979a,c), Kress et al. (1988), and Lamb and Tess (1989a,b). The ROT3 and ROT systems were also greater than any of the purebred systems. The ROT3 ranked higher then ROT for both comparisons, however, neither was significant.

Comparison of purebred systems for net income per cow exposed showed M2, M4 and Tx being the most profitable, followed by M1 and then M3. It is understandable that M3 has the lowest net income per cow as they are smaller cows with a lower probability of conception than the other strains (except M4). This strain of cattle was developed for use as a sire line. Thus, previous selection pressures have not been on maternal traits but instead on decreasing birth weight.

When net income was adjusted to fixed feed resource M2 and M3 were the only purebred strains which did not change rank. Ranking for M1 moved from fourth to second. The Tx strain moved down a rank into fourth and was significantly different from M2. The reason for this was that when adjusted, the number of Tx cattle had to be decreased more than any other strain. This was because Tx was a larger strain and thus had higher feed requirements than other strains; however, due to their large size, when measuring net income per cow exposed, they had more product to sell.

All maternal strains were fairly similar in profitability when adjusted to a fixed feed resource base. All three maternal strains have been selected for maternal characteristics. When adjusted to a fixed feed resource base, differences between strains became even less evident. The Tx strain has not been selected for high maternal abilities, however, growth rates of calves allowed for this strain to be somewhat competitive with maternal strains when adjusted to a fixed feed resource base. The M3 cows have been selected for low birth weight which has resulted in a smaller strain than the other four. As well as being smaller in size, M3 also had a low conception rate. Due to smaller size, it was likely that M3 was more sensitive to conception rate than other strains. The result of this may be that if estimated conception rate of M3 was not accurate it may have had more of an effect than on other strains.

Effects of Changes in Individual Traits on Profit

Tables 10 through 14 show the results of moving single genetic traits by a set percentage. Tables 15-19 show change in profit for a one unit change in each trait. All income values are given as a difference from base profit. Simulation runs from ROT3X given above were used as base profit. There were a total of six traits examined: mature weight, birth weight, weaning weight, conception rate, age at puberty and milk production. All six traits were examined with maternal strains (M1, M2, and M4), however, only birth weight and weaning weight were considered with terminal strains (M3 and Tx). Analysis of variance were computed by trait. Standard errors for net income per cow exposed were 1.67, 1.66, 1.63, 1.63, 1.71, and $1.73 for mature weight, birth weight, weaning weight, conception rate, age at puberty and milk production, respectively. Standard errors for adjusted net income were 933, 886, 875, 993, 877, and $973 for mature weight, birth weight, weaning weight, conception rate, age at puberty and milk production, respectively.

Maternal Strains

Puberty. Changing age of puberty had no significant effect on any strain. This was understandable because puberty occurred approximately three months prior to breeding and a 20% change resulted in approximately a 2.5 month change. A 20% change in puberty in purebred strains would likely have an effect. Puberty occurs approximately fifteen days later in purebreds; hence purebred systems may have been affected by change in age at puberty. Age of puberty in all strains were estimated based on probable condition score and weight of animals. If estimates were not correct then there may be some response to a change in puberty.

Milk. The only time that changing milk production had an effect was when there was a decrease in M4 which caused a decrease in net income. The probable reason for this was that M4 had the lowest milk production of all maternal strains and decreasing by 20% may have caused it to reach a low enough production level to adversely affect calves growth rate enough to become significant. Decreased milk production caused a significant decrease in average calf weaning weight and the inverse was also true with increased milk production (table 21). Genetic changes in milk production had no significant effect on survival of calves to weaning (table 29).

Increased milk production might have been important if genetic potential for weaning weight was increased. Average weaning weight of calves were higher than estimated genetic potentials for weaning weight when milk production was increased. This increase in weaning weight was probably due to an increase in fat percentage of the calves and not lean tissue growth. This agrees with Notter et al. (1979a) that cows which had higher milk production produced calves which had increased percentage fat.

Another situation when milk production may have been important was if cattle had poorer quality forage resources during summer months. If this was the case, cows may not have been able to consume enough energy to meet genetic potential of milk production. This would especially affect cows with increased milk production. The result of this would be a decrease in weaning weight. If both weaning weight and milk production were increased, there may be minimal benefit with low quality forages.

Conception Rate. Decreasing conception rate had a significant detrimental effect on all three maternal strains for net income per cow exposed. Increasing conception rate resulted in an increase in net income per cow exposed in maternal strains, however none were significant. This indicated that increasing conception rate may be limited in benefit to the system, however, decreasing it can be harmful. This very likely was linked to diminishing marginal returns when increasing conception rate.

Unexpectedly, when net profit was adjusted to a fixed feed resource, an inverse relationship was observed between change in conception rate and change in net income; however, changes were not significant except in M4 with a decreased conception rate. Table 22 shows differences in herd size both before and after adjustment to the fixed feed resource. Herd size was measured as the total number of cows exposed to breeding including replacement heifers. Before adjustment, there was clearly a difference between conception rates of approximately 100-120 more cows being bred at the higher conception rate due to more cows staying in herd to an older age. After adjustment differences between herd size, there were only 7-9 cows difference between low and high conception rate, however, this was still significant (P<.05). The lower conception rate had a higher adjusted herd size. The difference between the two herd sizes related to age distribution of the cattle. With a lower conception rate there were less older cows maintained in the herd (as the unadjusted herd size indicates), which resulted in the herd having more young cows (heifers), relative to old cows. Growing heifers have lower forage requirements allowing for a few more to be maintained on the same feed resource. Results suggested an optimum replacement rate existed with a younger age distribution in the herd being more efficient. Table 23 shows the average age of cows weaning calves. These results agree with Bourdan and Brinks (1987c), where they showed that both economic and biological efficiency decreased with increased fertility due to mature cows being less efficient. If the model stochastically determined breeding values of cows and they were culled based on performance, similar results may have been seen due to a shift in age distribution of the herd.

Another factor important in consideration of forage requirements was type of forage being consumed. Young growing heifers require higher quality feedstuffs than mature cows on maintenance diets. However, with an older age distribution due to increased fertility, feed expenses were higher on a per cow basis.

Income from sales of yearling heifers was higher when conception rate was lower ($P<.05$), as would be expected (table 25). Yearling heifer sales from low and high conception rates were approximately 4% and 1.5%, respectively, of total income from livestock sales (tables 25 and 27). Price received for yearling heifers was $1.79/kg while cows three years and older received $1.12/kg. The only reason for selling yearling heifers in the simulations was failure to conceive, thus this allowed a direct examination of effects of conception rate. Income from sales of two year old heifers (weaning first calf), also showed some effect of changing conception rate (table 24), but only decreasing conception rate in M4 was different from the base ($P<.05$). One problem with attempting a direct comparison with this age group was that there were more factors involved which diluted effects of conception rate. These factors were dystocia and calf death. More two year old heifers due to a higher conception resulted in more calves being born, which meant that there were higher actual number of cases of dystocia as well as more death losses, leading to higher culling and subsequent sale of two year olds.

Kress et al. (1988) found that older average age of cattle within the cow herd led to an increase in biological and economic efficiency and profit. However, their results were based on net income per cow and not a herd basis adjusted to a fixed feed resource.

Short et al. (1990) stated that maximal fertility, or conception rate, will not necessarily be the most profitable to producers. Instead, an optimum level is more often desirable.

<u>Birth Weight</u>. Manipulating birth weight had no significant effect on net income per cow exposed in maternal strains. There was a trend for birth weight to have opposite effects on adjusted net income from what was expected. Reduced birth weight resulted in decreased adjusted net income while increased birth weight caused an increase in adjusted net income.

Changing birth weight resulted in a change in the incidence of dystocia (table 20). More cases of dystocia from higher birth weights caused more two year old heifers to be sold. This is shown in table 26 as a change in the income from the sale of these animals. Approximately one third of heifers which experience dystocia were sold. These were considered to be severe cases and animals were culled. Furthermore, probability of conception was decreased by 10% in animals which experienced dystocia, and any cow which did not conceive was sold. These two factors resulted in an increased number of two year old heifers being sold. This resulted in a similar condition as what was observed when conception rate was altered causing a change in distribution of ages within the herd.

Differences in net income were not as large when birth weight was changed as when conception rate was changed. Birth weight only had a large effect on two year old heifers while conception rate caused a decrease in number of pregnant yearling heifers maintained.

<u>Mature Weight</u>. In all maternal strains, decreasing mature weight resulted in a decrease in net income per cow exposed. Increasing mature weight had virtually no effect. This can be explained by the fact that when mature size was decreased, the cows still had the same milk demands from the calf yet intake of adequate amounts to support calf became a factor. This decrease in milk production resulted in lighter weaning weights (table 21). Increasing mature size had relatively no effect as the cow was close to optimum size for calf production already and thus intake was already adequate to support calf.

All changes in net profit were significant in maternal strains when effects of changing mature weight were adjusted to fixed feed resource and in the direction expected. Changes in mature weight had an inverse relationship to adjusted net income. As mature weight increases, so do nutritional requirements of cattle. By adjusting just mature weight of a cow and holding most everything else constant, productivity of the animal remains constant while more forage was required for maintenance. Decreasing mature size resulted in decreased net income per cow exposed due to some decrease in product produced, however, this change was offset by decreased forage requirements. This is in agreement with Dickerson (1970) who stated that "body size <u>per se</u> is of little importance in determining either feed energy conversion or total economic efficiency in animal meat production, when compared with functional output per unit of body size". Long et al. (1975) found that when cows were fed in a pasture regimen, smaller mature size was more profitable.

A further effect of adjusting mature size was on incidence of dystocia. Increasing mature size decreased incidence of dystocia while decreasing mature size increased incidences (table 20). The decrease in total number of calves weaned contributed to the inverse relationship seen with adjusted net income. This occurred under the same principles which were described above for conception rate and birth weight.

Number of calves weaned per cow exposed was significantly less (P<.05) in cows which had a decreased mature weight. Increasing mature weight had no effect on fertility (table 29). Number of calves weaned per cow exposed at the low conception rate was similar to number weaned at low mature weight showing that decreasing mature weight by 20% had a similar effect on fertility as decreasing conception rate by 6%. Thus, estimates of the effects of changing mature weight on profit were confounded by changes in fertility. Tables 10, 11, and 12 show changes in profit for the three maternal strains. Changing mature weight had a larger effect on adjusted net profit than changing conception rate so it can be concluded that changing mature weight did have an effect on profitability of the systems beyond that explained by changes in fertility alone. M4 had the lowest change in profit for mature weight after effects of conception rate were subtracted from it. The difference of $3286 was still greater than $1854 which was the difference required to be significant. The difference can not be used as an actual figure, however, it does still show a large amount of the effect of changing mature weight.

Weaning Weight. Adjusting weaning weight caused net income to shift in anticipated directions. Changes were significant for a decrease in weaning weight for net income per cow exposed and increased weaning weight for adjusted net income for all maternal strains. All other values approached significance ($P<.05$). As discussed previously, there may have been greater differences if milk production would have been changed at the same time as weaning weight.

Terminal Strains

Birth Weight. When birth weight was increased in M3, net income per cow exposed was significantly decreased. Decreasing birth weight did cause an increase in net income per cow exposed, however the change was not significant ($P<.05$). This would seem to suggest that the system was sensitive to increasing birth weight but that birth weight possibly should not decrease any more than where it is presently. Opposite results were observed with adjusted net income. As with maternal strains an inverse relationship was present when profit was expressed on a ranch basis. Adjusted net income significantly decreased with decreased birth weight for M3. Increased birth weight caused a slight increase in adjusted net income but it was not enough to consider it to be any different from the base run.

Birth weight had no effect on Tx. This was not surprising as the model was not sensitive to changes in birth weight for mature cattle.

Weaning Weight. Decreasing weaning weight was significant for both measures of profit in M3. Increasing it did not cause any significant effect.

Both increasing and decreasing weaning weight were significant for both measures of profit in Tx. The Tx strain was a specialized sire strain with a primary purpose of increasing both preweaning and postweaning growth of calves. Tx sires were used on cows six to twelve years of age. Resulting changes in growth of calves had a direct impact on productivity of the system which directly affected net income.

Table 10. Changes in profit due to changes in single traits -M1.

	Net income /cow exposed, $		Adjusted net income, $	
	+	-	+	-
Mature Weight[a]	-0.816	-6.866*	-3,021.8*	3,990.6*
Birth Weight[a]	-1.203	1.920	572.7	-425.5
Weaning Weight[b]	2.525	-5.139*	1,872.6*	-1,531.8
Conception Rate[c]	1.760	-3.920*	-168.9	400.6
Age at Puberty[a]	-1.065	0.060	825.7	591.5
Milk Production[a]	0.640	-2.977	-1,357.9	-1,395.7

[a] 20% change
[b] 22% change
[c] 6% change
* value differs from base (P<.05)

Table 11. Changes in profit due to changes in single traits -M2.

	Net income /cow exposed, $		Adjusted net income, $	
	+	-	+	-
Mature Weight[a]	-0.730	-4.799*	-3,354.1*	5,854.5*
Birth Weight[a]	-1.250	0.057	6.4	-465.7
Weaning Weight[b]	4.127*	-7.806*	4,254.9*	-1,586.9
Conception Rate[c]	0.454	-4.416*	-1,605.3	1,149.8
Age at Puberty[a]	-0.969	-1.539	555.7	351.9
Milk Production[a]	0.319	-2.377	139.9	-652.9

[a] 20% change
[b] 22% change
[c] 6% change
* value differs from base (P<.05)

Table 12. Changes in profit due to changes in single traits -M4.

	Net income /cow exposed, $		Adjusted net income, $	
	+	-	+	-
Mature Weight[a]	2.307	-6.181*	-2,177.1*	5,402.7*
Birth Weight[a]	0.256	-1.292	1,100.7	-1,390.9
Weaning Weight[b]	3.052	-7.550*	3,350.0*	-1,950.0*
Conception Rate[c]	1.433	-5.362*	-1,386.1	2,116.0*
Age at Puberty[a]	-1.358	-3.190	988.5	-905.3
Milk Production[a]	1.198	-7.143*	548.1	-2,380.5*

[a] 20% change
[b] 22% change
[c] 6% change
* value differs from base (P<.05)

Table 13. Changes in profit due to changes in single traits -M3.

	Net income /cow exposed, $		Adjusted net income, $	
	+	-	+	-
Birth Weight[a]	-4.953*	0.425	40.4	-1,957.9*
Weaning Weight[b]	-0.367	-4.228*	-202.0	-2,087.2*

[a] 20% change
[b] 22% change
* value differs from base (P<.05)

Table 14. Changes in profit due to changes in single traits -Tx.

	Net income /cow exposed, $		Adjusted net income, $	
	+	-	+	-
Birth Weight[a]	1.491	-0.601	9.9	-877.1
Weaning Weight[b]	5.026*	-9.225*	1,922.7*	-3,682.2*

[a] 20% change
[b] 22% change
* value differs from base (P<.05)

The following tables (15 through 19) show effect of changing genetic potential of traits. These tables are similar to tables 10 through 14, however, they are expressed as change in profit per unit change in each trait. They were determined by dividing the total change by the number of units that trait was changed (i.e. M1 mature weight change in adjusted net profit per unit change in trait = -3021.8/103.2= -29.28). Tests of significance for tables 15 through 19 were carried over from tables 10 through 14. Traits were changed a fixed percentage for each trait ranging from 6% to 22%. These changes resulted in a large difference in actual amount each trait was changed. For example, in M1 a 20% change in mature weight resulted in a 103.2 kg difference while a 20% change in birth weight caused a 7.402 kg change (table 15).

Table 15. Changes in profit per unit change in trait -M1.

	Net income /cow exposed, $		Adjusted net income, $	
	+	-	+	-
Mature Weight[a]	-.01	.07*	-29.28*	38.67*
Birth Weight[b]	-.16	.26	77.37	-57.48
Weaning Weight[c]	.05	-.10*	38.20*	-31.25
Conception Rate[d]	.31	-.69*	-29.92	70.96
Age at Puberty[e]	-.01	.00	10.89	7.80
Milk Production[f]	.28	-1.31	-595.23	-611.8

[a] 103.2 kg change
[b] 7.402 kg change
[c] 49.018 kg change
[d] 5.65% change
[e] 75.8 day change
[f] 2.281 kg change
* value differs from base (P<.05)

Table 16. Changes in profit per unit change in trait -M2.

	Net income /cow exposed, $		Adjusted net income, $	
	+	-	+	-
Mature Weight[a]	-.01	-.04*	-30.44*	53.13*
Birth Weight[b]	-.17	.01	.86	-61.99
Weaning Weight[c]	.08*	-.15*	86.80*	-31.33
Conception Rate[d]	.08	-.78*	-284.12	203.50
Age at Puberty[e]	-.01	-.02	7.45	4.72
Milk Production[f]	.14	-1.03	60.59	-282.76

[a] 110.2 kg change
[b] 7.513 kg change
[c] 50.651 kg change
[d] 5.65% change
[e] 74.6 day change
[f] 2.309 kg change
* value differs from base (P<.05)

Table 17. Changes in profit per unit change in trait -M4.

	Net income /cow exposed, $		Adjusted net income, $	
	+	-	+	-
Mature Weight[a]	.31	-.83*	-19.03*	47.23*
Birth Weight[b]	.03	-.17	147.17	-185.97
Weaning Weight[c]	.06	-.15*	67.01*	-39.00*
Conception Rate[d]	.26	-.98*	-253.40	386.84*
Age at Puberty[e]	-.02	-.04	13.25	-12.14
Milk Production[f]	.53	-3.17*	243.28	-1056.59*

[a] 114.4 kg change
[b] 7.479 kg change
[c] 49.996 kg change
[d] 5.47% change
[e] 74.6 day change
[f] 2.253 kg change
* value differs from base (P<.05)

Table 18. Changes in profit per unit change in trait -M3.

	Net income /cow exposed, $		Adjusted net income, $	
	+	-	+	-
Birth Weight[b]	-.79*	.07	6.48	-314.12*
Weaning Weight[c]	-.01	-.09*	-4.43	-45.73*

[a] 95.2 kg change
[b] 6.233 kg change
[c] 45.645 kg change
* value differs from base (P<.05)

Table 19. Changes in profit per unit change in trait -Tx.

	Net income /cow exposed, $		Adjusted net income, $	
	+	-	+	-
Birth Weight[b]	.17	-.07	1.14	-100.91
Weaning Weight[c]	.10*	-.18*	37.00*	-70.86*

[a] 121.2 kg change
[b] 8.692 kg change
[c] 51.967 kg change
* value differs from base (P<.05)

Table 20. Average incidence of dystocia[a].

	Changes in mature weight		Changes in birth Weight	
	+	-	+	-
M1	27*	38*	37*	26*
M2	24*	40*	38*	25*
M4	25*	37*	39*	26*
M3	31	32	46*	15*
Tx	33	32	31	32

[a] average incidence of dystocia in base runs = 32
* value differs from base (P<.05)

Table 21. Average calf weaning weight (kg)[a].

	Changes in mature weight		Changes in peak milk		Changes in weaning weight	
	+	-	+	-	+	-
M1	228.3*	225.9*	232.8*	221.8*	232.0*	222.1*
M2	228.3*	225.9*	233.5*	221.4*	232.4*	221.7*
M4	228.2*	225.9*	233.2*	221.1*	232.4*	221.8*
M3	228.0	227.2	NA	NA	229.2*	225.4*
Tx	227.8	227.2	NA	NA	234.3*	220.5*

[a] average weaning weight in base runs = 227.5
* value differs from base (P<.05)

Table 22. Average herd size with changes in conception rate.

	Original herd size[a]		Adjusted herd size[b]	
	+	-	+	-
M1	674*	577*	493*	500*
M2	680*	570*	492*	501*
M4	684*	563*	493*	502*

[a] average adjusted base herd size = 637
[b] average adjusted base herd size = 496
* value differs from base (P<.05)

Table 23. Average years of age of cows weaning calves.

	Changes in conception rate[a]	
	+	-
M1	5.58	5.23*
M2	5.60*	5.22*
M4	5.58	5.22*

[a] average age of cow weaning calves in base herd = 5.49
* value differs from base (P<.05)

Table 24. Average adjusted net income[a].

	Changes in conception rate, $		Changes in Birth weight, $	
	+	-	+	-
M1	56,085	56,654	56,826	55,828
M2	54,648	57,403	56,260	55,788
M4	54,867	58,370*	57,254	54,863
M3	NA	NA	56,294	54,296*
Tx	NA	NA	56,263	55,376

[a] average income in base run = 56,254
* value differs from base (P<.05)

Table 25. Average income from sale of yearling heifers[ab].

	Changes in conception rate, $	
	+	-
M1	3,151.9	7,772.3*
M2	3,072.8*	8,614.7*
M4	3,200.2*	8,624.7*

[a] average income in base run = 5,812.8
[b] adjusted to fixed feed resource
* value differs from base (P<.05)

Table 26. Average income from sale of 2-year-old heifers[ab].

	Changes in conception rate, $		Changes in birth weight, $	
	+	-	+	-
M1	10,743	13,091*	12,468	9,743
M2	9,762	13,320*	13,257*	8,661*
M4	9,408	14,587*	13,684	9,311*
M3	NA	NA	16,491*	6,421*
Tx	NA	NA	9,382	10,671

[a] average income in base run = 10,825
[b] adjusted to fixed feed resource
* value differs from base (P<.05)

Table 27. Average total income from sale of all animals[ab].

	Changes in conception rate, $		Changes in birth weight, $	
	+	-	+	-
M1	202,151	204,609	203,716	201,995
M2	200,565*	205,468	203,243	202,079
M4	200,692*	206,782	204,264	201,353
M3	NA	NA	204,250	200,119*
Tx	NA	NA	202,570	202,082

[a] average income in base run = 202,896
[b] adjusted to fixed feed resource
* value differs from base (P<.05)

Table 28. Average total cost for system[ab].

	Changes in conception rate, $		Changes in birth weight, $	
	+	-	+	-
M1	146,067*	147,955*	146,890	146,167
M2	145,917*	148,065*	146,984	146,291
M4	145,825*	148,413*	146,910	146,491
M3	NA	NA	147,957*	145,824*
Tx	NA	NA	146,307	146,706

[a] average total cost in base run = 146,642
[b] adjusted to fixed feed resource
* value differs from base (P<.05)

Table 29. Average number of calves weaned per cow exposed[ab].

	Changes in conception rate		Changes in mature weight		Changes in milk prod.	
	+	-	+	-	+	-
M1	.837	.799*	.836	.795*	.827	.824
M2	.839*	.796*	.823	.802*	.821	.827
M4	.840*	.791*	.833	.794*	.819	.814
M3	NA	NA	.837	.820	NA	NA
Tx	NA	NA	.921	.815	NA	NA

[a] average calves weaned per cow exposed in base run = .826
[b] adjusted to fixed feed resource
* value differs from base (P<.05)

Regression Estimates

Tables 30 through 34 give regression estimates of change in profit per unit change for all traits examined in all strains. Regressions predict the slope of a line caused by changing a variable by one unit. The regressions calculated were essentially the average effects (both increase and decrease) from previous tables.

Most estimates were expected after examining above results. One regression estimate which appeared to be significant but unexplained, was the effect of changing age at puberty on adjusted net income in M4. This result was perhaps due to random variation.

Table 30. M1 regression estimates of economic weights.

	Net income /cow exposed	Adjusted net income
Mature Weight ($/kg)	.0293**	-33.97**
Birth Weight ($/kg)	-.2110*	67.43
Weaning Weight ($/kg)	.0782**	34.73**
Conception Rate ($/%)	.4271**	-50.40
Age at Puberty ($/day)	-.0074	1.54
Milk Production ($/kg)	.7926*	8.30

* P<.05
** P<.01

Table 31. M2 regression estimates of economic weights.

	Net income /cow exposed	Adjusted net income
Mature Weight ($/kg)	.0185*	-41.78**
Birth Weight ($/kg)	-.0870	31.42
Weaning Weight ($/kg)	.1178**	57.67**
Conception Rate ($/%)	.4310**	-243.81**
Age at Puberty ($/day)	.0038	1.37
Milk Production ($/kg)	.5838	171.68

* P<.05
** P<.01

Table 32. M4 regression estimates of economic weights.

	Net income /cow exposed	Adjusted net income
Mature Weight ($/kg)	.0371**	-33.13**
Birth Weight ($/kg)	.0135	166.57**
Weaning Weight ($/kg)	.1060*	53.00**
Conception Rate ($/%)	.6212*	-320.11**
Age at Puberty ($/day)	.0121	12.69*
Milk Production ($/kg)	1.8513*	649.95**

* P<.05
** P<.01

Table 33. M3 regression estimates of economic weights.

	Net income /cow exposed	Adjusted net income
Birth Weight ($/kg)	-.4314**	160.30*
Weaning Weight ($/kg)	.0423*	20.65*

* P<.05
** P<.01

Table 34. Tx regression estimates of economic weights.

	Net income /cow exposed	Adjusted net income
Birth Weight ($/kg)	.1203	51.02
Weaning Weight ($/kg)	.1371**	53.93**

** P<.01

Selection Indexes

Selection indexes were calculated using the regression estimates of economic weights from tables 30 through 34. Phenotypic and genotypic parameters used to calculate the indexes (tables 35 and 36) were taken from Koots (1993a,b). Only regression estimates of economic weights which were significant were used in determining selection indexes. Despite being significant in some strains, conception rate and birth weight were not included in selection index calculations. As previously discussed, changing either conception rate or birth weight resulted in a change in the average age of the herd and it was not necessarily desirable to include these traits in the selection indexes with the determined estimated economic weights. Voluntary culling of a greater number of animals could produce the same result of decreasing average age of the cows. This would be more desirable than a decreased conception rate as this gives the producer the option of which animals to cull.

Table 35. Heritabilities and phenotypic standard deviations.[a]

Trait	h^2	S.D.
Birth Wt, kg	.31	4.3
Weaning Wt, kg	.24	25.
Test ADG, kg/d	.31	.134
Scrotal Circ., cm	.48	2.7
Backfat, mm	.44	2.6
Mature Cow Wt, kg	.50	54.
Mat. Birth Wt	.14	
Mat. Weaning Wt	.13	

[a] Taken from review by Koots, 1993a.

Table 36. Genetic and phenotypic correlations.[a]

Trait (No.)	1	2	3	4	5	6	7	8
Birth Wt (1)		.50	.32	.04	-.27	.67	-.35	-.14
Weaning Wt (2)	.46		.44	.19	.24	.57	-.05	-.16
Test ADG (3)	.19	.09		.28	.19	.06	.04	.11
Scrotal Circ. (4)	.13	.34	.36		.78	.00	-.07	.19
Backfat (5)	-.07	.16	.18	.27		.00	.00	.00
Mature Cow Wt (6)	.34	.45	.10	.00	.00		.00	.00
Mat. Birth Wt (7)								.39
Mat. Weaning Wt (8)								

[a] Taken from review by Koots, 1993b.
Genetic correlations above diagonal, phenotypic correlations below diagonal.

Tables 37 through 44 give selection indexes for the five strains of cattle. The economic weight of mature weight in maternal strains was considered to be 2/3 of estimated regression to account for previously discussed effects of mature weight on profit. Only those regression estimates of economic weight of a trait which were significant ($P<.05$) were included in selection index calculations.

The predicted responses in all maternal strains show a desirable decrease in mature weight. As well, birth weight is also predicted to decrease. M1 and M2 both have a decrease in weaning weight which may not be desirable, however, it was determined that decreasing mature weight had a more significant effect on profit.

M1 and M2 were weighted for weaning weight and mature weight only. Maternal effect on weaning weight was used with M4 along with weaning weight and mature weight. This was done because it was shown that milk had a significant effect on profit with M4 and this is translated through its effect on weaning weight.

Table 37. Selection indexes for the M1 strain.[a]

Trait	Economic Weight	Bull Index Weight	Predicted Response	Heifer Index Weight
Birth Wt, kg	0.0	-55.1	-.97	-50.0
Weaning Wt, kg	35.0	2.92	-1.60	2.99
Test ADG, kg/d	0.0	874.	.008	
Scrotal Circ., cm	0.0		.15	
Backfat, mm	0.0		.31	
Mature Cow Wt, kg	-22.6	-3.63	-16.3	-3.66
Mat. Birth Wt, kg	0.0		.04	
Mat. Weaning Wt, kg	0.0		.46	

[a] Economic weight = predicted change in adjusted net income per unit change in trait.
Bull index = index weights used to rank bulls at end of gain test.
Predicted response = predicted response in each trait per phenotypic standard deviation of selection applied in bull index.
Heifer index = index weight used to rank heifers and bulls at weaning. For bulls, this is the "Pretest Index".

Table 38. Selection indexes for the M2 strain.[a]

Trait	Economic Weight	Bull Index Weight	Predicted Response	Heifer Index Weight
Birth Wt, kg	0.0	-67.5	-.80	-59.6
Weaning Wt, kg	58.0	6.61	-.03	6.72
Test ADG, kg/d	0.0	1347.	.016	
Scrotal Circ., cm	0.0		.23	
Backfat, mm	0.0		.38	
Mature Cow Wt, kg	-28.0	-3.98	-13.5	-4.03
Mat. Birth Wt, kg	0.0		.06	
Mat. Weaning Wt, kg	0.0		.71	

[a] Economic weight = predicted change in adjusted net income per unit change in trait.
Bull index = index weights used to rank bulls at end of gain test.
Predicted response = predicted response in each trait per phenotypic standard deviation of selection applied in bull index.
Heifer index = index weight used to rank heifers and bulls at weaning. For bulls, this is the "Pretest Index".

Table 39. Selection indexes for the M4 strain.[a]

Trait	Economic Weight	Bull Index Weight	Predicted Response	Heifer Index Weight
Birth Wt, kg	0.0	-57.8	-.60	-50.0
Weaning Wt, kg	53.0	8.23	1.51	8.34
Test ADG, kg/d	0.0	1328.	.022	
Scrotal Circ., cm	0.0		.30	
Backfat, mm	0.0		.42	
Mature Cow Wt, kg	-22.0	-2.89	-9.88	-2.93
Mat. Birth Wt, kg	0.0		.08	
Mat. Weaning Wt, kg	32.0		.91	

[a] Economic weight = predicted change in adjusted net income per unit change in trait.
Bull index = index weights used to rank bulls at end of gain test.
Predicted response = predicted response in each trait per phenotypic standard deviation of selection applied in bull index.
Heifer index = index weight used to rank heifers and bulls at weaning. For bulls, this is the "Pretest Index".

Two selection indexes were calculated for M3. The first selection indexes (table 40) give those calculated using economic weights determined previously. The second selection indexes (table 41) were calculated with change in birth weight constrained to zero. This was done because the marketing strategy for M3 is based on low birth weight. Constraining change in birth weight to zero would reflect a continuing commitment to this strategy. Increased birth weight is not desirable and when not constrained the predicted response was an increase of .69 kg for every standard deviation of selection applied.

Table 40. Selection indexes for the M3 strain.[a]

Trait	Economic Weight	Bull Index Weight	Predicted Response	Heifer Index Weight
Birth Wt, kg	0.0	2.16	0.69	4.34
Weaning Wt, kg	21.0	4.37	6.16	4.40
Test ADG, kg/d	0.0	374.	.032	
Scrotal Circ., cm	0.0		.32	
Backfat, mm	0.0		.22	
Mature Cow Wt, kg	0.0		10.5	
Mat. Birth Wt, kg	0.0		.08	
Mat. Weaning Wt, kg	0.0		.99	

[a] Economic weight = predicted change in adjusted net income per unit change in trait.
Bull index = index weights used to rank bulls at end of gain test.
Predicted response = predicted response in each trait per phenotypic standard deviation of selection applied in bull index.
Heifer index = index weight used to rank heifers and bulls at weaning. For bulls, this is the "Pretest Index".

Table 41. Selection indexes for the M3 strain - change in birth weight constrained to zero.[a]

Trait	Economic Weight	Bull Index Weight	Predicted Response	Heifer Index Weight
Birth Wt, kg	0.0	-9.9	0.00	-11.5
Weaning Wt, kg	21.0	4.04	5.35	4.44
Test ADG, kg/d	0.0	236.	.025	
Scrotal Circ., cm	0.0		.62	
Backfat, mm	0.0	14.9	.73	
Mature Cow Wt, kg	0.0		4.5	
Mat. Birth Wt, kg	0.0		.08	
Mat. Weaning Wt, kg	0.0		1.00	

[a] Economic weight = predicted change in adjusted net income per unit change in trait.
Bull index = index weights used to rank bulls at end of gain test.
Predicted response = predicted response in each trait per phenotypic standard deviation of selection applied in bull index.
Heifer index = index weight used to rank heifers and bulls at weaning. For bulls, this is the "Pretest Index".

Three selection indexes were calculated for Tx. Table 42 gives selection indexes when only weaning weight is given importance. Table 43 shows selection indexes when weaning weight and test average daily gain are given equal importance. Table 44 gives selection indexes when only test average daily gain is given importance. Test average daily gain is considered to be important in Tx and is the measurement that has been used in the past for Tx. MacNeil et al (1993) were able to show that economic weight weaning weight was an important trait to consider when weaning was the endpoint (calves sold at weaning), but had less importance when ownership of calves was retained for a longer period of time. Bourdan and Brinks (1987) also had similar results.

Test average daily gain was not measured in simulations as all calves were considered to have been sold at weaning, however, economic weights were estimated using weaning weight economic weights. This was done by determining the amount of change required in kilograms per day in average daily gain to equal a total change in weaning weight.

Table 42. Selection indexes for the Tx strain.[a]

Trait	Economic Weight	Bull Index Weight	Predicted Response	Heifer Index Weight
Birth Wt, kg	0.0	5.55	.69	11.17
Weaning Wt, kg	54.0	11.24	6.16	11.31
Test ADG, kg/d	0.0	963.	.032	
Scrotal Circ., cm	0.0		.32	
Backfat, mm	0.0		.22	
Mature Cow Wt, kg	0.0		10.51	
Mat. Birth Wt, kg	0.0		.08	
Mat. Weaning Wt, kg	0.0		.99	

[a] Economic weight = predicted change in adjusted net income per unit change in trait.
Bull index = index weights used to rank bulls at end of gain test.
Predicted response = predicted response in each trait per phenotypic standard deviation of selection applied in bull index.
Heifer index = index weight used to rank heifers and bulls at weaning. For bulls, this is the "Pretest Index".

As more emphasis was put on test average daily gain, the predicted response of mature weight decreased. However, the predicted response of weaning weight also decreased slightly but test average daily gain increased, especially between the index with no weight for test average daily gain and where weaning weight and test average daily gain are considered with equal importance. With this in mind, it might be desirable to use the selection index which weights weaning weight and test average daily gain with equal importance. This would allow weaning weight to still increase, as well as test average daily gain, while mature weight does not increase as much as with all weight on weaning weight.

Table 43. Selection indexes for the Tx strain - equal importance given to weaning weight and test average daily gain.[a]

Trait	Economic Weight	Bull Index Weight	Predicted Response	Heifer Index Weight
Birth Wt, kg	0.0	5.21	.67	11.17
Weaning Wt, kg	54.0	15.35	5.74	11.31
Test ADG, kg/d	7560.	3231.	.041	
Scrotal Circ., cm	0.0		.35	
Backfat, mm	0.0		.24	
Mature Cow Wt, kg	0.0		8.05	
Mat. Birth Wt, kg	0.0		.07	
Mat. Weaning Wt, kg	0.0		.96	

[a] Economic weight = predicted change in adjusted net income per unit change in trait.
Bull index = index weights used to rank bulls at end of gain test.
Predicted response = predicted response in each trait per phenotypic standard deviation of selection applied in bull index.
Heifer index = index weight used to rank heifers and bulls at weaning. For bulls, this is the "Pretest Index".

Table 44. Selection indexes for the Tx strain - importance given to only to test average daily gain.[a]

Trait	Economic Weight	Bull Index Weight	Predicted Response	Heifer Index Weight
Birth Wt, kg	0.0	-.34	.55	11.17
Weaning Wt, kg	0.0	4.11	4.51	11.31
Test ADG, kg/d	7560.	2268.	.044	
Scrotal Circ., cm	0.0		.34	
Backfat, mm	0.0		.23	
Mature Cow Wt, kg	0.0		4.43	
Mat. Birth Wt, kg	0.0		.06	
Mat. Weaning Wt, kg	0.0		.79	

[a] Economic weight = predicted change in adjusted net income per unit change in trait.
Bull index = index weights used to rank bulls at end of gain test.
Predicted response = predicted response in each trait per phenotypic standard deviation of selection applied in bull index.
Heifer index = index weight used to rank heifers and bulls at weaning. For bulls, this is the "Pretest Index".

CONCLUSION

The objectives of this project were to determine economic measures for different strains of cattle in different mating systems and calculate economic weights and selection indexes for genetic traits within the different strains. The system simulated an operation which retained ownership of calves only to weaning.

Several limitations of this research must be considered when interpreting and using the results. The environment which was simulated was the Northern Great Plains with costs and price received for livestock taken from Montana. Further, calves were simulated only until weaning. It would be possible to apply these results to other breeds of cattle, however, only if they are of similar biological types. Economic weights and selection indexes were determined using a rotational-terminal mating system (ROT3X).

Using a rotational crossbreeding system with easy calving sires bred to replacement heifers and high growth rate terminal cross sires used on mature cows proved to be the most profitable system. Most purebred strains, especially maternal strains, were fairly similar in estimates of adjusted net profit.

Performance traits in ROT3X system were compared using net profit per cow exposed and adjusted net income. Both mature weight and weaning weight were important traits considered in maternal strains. Weaning weight and birth weight were important in M3. The only trait important in Tx was weaning weight.

When attempting to determine breeding goals for Beefbooster Cattle Alberta Ltd., many factors should be taken into account. The previous traits mentioned were obviously important, however, as noted earlier, mature weight had confounding factors. Part of the profit differences exhibited due to changes in mature weight in maternal strains were associated with changes in fertility. Despite this, changes in adjusted net income were still large enough for mature weight to be considered important in selection of maternal strains.

Rate of conception and birth weight had effects opposite to what was expected. This was due to a shift in distribution of age of the herd. Upon initial examination, this would seem to indicate that it would be desirable to select for decreased rate of conception and increased birth weight. This was not the case. Changes in both of these traits resulted in different culling rates within the herd which resulted in changing distribution of age of the herd. If pregnancy rate were to decrease and birth weight increase, "involuntary" culling would increase leading to less choice of the producer to select desired animals. Furthermore, adequate or even excellent producing animals may be culled. For these reasons it is desirable to maintain rate of conception as high as possible and birth weight low and to voluntarily cull low producing cows and poor replacement heifers trying to maintain as young of an age distribution in the herd as possible.

The model proved to be more sensitive to reproductive traits than any other. Any errors in predicting these traits for current beefbooster strains would then have had a larger effect on the system. It is important to estimate these traits as accurately as possible, especially rate of conception.

In the model, birth weight only affected incidence of dystocia in first calf heifers. Because of this, estimates of economic efficiency may have been underestimated, especially in Tx. This is because it is possible that an increase in birth weight may cause an increase in dystocia in older cows.

Age at first estrus was estimated from mature weight as no direct data on puberty were available. Using estimated ages, changing these ages has no effect on the system. It is important to realize that if actual age at first estrus is later than what was estimated, then it may be an important factor.

Changing milk production essentially had no effect on the results. This was a result of a tradeoff between higher weight output and higher forage consumption. It may have been more important if weaning weight was altered at the same time. As weaning weight was shown to be one of the more important traits, it might be considered wise to add some emphasis on increasing milk production when selecting for higher weaning weights.

LITERATURE CITED

Amer, P. R. 1992. Economic Evaluation of Beef Cattle Genotypes Using Neoclassical Production Theory. Ph.D. Thesis.

Azzam, S. M., J. E. Kinder, M. K. Nielsen, L. A. Werth, K. E. Gregory, L. V. Cundiff and R. M. Koch. 1993. Environmental Effects on Neonatal Mortality of Beef Calves. J. Anim. Sci. 71:282-290.

Belcher, C. G. and R. R. Frahm. 1979. Productivity of Two-Year-Old Crossbred Cows Producing Three-Breed Cross Calves. J. Anim. Sci. 49:1195-1206.

Bellows, R. A., R. B. Gibson, D. C. Anderson and R. E. Short. 1971. Precalving Body Size and Pelvic Area Relationships in Hereford Heifers. J. Anim. Sci. 33:455-457.

Bourdon, R. M. and J. S. Brinks. 1987a. Simulated Efficiency of Range Beef Production. I.Growth and Milk Production. J. Anim. Sci. 65:943-955.

Bourdon, R. M. and J. S. Brinks. 1987b. Simulated Efficiency of Range Beef Production. II.Fertility Traits. J. Anim. Sci. 65:956-962.

Bourdon, R. M. and J. S. Brinks. 1987c. Simulated Efficiency of Range Beef Production. III.Culling Strategies and Nontraditional Management Systems. J. Anim. Sci. 65:963-969.

Brascamp, E. W., C. Smith and D. R. Guy. 1985. Derivation of Economic Weights From Profit Equations. Anim. Prod. 40:175-180.

Buchanan, D. S., M. K. Nielsen, R. M. Koch and L. V. Cundiff. 1982a. Selection for Growth and Muscling Score in Beef Cattle. I.Selection Applied. J. Anim. Sci. 55:516-526.

Buchanan, D. S., M. K. Nielsen, R. M. Koch and L. V. Cundiff. 1982b. Selection for Growth and Muscling Score in Beef Cattle. II.Genetic Parameters and Predicted Response. J. Anim. Sci. 55:526-532.

Cartwright, T. C. 1970. Selection Criteria for Beef Cattle for the Future. J. Anim. Sci. 30:706-711.

Cartwright, T. C., H. A. Fitzhugh, Jr. and C. R. Long. 1975. Systems Analysis of Sources of Genetic and Environmental Variation in Efficiency of Beef Production: Mating Plans. J. Anim. Sci. 40:433-443.

Cattle Fax. 1990 and 1991. Vol. XXII and XXIII:Issue 36-47. Cattle Marketing Information Service, Inc., Englewood, CA.

Clarke, S. E., C. T. Gaskins, J. K. Hillers and W. D. Hohenboken. 1984. Mathematical Modeling of Alternative Selection Strategies for Beef Production. J. Anim. Sci. 59:308-316.

Cook, B. R. 1991. A Comprehensive Analysis of Pelvic Measurements in Beef Cattle. M.S. Thesis.

Davis, K. C. 1992. Life Cycle Evaluation of Five Biological Types of Beef Cattle in a Range Production System. Masters Thesis.

Dent, J. B. and M. J. Blackie. 1979. Systems Simulations in Agriculture. Applied Science Publications, Ltd., Essex, England.

Dickerson, G. E. 1970. Efficiency of Animal Production - Molding the Biological Components. J. Anim. Sci. 30:849-859.

Dickerson, G. E. 1978. Animal Size and Efficiency: Basic Concepts. Anim. Prod. 27:367-379.

Fitzhugh, H. A., Jr., C. R. Long and T. C. Cartwright. 1975. Systems Analysis of Sources of Genetic and Environmental Variation in Efficiency of Beef Production: Heterosis and Complementarity. J. Anim. Sci. 40:421-432.

Forbes, J. M. 1977. Development of a Model of Voluntary Food Intake and Energy Balance in Lactating Cows. Anim. Prod. 24:203-214.

Forbes, J. M. 1977. Interrelationships Between Physical and Metabolic Control of Voluntary Food Intake in Fattening Pregnant and Lactating Mature Sheep: A Model. Anim. Prod. 24:91-101.

Forbes, D. and J. Oltjen. 1985. Historical Perspective of Biological Simulation with Special Reference to Beef-Forage Systems. Proceedings of Symposium: Simulation of Beef Cattle Production Systems and Its Use in Economic Analysis. April 30-May 1. 1-18.

Fowler, V. R., M. Bichard and A. Pease. 1976. Objectives in Pig Breeding. Anim. Prod. 23:365-387.

Frahm, R. R., C. G. Nichols and D. S. Buchanan. 1985a. Selection for Increased Weaning or Yearling Weight in Hereford Cattle. I.Measurement of Selection Applied. J. Anim. Sci. 60:1373-1384.

Frahm, R. R., C. G. Nichols and D. S. Buchanan. 1985b. Selection for Increased Weaning or Yearling Weight in Hereford Cattle. II.Direct and Correlated Responses. J. Anim. Sci. 60:1385-1395.

Gregory, K. E., and L. V. Cundiff. 1980. Crossbreeding in Beef Cattle: Evaluation of Systems. J. Anim. Sci. 51:1224.

Gregory, K. E., L. V. Cundiff and R. M. Koch. 1991a. Breed Effects and Heterosis in Advanced Generations of Composite Populations for Preweaning Traits of Beef Cattle. J. Anim. Sci. 69:947-960.

Gregory, K. E., D. D. Lunstra, L. V. Cundiff and R. M. Koch. 1991b. Breed Effects and Heterosis in Advanced Generations of Composite Populations for Puberty and Scrotal Traits of Beef Cattle. J. Anim. Sci. 69:2795-2807.

Gregory, K. E., L. V. Cundiff and R. M. Koch. 1991c. Breed Effects and Heterosis in Advanced Generations of Composite Populations for Growth Traits in Both Sexes of Beef Cattle. J. Anim. Sci. 69:3202-3212.

Gregory, K. E. and R. R. Maurer. 1991d. Prenatal and Postnatal Maternal Contributions to Reproductive, Maternal, and Size-Related Traits of Beef Cattle. J. Anim. Sci. 961-976.

Gregory, K. E., L. V. Cundiff and R. M. Koch. 1992a. Breed Effects and Heterosis in Advanced Generations of Composite Populations for Reproductive and Maternal Traits of Beef Cattle. J. Anim. Sci. 70:656-672.

Gregory, K. E., L. V. Cundiff and R. M. Koch. 1992b. Breed Effects and Heterosis in Advanced Generations of Composite Populations on Actual Weight, Adjusted Weight, Hip Height, and Condition Score of Beef Cattle. J. Anim. Sci. 70:1742-1754.

Gregory, K. E., L. V. Cundiff and R. M. Koch. 1992c. Effects of Breed and Retained Heterosis on Milk Yield and 200-day Weight in Advanced Generations of Composite Population of Beef Cattle. J. Anim. Sci. 70:2366-2372.

Harris, D. L. 1970. Breeding for Efficiency in Livestock Production: Defining the Economic Objectives. J. Anim. Sci. 30:860-865.

Harris, D. L., T. S. Stewart and C. R. Arboleda. 1984. Animal Breeding Programs: A Systematic Approach to Their Design. USDA-ARS-Adv. Agr. Technol. AAT-NC-8. USDA-ARS, Peoria,IL.

Hazel, L. N. 1943. The Genetic Basis For Constructing Selection Indexes. Genetics. 28:476-490.

Irgang, R., E. U. Dillard, M. W. Tess and O. W. Robison. 1985a. Selection for Weaning Weight and Postweaning Gain in Hereford Cattle. I.Population Structure and Selection Applied. J. Anim. Sci. 60:1133-1141.

Irgang, R., E. U. Dillard, M. W. Tess and O. W. Robison. 1985b. Selection for Weaning Weight and Postweaning Gain in Hereford Cattle. II.Response to Selection. J. Anim. Sci. 60:1142-1155.

Irgang, R., E. U. Dillard, M. W. Tess and O. W. Robison. 1985c. Selection for Weaning Weight and Postweaning Gain in Hereford Cattle. III.Correlated Responses to Selection In Milk Yield, Preweaning and Postweaning Traits. J. Anim. Sci. 60:1156-1164.

James, J. W. 1982. Economic Aspects of Developing Breeding Objectives: General Considerations. Future Developments in the Genetic Improvement of Animals. Academic Press.

James, W. C. 1978. Index Selection For Both Current and Future Generation Gains. Anim. Prod. 26:111-118.

Jarrige, R., C. Demarquilly, J. P. Dulphy, A. Hoden, J. Robelin, C. Beranger, Y. Gaey, M. Journet, C. Malterre, D. Micol and M. Petit. 1986. The INRA "Fill Unit" System for Predicting the Voluntary Intake of Forage-Based Diets in Ruminants: A Review. J. Anim. Sci. 63:1737-1758.

Koch, K. E., R. M. Gregory and L. V. Cundiff. 1974. Selection in Beef Cattle. II.Selection Response. J. Anim. Sci. 39:459-470.

Koch, R. M., L. V. Cundiff and K. E. Gregory. 1982. Heritabilities and Genetic, Environmental and Phenotypic Correlations of Carcass Traits in a Population of Diverse Biological Types and Their Implication in Selection Programs. J. Anim. Sci. 55:1319-1329.

Koots, K. R., J. P. Gibson, C. Smith and J. W. Wilton. 1993a. Analyses of Published Genetic Parameter Estimates for Beef Production Traits: 1. Heritability. In preparation.

Koots, K. R., J. P. Gibson, C. Smith and J. W. Wilton. 1993a. Analyses of Published Genetic Parameter Estimates for Beef Production Traits: 1. Phenotypic and Genetic Correlations. In preparation.

Kress, D. D., D. E. Doornbos and D. C. Anderson. 1990. Performance of Crosses Among Hereford, Angus and Simmental Cattle with Different Levels of Simmental Breeding: IV. Maternal Heterosis and Calf Production by Two-Year-Old Dams. J. Anim. Sci. 68:54-63.

Kress, D. D., D. E. Doornbos, D. C. Anderson and D. Rossi. 1991. Performance of Crosses Among Hereford, Angus and Simmental Cattle with Different Levels of Simmental Breeding: IV. Maternal Heterosis of 3- to 8-Year-Old Dams and the Dominance Model. J. Anim. Sci. 70:2682-2687.

Kress, D. D., M. D. MacNeil and G. E. Dickerson. 1988. Effect of Mating System, Cow Culling Policy and Maximum Cow Age on Beef Cattle Biological and Economical Efficiency. Proc. West. Sec. Amer. Soc. Anim. Sci. 39:23-26.

Lamb, M. A. and M. W. Tess. 1989. Evaluation of Crossbreeding Systems for Small Beef Herds: II.Two-Sire Systems. J. Anim. Sci. 67:40-47.

Lamb, M. A. and M. W. Tess. 1989. Evaluation of Crossbreeding Systems for Small Beef Herds: I.Single-Sire Systems. J. Anim. Sci. 67:28-39.

Lamb, M. A. 1991. Evaluation of Mating Systems Involving Five Breeds for Integrated Beef Production Systems. Ph.D. Thesis.

Legates, J. E. and E. J. Warwick. 1990. Breeding and Improvement of Farm Animals. 8th Ed. McGraw-Hill Publishing Company.

Long, C. R., T. C. Cartwright and H. A. Fitzhugh, Jr. 1975. Systems Analysis of Sources of Genetic and Environmental Variartion in Efficiency of Beef Production: Cow Size and Herd Management. J. Anim. Sci. 40:409-420.

Long, C. R. 1980. Crossbreeding for Beef Production: Experimental Results. J. Anim. Sci. 51:1197-1223.

Lush, J. L. 1945. Animal Breeding Plans. Iowa State College Press, Ames.

MacNeil, M. D. and S. Newman. 1993. Selection Indices for Canadian Beef Production Using Specialized Sire and Dam Lines. Submitted.

MacNeil, M. D., S. Newman, R. M. Enns and J. Stewart-Smith. 1993. Relative Economic Values for Canadian Beef Production Using Specialized Sire and Dam Lines. Submitted

Mertens, D. R. 1987. Prediction of Intake and Digestibility Using Mathematical Models of Ruminal Function. J. Anim. Sci. 64:1548-1558.

/Miller, R. H. and R. E. Pearson. 1979. Economic Aspects of Selection. Anim. Breeding Abstr. 47:281-290.

Moav, R. 1966a. Specialised Sire and Dam Lines. I.Economic Evaluation of Crossbreds. Anim. Prod. 8:193-202.

Moav, R. 1966b. Specialised Sire and Dam Lines. II.The Choice of the Most Profitable Combination When Component Traits are Genetically Additive. Anim. Prod. 8:203-210.

Moav, R. 1966c. Specialised Sire and Dam Lines. III.Choice for the Most Profitable Combination When Component Traits are Genetically Non-Additive. Anim. Prod. 8:365-374.

Newman, S., D. L. Harris and D. P. Doolittle. 1985. Economic Efficiency of Lean Tissue Production Through Crossbreeding: Systems Modeling with Mice. I.Definition of the Bioeconomic Objective. J. Anim. Sci. 60:385-394.

Newman, S., D. L. Harris and D. P. Doolittle. 1985. Economic Efficiency of Lean Tissue Production Through Crossbreeding: Systems Modeling with Mice. II.Reproduction-Growth Termination Alternatives. J. Anim. Sci. 60:395-412.

Newman, S., C. A. Morris, R. L. Baker and G. B. Nicoll. 1992. Genetic Improvement of Beef Cattle in New Zealand: Breeding Objectives. Livest. Prod. Sci. 32:111-130.

Notter, D. R. 1977. Simulated Efficiency of Beef Production For a Cow- Calf-Feedlot Management System. Ph.D. Dissertation.

Notter, D. R., J. O. Sanders, G. E. Dickerson, G. M. Smith and T. C. Cartwright. 1979a. Simulated Efficiency of Beef Production for a Midwestern Cow-Calf-Feedlot Management System. I.Milk Production. J. Anim. Sci. 49:70-82.

Notter, D. R., J. O. Sanders, G. E. Dickerson, G. M. Smith and T. C. Cartwright. 1979b. Simulated Efficiency of Beef Production for a Midwestern Cow-Calf-Feedlot Management System. II.Mature Body Size. J. Anim. Sci. 49:83-91.

Notter, D. R., J. O. Sanders, G. E. Dickerson, G. M. Smith and T. C. Cartwright. 1979c. Simulated Efficiency of Beef Production for a Midwestern Cow-Calf-Feedlot Management System. III.Crossbreeding Systems. J. Anim. Sci. 49:92-102.

Nunez-Dominguez, R., G. E. Dickerson, L. V. Cundiff, G. E. Gregory and R. M. Koch. 1992. Economic Evaluation of Heterosis and Culling Policies for Lifetime Productivity in Hereford, Angus, Shorthorn, and Crossbred Cows. J. Anim. Sci. 70:2328-2337.

Ollivier, Louis. 1986. Economic Evaluation of Breeding Objectives in Swine. Introductory Remarks. 3rd World Congress on Genetics Applied to Livestock Production. July 17-22. xiii-xvi.

Patterson, D. J., R. A. Bellows, P. J. Burfening and J. B. Carr. 1987. Occurrence of Neonatal and Postnatal Mortality in Range Beef Cattle. I.Calf Loss Incidence From Birth to Weaning, Backward and Breech Presentations and Effects of Calf Loss on Subsequent Pregnancy Rate of Dams. Theriogenology. 28:557-571.

Ponzoni, R. W. 1986. A Profit Equation For the Definition of the Breeding Objective of Australian Merino Sheep. J. Anim. Breed. Genet. 103:342-357.

Ponzoni, R. W. 1987. The Derivation of Economic Values Combining Income and Expense in Different Ways: An Example With Australian Merino Sheep. J. Anim. Breed. 105:143-153.

Ponzoni, R. W. and S. Newman. 1989. Developing Breeding Objectives For Australian Beef Cattle Production. J. Anim. Breed. 49:35-47.

Sanders, J. O. 1977. Application of a Beef Cattle Production Model to the Evaluation of Genetic Selection Criteria. Ph.D. Dissertation. Texas A&M Univ. College Station.

Sanders, J. O. and T. C. Cartwright. 1979. A General Cattle Production Systems Model. Part I:Structure of the Model. Agric. Syst. 4:217.

SAS. 1985. SAS User's Guide: Statistics. Statistical Analysis Systems Institute, Inc., Cary, NC.

Setshwaelo, L. L., L. V. Cundiff and G. E. Dickerson. 1990. Breed Effects on Crossbred Cow-Calf Performance. J. Anim. Sci. 68:1577-1587.

Short, R. E., R. A. Bellows, R. B. Staigmiller and J. B. Carr. 1979. Multiple Linear and Nonlinear Regression Analyses of Factors Causing Calving Difficulty. Theriogenology. Sept. 12:121-130.

Short, R. E., R. A. Bellows, R. B. Staigmiller, J. B. Berardinelli and E. E. Custer. 1990. Physiological Mechanisms Controlling Anestrus and Infertility in Postpartum Beef Cattle. J. Anim. Sci. 68:799-816.

Smith, C. 1964. The Use of Specialised Sire and Dam Lines in Selection for Meat Production. Anim. Prod. 6:337-344.

Smith, G. M. and L. V. Cundiff. 1976. Genetic Analysis of Relative Growth Rate in Crossbred and Straightbred Hereford, Angus and Shorthorn Steers. J. Anim. Sci. 43:1171-1175.

Smith, G. M., D. B. Laster and K. E. Gregory. 1976. Characterization of Biological Types of Cattle. I.Dystocia and Preweaning Growth. J. Anim. Sci. 43:27-36.

Smith, G. M. 1976. Sire Breed Effects on Economic Efficiency of a Terminal-Cross Beef Production System. J. Anim. Sci. 43:1163-1170.

Spedding, C. R. W. 1988. General Aspects of Modelling and Its Application in Livestock Production. Current Topics in Veterinary Medicine and Animal Science. 3-9.

Tess, M. W. 1981. Simulated Effects of Genetic Change Upon Life-Cycle Production Efficiency in Swine and the Effects of Body Composition Upon Energy Utilization in the Growing Pig. Ph.D. Thesis.

Tess, M. W. 1986. The Impact of Production/Marketing System on Breeding Objectives in Swine. Third World Congress on Genetics Applied to Livestock Production. July 16-22. 3-13.

Vesely, J. A. and O. W. Robison. 1972. Empirical Selection Indexes for Beef Cattle. J. Anim. Sci. 34:549-554.

APPENDICES

APPENDIX A

Sample Output From Simulation Run
of ROT3X System

EXECUTION BEGAN 04-21-1993 09:16:55:07 INPUT FILE = RN\RUN\1243X.002

MATING SYSTEM = M3 + Tx + Rotational

GENOTYPE	NUMBER
124	17
142	17
214	17
241	17
412	17
421	17

NO. OF YEARS	NO. OF COWS	NO. OF MGT. GRPS.
12	102	4

	NO. OF CALVES								
YR	STRS	AVGWT	RHF	T HF	AVGWT	TCV	AVGWT	AVEAGE	CWT
2	0	.00	0	0	.0	0	.0	.0	.0
3	48	222.63	0	39	220.2	87	221.5	207.7	19273.5
4	31	227.39	0	39	217.6	70	221.9	194.4	15535.0
5	31	228.20	0	33	209.8	64	218.7	192.5	13996.9
6	28	235.49	0	30	224.5	58	229.8	193.2	13329.7
7	22	236.24	0	29	231.1	51	233.3	192.8	11898.1
8	26	244.31	0	20	233.9	46	239.8	196.8	11030.8
9	20	237.39	0	20	221.8	40	229.6	188.9	9184.6
10	19	239.96	0	15	226.7	34	234.1	192.2	7959.4
11	16	240.81	0	15	230.8	31	235.9	195.1	7314.3
12	13	238.14	95	14	235.5	27	236.8	196.4	6393.2

YR	AGE	#COWS	DEAD COWS	SOLD COWS	#DYSTO	AVG WT	AVGFAT% (@BRDING)
2	1	95	0	7	0	418.63	.1068
3	2	76	0	26	28	621.68	.2619
4	3	66	0	36	4	631.07	.2694
5	4	60	0	42	1	628.36	.2666
6	5	55	0	47	0	619.52	.2543
7	6	48	1	53	5	610.81	.2424
8	7	43	1	58	2	607.45	.2373
9	8	39	1	62	2	611.81	.2438
10	9	33	2	67	1	611.09	.2428
11	10	27	2	73	3	611.23	.2424
12	0	0	2	100	2	611.03	.2416

CLVS BORN	CLVS WEANED	M1	M2	M3	M4	Tx
540	508	58	66	87	68	229

CLVS BORN	CLVS WEANED	M1	M2	M3	M4	Tx
540	508	58	66	87	68	229

CALF WT. WEANED/COW EXP.	NUM. CALVES PER COW EXP.
188.481	.826
# COWS EXP. (NOT LAST EXP)	TOTAL # OF COWS EXP.
615	642

TOTDM (kg)	TOTME (kg)	TOTCP (kg)	TOTMLK (kg)
2739221.0	6548128.0	393280.3	785989.2

Biological Inputs ($/kg)

Output	DM	ME	CP
Calf Weight	28.8195	68.8932	4.1377
Yr. Heifer Weight	703.5104	1681.7470	101.0056
2 Yr. Weight	217.9291	520.9612	31.2889
3+ Yr. Weight	57.0610	136.4049	8.1925
Total Cow Weight	42.4896	101.5717	6.1004
Total Weight	17.1721	41.0501	2.4655
Steer Wt. Equiv.	21.7073	51.8915	3.1166

FEED ($)	NONFEED ($)	CASH ($)
132462/80	58452.48	194030.00

	GRASS HAY	ALFALFA HAY	RANGE
kg	439711.60	605656.30	1656532.00
AUM	1444.52	1989.67	5441.96

Cash Inputs ($/kg)

Output	FEED	NONFEED	CASH
Calf Weight	1.3936	.6150	2.0414
Yr. Heifer Weight	34.0202	15.0123	49.8325
2 Yr. Weight	10.5386	4.6504	15.4368
3+ Yr. Weight	2.7593	1.2176	4.0419
Total Cow Weight	2.0547	.9067	3.0097
Total Weight	.8304	.3664	1.2164
Steer Weight Equiv.	1.0497	.4632	1.5376

	STEER	HEIFER	YRLNG	2-YR	3&>-YR	TOT
PRCE ($)	2.08	1.99	1.79	1.32	1.12	
WT (kg)	659208.19	35839.38	3893.65	12569.32	48005.09	159515.60
DLRS ($)	119700.50	69285.12	6601.38	15678.97	51738.88	263004.90

NET INCOME ($) = 68974.92
NET INCOME/EXP ($) = 112.15
NET INCOME/TEXP ($) = 107.44

ADJUST = .7718

	Adjusted Cash Inputs ($/kg)		
Output	FEED	NONFEED	CASH
Steer Wt. Equiv.	.1304	1.3759	1.5063

HAY BOUGHT	kg	$
GRASS HAY	114361.10	6303.58
ALFALFA HAY	42434.13	3508.03

NET INCOME ($) = 56285.97

AGE IN YEARS =	0	1	2	3	4	5	6	7	8	9	10	11	12
MGT GROUP =	1	2	3	4	5	6	7	8	9	10	11	12	13

MGMT GROUP	START BRDNG	STOP BRDNG	WEAN DATE	SELL DATE	NO. FOR.	NO. SUP.	CREEP CODE
1	130	190	275	300	2	1	0
2	130	190	275	300	3	3	0
3	144	204	275	300	3	2	0
4	144	204	275	300	4	0	0

MANAGEMENT GROUP NO. 1

FORAGE CODE	BEGIN	LIMIT	ME/DM	NDF/DM	CP/DM	RDP/CP	$/DM	CONSUMED
1	280	1.0	2.60	.5000	.1400	.6500	.03	24081.05
2	331	99.0	2.10	.4600	.1700	.6500	.08	26260.58
SUPPLEMENTS								
1	280	1.0	3.04	.1900	.1350	.7300	.10	9527.03

MANAGEMENT GROUP NO. 2

FORAGE CODE	BEGIN	LIMIT	ME/DM	NDF/DM	CP/DM	RDP/CP	$/DM	CONSUMED
2	1	99.0	2.10	.4600	.1700	.6500	.08	109264.50
1	121	1.0	2.60	.5000	.1400	.6500	.03	199453.20
2	331	99.0	2.10	.4600	.1700	.6500	.08	40218.90
SUPPLEMENTS								
1	1	1.0	3.04	.1900	.1350	.7300	.10	16617.19
2	151	.0	3.04	.1900	.1350	.7300	.10	.00
3	331	1.0	3.04	.1900	.1350	.7300	.10	3611.84

MANAGEMENT GROUP NO. 3

FORAGE CODE	BEGIN	LIMIT	ME/DM	NDF/DM	CP/DM	RDP/CP	$/DM	CONSUMED
2	1	99.0	2.10	.4600	.1700	.6500	.08	148452.50
1	121	1.0	2.60	.5000	.1400	.6500	.03	245638.00
3	331	99.0	2.05	.6000	.1200	.6500	.06	23418.59
SUPPLEMENTS								
1	1	1.0	3.04	.1900	.1350	.7300	.10	7636.17
2	75	.0	3.04	.1900	.1350	.7300	.10	.00

MANAGEMENT GROUP NO. 4

FORAGE CODE	BEGIN	LIMIT	ME/DM	NDF/DM	CP/DM	RDP/CP	$/DM	CONSUMED
3	1	99.0	2.05	.6000	.1200	.6500	.06	298675.40
2	75	99.0	2.10	.4600	.1700	.6500	.08	281459.80
1	121	1.0	2.60	.5000	.1400	.6500	.03	1187359.00
3	331	99.0	2.05	.6000	.1200	.6500	.06	117617.50

SUPPLEMENTS

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APPENDIX B

Supplementary Tables for
Systems Profitability

Table 45. Calf weight weaned per cow exposed.

Strain/mating system	Calf weight weaned per cow exposed, kg
ROT3	189.98[a]
ROT3X	187.90[a]
ROT	186.98[a]
M2	175.51[b]
M1	166.06[c]
M4	165.07[c]
Tx	163.42[c]
M3	140.84[d]

[abcd] Means within columns with different subscripts differ significantly (P<.05).

Table 46. Number of calves per cow exposed.

Strain/mating system	Number of calves per cow exposed
ROT3	.833[a]
ROT3X	.826[a]
ROT	.823[a]
M2	.808[b]
M1	.789[c]
M4	.780[c]
Tx	.774[c]
M3	.722[d]

[abcd] Means within columns with different subscripts differ significantly (P<.05).

Table 47. Number of cows exposed.

Strain/mating system	Original	Adjusted[a]
ROT3	649[b]	496[f]
ROT3X	637[b]	495[f]
ROT	632[b]	496[f]
M2	592[c]	511[d]
M1	544[d]	537[c]
Tx	532[d]	501[e]
M4	524[d]	512[d]
M3	421[e]	587[b]

[a] Adjusted to the fixed feed resource base
[bcdef] Means within columns with different subscripts differ significantly (P<.05).

Table 48. Breakeven prices.

Strain/mating system	Original	Adjusted
M3	1.73[b]	1.71[b]
Tx	1.65[c]	1.64[c]
M1	1.64[c]	1.63[c]
M4	1.64[c]	1.63[c]
M2	1.63[d]	1.60[d]
ROT	1.57[e]	1.56[e]
ROT3	1.56[e]	1.56[e]
ROT3X	1.55[e]	1.51[f]

[a] Adjusted to the fixed feed resource base
[bcdef] Means within columns with different subscripts differ significantly (P<.05).