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Selection Objective for Improving Efficiency of Beef Cattle

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SELECTION OBJECTIVE FOR IMPROVING EFFICIENCY OF BEEF CATTLE

by

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Simulation studies based on 1000 cows were used to evaluate biological and economic efficiency of level of milk production and two production systems, and to estimate economic values for a breeding objective and selection indexes for beef cattle. Published data were used as information for this study. Average 10-yr prices, reproduction, survival, growth, carcass characteristics, and genetic parameters from journal papers were used in the simulations. In the first study, low (L), medium (M), and high (H) milk production cows, and calf-fed and yearling systems, were analyzed. Biological and economic efficiencies were estimated for weaning and slaughter endpoints. In the second study, economic values for a breeding objective based on eleven traits and selection indexes using reported estimated breeding values were estimated for a total production system. Biological efficiencies were 29.77, 27.29, and 27.39 g weaning weight and 21.76, 19.92, and 19.81 g carcass weight per Mcal for L, M, and H cattle, respectively. Economic efficiencies (%) to weaning and to slaughter were 98.9, 94.2, and 94.6 and 105.8, 99.0, and 98.8 for L, M, and H cattle, respectively. Economic values and relative economic values ($/genetic SD) for milk production, average postweaning daily gain (ADG), mature weight, dressing percentage, rib fat thickness (FAT), kidney-pelvic-heart fat, ribeye area (REA,), marbling score (MS), calving difficulty, heifer pregnancy (HP), and gestation length were -0.046 $\$/\text{kg}\cdot 205\ \text{d}^{-1}$ and -9.068; 56.195 ($\$/\text{kg}\cdot\text{d}^{-1}$) and 4.957; -0.207 ($/kg) and -7.042; 1.970 ($/%) and 2.065; -39.285 ($/cm) and -6.904; -7.944 ($/%) and -2.401; 2.044 ($\$/\text{cm}^2$) and 9.311; 21.974 ($/score unit) and 11.023; -0.168 ($/%) and -4.095; 0.092 ($/%) and 1.633; and -1.177

($/d) and -3.155, respectively. The selection index with greatest correlation with the breeding objective included ADG, FAT, REA, MS, HP, birth weight (BWT, kg), yearling height (cm), and maternal weaning weight (WWM, kg) with index weights of 128, -53.0, 1.92, 25.3, 0.08, -3.52, -2.39, -0.72, respectively. Characteristics consistently included in an index, in order of importance, were MS, WWM, yearling weight, and BWT.

DEDICATION

To my daughter and son, Anapaula and Carlos Alberto

To my father and to the memory of my mother

To my brothers and sisters

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INTRODUCTION

Effects of milk production level of beef cows on the biological and economic efficiency are not well defined. Increasing milk production increases the weaning weight and carcass weight (Clutter and Nielsen, 1987; Freking and Marshall, 1992; Miller et al., 1999) but increases maintenance requirement as well (Montaño-Bermudez et al., 1990a). Conflicting effects of milk yield on biological and economic efficiency of beef cattle have been reported in the literature. Greater biological efficiency to weaning, and greater profit to slaughter for cows with greater milk production were reported by Miller et al. (1999) and Freking and Marshall (1992), respectively. However, Van Oijen et al. (1993) found greater biological and economic efficiency at weaning and slaughter in low milk production cows. Greater output in cows with higher milk production is offset by higher feed cost (Van Oijen et al., 1993), and lower weaning weight in offspring of cows with low milk production is countered by compensatory growth postweaning (Clutter and Nielsen, 1987). The economic effects of milk production level are associated with the relationship between preweaning and postweaning feed cost (Notter et al., 1979; Bourdon and Brinks, 1987), where at higher postweaning feed cost, high milk yield cows are more efficient, and vice versa (Freking and Marshall, 1992).

Economic analyses for calf-fed vs. yearling systems have been reported with contradictory results. Lower weaning and slaughter breakeven prices for yearling systems than for calf-fed systems were reported for Anderson et al. (2005). However, greater profit in a calf-fed system than in a yearling system was reported by Small et al. (2009).

The foundation paper establishing the selection index was written by Hazel (1943), which gave the principles of developing and using a selection index, allowing maximum genetic progress. The breeding objective should be maximizing the aggregate value of an animal, which

is the breeding value weighted by the relative economic values (REV) of the economically relevant traits (ERT). Garrick and Golden (2009) suggested that to develop a breeding objective, breeders should define the goal of the breeding program, identify traits that influence the goal, determine the economic importance of each trait in the goal, and quantify the value and cost to measure the traits. Similarly, MacNeil (2008) suggested that for implementing a breeding objective, one develops a bio-economic simulation model that describes the production system defined, estimate the REV for each ERT using partial derivatives of profit with respect to each trait, develop a genetic covariance matrix for ERT and traits for which EPD are available, estimate the weights for the EPD produced in national cattle evaluation, and then apply the relative weights to the EPD to evaluate individuals for economic merit.

Quantifying the importance of each trait in the breeding objective is useful to not only select animals with greater rank but also to determine the priority in relation to research and to develop systems for collecting information and evaluating these traits (Garrick and Golden, 2009). The REV for a trait differs with the goal of the breeding objective and subsequent market, and the value that can be realized in those markets (Melton, 1995). Melton (1995) found greater REV for maternal and reproductive traits and lower REV for retail product for cow-calf producers than for the entire beef industry. MacNeil and Newman (1994), considering the Canadian beef industry, found that cow weight, female fertility, and maternal effect on weaning weight had economic importance in maternal lines but not in sire lines; growth had greater REV for finishing than in backgrounding.

Garrick and Golden (2009) reported that enterprises of beef breeding cows can be classified into the bull-breeding and bull-buying sectors, where the bull-breeding sector represents less than 5% cows. Thus, most of the beef supply is produced by offspring of cows in

the bull-buying herds. Improvement of efficiency of beef production can be achieved by changing the performance of cows in these bull-buying herds. With few exceptions, current information systems for beef cattle genetic evaluation are administered by breed associations, and provide predictions of performance for individual traits, presented as single trait or economic index EPD (Garrick and Golden, 2009). Harris (1970) suggested that the segmentation of the industries with marketing arrangements that do not sufficiently lead to accurate payment for value is seen to be a serious detriment to effective animal breeding. Thus, cattleman should increase final market product rather than sell commodities to increase their profitability (Melton, 1995).

Studies have identified the necessity for analyzing the production system to define the bio-economic objective (MacNeil et al., 1988), based on the ERT that affect profit. Income and cost should be based on future conditions (Garrick and Golden, 2009; Dickerson et al., 1974; Harris, 1970). Yielding reliable multiple-trait selection (MacNeil et al., 2005b) and the ability to rely on long-term of economic and production data (MacNeil and Newman, 1994) are critical to enable the evaluation of a breeding objective for the entire industry where the cattleman must increase market product rather than sell commodities (Melton, 1995).

The objective of this study was to develop a breeding objective for improving efficiency of U.S. beef production. To achieve this objective, this study was separate into two parts. Part I used 10-yr prices and performance from historical data in a deterministic simulation model to analyze the effect of milk level on breakeven and profit to weaning, and in yearling system and calf-fed systems, and to evaluate the biological and economic efficiency to weaning and to slaughter. Part II used a stochastic simulation model to estimate the relative economic value for

eleven traits for a general-purpose beef production system, based on long-term economic conditions, and to estimate the selection index economic weights for traits having EPD available.

LITERATURE REVIEW

Milk production

Milk production has a large economic effect in the beef industry, and is associated with maternal effect in the preweaning gain of the calf, commonly referred to as milk EPD, and includes costs associated with energy both for lactation and for maintenance (NRC, 1996; BIF, 2010). Milk production is directly related to the metabolic activity of the tissues that must be maintained, thus increases in milk yield also increase the feed cost to be considered in a breeding program (BIF, 2010).

Milk production in beef cattle depends on genetic potential, age, and breed of the cow; milk consumption of the calf; and other environmental conditions (NRC, 1996). The NRC (1996), based on various studies involving different purebred and crossbred cows, reported performance of milk production, milk composition, and cow age effects on milk production for beef cattle. According to these studies analyzed for the NRC (1996), peak of lactation was reached at 8.5 wk after parturition. Milk production for 205-d period totaling 701, 1122, 1543, and 1963 kg had estimated peak yield of 5, 8, 11, and 14 kg, respectively; phenotypic mean (SD) milk composition was 4.03% (1.24 %) for milk fat, 3.38 % (0.27 %) for milk protein, 8.31% (1.38 %) for non-fat solids, and 4.75% (0.91%) for lactose. The milk production was 26 and 12 % less for cows of 2 and 3 yr, respectively, than for cows at 4 yr or older.

Levels of production and milk composition have been established as factors affecting maintenance requirements for cows. NRC (1996) predicted maintenance requirements based on

breed, body weight, and peak of milk production (kg). They reported that maintenance requirement was 20% greater in Simmental (12 kg), and Holstein (15 kg); 10 % lower in Brahman (8.0 kg), Nellore (7 kg), and Sahiwal (8 kg); and 5 % lower in Brangus (8 kg), and Braford (7 kg) compared to Angus (8 kg), Charolais (9 kg), Limousin (9 kg), Shorthorn (8.5 kg of milk at peak), and other breeds with medium milk production. Burke et al. (2010) reported the effect of milk production and milk fat content in the preweaning gain of calves in Angus and Romosinuano. They found that calves from Angus cows had the same preweaning gain as calves from Romosinuano cows; thus the higher milk production of Angus cows was compensated by higher milk fat content of Romosinuano cows. In general, the maintenance requirement increases with the level of production (NRC, 1996), the regression of milk fat production on calf preweaning gain explained 25.8% of variation (Burke et al., 2010), and the efficiency of metabolizable energy (ME) utilization for milk production are not significantly different among breeds (NRC, 1996).

Means ± SE (NR stands for non reported values) for milk yield of 9.5 ± NR $kg.d^{-1}$, 6.65 ± 0.34 $kg.d^{-1}$ and 6.13 ± 0.33 $kg.d^{-1}$, and 1434 ± 61 $kg.205d^{-1}$ and 1084 ± 28 $kg.205^{-d}$ were reported by MacNeil and Mott (2006) for Line 1 Hereford cattle, by Brown and Brown (2002) for Angus and Brahman, and by Mallinckrodt et al. (1993) for Simmental and Polled Hereford, respectively. Estimates of heritability for milk production of 0.25 ± 0.06, 0.35 ± 0.18, and 0.12 ± NR were reported for MacNeil and Mott (2006) for in Line1 Hereford, for Miller and Wilson (1999) for multibreed, and by Meyer et al. (1994) for Hereford, respectively.

Milk production in beef cattle is not always easy to measure in field conditions, and usually the maternal effect on preweaning gain is used as an indicator trait to select for milk production in beef cattle (NRC, 1996). Estimates of maternal additive genetic variance for

weaning weight of 168 ± 4.8 kg^2 and 93.4 ± 14.8 kg^2 were reported in Angus (Costa et al., 2011) and in multiple breeds in USA (De Mattos et al., 2000). High phenotypic correlation (0.9855) between preweaning gain and weaning weight was reported by Koch et al. (2004). Estimates of maternal additive genetic variance for preweaning gain of 121.7 ± NR kg^2, 161.2 ± 9.3 kg^2 , and 88.5 ± NR kg^2, were reported in Line 1 Hereford (MacNeil and Mott, 2006), in 10 purebreds and their crosses (Roso et al., 2005), and in Angus (Kaps et al., 1999), respectively. Koch et al. (2004) reported that maternal effects are more important for birth weight and weaning weight, whereas for postweaning growth and carcass traits, the direct effect is more important than maternal effect. Costa et al. (2011) reported that additive maternal genetic effect on offspring body weight is small after weaning, decreasing with the age of the animal.

Estimates of heritability for maternal weaning weight of 0.25 ± 0.01, 0.19 ± 0.02, 0.16 ± 0.03, and 0.17 ± NR, were reported in Angus cattle (Costa et al., 2011), in mixed breeds of cattle (Splan et al., 2002), in Hereford (De Mattos et al., 2000), and in Angus (Kaps et al., 1999), respectively. Estimates of maternal heritability for preweaning gain of 0.25 ± 0.04, and 0.20 ± 0.00 were reported by MacNeil and Mott (2006) for Line 1 Hereford, and by Roso et al. (2005) for 10 breeds and their crosses, respectively.

Estimates of the genetic correlation between milk production and maternal preweaning gain of 0.80 ± 0.08, 0.76 ± 0.18, and 0.80 ± NR were reported by MacNeil and Mott (2006) for Line 1 Hereford, by Miller and Wilton (1999) for multibreed, and by Meyer et al. (1994) for Hereford and Wokalups, respectively. The high correlation between milk production and maternal preweaning gain suggests that breeding value for preweaning gain is a good indicator of breeding value for milk production (MacNeil and Mott, 2006; Miller and Wilton, 1999). MacNeil and Mott (2006) estimated that selection for maternal preweaning gain to change the

milk production would be, on average, 82 ± 14% as effective as direct selection for milk production.

Estimates of genetic correlations between maternal additive genetic effect for weaning weight (WWT) with direct additive genetic effect for yearling weight (YWT), and mature weight (MWT) of -0.49 ± 0.03 and -0.35 ± 0.04, respectively, was reported for Costa et al. (2011) for Angus. Estimates of genetic correlation between maternal additive genetic effect for WWT with direct additive genetic effects for WWT and MWT of –0.53 and -0.45, respectively, was reported for Kaps et al. (1999) for Angus. Estimates of genetic correlations between maternal weaning weight and carcass traits were reported by Splan et al. (2002). They found positive correlations between maternal weaning weight with carcass weight (0.61), ribeye area (0.29), fat thickness (0.29), marbling score (0.28), and kidney, pelvic, and heart fat percentage (0.19). From these data, based on the genetic correlation for maternal weaning weight, selection for milk or the maternal effect on weaning weight would not have significant effect on carcass traits, except on carcass weight (Splan et al., 2002).

Fiss and Wilton (1993) analyzed the phenotypic relationship between milk production and reproductive, growth, carcass traits in three breeding systems in beef cattle in Canada. They found positive significant effect of milk production on ADG in feedlot and high linear effect of milk production on calf preweaning gain. However, they did not find significant relationships of milk production with gestation length, birth weight, carcass weight, fat thickness, marbling, ribeye area, or feed intake during the feedlot period.

The effect of milk production level of cows on beef efficiency has been studied with different conclusions among studies. Milk yield positively influences preweaning weight, carcass

weight, and average energy intake during lactation, but not postweaning (Miller et al., 1999; MacNeil and Mott, 2006; Brown and Brown, 2002). Milk yield is also directly associated with maintenance requirements, which accounts for about 70 to 75% of energy required for beef production (Montaño-Bermudez et al., 1990a). The increment of energy for maintenance in high milk yield cows may be related in part to the increase in size of the lung and liver (Ferrell and Jerkins, 1985). Miller et al. (1999) evaluated the effect of milk yield on the biological efficiency and gross margin in three breeding systems of beef cattle in Canada. From birth to weaning, they found that cows with high levels of milk production had greater biological efficiency than cows with low milk yields for breeding systems where the milk productions were, on average, 1,066 ± 284 and 1,643 ± 417 $kg.200d^{-1}$. However, for breeding systems where the milk production was, on average, 1,854 ± 522 $kg.200d^{-1}$, there was potential positive association between milk yield and biological efficiency. From birth to slaughter they found that cows with high levels of production showed higher gross margin and potentially greater biological efficiency for all the breeding systems studied. The result found by Miller et al. (1999) are contrary to that reported by Van Oijen et al. (1993), in three breeds with different levels of production in USA, who found that cows with lower milk production were both more biologically and economically efficient than cows with high milk production both from birth to weaning and from birth to slaughter. This difference may be explained in part to the breed difference, feed cost, and the ratio of feed cost between feedlot and cow-calf sectors. Increasing milk production will increase the efficiency of beef production if the price of feedlot feed increases (Notter et al., 1979) and the ratio of feed cost feedlot:cow-calf increases (Bourdon and Brinks,1987).

Freking and Marshall (1992), studied crossbred Angus-Hereford, Simmental-Hereford, and Tarentaise-Hereford, and found that milk production was positively associated with the feed

energy intake during lactation and showed linear and quadratic effects on the efficiency of the energy utilization of calves for preweaning gain. However, this efficiency varied with the level of production, where the cows with lower level of milk production were more efficient. The optimum level of milk production was derived by Freking and Marchall (1992) for heifers at 6.66 $kg.d^{-1}$. Level of milk production did not show an association with the body weight and reproductive performance of the cow. In a simulation study, Stokes et al. (1986) analyzed the economic effects of cow size and milking level on production in cow-calf operations using 1972 to 1981 prices, in Texas. They found that calves from dams with high milk production were fatter and received lower price due to the waste-fat discount, and the highest return to land was found in lower milk production and greater cow size.

Literature reports are consistent in the strong relationship between milk yield and preweaning ADG. Brown and Brown (2002), in purebred Angus and Brahman and their respective crosses, reported that in cows with lower milk production there was stronger relationship between milk yield and preweaning ADG than in cows with high milk yield. Similarly, greater regression coefficient for preweaning ADG on milk production, in cows with low milk yield than in high milk yield, was reported by Mallinckrodt et al. (1993) comparing Hereford and Simmental. The same was true for results reported by Fiss and Wilton (1993) comparing different systems of production and Clutter and Nielsen (1987) comparing 3 breeds with different levels of milk production. Conversely, lower regression coefficient for preweaning ADG on yield milk was reported in cows with high yield milk than in cows with low milk production by Marston et al. (1992) comparing Simmental and Angus cattle. On the other hand, Miller et al. (1999), in different rotation systems, did not find differences in regression coefficients for preweaning ADG on yield milk between the systems, even though there was

difference in milk production among them. In general, there is more agreement in the literature that calves from cows with lower milk production use the available milk more efficiently (Clutter and Nielsen, 1987), and this higher efficiency can be explained in part, because calves from dams with low milk yield utilize most of the milk produced, whereas calves from dam with high milk yield can not utilize the excess milk produced by the dam (McMorris and Wilton, 1986). Additionally, Brown and Brown (2002) and Marston et al. (1992) reported a higher positive relationship between fat and protein content in milk with weaning weight and preweaning ADG, respectively.

Diaz et al. (1992) evaluated the relationship between milk EPD of Polled Hereford sires and the actual milk production of their crossbred daughters, Polled Hereford x Angus. A significant effect of milk production on weaning weight of calf was reported. Sire’s milk EPD was associated linearly and positively with daughter’s actual milk production. Thus, milk EPD can be used as selection criterion to change milk production in beef cattle.

In conclusion, milk yield, fat and protein in milk have been shown to be associated with preweaning ADG. Due to difficulty for measuring milk production directly in field conditions, and the high phenotypic correlation between milk production in cows and preweaning gain of calf, selection for milk production should be based on the breeding value of maternal preweaning gain as compared to the direct selection for milk itself. Finally, to define the direction of selection for milk production, both the effect on preweaning gain and on the energy cost required should be considered.

Heifer pregnancy

Heifer pregnancy (HP) is frequently included in a breeding objective and is an indicator of sexual maturity in cattle (Cammack et al., 2009). Heifer pregnancy is a binary trait (1=pregnancy; 0= not pregnant) measured as probability of successful conception in heifers exposed (BIF, 2010). Estimated heritability for heifer pregnancy ranged from 0.14 to 0.27, and phenotypic means estimated for heifer pregnancy range from 0.74 to 0.80 (McAllister et al., 2011; Evans et al., 1999; and Toelle and Robinson, 1985; Doyle et al., 2000). Earlier pregnancy in heifers has been associated with greater lifetime production (Lesmeister et al., 1973). Calving heifers at 2 yr of age and maintaining cows in the herd producing calves should be the goal to increase the economic efficiency in the operation, due to the high cost of replacement females (Cammack et al., 2009). The heifer pregnancy increases in longer breeding season, but the average weaning weight decreases at a constant weaning date (Werth et al., 1991).

Genetic correlations of heifer pregnancy with scrotal circumference (SC), intramuscular fat percentage (IMF), and marbling score (MS) were reported in the literature. Estimate of genetic correlation between HP and SC range from 0.02 to 0.31. Toelle and Robinson (1985) reported moderate genetic correlation (0.31) between HP and SC. However in more recent papers, almost no genetic correlation between these two traits was found; McAllister et al. (2011) and Evans et al. (1999) reported genetic correlation between HP and SC of 0.05 and 0.02, respectively. The nonlinear relationship between HP and SC could explain the low genetic correlation between these traits (Evans et al., 1999). Genetic correlations between HP with IMF (0.13 ± 0.09) and MS (0.1 ± 0.15) were reported by McAllister et al. (2011). They suggested that even though there is a low correlation between HP and IMF and almost zero correlation between HP and SC, the use of IMF and SC would help to increase the accuracy in the estimation of EPD

value for HP. On the other hand, the correlation between HP and MS (0.1 ± 0.15) could be neglected because of the large standard error.

In general, the low genetic correlations of HP with SC, IMF and MS, suggest that selection based on heifer pregnancy would be more efficient to increase the percentage of female calving at 2 yr than selection based on SC as indicator trait. However the low heritability of HP and the small genetic correlation between HP and SC necessitate developing methodologies and unconventional indicators for increasing accuracy of HP genetic evaluation (McAllister et al., 2011; Evans et al., 1999).

Gestation length

Gestation length (GL) is calculated as the number of days between conception and subsequent calving date (BIF, 2010). Gestation length is affected by the sire and dam breed, and sex of calf (Casas et al., 2011). Literature reported mean estimates ranging from 281 d in Red Angus, Angus, and Hereford female calves (Bourdon and Brink, 1982) to 292 d in Brahman and Boran calves (Casas et al., 2011). Gestation length has been treated as dam trait. Therefore, the contribution to the expression of GL is maternal effect and half of direct effect. Thus, the parameters estimated should be interpreted considering not only for direct effect and maternal effect, but also for possible covariance of direct and maternal effect (MacNeil et al., 1984).

Casas et al. (2011) compared the GL of animals derived from British, Brahman, Boran, Tuli, and Belgium Blue sires. They reported that animals with Brahman, Boran, and Tuli had longer gestation than animals with British and Belgium Blue (292, 292, and 290 d vs. 285 and 285 d, respectively). Casas et al. (2011) reported that progeny of Hereford dams had longer GL than progeny from Angus dams (290 d vs. 289 d). Wulf et al. (1996) reported longer GL in

Limousin than in Charolais (287 d vs. 283 d). Casas et al., (2011) compared their study with previous studies and concluded that GL has not changed in Brahman cattle in more than 30 yr. However, Bennett et al. (2008) found that GL decreased by 2 d on average in 7 breeds selected to reduce calving difficulty in 2-yr-old heifers. This indicates that selection can change GL in multiple breeds (Casas et al., 2011).

Male calves have a longer GL than female calves. Casas et al. (2011) reported a difference of 1 d between male calves (289 d) and female calves (288 d). Similarly, Gregory et al. (1995b,c) reported GL of 288 d in male calves and 287 d in female calves in 9 purebreds and 3 composite breeds of cattle. Bourdon and Brink (1982) reported gestation length of 282.9 d in male calves and 281.4 d in female calves in Red Angus, Angus, and Hereford cattle. Interaction of breed and sex has been reported for GL. Casas et al. (2011) found that female offspring of Brahman sires had 3 d shorter GL than male offspring. However, female calves from Tuli sires showed no difference in GL compared to male calves.

Moderate to high heritability for GL was reported in the literature ranging from 0.30 ± 0.18 in crossbreds (MacNeil et al., 1984) to 0.67 ± 0.24 in Charolais and Limousin (Wulf et al., 1996). Bourdon and Brink (1982) reported heritability of GL of 0.36 ± 0.10 and 0.37 ± 0.11 for male and female calves, respectively, in Red Angus, Angus, and Hereford. Gregory et al. (1995b) reported heritability of GL of 0.46 ± 0.06, 0.44 ± 0.09, and 0.44 ± 0.10 in male calves from 9 purebreds and 3 composite, 9 purebreds, and 3 composite breeds of cattle, respectively. Gregory et al. (1995c) reported heritability of GL of 0.45 ± 0.06, 0.34 ± 0.08, and 0.58 ± 0.10 in female calves from 9 purebreds and 3 composite, 9 purebreds, and 3 composite breeds of cattle, respectively.

Medium to high genetic correlations of GL with birth weight (BWT) and calving difficulty percentage (CD) are reported in the literature. Genetic correlation of 0.63 ±0.06; 0.21 ± 0.1; and 0.25 ±0.26 and 0.22±0.24 between GL and birth weight were reported by Cundiff et al. (1986) in 12 breeds, by Gregory et al. (1995b) in 9 purebreds and 3 composite cattle, and by Bourdon and Brinks (1982) in Red Angus, Angus, and Hereford, respectively. Genetic correlations of 0.56 ± 0.07 and 0.54 ± 0.26 between GL and CD were reported for Cundiff et al. (1986) in 12 breeds, and by Gregory et al. (1995b) for 9 purebreds and 3 composite breeds of cattle, respectively.

Medium to low genetic correlations were reported for GL with weaning weight, preweaning ADG, scrotal circumference, and marbling score, and from low to not different from zero correlations were reported for gestation length with yearling weight, fat thickness carcass, postweaning average daily gain, and carcass weight (MacNeil et al., 1984; Bourdon and Brink, 1982; Gregory et al., 1995b,c).

In conclusion, the moderate heritability of GL and the relatively high correlation between gestation length and percentage of calving difficulty and BWT, and low genetic correlation of gestation length with postweaning average daily gain (ADG) and carcass trait suggest that selection to reduce GL should reduce calving difficulty (Gregory et al., 1995b), without decreasing postweaning average daily gain or affecting carcass trait.

Postweaning gain

Postweaning average daily gain (ADG) is measured as average daily body weight change after weaning over a period of time of an animal on a feed test (BIF, 2010). Phenotypic means ± SE (or SD in ()) for ADG of 1.49 ± 0.01 $kg.d^{-1}$, 1.65 ± 0.01 $kg.d^{-1}$, 1.33 ± NR $kg.d^{-1}$, 1.59 (0.22)

kg.d^{-1}, and 1.49 ± NR kg.d^{-1} were reported in Angus and Simmental heifers and steers (Schneider et al., 2010), in Irish bulls (Crowley et al., 2010), in Angus bulls and heifers (MacNeil et al., 2011), in mixed steers (Rolfe et al., 2011), and in 7 breeds of steers (Cooper et al., 2010), respectively. Data suggest breed differences in ADG.

Estimates of heritability for ADG reported in the literature range from 0.21 ± 0.12 in Brangus heifers (Lancaster et al., 2009) to 0.64 ± 0.06 in Hereford bulls (Bourdon and Brinks, 1986). Rolfe et al. (2011) reported heritability for ADG of 0.26 ± 0.1 in mixed breeds of steers. MacNeil et al. (2011) reported heritability for postweaning BW gain (PGN) of 0.26 ± 0.04 in Angus cattle.

Strong to moderate genetic correlation between PGN and ADG with dry matter intake (DMI), standardized feed intake (SFI), and metabolizable energy intake (MEI) were found. Estimates of genetic correlation between ADG and DMI of 0.56 ± 0.22 and 0.56 ± 0.16 were reported by Lancaster et al. (2009) for Brangus heifers and by Rolfe et al. (2011) for mixed breeds of steers, respectively. High estimate of genetic correlation were reported between PGN and SFI (rg =0.55 ± 0.10; MacNeil et al., 2011, in Angus) and between ADG and MEI (rg = 0.73 ± 0.13; MacNeil, 1991, in crossbreed steers). Rolfe et al. (2011) reported strong genetic correlation between ADG and midpoint BW (r_g=0.86; MBW). Castro Bulle et al. (2007) reported that mixed breeds of steers selected for high growth (HG) had greater DMI (7.52 vs. 6.37 kg/d), G:F (0.176 vs. 0.133 kg/kg), gained fat (676 vs. 475 g/d), MEI (0.233 vs. 0.201 Mcal.kg.BW$^{0.75}$.d^{-1}), and retained energy (RE; 0.0711 vs. 0.0558 Mcal.kg BW$^{0.75}$.d^{-1}) than steers selected for low growth (LG). Animals selected for HG tended to gain more protein (100 vs. 72 g/d) than animals selected for LG. However, estimated net energy efficiency of gain (kcal/kcal)

and ME requirement for maintenance ($Mcal.kg^{-075}.d^{-1}$) was similar in HG and LG, averaging 0.62 and 0.114, respectively.

Moderate genetic correlations between PGN with the ratio Gain:feed (G:F), feed conversion ratio (FCR), and weaning weight (WWT) were found. Rolfe et al. (2011) reported estimates of genetic correlation of 0.31±0.25 between ADG and G:F for mixed breeds of steers. Strong and moderate negative genetic correlation between ADG and FCR were reported in the literature and include -0.53±0.10 in Irish bulls (Crowley et al., 2010), and -0.36 ±0.31 in Brangus heifers (Lancaster et al., 2009). MacNeil et al. (2011) reported medium genetic correlation between PGN and WWT in Angus (r_g= 0.40 ± 0.07). The negative correlation between ADG and FCR suggest that selection for faster growing animals will decrease FCR. However there should be caution with the unfavorable effect on the mature BW and additional energy requirement (Lancaster et al., 2009).

Low and not different from zero genetic correlations were reported between postweaning gain with residual feed intake (RFI), kidney, pelvic and heart fat (KPH), marbling score (MS), and dressing percentage (DRE). Rolfe et al. (2011) reported estimates of genetic correlation between RFI with ADG and postweaning gain of -0.15 ± 0.25 and -0.02±0.24, respectively, in mixed breeds of steers. Crowley et al. (2010) reported no difference from zero correlation between ADG and RFI in Irish bulls (r_g = 0.01±0.13). Veseth et al. (1993) reported low correlation between ADG and KPH (0.15). Castro Bulle et al. (2007) reported not difference in RFI, KPH, MS, and dressing percentage (DRE) between mixed breed steers selected for high growth and low growth.

In conclusion, postweaning growth has moderate heritability and selection in favor of increasing growth will increase the DM, MEI, RE, and G:F, without affecting RFI, DRE, KPH, net energy efficiency of gain, and ME requirement for maintenance. Additionally Castro Bulle et al. (2007) concluded that animals with low RFI have low ME requirement for maintenance and lower rate of muscle protein degradation, and animals with low RFI do not affect BW gain but eat less fed showing then to be more efficient in feed utilization. Thus, selection based on increasing growth and decreasing feed intake is the most promising to yield economic results, and index including gain and RFI gave the best economic result (Rolfe et al., 2011).

Calving difficulty

Calving difficulty (CD) or dystocia is widely identified as a factor that negatively affects the economics of the beef industry (Colburn et al., 1997; Laster et al., 1973), and may arise from genetic and several environmental causes (Berger et al., 1992). Dystocia can be measured in categories on a scale of 1 to 5, where the lowest (1) indicates no assistance required at calving and the highest (5) considerable assistance or caesarian is needed (BIF, 2010). Causes of dystocia are contributed to the sire, the dam, and the calf, and the effects of dystocia are seen in calf losses, death of dams, and reduction of subsequent reproductive performance.

Cow age is identified as a main dam factor for the presence of dystocia, where heifers have greater percentage of assisted birth than older cows (Berger et al., 1992). Laster et al. (1973), in Hereford and Angus cows, reported 36.03%, and 44.62% more dystocia in 2-yr-old than in 3-yr-old, and in 4 and 5-yr-old cows, respectively. The main reason for this difference in CD incidence may be explained by the smaller pelvic area in heifers than in older cows (Meijering, 1984; Bellows, 1971). Bennett and Gregory (2001b), in 9 purebreds and 3 composite

breeds of cattle, and Bellows et al. (1971), in Angus, reported negative correlation between pelvic width and calving difficulty score.

Casas et al. (2011) analyzed sire and dam breed effect on calving difficulty. They found that offspring from Brahman and Belgian Blue sires needed more assistance at calving than offspring from British breeds, Boran, and Tuli sires (9.1% and 7 % vs. 2.5%, 4.4%, and 2.7%, respectively); and offspring from Hereford dams needed more assistance at calving than offspring from Angus and MARC III dams (8.1% vs. 4.3% and 3.1%, respectively). Similarly, Laster et al. (1973) reported greater incidence of calving difficulty in Hereford cows than in Angus cows bred to the same breed of bulls (34.78 vs. 27.02 %). Brandt et al. (2010) reported greater calving difficulty in cows with purebred calves compared with those with crossbred calves. They reported 7.7, 12.4, 3.1, and 2.0 % of assisted calving for German Angus, Simmental, German Angus x Simmental, and Simmental x German Angus calves, respectively.

Calf birth weight and size of calf are the most important factors related to the calf in the incidence of dystocia. Laster et al. (1973) reported that calving difficulty increased 2.3 % for each kilogram increase in birth weight. Similarly, Casas et al. (2011) reported that calves from Brahman sires were the heaviest and had most difficulty at calving than calves from British, Belgian Blue, Boran, and Tuli sires. Birth weight is highly correlated with CD (0.57), and explains 36.6% of variation in traction pressure, indicating that calf weight is the primary calf factor affecting dystocia in heifers (Colburn et al., 1997).

Sex of calf and sex of calf x dam breed interactions are important contributors to CD. Greater calving difficulty was reported for male calves than for female calves with values of 7.2 vs. 3.12%; 28 vs. 7%; 64.6 vs. 30.3%; and 66.9 vs. 43.4 %, by Casas et al. (2011), for offspring

of British, Brahman, Boram Tuli, and Belgian Blue breed sires; by Laster et al. (1973) for several breeds; by Bellows et al. (1971) for Angus and Hereford cross calves; and by Bennett and Gregory (2001a) for 2-yr-old purebred and composite heifers, respectively. Similarly, Berger et al. (1992) reported 1.45 times greater ratio of odds for unassisted vs. assisted births for female than for male calves, and increase in a rate of 1.24 per month from 22 to 29 mo at a constant birth weight, and decrease in a rate of 0.81/ kg for birth weights from 20 to 40 kg at a constant age. Sex of calf and dam breed interaction was reported by Casas et al. (2011) and Bellows et al. (1971). Casas et al. (2011) reported greater calving difficulty in male calves than female calves from Hereford dams, but they did find sex to affect calving difficulty among offspring from Angus and Marc III cows. Similarly, Bellows et al. (1971) reported 40.2% and 28.6% more assistance at calving in male calves than in female calves for Angus x Hereford calves and Hereford x Angus calves, respectively.

Gestation length was reported as the second most important factor, after birth weight, on calving difficulty direct. Bellows et al. (1971) reported a positive correlation between birth weight and gestation length, and weight gains of cows during the first half of gestation in Hereford and Angus. Other causes associated with CD like weak labor, uterine torsion or insufficient cervical dilation were observed more in older cows, and they can cause severe dystocia.

Costs directly associated with dystocia include: loss of calf, death of dam, and extra labor required from the producer and veterinary assistance. Half of these costs are associated with the loss of calf, and 40 to 60% of losses in calf at birth or during the first 24 h are associated with CD (Meijering, 1984). Laster and Gregory (1973) reported, for all types of parturition, 8.6% overall calf mortality at birth or within 24 h after birth, and this mortality was greater in calves

experiencing CD (20.4%) than in those not experiencing CD (5%), and higher incidence in 2-yr olds (15%) than in 3-yr-old (7.5%) and in cows 4 yr and older (5.6%). However, cow age had no significant influence on calf mortality in parturitions not involving dystocia. Menissier and Foulley (1979), reported by Berger et al. (1992), showed a nonlinear effect of age at first calving on mortality of calves in Charolais heifers. This relationship may be explained because extremely young heifers produced calves too weak to survive, and extremely old heifers produced calves too heavy, thereby increasing the frequency of dystocia and perinatal mortality due to traumatic births. Berger et al. (1992) reported greater perinatal mortality in younger heifers than in later ages. However, they indicated that postcalving mortality may not be associated with calving difficulty. Additionally, Berger et al. (1992) reported that birth weight (BWT) had a nonlinear relationship with survival to 24 h, where survival was greater for 26 to 35 kg BWT and lowest at BWT >35 kg. Losses in calves experiencing CD are greater for males (22.4 %) than females (16%). But there is no difference in losses based on sex for calves not experiencing CD (Laster and Gregory, 1973). Berger et al. (1992) reported the odds of a calf weaned alive vs. dead preweaning were 1.24 times greater for female calves than for males and 2.06 times greater in cows than in heifers. The relative odds of survival to 24 h were 1.47 times greater for females than for males and 2.66 times greater in cows than in heifers.

Calving difficulty and breed interaction were reported for perinatal survival in beef cattle. Costa et al. (2011) found that Brahman and Hereford sires presented higher calving difficulty and lower perinatal survival compared with British, Boran, and Tuli sires and Angus dams. Similarly, Laster and Gregory (1973), evaluating 18 sire breeds using Hereford and Angus as a dams, found calf genotype effects on calf mortality in calves born with assisted parturitions, but no effect in calves born unassisted. They found ranges of calf losses of 6.6 and 28.8% in

dystocia parturitions for Jersey x Angus and for straightbred Hereford, respectively. Additionally, Laster and Gregory (1973) reported 11.6% greater perinatal mortality for the average of straightbred Hereford and Angus calves than for the average Hereford x Angus and Angus x Hereford calves in calving assisted, but no difference was found in unassisted parturitions between these breed groups. These results indicate that crossbred calves can tolerate more stress associated with difficult birth than straightbreds, and indicate direct association of dystocia and perinatal mortality.

Reproductive performance decreases in cows experiencing calving difficulty (Cammack et al., 2009). Laster et al. (1973), in all ages of cows, reported 14.4% lower percentage of cows detected in estrus during the 45-d AI period in cows requiring assistance at calving than in those not requiring assistance; conception rate to AI at first breeding and total breeding season were 53.6 and 69.4% in cows experiencing dystocia and 69.2 and 85.3% in those not experiencing dystocia, respectively. The average subsequent calving date was 5.8 d later in cows experiencing dystocia than in those with no dystocia. However, Colburn et al. (1997) reported no difference among CD on percentage of rebreeding pregnancy. These results are in disagreement with those of Laster et al. (1973), who found 6.1 % lower conception rate in cows experiencing dystocia than cow with no dystocia. Meijering (1984) reported the effect of dystocia on non-return rate after first insemination depends on degree of difficulty and varies from 5 to 15% when calving was assisted by moderate traction up to 25 to 45% after caesareans.

Heritability of CD percentage ranged from 0.11± 0.05 (Splan et al., 1998) to 0.42 ± 0.08 (Cundiff et al., 1986). Additionally, heritability of CD percentage of 0.22 ± 0.18, 0.31 ± 0.09, and 0.26 ± 0.09 were reported for MacNeil et al. (1984), Gregory et al. (1995b), and Gregory et al. (1995c), respectively. Direct genetic correlation between calving difficulty and birth weight

was greater than maternal genetic correlation between these traits (0.81 vs. 0.34). This high correlation between calving difficulty and birth weight present a challenge to reduce calving difficulty without decreasing birth weight as well (Bennett and Gregory, 2001a).

Bennett and Gregory (2001b) working with 2-yr-old heifers in 9 purebreds and 3 composite breed populations, found that direct genetic effect for longer gestation length was moderately and significantly correlated with 2-yr-old calving difficulty (0.31) and birth weight (0.36), but the genetic correlation declines for 200-d weight (0.16) and postweaning gain (0.09). Predicted genetic change suggests that the most accurate selection criteria for heifer calving difficulty are calving difficulty score and birth weight. They found that gestation length was the third most effective selection criterion for changing calving difficulty score but results in less than half the change predicted for birth weight or calving difficulty score.

Splan et al. (1998) working in 2-yr-old heifers in 21 purebred and 3 composite breed populations for calving difficulty measured on a binomial scale (0= no assistance, 1= assistance). reported that CD had low positive genetic correlation with retail product percentage (0.18), negative genetic correlation with carcass weight (-0.17); fat percentage (-0.23); adjusted fat thickness (-0.14); and kidney, pelvic, and hear fat (-0.29), and negative genetic correlation close to zero with ribeye area (-0.04) and marbling score (-0.09).

In general, there is potential opportunity for reducing CD in calves born to 2-yr-old heifers without reducing yearling weight, with little effect in postweaning ADG, age at puberty, scrotal circumference, and retail product percentage. Correlation of calving difficulty and carcass traits has been shown to be generally low to moderate, and in some cases almost no association was found.

Mature weight

Mature weight (MWT) is associated with maintenance requirements, reproduction, and other physiological traits, has economic impact in beef production and should be considered in breeding programs (Costa et al., 2011). Costa et al. (2011) reported that variances for additive genetic effect in Angus cows are stable at 4 and 5 yr of age (4 yr = 1406 ± 80.4 kg^2, 5 yr =1403 ± 66.9 kg^2) after greater increases from weaning to 3 yr of age (at weaning = 298 ± 7.18 kg^2, 3 yr =1221 ± 65.8 kg^2). Similar results had been reported for other breeds adapted to temperate environments, but not for tropical breeds (Costa et al., 2011). Mean (SD) for MWT of 614 kg (70 kg), 522 kg (69.30 kg), 593.9 kg (71 kg), and 592 kg (45.49 kg) were reported for 5-yr-old Angus cows (Costa et al., 2011), for average of 5-yr-old mixed breeds (Arango et al., 2002), for 5-yr-old Angus cows (Kaps et al., 1999), and for average of 9 purebreds and 3 composite breeds of cows (Gregory et al., 1995a), respectively.

Moderate to high heritability for mature weight was reported in the literature and ranged from 0.31 ± 0.10 for 9 purebreds of 4-yr-old cows (Gregory et al., 1995c) to 0.57 ± 0.05 in mixed breed 5-yr-old cows (Arango et al., 2002). Costa et al. (2011) reported direct heritability for body weight of 0.44 ± 0.11, 0.43 ± 0.07, 0.52 ± 0.01, 0.54 ± 0.01, 0.56 ± 0.01, and 0.50 ± 0.01 for 205 d, 1 yr, 2 yr, 3 yr, 4 yr, and 5 yr of age Angus cows, respectively. Nephawe et al. (2004) reported heritability of 0.52 ± 0.04 and 0.57 ± 0.04 for body weight and body weight adjusted for condition score (CS), respectively, for mixed breed cows at 4 yr of age. Arango et al. (2002) reported, in mixed breeds, average heritability of 0.49 ± 0.04 (ranged from 0.47 ± 0.08 for 7 yr of age to 0.58 ± 0.20 for 8 yr of age) and 0.54 ± 0.04 (ranged 0.51 ± 0.08 for 7 yr of age to 0.63 ± 0.05 for 5 yr of age) for mature weight and adjusted mature weight, respectively. Gregory et al. (1995c) reported similar heritability for MWT in 9 purebreds (ranged from 0.31 ±

0.1 to 0.58 ± 0.07) and in composite breed cows (ranged from 0.38 ± 0.09 to 0.52 ± 0.12) from the Germplasm Utilization Program at MARC, in cows from 2 yr to 5 yr of age. Thus, selection for mature weight should be the same response in purebred or composite populations (Gregory et al., 1995c).

Body weight adjusted by CS reduced the phenotypic variance and the fraction of the variance due to permanent environmental effect, and thus increased the fraction of variance due to additive genetic effect. However the adjustment of body weight by CS is questionable because CS is a subjective measure, not always recorded, and shows low heritability (0.16 ± 0.02) (Nephewe et al., 2004; Arango et al., 2002).

Moderate to high genetic correlations were reported between mature weight (MWT) with yearling weight (YWT), weaning weight (WWT), and carcass weight (CWT). Costa et al. (2011) reported, in Angus cows, direct genetic correlation between MWT and WWT in the range from 0.66 ± 0.06 (WWT and weight at 4 yr) to 0.72 ± 0.11 (WWT and weight at 2 yr), and between MWT and YWT in the range from 0.77 ± 0.08 (YWT and weight at 5 yr) to 0.85 ± 0.07 (YWT and weight at 2 yr), and direct genetic correlation among body weight (BW) of cows at 2 yr, 3 yr, 4 yr and 5 yr of age were greater than 0.95 for all of the cases. Similarly, Arango et al. (2002) reported high genetic correlation among cows from 2 yr to 8 yr of age ranged from 0.92 (between 2 yr and 5 yr of age) to 1.00 (between 5 yr and 6 yr of age) in mixed breeds cows. The previous result illustrates that body weights measured in cows after 2 yr are nearly the same trait.

High, moderate, low, and not different from zero genetic correlations were reported between MWT and carcass weight (CWT), longissimus muscle area (LMA, %), marbling (MARB, score), fat trim (FAT, %), retail product (RPP, %) and kidney, pelvic, and heart fat

(KPH, %). Nephewe et al. (2004) reported high correlation between MWT in 4-yr-old cows and mixed breed steers CWT (0.81 ± 0.06), medium genetic correlation of 0.34 ± 0.07 between MWT and LMA, low genetic negative correlation of -0.15 ± 0.08 between MW and MARB, and genetic correlation not different from zero of between MW with FAT, RPP, and KPH with values of -0.02 ± 0.08, -0.05 ± 0.07, and 0.00 ± 0.07, respectively.

In conclusion, based on the direct genetic correlations of BW among cows from 2 yr to 5 yr are greater than 0.92, body weight of 2 yr old cow should be used as an early measure of MWT (Costa et al., 2011; Arango et al., 2002). Additionally, due to the moderate to high heritability of mature weight and the genetic correlations reported with other traits, selection for reducing mature weight in cows can be effective, with correlated effects of reduction of steer carcass weight, slowly increasing marbling score, and not changing retail product, fat percentage, and kidney, pelvic, and heart fat. Finally, including a reduction of MWT in the breeding objective will help to reduce energy cost for maintenance. However, because the high correlation with steer carcass weight, and the possible effect in price discount due to light weight, postweaning BW gain should be include in the breeding objective as well.

Kidney, pelvic, and heart fat

Phenotypic means for kidney, pelvic, and heart fat (KPH, %) of 2.80 %, 2.78, 3.95 %, and 3.95 % were reported in purebreds and composite steers by Snowder et al. (2007), by Rios-Utrera et al. (2005), by Nephawe et al. (2004), and by Splan et al. (2002), respectively. Slightly low to high estimates of heritability for KPH were reported in the literature ranging from 0.23 ± 0.08 (Rios-Utrera et al., 2005; Snowder et al., 2007) to 0.65 ± 0.07 (Nephawe et al., 2004). Heritability for KPH of 0.60 ± 0.07 and 0.45 ± 0.19 were reported by Nephawe et al. (2004) in

composite steers and by Pariacote et al. (1998) in Shorthorn-cross steers, respectively. Lower heritability for KPH of 0.26 ± 0.07, and 0.37 ± 0.18 were reported by Snowder et al. (2007) in 9 pure breeds and 3 composite breeds of steers, and for Veseth et al. (1993) in Hereford bulls. Rios-Utrera et al. (2005) reported estimate of heritability for KPH when carcass was adjusted at age constant (0.37 ± 0.09), at weight constant (0.26 ± 0.08) and at fat thickness constant (0.23 ± 0.08) in 9 pure and 3 composites breeds of steers.

Moderate to high genetic correlation estimates were reported between KPH with birth weight, and fat thickness with values, respectively, of -0.59 ± 0.54 in Hereford bulls (Veseth et al., 1993), and 0.40 ± 0.18 in purebreds and composite steers (Rios-Utrera et al., 2005). Moderate genetic correlations of 0.33 ± 0.5 and 0.25 ± 0.32 were reported between KPH and weaning weight, and between KPH and yearling weight, respectively, both in Hereford bulls Veseth et al. (1993). Estimates of genetic correlation between KPH with carcass weight (CWT), MS, and REA were not clear in the literature. Positive estimated genetic correlations between KPH and CWT were reported by Rios-Utrera et al. (2005) in purebred and composite steers (r_g = 0.35 ± 0.21), and for Vaseth et al. (1993) in Hereford bulls (r_g = 0.21 ± 0.38). However, negative genetic correlation between KPH and CWT was reported by Pariocate et al. (1998) in Shorthorn-cross steers (r_g = -0.30 ± 0.29). High, medium, and no different from zero correlation between KPH and MS were reported by Veseth et al. (1993) in Hereford bulls (r_g = 0.59 ± 0.35), by Rios-Utrera et al. (2005) in purebred and composite steers (r_g = 0.27 ± 0.19), and by Pariacote et al. (1998) in steers crossed with Shorthorn (r_g = 0.1 ± 0.25), respectively. Moderate, negative, and no different from zero genetic correlation between KPH and REA were reported by Veseth et al. (1993) in Hereford bulls (r_g = 0.36 ± 0.33), by Pariacote et al. (1998) in Shorthorn-cross steers (r_g

= -0.31± 0.24), and by Rios-Utrera et al. (2005) in purebred and composite steers (r_g = -0.01 ± 0.23), respectively.

In conclusion, based on the moderate heritability and variance reported in the literature, selection for decreasing KPH will be possible. However, the genetic correlation between KPH and others traits reported in the literature should be analyzed with caution, due to both the differences in the values reported and the high standard error reported in the estimation.

Marbling score

Means ± SE or (SD) for MS of 5.42 ± 1.0, 5.59 ± 0.04, 6.05 (0.89), 6.02 (0.78), and 4.95 (0.71) were reported by McAllister et al. (2011) for Red Angus, by Schneider et al. (2010) for Angus and Simmental, by MacNeil et al. (2010) for Angus, by MacNeil and Northcutt (2008) for Angus, and by Snowder et al. (2007) for 9 pure breeds and 3 composite breeds of steers, respectively.

Estimates of heritability for MS reported in the literature range from 0.16 ± 0.10 in Charolais and Limousin (Wulf et al., 1996) to 0.88 ± 0.21 in Shorthorn-cross steers (Pariacote et al., 1998). In the last decade, moderate to slightly high heritability for MS were reported, including 0.35± 0.06 reported by McAllister et al. (2011) for Red Angus, 0.54 ± 0.05 reported by Crews et al. (2003) for Simmental heifers and steers, 0.45 ± 0.025 reported by MacNeil and Northcutt (2008) for Angus steers, and 0.47 ± 0.08 reported by Snowder et al. (2007) for 9 pure breeds and 4 composite breeds of steers. These values are in agreement to average heritability of 0.46 reported by Bertrand et al. (2001), based on 17 studies analyzed on carcass adjusted to age constant basis. Effect of slaughter endpoint was analyzed by Rios-Utrera et al. (2005) for 9 pure breeds and 3 composite breeds of steers They found higher estimate of heritability for MS in data

adjusted for age or carcass weight than in data adjusted for fat thickness, (0.40 ± 0.09 and 0.41 ± 0.09 vs 0.35 ± 0.09). In general, the estimates of heritability for MS are moderate to high making MS a potential trait for improvement in a selection program.

Carcass data for MS is sometimes limited, due to the high cost and difficulty of data collection. Ultrasound information, measured in yearling seedstock animals, has been studied to measure carcass traits (Bertrand et al., 2001). Intramuscular fat percentage (IMF) measured in live animals has been used to measure marbling score of carcass. McAllister et al. (2011) and MacNeil et al. (2010) have reported average IMF of 3.79 % for Red Angus and 3.91% for Angus bulls, respectively. Higher IMF has been reported in heifers than in bulls. MacNeil and Northcutt (2008) reported IMF of 4.46 ± 0.76 % for Angus heifers, and 3.73 ± 0.47 % for bull counterparts. Similarly, Crews et al. (2003), in Simmental, reported higher IMF in heifers than in bulls (3.40% vs. 2.68%).

Marginal lower heritability was reported for IMF than for MS. In the last decade heritability for IMF of 0.29 ± 0.01 was reported by McAllister et al. (2011) for Red Angus, 0.38 ± 0.02 and 0.52 ± 0.09 were reported by Crews et al. (2003) for Simmental bulls and heifers, respectively, 0.31 ± 0.03 was reported by MacNeil et al. (2010) for Angus bulls, 0.38 ± 0.02 and 0.40 ± 0.03, and 0.26 ± 0.086 was reported by MacNeil and Northcutt (2008) for Angus bulls, heifers and steers, respectively. In general, these values are in agreement with heritability for IMF reported by Bertrand et al. (2001) based on two studies (h^2 = 0.41).

Moderate to high genetic correlations were reported between carcass marbling score and ultrasound measured of IMF in live animals. High genetic correlations between MS and IMF were reported by McAllister et al. (2011) for Red Angus (r_g = 0.80 ±0.05), and by MacNeil and

Northcutt (2008) for Angus steers (r_g = 0.84 ± 0.116). Sex-specific genetic correlation between MS and IMF was analyzed by MacNeil and Northcutt (2008) and Crews et al. (2003). MacNeil and Northcutt (2008), in Angus, reported genetic correlation of 0.52 ± 0.06 and 0.66 ± 0.05 between MS with IMF measured in heifers, and IMF measured in bulls, respectively. In a study with Simmental, Crews et al. (2003) reported genetic correlation of 0.69 ± 0.13 between MS and IMF measured in heifers, and 0.74 ± 0.11 between MS and bulls IMF. The higher correlation between MS and bull IMF than MS and heifer IMF is mainly due to the difference in the additive genetic variance (MacNeil and Northcutt, 2008). Assuming that two traits with a genetic correlation ≥ 0.80 can be considered the same, from previous studies, IMF and MS are not the same trait (MacNeil and Northcutt, 2008). However, IMF can be an indicator trait of MS, and the use of IMF in predicting carcass marbling will increase the accuracy in the estimation of MS EPD, reduce the cost of progeny testing, and reduce generation interval (McAllister et al., 2011; MacNeil et al., 2010).

Differences among the correlation between MS and IMF measured in steers, bulls and heifers suggest that IMF measured in steers will have greater value in predicting carcass marbling than IMF measured in bulls, and IMF measured in bulls greater value than IMF measured in heifers. Additionally, MacNeil et al. (2011) suggested that the use of molecular breeding value (MBV) for marbling will lead to increase in the accuracy of genetic evaluation of marbling, due to the high genetic correlation between IMF and MBV (0.80 ± 0.22) and the positive genetic correlation between MS and MBV (0.38 ± 0.10).

Genetic correlations between MS with other traits have been reported in the literature. Bertrand et al. (2001) analyzed studies from 1980 to 2000 for data adjusted to constant age. They reported low average genetic correlations of 0.10 and -0.01 between MS and fat thickness,

between MS and ribeye area, respectively; and medium negative correlation between MS and retail product (-0.28). These results indicate that it is possible increase marbling without increasing backfat thickness. However, the negative correlation between marbling score and percentage of retail product may be challenging to select to increase both marbling score and retail product at the same time.

Rios-Utrera et al. (2005) analyzed the slaughter endpoint effect on the genetic correlation between MS and carcass weight (CWT), dressing percentage (DRE), fat thickness (FAT), and ribeye area (REA). They found higher genetic correlation between MS and CWT at constant age than at constant fat thickness (0.39 ± 0.17 vs. 0.24 ± 0.17); Low positive genetic correlation between MS and DRE was reported for age constant (0.29 ± 0.20), weight constant (0.12 ± 0.19), and fat thickness constant (0.26 ± 0.22); similar genetic correlation between MS and fat thickness for age constant (0.34 ± 0.19) and weight constant (0.35 ± 0.19); low genetic correlation was reported between MS and REA for age constant (-0.05 ± 0.19), weight constant (-0.14 ± 0.18), and fat thickness constant (0.10 ± 0.2); moderate genetic correlation was reported between MS and yield grade (YG) at constant age (0.32 ± 0.16) and at constant weight (0.27 ± 0.16), but low correlation at constant fat thickness (0.11 ± 0.2). In general, the estimate of genetic parameters for MS do not show much difference when they are estimated at age or weight constant, however they show more difference when are estimated at fat thickness constant.

In conclusion, the moderate to high heritability for MS measured in carcasses of steers and heifers and the favorable association between MS measured in carcasses and IMF measured in live yearling bulls and heifers indicate that inclusion of IMF data would improve the evaluation of MS and would permit early information about MS. Furthermore, the genetic

correlations with others traits suggest that selection for MS should be done including traits that affect the profitability of the beef industry in a multiple-trait selection based on selection index (Bertrand et al., 2001).

Dressing percentage

Phenotypic means for dressing percentage of 60.6 %, 61.7%, 62.6%, 62.4 %, and 65.0 %, and 65.8 % were reported in purebreds and composite steers (Rios-Utrera et al., 2005); in Hereford steers, and steers and heifers (Koch et al., 2004); in Shorthorn-cross steers (Pariacote e, 1998); and in Charolais and Limousin steers and heifers (Wulf et al., 1996), respectively.

Low to moderate estimates of heritability ranging from 0.19 ± 0.07 (Rios-Utrera et al., 2005) to 0.49 ± 0.19 (Pariacote et al., 1998) were reported in the literature. Additional estimates of heritability for DRE of 0.21 ± 0.13, 0.22 ± 0.10, and 0.25 ± 0.17 were reported by Wulf et al. (1996) for Charolais and Limousin steers, by Gregory et al. (1995a) for composites steers, and by Veseth (1993) in Hereford bulls, respectively. Slaughter endpoint effect on the estimate of heritability for DRE was analyzed by Rios-Utrera et al. (2005) and Veseth et al. (1993). Rios-Utrera et al. (2005) using purebreds and composite steers, reported slightly higher heritability when DRE was adjusted to constant carcass weight (h^2 = 0.21 ± 0.07) than when adjusted to constant age (h^2 = 0.19 ± 0.07) or at constant fat thickness (h^2 = 0.18 ± 0.07). However, Veseth et al. (1993) did not find important difference in estimated heritability for DRE between adjusted by age (h^2 = 0.25 ± 0.17) and adjusted by weight (h^2 = 0.26 ± 0.17).

Moderate to high estimates genetic correlations were reported between DRE and birth weight (BWT), ribeye area (REA), and carcass weight (CWT). Negative genetic correlation between DRE and BWT, -0.57 ± 0.64, was reported by Vaseth et al. (1993) for Hereford bulls.

No clear estimate of genetic correlation between DRE and CWT was reported in the literature. Genetic correlation between DRE and CWT of 0.65 ± 0.19, 0.34 ± 0.4, 0.03 ± 0.25, and 0.04 ± 0.38 were reported by Pariacote et al. (1998) Shorthorn-cross steers, for Veseth et al. (1993) for Hereford bulls, for Rios-Utrera et al. (2005) for mixed breeds, and for Reynolds et al. (1991) for Hereford bulls, respectively. Similarly, no clear genetic correlations were reported between DRE and REA. Genetic correlation between DRE and REA of 0.79 ± 0.16, 0.41 ± 0.22, and -0.11 ± 0.41 were reported by Pariacote et al. (1998) for Shorthorn-cross steers, by Rios-Utrera et al. (2005) for purebred and composite steers, and by Veseth et al. (1993) for Hereford bulls.

Low or not different from zero estimate genetic correlations between DRE and others traits were reported in the literature. Veseth et al. (1993), in Hereford bulls, reported low estimates of genetic correlation, 0.18 ± 0.38, between DRE and yearling weight, and not different from zero genetic correlation, 0.01 ± 0.62, between DRE with weaning weight. Rios-Utrera et al. (2005) and Pariacote et al. (1998) reported low estimate genetic correlation between DRE and carcass fat thickness of 0.09 ± 0.26 and 0.16 ± 0.31 in Shorthorn-cross and mixed breed steers, respectively.

In conclusion, based on the moderate heritability, genetic variance, and genetic correlations reported in the literature points to the opportunity to increase dressing percentage with a positive effect on longissimus muscle area, carcass weight, and with little effect on fat thickness. Additionally according the large negative correlation between DRE and birth weight reported for Veseth et al. (1993) seems that selection for increasing DRE will reduce the birth weight. However this should be viewed with caution due to high standard error of the estimate.

Longissimus muscle area

Means (SD) for longissimus muscle area or ribeye area (REA), of 80.6 (7.1 cm^2); 78.7 cm^2 (10.4 cm^2) and 78.7 cm^2 (10.4 cm^2); 78.6 cm^2 (7.1 cm^2); 68.5 cm^2; 86.1 cm^2 (10.7 cm^2); 91.5 cm^2 (7.6 cm^2) and 94.4 cm^2 (7.6 cm^2) were reported in Angus steers (MacNeil and Northcutt, 2008); in purebreds and composite steers (Rios-Utrera et al., 2005; Snowder et al., 2007); in Hereford steers (Koch et al., 2004); in Simmental steers and heifers (Crews et al., 2003); and in Charolais and Limousin steers and heifers (Wulf et al., 1996), respectively.

Heritability estimates for ribeye area (REA) measured in the carcass ranged from 0.17 ± 0.09 for composite steers (Gregory et al. 1995a) to 0.61 ± 0.06 for mixed-breed steers (Splan et al., 1998). High heritability estimates for REA were reported by Schneider et al. (2010) for Angus and Simmental steers and heifers (0.58 ± 0.08), by Nephawe et al. (2004) in mixed breeds (0.57 ± 0.07), and by Crews et al. (2003) in Simmental heifers and steers (0.46 ± 0.05). Low to moderate heritability estimates for REA were reported by MacNeil and Northcutt (2008) for Angus steers (0.33 ± 0.02), by Snowder et al. (2007) for mixed breeds steers (0.30 ± 0.07), by Rios-Utrera et al. (2005) for mixed-breed steers (0.24 ± 0.07), by Koch et al. (2004) for Hereford steers and heifers (0.31), by Kemp et al. (2002) for Angus steers (0.36), and by Shanks et al. (2001) for Simmental cattle (0.36). In general, the estimates of heritability for REA in the last decade are in agreement with the average heritability for REA (0.47) reported by Bertrand et al. (2001) based on 12 studies.

Ultrasound longissimus muscle area (uLMA) measured in live animals has been studied as a predictor of longissimus muscle area measured in the carcass (LMA). MacNeil and

Northcutt (2008), in Angus cattle, reported similar estimated heritability for uLMA measured in bulls to LMA measured in carcasses of steers (0.328 ± 0.029 and 0.332 ± 0.022, respectively), however they reported that heritability estimates for uLMA measured in heifers and steers were lower than for LMA measured in carcasses of steers (0.28 ± 0.03 and 0.18 ± 0.06 vs. 0.332 ± 0.022). In contrast, Crews et al. (2003) for Simmental cattle, reported estimates of heritability for uLMA measured in heifers higher and in bulls lower than for LMA measured in carcass of steers (0.51 ± 0.15 and 0.37 ± 0.06 vs. 0.46 ± 0.05). Bertrand et al. (2001) reported, on average, lower estimate of heritability for uMLA based on 9 studies than for estimate of heritability for MLA based on 12 studies (0.32 vs. 0.47).

Moderate to high genetic correlations between LMA and uLMA have been reported in the literature. MacNeil and Northcutt (2008), in Angus, reported high estimate genetic correlation between LMA measured in steers with uLMA measured in heifers and in steers (0.78 ± 0.05 and 0.90 ± 0.18, respectively), and moderate genetic correlation between LMA measured in steers with uLMA measured in bulls (0.63 ± 0.06). Crews et al. (2003), in Simmental, reported high genetic correlation between LMA measured in heifers and steers with uLMA measured in bulls, and both in bulls and heifers (0.80 ± 0.11, 0.85 ± 0.10, respectively); and moderate genetic correlation between LMA measured in heifers and bulls with uLMA measured in heifers (0.54 ± 0.15). Data suggest that independent of the sex, LMA measured by ultrasound seems to be the same trait. In general, due to the high genetic correlation between uLMA and LMA reported in the literature, we can suppose that longissimus muscle area measured by ultrasound in live animals is the same trait as LMA measured in carcass, however, some reports show medium genetic correlation between both traits indicating that uLMA and LMA may be slightly different

traits (MacNeil and Northcutt, 2008). However, there is general agreement that uLMA shows to be a very good indicator of LMA.

High estimate of genetic correlation between REA and retail product percentage was reported, 0.70 on average from 3 studies (Rios-Utrera et al., 2005; Shanks et al., 2001; and Koch et al., 1982). High negative genetic correlation between REA and yield grade, -0.71± 0.12, was reported by Rios-Utrera et al. (2005) for mixed breeds. Moderate to high genetic correlation of 0.51 and 0.52, were reported between REA and yearling weight, and REA and carcass weight, on average from 5 studies (Kemp et al., 2002; Splan et al., 1998; Moser et al., 1998; Veseth et al., 1993; and Johnson et al., 1993), and on average from 10 studies (MacNeil and Northcutt, 2008; Rios-Utrera et al., 2005; Kemp et al., 2002; Shanks et al., 2001; Pariacote et al., 1998; and others), respectively. Negative genetic correlation was reported between REA and fat thickness, -0.36 on average from 4 studies (Rios-Utrera et al., 2005; Gregory et al., 1995a; Wilson et al., 1993; and Koch et al., 1982). Low estimates of the genetic correlation between REA with calving rate (0.15) and age at puberty (0.04) were reported by Splan et al. (1998) for mixed breeds.

In conclusion, based on the moderate to high heritability for longissimus muscle area, and the genetic variance, selection for increasing LMA in cattle will be effective. Based on the correlation, a breeding program for increasing LMA will increase retail product percentage, increase carcass weight, increase slightly yearling weight, and decrease yield grade, however calving rate and age of puberty seem to not be affected by selection for LMA. Finally, due to strong association between LMA measured by ultrasound in live animals with LMA measured in carcass, the use of LMA measured by scan will be useful for estimating LMA in the carcass.

Fat thickness

Since 2000, mean (SD) for fat thickness (FAT) of 1.24 cm (0.79 cm), 1.42 cm (0.38 cm), 0.66 cm (0.45 cm), 0.65 cm (0.44 cm), 1.22 cm (0.49 cm), 1.22 cm (0.49 cm), 1.41 cm (0.45 cm), 1.09 cm (0.44 cm), and 0.95 cm (0.41 cm) were reported in Angus and Simmental steers and heifers (Schneider et al., 2010), in Angus steers (MacNeil and Northcutt, 2008), in mixed-breed steers (Snowder et al., 2007), in purebred and composite steers (Rios-Utrera et al., 2005), in mixed-breed steers (Nephawe et al., 2004), in mixed-breed steers (Splan et al., 2002), in Angus steers (Kemp et al., 2002), in mixed-breed steers (Greiner et al., 2003), and in Hereford steers (Koch et al., 2004), respectively.

Heritability estimates for fat thickness (FAT) measured in the carcass reported in the literature range from 0.20 ± 0.07 in multiple breeds of steers (Rios-Utrera et al., 2005) to 0.66 ± 0.07 in mixed-breed steers (Splan et al., 1998). Since 2000, moderate estimates of heritability for FAT were reported by Schneider et al. (2010) in Angus and Simmental steers and heifers (0.34 ± 0.07), by Nephawe et al. (2004) in mixed breeds (0.46 ± 0.07), by Koch et al. (2004) in Hereford steers and heifers (0.40), by Kemp et al. (2002) in Angus steers (0.39), by MacNeil and Northcutt (2008) in Angus steers (0.34 ± 0.02), by Crews et al. (2003) in Simmental bulls (0.35 ± 0.05), and by Snowder et al. (2007) in multiple-breed steers (0.31 ± 0.15). In general, the estimates of heritability reported during the last decade are in agreement with the average heritability of 0.34 reported by Bertrand et al. (2001) based on 12 studies reviewed.

Subcutaneous fat depth (uFAT) of live animals measured by using ultrasound was studied as an indicator of fat thickness measured in the carcass (FAT). Higher estimate of heritability for fat depth measured by ultrasound in bulls (0.39 ± 0.03 and 0.53 ± 0.07) and in heifers (0.46 ±

0.04 and 0.69 ± 0.10) than heritability for carcass fat depth (0.34 ± 0.02 and 0.35 ± 0.05) was reported by MacNeil and Northcutt (2008), and Crews et al. (2003), respectively. In contrast, lower estimate of heritability for uFAT measured in steers than heritability measured in the carcass was reported by MacNeil and Northcutt (2008), 0.25 ± 0.08 vs. 0.34 ± 0.02. These differences in estimate of heritability for FAT measured by ultrasound may indicate that heritability of uFAT is sex specific and slightly greater than heritability of FAT. However, Bertrand et al. (2001), based on a review of several studies, reported than in average heritability for fat depth measured in carcass is marginally greater than measured by ultrasound in live animals (0.28 vs 0.34).

High genetic correlations were reported between FAT and uFAT. Crews et al. (2003), in Simmental, reported high genetic correlation between fat measured in carcass of heifers and steers with fat measured by ultrasound in live bulls (0.79 ± 0.13) and heifers (0.83 ± 0.12). Similarly, MacNeil and Northcutt (2008), in Angus, reported positive genetic correlation between fat depth measured in carcass of steers with fat depth measured by scan in bulls (0.52 ± 0.06), heifers (0.55 ± 0.06), and steers (0.90 ± 0.11). High estimates of genetic correlation between fat depth measured by ultrasound in bull and in heifers were reported for MacNeil and Northcutt (2008) and Crews et al. (2003), (of 0.88 ± 0.02 and 0.67 ± 0.12, respectively). The high genetic association between carcass and live measurement of fat depth, suggest that fat depth measured using ultrasound is a good indicator of fat depth measured in carcass of slaughtered animals.

High, moderate, and no clear genetic correlation of fat thickness with others traits was reported in the literature. High estimate of genetic correlation between FAT and yield grade was reported by Rios-Utrera et al. (2005) in purebreds and composite steers (0.86 ± 0.07) and by

Pariacote et al. (1998) in Shorthorn-cross steers (0.67 ± 0.15). Moderate estimate of genetic correlation between FAT and ratio of MEI/ADG (Mcal/kg) was reported for MacNeil et al. (1991) in crossbred steers (0.30 ± 0.26). No clear estimate of genetic correlation between FAT with carcass weight (CWT) and yearling weight (YWT) was reported in the literature. Positive genetic correlations between FAT and CWT of 0.38, 0.36, 0.27 ± 0.22, 0.17, and 0.13 were reported by Wilson et al. (1993), Arnold et al. (1991), Rios-Utrera et al. (1995), Kemp et al. (2002), and Gregory et al. (1995a), respectively. However, negative genetic correlation between FAT and CWT of -0.37, and -0.22 ± 0.30 was reported for Shanks et al. (2001), and Pariacote et al. (1998), respectively. Similarly, Positive genetic correlation between FAT and YWT of 0.34 and 0.10 was reported by Splan et al. (2002) and Kemp et al. (2002), respectively; and negative genetic correlation between FAT and YWT of -0.19 ± 0.15 and – 0.13 ± 0.35 was reported by Moser et al. (1998) and Arnold et al. (1991). Low (0.19) and no different from zero (-0.01) estimate of genetic correlation between FAT with calving rate and age at puberty, respectively, was reported by Splan et al. (2002).

In conclusion, the moderate to high heritability for FAT reported in the literature suggest that there is a potential benefit in the inclusion of fat thickness in the breeding program. The correlation of FAT with other traits indicate that selection for reducing fat thickness in carcass is possible and should reduce yield grade and required MEI/ADG (Mcal/kg), without an important effect on female traits like calving rate and age at puberty. However, the direction of the effect on yearling weight and carcass due to reducing FAT in carcass is not clear in the literature.

Breeding objective

Garrick and Golden (2009) suggested development of a breeding objective would follow steps: definition of a goal for the breeding program, identification of traits that influence the goal, determination of the economic importance of each trait in the goal, and quantification of the value and cost to measure the traits. Similarly, MacNeil (2008) suggested five steps for implementing a breeding objective: 1) development of a bio-economic simulation model that describes the production system defined; 2) identify the economically relevant traits (ERT) using partial derivatives of profit with respect to each biological driving variable; 3) development of a genetic covariance matrix for ERT and traits for which EPD are available; 4) estimation of the weights for the breeding values produced in national cattle evaluation; and 5) application of the relative weight to the EPD to evaluate individuals for economic merit.

Definition of breeding objective

There are different opinions on how to define the breeding objective, but all of them converge to the objective should be measured in profit, on a future conditions basis. Garrick and Golden (2009) proposed that the goal should be "produce beef that is nutritious, healthful, and desirable", with profit in a cow-calf system measured as "profit per unit land" and in a feedlot system as "profit per pen". Dickerson et al. (1974) suggested that breeding objective should be more efficient growth accompanied by earlier sexual maturity to reduce replacement cost, lengthen productive life, and minimize increase in mature body size; and the efficiency should be measured as cost per unit of product from females and their progeny over a given period of time; including traits of carcass composition, meat quality, optimum economic weight at slaughter of

calves and mature size, milk production, and calving difficulty of cows. Harris (1970) suggested that the main source of long-term profitability for a livestock producer lies in his efficiency relative to other livestock producer, due to the extremely large number of livestock producers. Thus the goal of genetic improvement in livestock should be expressed on per animal basis and measured in profit (income-expensive), return on investment (income/expensive), or cost per unit production (expensive / product). And if a constant slaughter weight or age is considered, it should be the optimum weight or age from economic consideration. Furthermore, one genetic group may have one optimum slaughter weight or age, while another group may have another.

Determination of traits in the breeding objective

Identification of the traits for the breeding objective should be based on the traits that affect the income and cost of the system. Income is related with the number and the value of sale animals, and cost is associated with the amount and price of the different sources required in the production process (Garrick and Golden, 2009). Garrick and Golden (2009) described these components for a cow-calf system: the number of animals for sale is associated with the number of animals at breeding, reproductive performance, survival, and the replacement rate, and the value of sale animals is associated with sex, and age of the sale animal. For the feedlot system, income is associated with the number of sale animals, their BW and carcass attributes, and survival rate determines number of sale animals in relation to purchased animals, and expenses are associated with feed cost, veterinary and animal health cost, and labor.

Harris (1970) indicated that the relative emphasis to be placed on each trait in a selection program depends on the combination of economic importance of the trait, potential for genetic improvement of the trait, genetic interrelationships between trait, and cost of measurement in

labor, facilities and time (generation interval). The potential for genetic improvement also depends of the genetic variability, and accuracy of selection decisions.

Relative importance of the each trait in the breeding objective

Quantifying the importance of the each trait in the breeding objective will be useful to not only select animals with higher rank for the defined breeding objective but also to determine the priority in relation to further research and development of systems for collecting information and evaluation of these traits (Garrick and Golden, 2009). MacNeil (2008) suggested that the relative importance of the traits in the breeding objective should be obtained by deriving a profit function. Systems of profit equations can be thought of as highly aggregated simulation model (MacNeil and Harris, 1988), or more explicit and complex bio-economic simulation models using the principles of sensitivity analysis to approximate the required partial derivatives (MacNeil, 2008).

Melton (1995) analyzed a fully integrated systems and a commercial cow-calf system to estimate the economic impact of a group of economic relevant traits in the U.S. industry. He evaluated 16 traits: gestation length (days), weaning rate (%), birth weight (kg), lactation ability (milk), rate of maturity (ratio), weaning weight (kg), feed efficiency (kg/Mcal), mature cow weight (kg), post-weaning rate of gain (kg/d) , slaughter weight (kg), carcass weight (kg), retail product (%), marbling score (score; 1-10), tenderness score (0-100), flavor score (1-100), and juiciness score (0-100). The economic values measured as profit.head^{-1}.yr^{-1}, were estimated, for a representative West Texas producer-feeder-packer-processor-marker using average long-term price data for 1980-84.

For a fully integrated system, Melton found that from the 16^{th} traits analyzed, only flavor score showed economic effect on profit (profit.$head^{-1}$.yr^{-1}). Four variables and the partial regression on profit (in parentheses) were: weaning weight ($0.64/kg), postweaning average daily gain ($ -178.8/kg), marbling score ($ -10.87/score), and feed efficiency ($ 2,736.07). Despite eliminating 9 of the 16 characteristics, the R^2 value was reduced only slightly (from 0.62 to 0.57). Estimation of economic values was adjusted for time over a total 6 generations assuming a discount rate of 5%, and a total economic life of 10 yr. Adjusted economic values for an integrated system expressed as $/head were 5.98, 24,738.21, -1.616.98, -95.06, 3.51, 67.44, and 27.59 for weaning weight (kg), feed efficiency (kg/Mcal), post-weaning rate of gain (kg/d), marbling score (0-10), tenderness score (0-100), flavor score (0-100), and juiciness score (0-100), respectively.

For a commercial cow-calf system, Melton found that only 7 traits from the 16 analyzed had economic values different from zero. The economic values in $/head basis after adjusted for time were 3,795.91, 19.42, 12.58, -0.43, -251.84, 1,082.47, and 31.71 for weaning rate, lactation ability, weaning weight, mature cow weight, post-weaning rate of gain, retail product, and marbling score, respectively. Thus for cow-calf producers, maternal and reproductive characteristics have a greater value, and the economic value of retail product was only 20% of its value to the total industry system.

Finally, Melton reported the relative economic weight on a standardized basis (per phenotypic standard deviation). For the total industry system, the standardized relative economic weights were: for reproduction 87.57 (ratio=1), for production $ 857.55 (ratio = 9.79), and for carcass characteristic $1,184.19 (ratio = 13.52); and for commercial cow-calf system were: for reproduction $346.99 (ratio = 3.24), for production $306.72 (ratio=3.87), and for carcass

characteristic \$106.98 (ratio = 1). The overall profit \$/head was three times greater for fully integrated system than for the cow-calf system (\$ 2129 vs. \$ 761). Additionally, Melton analyzed the economic value based on formula sales of slaughter cattle where each participant receives an equitable portion of the total value based on their individual contribution to that total. He found that from the 16 traits analyzed only weaning rate (\$711.88), slaughter weight (\$0.81), retail product (\$1,576.19) and marbling score (\$18.2) showed economic values different from zero. Comparing theses values with cow-calf producer values, substantially greater value is attached to retail product and lower value to weaning rate. It is important to recognize that there is not a "correct" formula. It, like other economic values, depends on subsequent market and the value that can be realized in those markets.

MacNeil and Newman (1994), using a deterministic model to simulate profit for 100 beef cows, estimated the relative economic values in Canadian beef production for 12 traits for 3 synthetic strain (specialized maternal lines in rotation, M1, and 2 terminal sires, one specialized sire for breeding yearling heifers, M3, and the other a terminal sire for breeding mature cows, TX). They found that the maternal lines had similar economic values for all traits analyzed. The relative economic value was greater for growth in finishing phase than in background phase for all cases (16.27 vs. 1.90 for M1, 4.74 vs. 0.95 for M3, and 16.07 vs. 1.32 for TX). For cow weight (kg), female fertility (%), and maternal effect in weaning weight (%), the economic values for maternal lines were -0.11, 1.31, and 0.06, respectively, and zero for both sire lines. The economic value (\$) for male fertility (%), calf survival (%), direct effect on weaning weight, feed:gain (kg. kg^{-1}), and A carcass grade (%) were small compared to the other traits include for M1: 0.87, 0.90, 0.06, -0.61, and 0.18; for M3: 0.38, 0.28, 0.03, -0.21, and 0.06; and for TX: 1.90, 0.89, 0.06, -0.64, and 0.19, respectively. The economic values (\$) for dressing percentage

(%) and cutability (%) were for M1: 2.78 and 4.81, for M3: 0.92 and 1.76, and for TX: 2.85 and 5.10, respectively. After rescaled for frequency of expression and standardized for differences in variability among traits, the relative economic value ($) for male and female fertility, calf survival, and milk production increased significantly. The necessity for long-term economic and production data was observed. The number of years required to reduce standard deviation of relative economic value to 10% of the mean for maternal line varied from 3 yr for direct effect for weaning weight to 10 yr for most of the traits, with the only exception of finishing ADG that required 23 yr. The effect of endpoint occurring at weaning, after backgrounding, and after finishing, did not affect the relative economic values with the exception of direct and maternal effect on weaning weight.

MacNeil et al. (2005b) analyzed the development of breeding objective for four terminal sires (Angus, Charolais, Hereford, and Limousin) for use in U.S. beef production system for seven economically important traits. In general, they found a relatively uniform economic value for all traits across the breeds evaluated. The range of the product of genetic standard deviation and breed-specific relative economic values for phenotypes in the breeding expressed in $/an enterprise basis were: 2,167 to 3,239 for calf survival ($ / %), 2,803 to 4,012 for direct weaning weight ($.lb^{-1} ADG), 796 to 1,418 for ADG during finishing period ($.lb^{-1}.d^{-1}), -2,124 to -3,391 for postweaning feed intake during finishing period ($.lb^{-1}.d^{-1}), 1,077 to 3,159 for dressing percentage ($ / %), -77 to 2,741 for USDA yield grade ($), and 41 to 3,874 for marbling score ($; 4.0 slight, 5.0 small, so on). The correlation among breeding objectives for terminal sires for the four breeds evaluated were high with a range of 0.74 to 0.98. In general, they concluded that there is the necessity for reliable multiple-trait selection.

Aby et al. (2012a), using a bio-economical model, estimated the economic value for functional and productive traits for intensive and extensive system for British and Continental breeds in Norway. They found that functional traits had the same importance as production traits with higher emphasis in intensive production system. The traits that had positive association with the profit in intensive and extensive system were, respectively, herd life (1.10 and 0.62 EUR. day^{-1}), twinning frequency (4.78 and 2.75 $EUR.\%^{-1}$), growth during finishing phase (0.30 and 0.24 $EUR.gram^{-1}.day^{-1}$), carcass weight (5.57 and 5.05 EUR. kg^{-1}), and carcass conformation (34.98 and 25.92 EUR. $class^{-1}$). Based on the relative economic values (REV, in percentage),for intensive and extensive system, respectively the most economically important traits were: herd life of cow (39 and 29%), carcass weight (24 and 29%); growth rate from weaning to yearling (6 to 9%); growth rate from yearly to slaughter (7 and 7%); traits with little or no economic importance were: birth weight (0.09 and 0.21 %), preweaning weight (3.98 and 5.99%), stillbirth (0.04 and 0.03%), twinning (0.01 and 0.00%), calving difficulty (2.30 and 2.71%), limb and claw disorders (0.02 and 0.03) carcass fatness (2.35 and 4.54%).

Selection for increasing the ratio of calf weaning weight to dam weight as an indicator of efficiency and the response to selection in composite beef cattle, based on Charolais and Tarantaise sires, and Red Angus dams, were evaluated by MacNeil (2005a). He inferred that long-term genetic change in the ratio may be more difficult, due to the correlation between weaning weight and cow weight may become more positive after few generations of selection. Given opposite selection of two positively genetically correlated traits, it would be expected that allele frequencies at loci with directionally different effects would change rapidly toward fixation, whereas allele frequencies at loci with directionally similar effects would be less influenced (Falconer, 1989). Additionally, selection based on the phenotypic ratio of weaning

weight to cow weight would be complicated due to these traits being measured on different individuals, and the confounding direct and maternal genetic effects on these phenotypes (MacNeil, 2005a).

Index selection

The most well-known paper establishing the selection index was written by Hazel (1943). He gave the principles of developing and using selection index to realize of maximum genetic progress. With an index, selection identifies animals with greatest weighted sum genetic values for several traits of economic importance (ERT). Thus, the breeding objective should be maximizing the aggregate value (H) of an animal, which is the sum of its breeding values weighted by the relative economic values of the ERT. Breeding value may be improved by selecting indirectly for correlated variables included in an index selection (I) based on the phenotypic performance of each animal. The genetic gain for selection based on the index is a product of the standardized selection differential (i), the multiple correlations between aggregate breeding value and the selection index (R_{IH}), and genetic variability. The greatest opportunity of increasing the progress from selection is choosing an index to make R_{IH} as large as possible. When the traits are uncorrelated, R_{IH} is a maximum when each regression coefficient of the index is equal to (or proportional to) the product of the relative economic value and heritability for each trait. It is important to consider the length of generation when we want to maximize R_{IH}. Dickerson and Hazel (1942) have shown that the interval between generations can be increased by progeny testing to more than offset an increased accuracy of selection, thus the annual rate of genetic improvement should be considered.

However, there are limitations to immediate adoption in the form presented by Hazel (1943) due to genetic and residual covariances among indicator traits could be estimated from field data, but genetic covariances between ERT and the indicator traits could not (Garrick and Golden, 2009). Henderson (1963), as described by Garrick and Golden (2009), showed that the aggregate economic merit of Hazel (1943) could be derived equivalently in a 2-step procedure. In the first step predict the genetic merit of all the ERT for all the candidate individuals, and in the second step adding together the EPD for each trait in the objective weighted by its economics value. MacNeil (2008) indicated that the application of selection index weights to available EPD may be a starting point from which to implement genetic evaluation for profitability; where the ERT and EPD trait should be reconciled, which is difficult at least in part, due the lack of ERT phenotypes and the necessary genetic covariances of ERT with EPD traits.

Some breed associations have produced and published indexes with the goal of each index summarized by Spangler (2008). The list of traits that are assumed to influence the goal and the nature of the assumed cost and price information has been inadequately detailed, and in many cases, the resulting economic weights are not presented (Garrick and Golden, 2009).

Lindholm and Stonaker (1957) determined the relative economic importance of traits affecting net income in beef cattle and developed a selection index designed to attain the maximum genetic progress in net income per hundred weight of product. They used data from Herefords in the Colorado Agricultural Experimental Station from 1946 to1951. Weaning weight daily gain, days to finish, weaning grade, slaughter grade, and slaughter weight were highly correlated with net income per hundredweight. Lighter steers at weaning made more efficient gains, although daily gains were slightly less. Calves from lighter cows give a greater net return than calves from heavier cows. The four traits, weaning weight (W); daily gain (R); days to

finish (F); and feed conversion (E) were used in the determination to the aggregate genotype in the index computations. The index then became I = + 0.58 W + 18.64 R - 0.73 F – 5.87 E. high correlation between the index and the aggregate genotype was found. The standard error of the coefficients in the index showed that weaning weight appears to be most reliable, while feed conversion appears to be the least reliable. The products of the index coefficients with standard deviations indicate that weaning weight is over two times as important in determining the index values as days to finish, and that daily gain and feed conversion are the least important. When the index included only weaning weight the correlation between aggregate and the index was still high. This study indicated that weaning weight alone was an accurate basis for selection, and the addition of daily gain or feed conversion did little to increase the efficiency of selection for the aggregate genotype. Heavy weaning weight and rapid finishing ability appear to be the most important traits to select for in attempting to increase net income from combined calf raising and calf feeding enterprises.

MacNeil and Newman (1994) developed indices for specialized maternal and terminal sire lines for Canadian beef production. Low correlations of 0.22, 0.22, and 0.19 between the breeding objective and the index were found for dam line, terminal sire1 (M3) and terminal sire2 (TX). This low correlation can be explained because the large number of traits (12 traits in the breeding objective and 10 in the index) and the complex genetic correlation among the traits. Information of maternal half-sibs was not important to the index. Indexes in both terminal sires were quite similar except for birth weight where terminal sires were constrained to keep birth weight constant, and thus had greater importance for this trait. Growth from birth to weaning had higher importance compared to growing after weaning in maternal line, and this was opposite for terminal sire lines. In general, maternal line improvement was achieved by increasing fertility

and calf survival, reducing cow size, and easier fleshing. By contrast, terminal sires improve profitability by increasing male fertility, calf survival, growth rate, and carcass cutability. The correlation among goals between specialized and general purpose lines was higher for all maternal lines (0.98), but lower for terminal sires, 0.74 and 0.77 for M3 and TX, respectively.

Kahi and Hirooka (2005) evaluated the breeding objective developed for Hirooka et al (1998) in an integrated system for Japanese Black cattle in Japan. The breeding objective was based on genetic gain for maximizing profit per cow. The economic values for profit per cow per yr basis were for birth weight (BWT; ¥ -1,267.80/kg), weaning weight (WWT; ¥ 76.95/kg), Mature weight (MWT; ¥ -109.92/kg), daily gain during the feedlot (ADG; ¥ 85.20/kg), carcass marbling score (MS; ¥ 19,603.00/score), LM area (LMA; ¥ 204.63/mm^2), rib thickness at the 6^{th}- and 7^{th}- rib section (RT; ¥ 2,500.26/mm), and subcutaneous fat thickness at the 6^{th}- and 7^{th}-rib section (SFT; ¥ 925.19/mm). Index selection was evaluated for 10 schemes of selection. They found large importance by including information of carcass traits from relatives of the performance-tested young bulls. In Japan, carcass quality has a huge economic importance and is the most desired characteristic to be improved. Selecting young bulls on the basis of their growth ability during performance testing was less desirable strategy, both genetically and economically. There were small differences in the annual genetic gain, and return and profit per cow as a result of inclusion of scrotal circumference (SC) in the selection criteria. Inclusion of body weights markedly increased responses in BWT, WWT, MWT, and ADG. Inclusion of ultrasound information for carcass traits measured in live animals increased the index accuracy in the range of 18 to 30%, genetic gain 17 to 43%, costs 10 to 12%, returns 17 to 42%, and profit per cow 18 to 52%. Thus, the ultrasound scanning of live animals was more important than addition of any other traits in the selection criteria.

Evaluation of the index selection

Smith (1983) evaluated the effect of change in economic weights on the efficiency of index selection. Efficiency was evaluated for a wide range of parameters sets for phenotypic correlation (P), genetic correlation (G), economic weight standardized per SD (a), and product of economic weight standardized and the heritability (ah^2). They found that the product of ah^2 was the most important factor affecting the efficiency of the index. If the traits are balanced (for ah^2), change in the balance will reduce the efficiency of the index, resulting in significant losses in efficiency when there is large change in value and size of ah^2. If one trait dominates the index, the efficiency is mainly dependent on the changes in the dominant trait than on the other traits with lower economic weights. However, cumulative change in minor traits will gradually reduce the efficiency. For an index with more balance among traits, efficiency is much more sensitive to change in the economic values. Both genetic and phenotypic correlations affect the efficiency, but genetic correlations have more effect on the sensitivity. In conclusion, frequent readjustment in the index due to small changes in the production, market, or genetic change, will not be very helpful because the changes in efficiency are likely to be small.

Aby et al. (2012b), using a deterministic bio-economic model, evaluated the effect of change of production conditions on the economic values of seven functional and seven production traits in British and Continental beef cattle. Production traits increased their economic importance when the quality and price of forage increased, and vice versa for functional traits. In general, they concluded that economic values of the traits in the breeding objective has small to moderate effect relative to changes in external production conditions.

MacNeil (2003) evaluated the genetic changes and genetic parameters as a result of the use of a selection index based on the birth and yearling weight in composite beef cattle. Data from stabilized composite beef cattle, ½ Angus, ¼ Charolais and ¼ Tarentaise, using calves that were born from 1980 to 2000, were analyzed. The evaluation included birth weight, 200-d weight, 365-d weight, index, and cow weight. In the index line the bulls were selected using the index: I = 365-d weight – 3.2 birth weight, and in control line the bulls were randomly selected. The average generation intervals for the index line and control line were 3.16 ± 0.04 yr and 3.90 ± 0.08 yr, respectively. The accumulated selection differential for the index in the index line was 212 kg greater than in the control line at the end of the experiment. The heritability estimates for birth weight, 200-d weight, 365-d weight, and the index were 0.49 ± 0.05, 0.30 ± 0.04, 0.49 ± 0.05, and 0.32 ± 0.04 for direct effects, and 0.11 ± 0.03, 0.19 ± 0.04, 0.04 ± 0.02, 0.05 ± 0.02 for maternal effects, respectively. The direct genetic changes in the index line were 0.45 ± 0.09, 3.42 ± 0.55, 7.74 ± 0.55, 6.0 ± 0.3 and 6.3 ± 0.9 kg per generation, for the birth weight, 200-d weight, 365-d weight, the index, and cow weight, respectively. The maternal genetic changes in the index line and the direct and maternal genetic changes in control lines were small in all traits evaluated. Overall, the index used, which was based on reducing increases in birth weight while increasing 365-d weight, produced a positive genetic change in the postnatal growth. Therefore, the application of this index is recommended for beef cattle genetic improvement to increase efficiency in beef production.

Enns and Nicoll (2008) evaluated genetic change, in a commercial herd, due to long-term selection (from 1976 to 1993) using an economic breeding objective in New Zealand Angus. Selection using an economic breeding objective included four traits: harvest weight of progeny (HW), dressing percentage of the harvested progeny and cull cows (DP), and number of calves

weaned per cow throughout her lifetime (NCW). The breeding objective included feed intake and gross income adjusted for feed intake. The average annual genetic changes during the period evaluated were WWD (0.43 ± 0.05 $kg.yr^{-1}$), WWM (0.03 ± 0.22 $kg.yr^{-1}$), PWG (0.29 ± 0.03 $kg.yr^{-1}$), YW (0.72 ± 0.06 $kg.yr^{-1}$), HW (1.7 ± 0.13 $kg.yr^{-1}$), MW (0.13 ± 0.09 $kg.yr^{-1}$), NCW (0.006 ± 0.001 $calve.cow^{-1}$), and DP (-0.035 ± 0.003 $\%.yr^{-1}$). The cumulative gains obtained for HW, NCW, and breeding objective were similar or greater than the predicted values (28.9 kg vs. 27.7 kg; 0.102 vs. 0.065; 90.1 $ vs. 74.02 $, respectively). However, for mature BW and dressing percentage, the gains were smaller than the predicted values (2.21 kg vs. 29.3 kg; -0.595 % vs. -0.076 %). Overall, the use of the economic breeding objective produced positive genetic changes. Therefore, the application of an economics-based index is recommended for beef cattle genetic improvement programs.

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PART I: Biological and Economic Efficiency of Beef Cattle

ABSTRACT: A simulation based on 1000 cows at calving was used to evaluate biological and economic efficiency of three levels of milk production and two production systems. Data for this study were extracted from the literature. Low (L), medium (M), and high (H) milk production cows, in calf-fed (CS) and yearling systems (YS) were analyzed for a 1-yr cycle. Calf-fed system had a feedlot phase of 211 d and 240 d for steers and heifers, respectively, and YS had 315 d for growing, and 90 d and 120 d finishing periods for both heifers and steers. Average prices of 10-yr (2003-2012) adjusted for inflation to 2012 basis for cattle, feedstuffs and non-feed costs for Nebraska, interest, and premiums and discounts for carcasses were used. Cost, revenue, breakeven, and profit/loss were estimated for calves to weaning and from weaning to slaughter. Cost to weaning was estimated for the cowherd, breeding bulls, replacement heifers and bulls, and nursing calves. Cost from weaning to slaughter included initial cost of calves, and the expenses incurred in this phase. Feed cost was based on metabolizable energy (ME) consumed and appropriate feedstuffs. Breakeven was calculated by dividing the cost per cow exposed by body weight (BW) of calf produced. Biological and economic efficiency were estimated at weaning and slaughter endpoints. Biological efficiency was defined as grams of BW (to weaning) or carcass weight (CWT; to slaughter) per unit (Mcal) of ME consumed. Economic efficiency was defined as the ratio of dollars output to dollars input. Cost to weaning, growing in YS, finishing in YS, and finishing in CS were \$578.07, \$613.48, \$621.68/cow exposed; \$306.52, \$318.87, \$325.65/cow exposed; \$423.02, \$422.01, \$433.16/cow exposed; and 333.75, \$347.14, \$350.44/cow exposed for L, M, and H, respectively. Breakevens, in dollars value/ kg of BW, to weaning, for growing in YS, for finishing in YS, and for finishing in CS were 3.06, 3.27, 3.20; 2.46, 2.58, 2.58; 2.25, 2.28, 2.29; and 2.07, 2.16, 2.17 for L, M and H, respectively. Net

profit/loss, in dollars profit/cow exposed, to weaning, for growing in YS, for finishing in YS, and for finishing in CS were -6.4, -35.5, -33.5; 11.01, -3.53, -3.69; 22.31, 18.19, 15.99; and 25.20, 10.86, 9.70 for L, M and H, respectively. Biological efficiency to weaning and to slaughter were 29.77, 27.29, and 27.39 g/Mcal of weaning weight and 21.76, 19.92, 19.81 of g of/Mcal CWT for L, M, and H, respectively. Economic efficiency, in dollar output *100/dollar input, to weaning and to slaughter were 98.9, 94.2, and 94.6 and 105.8, 99.0, 98.8 for L, M, and H, respectively. Low-milk-yield cows had greater biological and economic efficiency than M and H group both to weaning and to slaughter, and slaughter was the more profitable endpoint.

Key Words: Biological Efficiency, Economic Efficiency, Carcass, System, Milk.

Introduction

Effects of milk production level of beef cows on biological and economic efficiency are not well defined. Increasing milk production increases weaning weight, and carcass weight (Clutter and Nielsen, 1987; Freking and Marshall, 1992; Miller et al., 1999), but increases maintenance requirement as well (Montaño-Bermudez et al., 1990a). Conflicting effects of milk yield on the biological and economic efficiency of beef cattle were reported in the literature. Higher biological efficiency to weaning and higher profit to slaughter for cows with higher milk production were reported by Miller et al. (1999) and Freking and Marshall (1992), respectively. However, Van Oijen et al. (1993) found greater biological and economic efficiency at weaning and slaughter in low-milk-production cows.

Economic efficiency analyzed for calf-fed and yearling systems were reported with contradictory results as well. Lower weaning and slaughter breakeven prices for yearling than for calf-fed systems were reported by Anderson et al. (2005). However, relatively greater profit in calf-fed than in yearling systems was reported by Small et al. (2009). Higher output in cows with higher milk production is offset by higher feed cost (Van Oijen et al., 1993), and lower weaning weights of offspring from cows with low milk production is compensated for by compensatory growth postweaning (Clutter and Nielsen, 1987). The economic effect of milk production level is also associated with the relationship between preweaning and postweaning feed cost (Notter et al., 1979; Bourdon and Brinks, 1987), where at higher postweaning feed cost, high-milk-yield cows may be more efficient, and vice versa (Freking and Marshall, 1992). Thus, 10-yr prices and animal performance from the literature were used in a deterministic simulation model to analyze milk level effect on breakeven and profit to weaning, and to slaughter in yearling and calf-fed systems, and to evaluate biological and economic efficiency to weaning and to slaughter in beef cattle.

Materials and Methods

Source of data

Literature values used in the simulation for birth weight, weaning weight, mature weight, and postweaning gain are shown in Table 1. Birth weight and weaning weight were obtained from Van Oijen et al. (1993), postweaning gain for calf-fed system, yearling system, and replacement heifers and bulls were based on Anderson et al. (2005), and effects of sex of calf, age and milk level of dam from Van Oijen et al. (1993). Cow weights after first calving were calculated using an exponential function (Brody, 1945):

$W_t = A.(1\text{-}be^{-kt})$,

where

W_t = body weight at time t,

A = mature weight or asymptote,

b = the “time-scale” parameter,

k = the “mature-rate” parameter, and

t = age in days.

Parameters used in Brody’s equation were obtained from Montaño-Bermudez and Nielsen (1990b), where: for b (time-scale) was 0.927, and k (maturing rate) was 0.00205. Mature size (A) in high (H) and medium (M) milk cows was assumed to be 558 kg based on Arango et al. (2002), Nephawe et al. (2004), and Costa et al. (2011); and for low milk cows (L) an increase in A of 6% was assumed (Montaño-Bermudez and Nielsen, 1990b).

Milk production, reproductive performance, and maintenance energy requirements are shown in Table 2. Milk production, pregnancy rate, and gestation length were obtained from Montaño-Bermudez and Nielsen (1990c), calving rate and crop-calf rate were estimated based on pregnancy rate, and calf and cow survival rates. Calving rate and calf-crop rate were estimated using the definition proposed by the Beef Improvement Federation (BIF, 2010).

Perinatal calf death (6.4%), preweaning calf death (2.9%), and fetal death during gestation (2.3%) assumptions followed the results of Maurer and Chenault (1983). Mortality of 1.0, 2.0, 1.5, and 0.5 % was considered for calves from weaning to 1 yr, calves from 1 to 2 yr, cows 2 yr of age or older, and cows at calving, respectively (Anderson et al., 2005). The effect of calving difficulty (CD) on calf and cow survival, and first calving pregnancy rate was

considered. For each 5% CD, an increment in 64% in death rate and a reduction in 6.2% of subsequent pregnancy rate of cows (Laster et al., 1973; Meijering, 1984; Berger et al., 1992; Colburn et al., 1997; Cervantes et al., 2010) was assumed. Feed cost was based on energy cost, with energy requirements for maintenance, growing, gestation, and lactation estimated by the Nutrient Requirements of Ruminant Livestock (ARC, 1980) and NRC (1996), as described by Montaño-Bermudez and Nielsen (1990c).

Production system

Cow-calf. Estimations were based on a simulated population of 1000 cows at calving in a cycle of 1 yr, beginning at weaning, October 15, and heifer calves are retained as replacements. Heifers were bred by natural service at 15 mo of age, on average. Open heifers were sent to the feedlot. Feed requirements for replacement heifers begin at weaning and continue through breeding and gestation until first calving. After calving, cows were divided into age groups of 2 yr, 3 yr, and 4 yr or older (mature cows). Feed requirements for replacement starting at weaning and breeding age bulls were also calculated on a 12-mo basis. The number of animals in the population was estimated using the formula shown in the Appendices 1A-1J.

The feeding program for the cow-calf segment was based on Werth (1990). In summary, summer grazing was considered between June 1 and October 31, winter grazing from November 1 to December 31, and from January 1 to May 30 prairie hay was considered as based of forage. To determine the amount of forage consumed, the Animal Unit Month (AUM) was used. The AUM is defined as the amount of forage dry matter consumed by the cow-calf pair (based on standard weight, 455 kg) in one month, which was assumed at 309 kg of dry matter. Diets for growing replacement heifers (Appendix 2) were described by Werth (1990): from October 15

following weaning to April 30, the diet was composed of 4.42, 1.19, and 0.34 $kg.hd^{-1}.d^{-1}$ of prairie hay, corn, and 44% protein supplement, respectively; from May 1 to May 31, the diet was composed of 5.13, 1.42, and 0.27 $kg.hd^{-1}.d^{-1}$ of prairie hay, corn, and 44% protein supplement, respectively; from June 1 to August 31 following breeding, and from September 1 to October 31, heifers was grazed summer pasture in 0.7, and 0.8 AUM equivalent, respectively; from November 1 to December 31, heifers grazed winter pasture (0.8 AUM) and received 0.82 $kg.hd^{-1}.d^{-1}$ of 44% protein supplement; and from January 1 to March 23 (calving), the diet was 7.15, 1.24, and 0. 40 $kg.hd^{-1}.d^{-1}$ of prairie hay, corn, and 44% protein supplement, respectively. The diet for 2-yr cow, 3-yr cow, mature cow, and bulls are shown in the Appendixes 3, 4, 5, and 6, respectively.

Postweaning. After weaning, heifers and bulls not retained for replacement were split into either a calf-fed or yearling system. In the calf-fed system, steers were fed a finishing diet for 211 d and heifers for 240 d (Appendix 7) composed of 43.8, 43.8, 7.5, and 4.9% on a DM basis of dry-rolled corn (DRC), wet distiller grains plus soluble (WDGS), alfalfa, and supplement, respectively (Wilken et al., 2009). The yearling system included 315 d of a growing period (198 d of winter and 117 d of summer), and 90 d and 120 d of finishing period for steers and heifers, respectively. Diets for the growing period (Appendix 8) were derived following Werth (1990) and diet for finishing period was the same as for the calf-fed system.

Livestock prices for Nebraska are shown in Appendix 9. Monthly Nebraska livestock prices for heifer and steer feeder calves, replacement heifers, heifer and steer carcasses, and premiums and discounts were collected from USDA Agricultural Marketing Service (2012) for a 10-yr period (2003-2012). The price for bull replacement was obtained from the American Angus Association (2012) for a 5-yr period (2008 to 2012). Prices were adjusted for inflation

using Consumer Price Index (CPI) for Midwest urban area (United States Department of Labor, Bureau of Labor Statistic, 2012) to adjust all prices to June-2012 dollars. Average October and November price was assumed for cull cows at weaning and weaned calves; average March and April price was assumed for cull cows following calving and replacement heifers; average February, March, and April price was assumed for replacement bulls; average May and June carcass price was assumed for heifers and steers from the calf-fed system; and average November and December carcass price was assumed for heifers and steers from the yearling system. Prices of calves at weaning and heifers for replacement were in dollars per kg of live weight, price of bulls for replacement was based on dollars per head, prices for cows and heifers sent to slaughter were on a heifer carcass price basis, and prices of bulls and steers sent to slaughter were on a steer carcass price basis. To find the final carcass price, the carcass base price was adjusted by average 10-yr period (2003-2012) premium and discount (Appendix 11).

Premiums and discounts in each group were considered using the USDA quality grade, yield grade, carcass weight, and carcass maturity over 30 mo. Carcass characteristics were based on Anderson et al. (2005) and Adams et al. (2009), phenotypic values for steers in calf-fed and yearling system were 5.80 and 5.17, 1.51 and 1.36 cm, 74.76 and 84.17 cm^2, 3.5 and 3.68 %, and 62.5 and 63.5 % for marbling score, 12^{th}-rib fat thickness, LM area, KPH, and dressing percentages, respectively. The carcass characteristics for the other groups were calculated in reference to a steer in the calf-fed system following the proportion shown in Appendix 12.

Feedstuff prices for Nebraska were collected from the USDA Agricultural Marketing Service (2012) for a 10-yr period (2003-2012, Appendix 10), price for summer pasture rent was obtained from Nebraska Farm Real Estate Market highlights (Johnson and Van Newkirk, 2012) for a 10-yr period (2003-2012), and winter rent price was assumed to be one-half the value of

summer pasture on an AUM basis (Werth, 1990). A 10% shrink, processing, and handling of feed was applied to corn price (Jordon, 2000). Prices from each year were adjusted for inflation using Consumer Price Index (CPI) for Midwest urban area (United States Department of Labor, Bureau of Labor Statistic, 2012) to adjust all prices to the first 6 mo average in 2012 dollars. Non-feed costs for the cow-calf production phase were obtained from USDA Agricultural Marketing Service (2012) for a 9-yr period (2003-2011), and non-feed cost for post-weaning period was extracted from Jordon (2000). Both non-feed costs for cow-calf and the postweaning period were adjusted for inflation to 2012 dollars.

Biological Efficiency of beef production

A deterministic model was used to simulate the input and output based on 1000 cows at calving, and then all the values were calculated on a one-bred-cow basis. Microsoft Office Excel 2007 was used to simulate this model. The herd composition was estimated based on reproduction, survival, and selection parameters (Figures A1, A2, and A3). Retention of cows was based on their reproductive performance and age limit, all cows failing to calve or if losing their calves within the 15 d after calving were culled, all cows diagnosed as non-pregnant at weaning were culled, and all cows over 9 yr of age were culled after weaning. Heifers diagnosed as non-pregnant were sent to the yearling finishing system. Calves at weaning were separated into heifers and bulls to be retained for replacement, heifers and steers for the calf-fed system, and heifers and steers for the yearling system.

The number of heifers and bulls retained for replacement was estimated in relation to the number of heifers at calving and young bulls for replacement at breeding required, maintaining the number of cows at calving constant. Weaning heifers that were not retained for replacement

were divided into heifers to the calf-fed system (50%), and heifers sent to the yearling system (50%). Weaned male calves that were not retained for replacement were split as steers sent to the calf-fed system (50%), and steers sent to the yearling system (50%). One calving season (March and April), ratio 50:50 male:female calves at birth, 205 d average weaning age, 25 cow per breeding bull, replacement of 20% of bulls every year, and 5% calving difficulty were assumed.

Output was estimated based on of the number and weight of animal groups from each scenario. Cow weight was estimated using Brody's equation described previously, depending on the milk production level and age of cows. Final weight in calf-fed or yearling systems was estimated using the weaning weight and postweaning gain shown in Table 1. Carcass weights and characteristics were estimated using the relationship shown in Appendix 12.

Input for feed cost was estimated on the basis of energy for maintenance, gestation, lactation, and tissue gain or loss in calves, cows, and bulls. The procedure to estimate the energy requirement followed the method explained by Montaño-Bermudez and Nielsen (1990c). Biological efficiency was estimated for two scenarios, one where calves were sold at weaning and another where calves were sold at slaughter. For the scenario where calves were sold at weaning, grams of live weight produced per cow bred per unit (Mcal) of metabolizable energy (ME) consumed was estimated; For those sold at slaughter, efficiency was measured as grams of carcass produced per megacalorie of ME consumed.

Economics Analysis: breakeven, profit, and economic efficiency

Cost, breakeven, profit/loss per cow exposed were analyzed to weaning (from birth to weaning), and for postweaning phase (growing in yearling system, finishing in yearling system, and finishing in calf-fed system). Economic efficiency was estimated to weaning and to

slaughter. The costs of labor and overhead were included. Breakevens were calculated by dividing the total cost by the total product produced (kg of BW or carcass); profit/loss was calculated as total revenue minus total cost; and economic efficiency was defined as the ratio of dollars output to dollars input.

To weaning. Input included feed and non-feed costs, and interest for the cowherd; output included income from calves sold at weaning, cull cows, and cull bulls. Feed cost was based on metabolizable energy (ME) consumed (Appendix 13) for the following categories: nursing calves, replacement heifers from weaning to calving, replacement bulls from weaning to breeding, lactating cows, pregnant cows, and aged bulls (bulls for breeding). The feeding programs and feedstuffs required for each category were those described by Werth (1990). The energy content of the diets was calculated following the Nutrient Requirements of Beef Cattle (National Research Council, NRC, 1996). Inflation-adjusted prices were for summer pasture, $ 0.095/kg; for winter pasture, $ 0.047/kg; for prairie hay, $0.069/kg; for corn, $0.139/kg; for 44% protein supplement, $0.413/kg (based on soybean price); and for salt and mineral, $3.98/cow. The non-feed cost was obtained from USDA Agricultural Marketing Service (2012) for a 9-yr period (2003-2011). Non-feed costs after adjustment for inflation to first semester 2012 average dollars were $31.86; $ 0.62; $10.41; $30.88; $53.46; and $42.19/per cow exposed for veterinary and medicine; bedding and litter; marketing; custom operation; fuel, lubricant, and electricity; and repairs, respectively. Average Effective Interest Rate on Non-Real Estate Bank Loans Made to Farmers was used to calculate the interest cost (Federal Reserve Bank of Kansas City, 2003-June 2012). Interest of 3.7% annually (6% minus 2.3% inflation adjusted) was considered, and half interest was charged on feed and variable costs incurred during ownership.

Adjusted cow cost to weaning was calculated by subtracting non-calf income (cull cows, cull bulls, and non pregnant heifers) from total operation cost. Breakeven was calculated by dividing the adjusted cow cost by weaning weight (live weight basis). Revenue for calves was calculated using the number of weaned calves, the corresponding weaning weight and feeder price, depending on parity of the mother. Profit/loss was calculated subtracting the revenue from weaned calves minus the adjusted cow cost.

Weaning income was estimated by using inflation-adjusted 10-yr (2003 – 2012) average October and November prices. Weaned feeder calf prices for steers and heifers from 181 to 204 kg, 204 to 227 kg, 227 to 250 kg, and 250 to 273 kg were $3.46 and $3.08, $3.28 and $2.95, $3.12 and $2.83, and $2.98 and $2.75 per kg of BW, respectively. To estimate the cull-cow and cull-bull income, inflation-adjusted 10-yr (2003-2012) average carcass price of October and November, and March and April was used for cows and bulls culled at weaning, and cull cows at calving, respectively; average carcass base price for cull cows at weaning and calving was $3.66 and 3.37 per kg of carcass, respectively; average carcass base price for cull bulls was $3.65/kg of carcass. Premiums and discounts were applied to estimate the final carcass price based on the relationship shown in Appendices 9 and11.

Postweaning. Income from carcasses of calves sold at slaughter; and costs for feed and non-fed expenses, initial cost of calves, and interest were included in the economic analysis. The prices for weaned calves were the same in the weaning phase for both the calf-fed and yearling systems. Grid base prices for calf-fed and yearling system calves sent to slaughter were $3.59 and $3.69/kg of carcass, respectively, for both heifers and steers. To find the final carcass price, the carcass base price was adjusted for premiums and discounts (Appendix 11).

Feed cost was estimated for heifers and steers in calf-fed and yearling systems, based on the ME requirement and the price per unit of ME, estimated by combining the price of the different amounts of feedstuffs with their respective ME content. Metabolizable energy required was estimated following the procedure described by Montaño-Bermudez and Nielsen (1990c). Levels of feedstuffs actually fed were assigned to meet the energy requirements. The feedstuff and inflation-adjusted price were: summer pasture, $ 0.095/kg; winter pasture $ 0.047/kg; prairie hay, $0.069/kg; corn $0.139/kg; soybean meal, $0.413/kg; and salt and mineral, $3.98/cow.

Data from Jordon (2000), adjusted for inflation, were used to derive the non-feed costs (medical, yardage, and miscellaneous) for the postweaning period. Prices after adjusted to first-semester-2012 dollars for growing period in the yearling system were $4.64, $8.04, and $0.69 per cow-bred.period^{-1} for processing, drylot yardage, and mineral supplementation, respectively; for finishing in yearling system were $8.20, and $1.27 per cow-bred.period^{-1} for yardage, and processing, respectively; for calf-fed system were $17.51, and $3.48 per cow-bred.period^{-1} for yardage, and processing, respectively. Interest of 3.7% annually (6% minus 2.3% inflation adjusted) was applied; full interest was charged on the initial cattle price cost, and half interest was charged on feed and variable costs incurred by each period during ownership.

Cost, breakeven, revenue and profit/loss were calculated for growing and finishing period of yearling system, and for calf-fed system. Calf purchase cost was included as initial cost for each phase; the price for calves at beginning of one phase was the same as the end of their previous phase. Breakeven was calculated in dollars by kg (on live base) for growing period in yearling system, in dollar by kg (carcass) for finishing period in yearling system and calf-fed system.

Economic efficiency. Economic efficiency, defined as dollars output per dollars input, was estimated to weaning and to slaughter. Input to weaning included feed and non-feed costs for cowherd, aged bulls, nursing calves, heifers from weaning to calving, and bulls from weaning to breeding. Output to weaning was income from calves at weaning (included non-replacement calves), from cull cows and aged bulls, and from non-pregnant heifers at pregnancy test. Input to slaughter included the input to weaning plus the feed and non-feed cost during the postweaning phase. Output to slaughter included the income from cull cows and aged bulls, and from heifers and steers sent to slaughter from yearling and calf-fed systems.

Results and Discussion

Biological output, input and efficiencies

Table 3 lists the weaning and carcass weights, the ME required for cows and calves, and the biological efficiency. Weaned calves produced, in kg of BW/cow exposed, was 3.8 and 8.0% greater for M and H groups, respectively, than for the L group. These differences reflect the effect of dam milk production on the preweaning gain; strong positive relationship between those two variables was reported in the literature (Clutter and Nielsen, 1987; Miller et al., 1999; Brown and Brown, 2002). However, these differences between milk level groups decreased when the total kg produced (cull cows and weaned calves)/ cow exposed to weaning were analyzed, where L group was 0.32% greater than group M, but 1.91 % less than group H. This reduction is explained by the greatest cull cow output for group L, due to the greatest cow BW in group L explained for the assumption made that L cows had a greater body condition score and thus were heavier. The total output at slaughter was 1.7 and 1.1% less for groups M and H, respectively, than for group L. This difference is mainly due to the greater cull-cow carcass weight in group L

than groups M and L, and the dam's milk effect during the preweaning period is offset by the compensatory growth after weaning. Maternal effect on the weaning weight decreases significantly during the postweaning period (Costa et al., 2011; Koch et al., 2004).

The low milk group required the least energy both when calves were sold at weaning and at slaughter. Energy input to weaning was 8.8 and 10.8% greater for M and H, respectively, than for L, mainly because of the greater input for M and H than for L cows, where the input in M and L group was 12.3 and 15.8% greater, respectively, than L. This difference is explained by the additional energy required for milk production in H and M than L. Milk production is directly associated with maintenance requirement, and milk production difference explained 23% of maintenance requirement in beef cattle (Montaño-Bermudez et al., 1990a). The potential increment of energy for maintenance in high milk yield cows may be related in part to the increase in size of the lung and liver (Ferrell and Jerkins, 1985).

Biological efficiency was highest for the L group to both weaning and to slaughter endpoints. The low milk group showed 8.3 and 8.0 % more biological efficiency to weaning than M and H, respectively; similarly, to slaughter low milk cows showed 8.4 and 9.0% more efficiency than M and H, respectively. The biological efficiency was similar for M and H groups to both weaning and slaughter endpoints. The differences in biological efficiency are mainly attributed to the greater input in M and H compared to L group. This result confirms that reported by Oijen et al. (1993) that also utilized data by Montaño-Bermudez et al. (1990a,b) to estimate the energy requirement for levels of milk production. But it contradicts results reported by Freking and Marshall (1992) and Miller et al. (1999). Freking and Marshall (1992) reported that increasing milk yield tended to improve biological efficiency to weaning. Under Canadian conditions, Miller et al. (1999) reported a positive relationship between milk level of cows and

biological efficiency for low and medium milk level cows. However, this relationship was much less evident in cows with high level of milk productions. These differences may be explained in part by breed differences, and level of milk production. Freking and Marshall (1992) reported that biological efficiency was greater at an intermediate level of milk production.

Economic evaluation: cost, revenue, breakeven, profit/loss, and economic efficiency

Calves sold at weaning. A summary of cost per cow, cost per calf weaned, and breakeven excluding overhead cost is shown in Table 4. Cost per weaned calf was 10.8 and 12.8% greater for M and H cows, respectively, than by L group cows. These differences are mainly due to the higher feed cost in M (8.7%) and H (10.8%) cows. Weaning calves per cow exposed breakeven was 6.7 and 4.4% higher in M and H group cows, respectively, than L cows. This difference was decreased compared to cost per weaning because the higher costs per weaning in M and H cows were compensated by the higher weaning weight in calves from M (3.8%) and H (8.0%) cows, respectively, than from L cows. Revenue was 3.6 and 6.2 % higher in M and H group cows, respectively, than L group cows. This difference is explained because the larger weaning weight in M and H group cows compared to L group cows; however, this advantage decreased compared to the difference found in weaning weight because of the variation in feeder calves price, where lighter weight feeder calves had higher price per kg basis. Net profit/loss in the scenario where calves were sold at weaning was greater for L at -$6.4/ cow exposed, followed by H at -$33.5/ cow exposed, and poorest for M (-$35.5/cow exposed). This economic advantage in L groups cows is explained mainly for the lowest cost in L than in M and H group cows, since the income difference was offset by the additional income from cull cows in L cows, due to assumption made that L cows weigh more than M and H group cows, and for the higher price per kg of feeder calves received from L group cows. Stokes et al. (1986), analyzing the economic

effects of cow size and milking level in cow-calf operations, found that calves from dams with high milk production were fatter and received lower price due to the condition discount, and the highest return to land was found in lower milk production and larger cow size. However, this economic advantage of L cow to weaning is in contrast to that reported by Miller et al. (1999). They reported, for beef cattle in Canada, higher profit occurred for cows with high levels of production.

Postweaning. Cost, breakeven, and profit/loss in yearling and calf-fed system are summarized in Table 5. Cost of growing in yearling system was 4.0 and 6.2% greater for groups M and H, respectively, than by L cows. These differences are explained for both the greater initial calf cost in M (3.6%) and H (6.2%) and greater feed cost in M (5.8%) and H (7.7%) compared to L group cows. Breakeven for kg of BW produced per cow exposed in growing period was 4.8 and 4.8% higher in M and H group, respectively, than in L group cows. Net profit/loss for growing period was higher for L, at $11.01/cow exposed; followed by M, at -$3.53/cow exposed; and lowest for H, at -$3.69/ cow exposed. This advantage in income in L is explained due to lowest initial calf and feed cost, and the postweaning compensatory growth; where, the lowest weaning weight in L calves was offset by compensatory growth after weaning.

Cost in the finishing period for yearling cattle was 0.2% lower in M and 1.2% greater in H, than by in L. In a calf-fed system, costs were 4.0 and 5.0% greater for M and H, respectively, than in L. Finishing breakeven in yearling, and calf-fed system was 0.9 and 1.5%, and 4.2 and 4.6% higher in M and H, respectively, than in L. Net profit/loss for finishing period for yearling and calf-fed system was highest for L ($22.31/cow exposed and $25.20 / cow exposed), followed by M ($18.19/cow exposed and $10.86/cow exposed), and lowest for H ($15.99/cow exposed and $9.70/cow exposed). The economic advantage for L was due to the lowest initial calf

purchased cost, lowest feed cost, and compensatory growth after weaning. The economic effect of compensatory growth demonstrated more profit for calves from L cows than from M and H cows, $11.01 vs. -$3.53 and -$3.69/cows exposed. The advantages of yearling system over calf-system confirm the results reported by Anderson et al. (2005); they found the yearling system was more profitable than the calf-fed system, working with cornstalks as a base diet for growing period in yearling system. However, this result contradicts that reported by Small et al. (2009) and Adams et al. (2009). Adams et al. (2009), analyzing sorting effect, found that a calf-fed system was more profitable than a yearling system, Small et al. (2009), analyzing the profit variability for calf-fed and yearling production systems from 1996 to 2007, found marginal additional profit in calf-fed system, $2.28/head higher, than in yearling system. This difference may be explained in part by the differences in source of feedstuffs especially in growing phase of a yearling system. Small et al. (2009) found that the economic efficiency in yearling systems is more variable than calf-fed systems due to the variability in the source of feedstuffs used in the growing period.

Total expenses, income, and economic efficiency to weaning and to slaughter are shown in Table 6. The total expenses for the scenario where calves are sold at weaning were 6.1 and 7.5% higher for M and H group, respectively, then L group. The respective values for the scenario where calves are sold at slaughter were 5.3 and 6.1%. Income for weaned calves was 3.6 and 6.2% greater for M and H group, respectively, than for L group. This difference is explained by the higher weaning weight in M and H group than in L group calves. However, this difference decreased at slaughter due to compensatory growth in L group. Total income for the scenario where calves were sold at slaughter was 1.5 and 0.9% lower for M and H group, respectively, than for L. This difference is explained for the higher cow carcass weight in L than

in M and H, and the fact that differences in weight at weaning eroded during the postweaning phase due to compensatory growth of L calves.

Economic efficiency (Table 6) was greater for L group to both weaning and slaughter endpoints. There was not much difference between groups M and H in both scenarios. Differences in expenses contributed more to variation in efficiency than the difference in income. This result confirms that reported by Van Oijen et al. (1993) and is in agreement to that reported by Stokes et al. (1986). However, it contradicts that reported by Miller et al. (1999), who found potential positive effect of milk production on the profit to slaughter. These discrepancies relative to milk production level on profitability may be explained by the breed used in the studies, feed costs, relationship of feed costs between feedlot and cow-calf periods, and level of milk production. Increasing milk production will increase the efficiency of beef production if the price of feed increases (Notter et al., 1979) and the ratio feed cost feedlot:cow-calf increase (Bourdon and Brinks,1987).

Comparison of Biological to Economic efficiency

The results of the economic efficiency were similar to the results of the biological efficiency. Figure 1 shows the comparison of biological to economic efficiency on relative basis (L=100) for the scenario where calves were sold at weaning. Figure 2 has the same comparison for the scenario where calves were sold at slaughter. For both economic and biological efficiencies, the higher output of the M and H were balanced by higher input. The M and H were 8.3 and 8.0%, respectively, lower in the scenario where calves were sold at weaning, and 8.4 and 9.0% lower in the scenario where calves were sold at slaughter than L for biological efficiency. Corresponding comparison for economic efficiency were 4.7 and 4.3% less when calves were

sold at weaning and 6.4 and 6.6% less when claves were sold at slaughter. Although the relative difference was not quite as large for economic efficiency compared to biological efficiency, the L group remained the most efficient of the three.

Implication

Because the higher biological and economic advantage of cows with low levels of milk production, a breeding objective including selection for reducing milk production seems reasonable. However, an optimum level of milk yield that may vary with the production system needs to be considered. Additionally, The advantage of a yearling system over a calf-fed system indicates that producers should consider selling at slaughter than at weaning. However, the variability in the profit on the growing phase of yearling system should be considered and is a function of the source of feedstuffs for growing period.

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Table 1. Mature weights of cows, and growth traits of calves from three milk-level groups

Trait	Age of cow at breeding, yr	Milk group		
		Low	Medium	High
Birth wt, kg[a]	1	34	34	34
	2 +	39	38	38
Weaning wt, kg[a]	1	199	216	224
	2	222	233	240
	3 +	243	248	259
Postweaning ADG, kg[b]				
Yearling system Growing period				
Winter period				
Females				
	1	0.43	0.41	0.41
	2 +	0.48	0.48	0.47
Males				
	1	0.50	0.48	0.48
	2 +	0.58	0.53	0.53
Summer period				
Females				
	1	0.75	0.72	0.72
	2 +	0.84	0.83	0.82
Males				
	1	0.88	0.84	0.84
	2 +	1.01	0.93	0.93
Yearling system, finishing period				
Females				
	1	1.55	1.51	1.47
	2 +	1.66	1.66	1.60
Males				
	1	1.87	1.82	1.76
	2 +	2.00	1.91	1.90
Calf-fed system				
Females				
	1	1.27	1.23	1.20
	2 +	1.35	1.35	1.31
Males				
	1	1.52	1.49	1.44
	2 +	1.63	1.56	1.55
Cows mature wt, at 5+ yr, kg[c]	5 +	591	558	558

[a] Van Oijen et al. (1993)

[b] Anderson et al. (2005) and Van Oijen et al. (1993)

[c] Montaño-Bermudez and Nielsen (1990b), Arango et al. (2002), Nephew et al. (2004), and Costa et al. (2011). Differences in MW between L, M, and H are explained by the difference in body condition score among these groups.

Table 2. Milk production of cows, reproductive performance, and maintenance energy requirements under three scenarios of milk-level groups

		Milk group		
Trait	Age of cow at breeding, yr	Low	Medium	High
Pregnancy rate, %[a]	1	90.2	90.2	90.2
	2	87.5	87.5	87.5
	3 +	93.3	93.3	93.3
Calving rate, %	1	88.0	88.0	88.0
	2	85.4	85.4	85.4
	3 +	91.1	91.1	91.1
Calf-crop rate, %	1	80.0	80.0	80.0
	2	77.8	77.8	77.8
	3 +	83.0	83.0	83.0
Gestation length, d[a]	1	282	281	281
	2 +	285	284	284
205-d milk production, kg[a]	1	990	1355	1511
	2	1227	1568	1730
	3 +	1285	1632	1879
Energy for maintenance[b], $kcal.kg^{-.75}.d^{-1}$				
Mature cows				
Gestation		97	112	112
Lactation		126	145	145
Growing cattle				
Replacement breeding stock		132	147	147
Feedlot animals		144	160	160

[a] Montaño-Bermudez and Nielsen (1990c)

[b] Van Oijen et al. (1993)

Table 3. Biological outputs, inputs, and efficiencies per cow exposed to breeding for cattle of three milk-level groups

Item	Milk level Low	Medium	High
Output, kg[1]			
For calves sold at weaning, kg of live weight basis			
Culled cows wt	104.0	98.2	98.2
Culled bulls from breeding wt	4.1	4.1	4.1
Non-pregnant heifers wt	8.0	8.0	8.0
Weaned calves wt[2]	132.0	137.0	142.6
Total at weaning wt	248.4	247.4	252.9
For calves sold at slaughter, carcass weight basis			
Culled cow carcass	55.3	52.2	52.2
Culled bulls from breeding carcass	2.5	2.5	2.5
Heifers and steers sold to slaughter carcass	219.1	217.5	220.3
Heifers and bulls sold for reproduction carcass	0.0	0.0	0.0
Total at slaughter, carcass base	276.8	272.1	274.9
Input[3], Mcal (x 10^3)			
For calves sold at weaning	8.34	9.06	9.23
Cows	5.44	6.11	6.30
Calves from sources other than milk	0.99	1.00	0.99
Heifer for replacement	1.69	1.74	1.73
Bulls for breeding and replacement	0.22	0.22	0.22
Calves postweaning	4.39	4.60	4.62
For calves sold at slaughter	12.73	13.66	13.85
Biological Efficiency			
For calves sold at weaning[4]	29.76	27.29	27.39
For calves sold at slaughter[5]	21.75	19.92	19.84

[1] Kilograms of live weight of carcass weight per cow exposed

[2] Non-include heifers and bulls retained for replacement

[3] Metablizable energy fed directly to cows, bulls and calves

[4] Kilograms of live weight when calves are sold at weaning per total cow, bulls, and calf energy, grams per megacalorie.

[5] Kilograms of carcass weight when calves are sold at slaughter per total cow, bulls, and calf energy, grams per megacalorie.

Table 4. Cost per cow, cost per calf weaned, and breakeven excluding overhead

	Milk group		
Item	Low	Medium	High
Operating costs:			
Feed, $/cow	405.67	440.95	449.15
Purchased cattle for backgrounding, $/cow[1]	0.00	0.00	0.00
Other operation cost, $/cow	172.52	172.52	172.52
Total operating costs, $/ cow	578.20	613.48	621.68
Noncalf revenue, $/Cow[2]			
Cull cow, $/cow	146.8	138.6	138.6
Bull cow, $/cow	6.7	6.4	6.4
Nonpregnant heifers, $/cow	20.5	20.5	20.5
Total noncalf revenue, $/cow	173.6	165.5	165.5
Adjusted cow cost, $/Cow[3]	404.6	448.0	456.2
Weaned Calf, kg/cow			
Number of female calves weaned, $head.cow^{-1}$	0.2	0.2	0.2
Number of male calves weaned, $head.cow^{-2}$	0.4	0.4	0.4
Average female weaning weight, $kg.head^{-1}$	218.0	226.3	235.5
Average male weaning weight, $kg.head^{-2}$	241.0	250.1	260.2
Weaning weight, $kg.Cow^{-1}$	132.0	137.0	142.6
Cost per weaned calf, $[4]	717.3	794.4	808.9
Breakeven, $/kg[5]	3.07	3.27	3.20
Revenue, $/cow-bred[6]	398.1	412.5	422.7
Net profit/loss, $/cow-bred[7]	-6.5	-35.5	-33.5

[1] Include purchase and interest of heifers and bulls

[2] Non-calf revenue = revenue for cow cull, bull cull and nonpregnant heifers.

[3] Adjusted cow cost = Cow cost - noncalf revenue.

[4] Cost per weaned calf = Adjusted cost calf / Number of calf per cow bred

[5] Breakeven =Cost per weaned calf /weaning weight per cow bred

[6] Revenue = weaning weight * price per kg

[7] Net profit/loss = Revenue - Adjusted cow cost

Table 5. Cost per cow, cost per calf weaned, and breakeven excluding overhead in yearling and calf-fed system

Item	Milk group		
	Low	Medium	High
Yearling system			
Growing period			
Initial steers and heifers cost, \$/cow-bred	199.03	206.27	211.36
Fed cost, \$/cow-bred	83.47	88.34	91.41
Other cost, \$/cow-bred	24.02	24.25	24.41
Total cost, \$/cow-bred[1]	306.52	318.87	327.18
BW, live base, kg/cow-bred	124.50	123.64	128.09
Breakeven, \$/ kg[2]	2.46	2.58	2.55
Revenue, \$/cow-bred[3]	317.53	315.34	326.68
Net profit/loss, \$/cow-bred[4]	11.01	-3.53	-0.50
Finishing period			
Initial steers and heifers cost, \$/cow-bred	338.03	335.85	347.18
Fed cost, \$/cow-bred	69.74	70.93	70.87
Other cost, \$/cow-bred	15.25	15.23	15.34
Total cost, \$/cow-bred[1]	423.02	422.01	433.39
BW, live base, kg/cow-bred	187.63	185.46	188.99
Breakeven, \$/kg[2]	2.25	2.28	2.29
Revenue, live basis, \$/cow-bred[3]	435.78	430.76	438.94
Net profit/loss, live basis, \$/cow-bred[4]	12.75	8.75	5.54
Revenue, grid basis, \$/cow-bred[3]	445.34	440.20	448.64
Net profit/loss, grid basis, \$/cow-bred[4]	22.31	18.19	15.24
Calf-fed system			
Initial steers and heifers cost, \$/cow-bred	199.03	206.27	211.36
Fed cost, \$/cow-bred	102.34	108.34	106.45
Other cost, \$/cow-bred	32.38	32.53	32.64
Total cost, \$/cow-bred[1]	333.75	347.14	350.44
BW, live base, kg/cow-bred	160.90	160.57	161.45
Breakeven, \$/kg[2]	2.07	2.16	2.17
Revenue, live basis, \$/cow-bred[3]	362.80	362.06	364.04
Net profit/loss, live basis, \$/cow-bred[4]	29.05	14.92	13.60
Revenue, grid basis, \$/cow-bred[3]	358.94	358.00	360.14
Net profit/loss, grid basis, \$/cow-bred[4]	25.20	10.86	9.70

[1] Total cost = Initial cost + fed cost +other cost
[2] Breakeven =Cost per weaned calf /weaning weight per cow bred
[3] Revenue = Total weight in kg * price per kg
[4] Net profit/loss = Revenue - total cost

Table 6. Income, expenses, and economic efficiencies per cow exposed to breeding for cattle of three milk-level groups

	Milk level		
Item	Low	Medium	High
Income			
When calves were sold at weaning			
Calves, $	398.1	412.5	422.7
Non-pregnant heifer, $	20.5	20.5	20.5
Cull cows, $	153.1	145.0	145.0
Total, $	571.68	578.01	588.17
When calves were sold at slaughter, $			
Calves, $	804.28	798.2	808.8
Heifers and bulls for replacement, $	0.0	0.0	0.0
Cull cows, $	153.5	145.0	145.0
Total, $	957.78	943.2	953.7
Expenses			
When calves were sold at weaning, $	578.20	613.48	621.68
When calves were sold at slaughter, $	905.4	953.1	962.8
Economic efficiency[a]			
When calves were sold at weaning, $	98.9	94.2	94.6
When calves were sold at slaughter, $	105.7	99.0	99.1

[a] (\$/\$) * 100

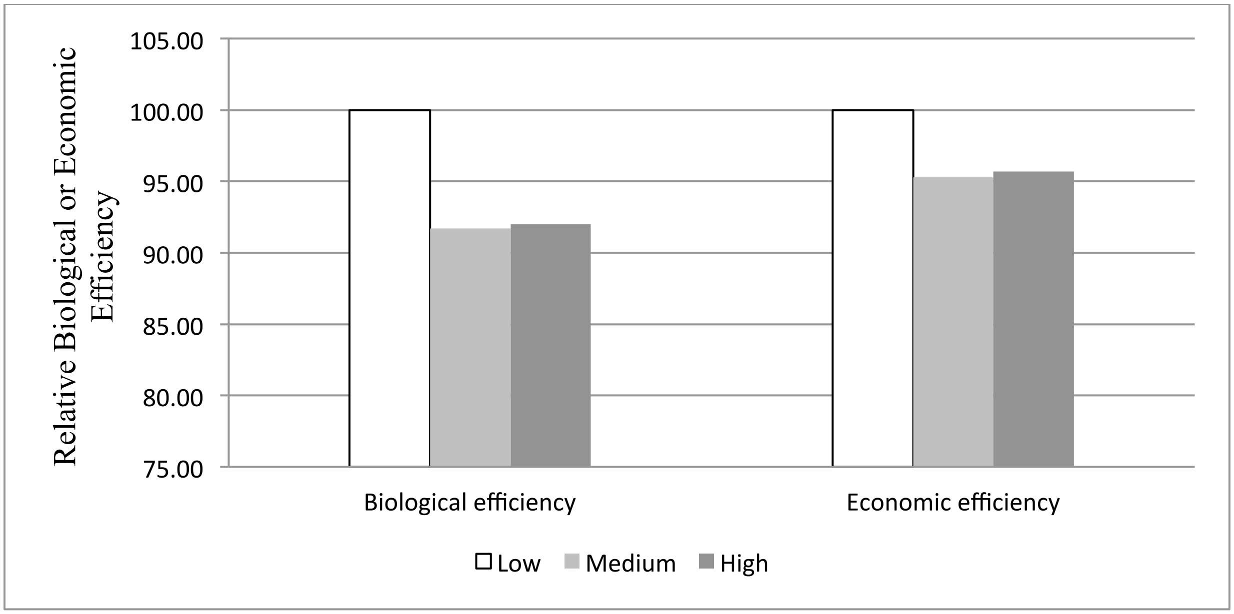

Figure 1. Biological and economic efficiencies when calves were sold at weaning for beef cattle with three levels of milk production, medium and high relative to low = 100

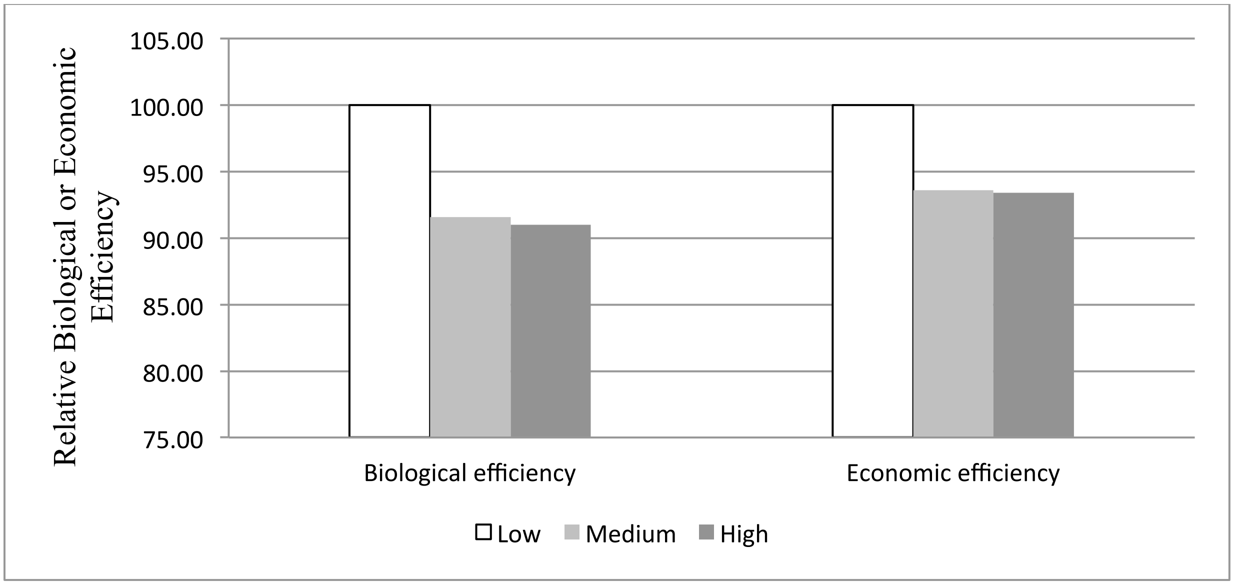

Figure 2. Biological and economic efficiencies when calves were sold at slaughter for beef cattle with three levels of milk production, medium and high relative to low = 100

PART II: Breeding Objective For Improving Efficiency Of Beef Cattle

ABSTRACT: A stochastic simulation model was used to estimate the economic values for a breeding objective based on eleven traits for beef cattle under Nebraska conditions, and selection indexes based on EBV were estimated. Published data were used as a source of information for this study. Average prices for a 10-yr period, production, reproductive, and survival performance since 2000, and genetic parameters published since1980 were used in the simulation. A total production system was considered, based on 1000 cows at calving, where the replacements were produced in the system, and calves were sold at slaughter. Profit (income minus expenses) was estimated on a per-cow basis. The economic value for each trait was estimated as change in profit/loss per unit change of each trait when the other traits were held constant. The relative economic value was estimated as a product of the economic value and the genetic standard deviation. Selection index weights were estimated based on genetic variances and covariances extracted from the literature. The eleven traits had significant effect on profit ($P < 0.001$). The economic values and the relative economic values for eleven traits considered were: milk production (milk, kg.205^{-1} d), average post weaning daily gain (ADG, kg/d), mature weight (MW, kg), dressing percentage (DP, %), rib fat thickness (FAT, cm), kidney-pelvic-heart fat (KPH, %), ribeye area (REA, cm^2), marbling score (MS; 5=Small^0, 6=Modest^0, 7=Moderate^0, and so on), calving difficulty (CD, %), heifer pregnancy (HP, %), and gestation length (GL, d) were: -0.046 and -9.068, 56.195 and 4.957, -0.207 and -7.042, 1.970 and 2.065, -39.285 and -6.904, -7.944 and -2.401, 2.044 and 9.311, 21.974 and 11.023, -0.168 and -0.200, 0.092 and 0.074, and -1.177 and -3.155, respectively. The selection index with the highest correlation with the breeding objective included ADG, FAT, REA, MS, HP, birth weight (BWT; kg), HP, yearling height (YH; cm), and maternal weaning weight (WWM; kg) with weights of 128, -53.0,

1.92, 25.3, 0.08, -3.52, -2.39, -0.72, respectively. For the system of beef production designed for this study, a breeding objective based on decreasing mature weight, milk production, and fat thickness, and increasing marbling score, ribeye area, and postweaning average daily gain would increase the profitability of the beef industry. An additional increase in profitability, but of less magnitude, may be obtained by reducing calving difficulty incidence and KPH, and increasing dressing percentage and heifer pregnancy.

Key words: Stochastic model, breeding objective, selection index, relative economic value

Introduction

Hazel (1943) gave the principles of developing and using a selection index which allow the realization of maximum genetic progress, where the breeding objective should be maximizing the aggregate value of an animal (the sum of its genotypes weighted by the relative economic values (REV) of the independent variable traits). Garrick and Golden (2009) and MacNeil (2008) suggested five steps for developing and implementing a breeding objective. The relative economic value of each economically relevant trait (ERT) should be estimated using the partial derivative of the profit function from a bio-economic model developed. Then, based on a genetic covariance matrix for ERT and traits for which EPD are available, the weights for the breeding values should be estimated, to produce the relative weight for the EPD to evaluate individuals for economic merit. Finally, quantifying the importance of the each trait in the breeding objective will be useful to not only select animals with higher rank, but also to determine the priority in relation to future research and to develop systems for collecting information and evaluation of these traits (Garrick and Golden, 2009). The REV for a trait differs

with the goal of breeding objective, and subsequent markets and the value that can be realized in those markets (Melton, 1995). Melton (1995) found greater REV for maternal and reproductive traits and lower REV for retail product for a cow-calf producer than for the full beef industry. MacNeil et al. (1994), for Canadian beef industry, found that cow weight, female fertility, and maternal effect on weaning weight had economic importance in maternal lines but not in sire lines; and growth had higher REV for the finishing phase than the backgrounding phase. In the U.S. beef system, MacNeil (2005) found a high correlation among breeding objectives for four terminal sire populations.

These studies have identified the necessity for analysis of the production system to define the bio-economic objective (MacNeil et al., 1988), based on the ERT that affect profit, where the income and cost should be based on future economic conditions (Garrick and Golden, 2009; Dickerson et al., 1974; Harris, 1970); the necessity for reliable multiple-trait selection (MacNeil, 2005); and the necessity of long-term economic and production information (MacNeil et al., 1994). Thus, the objective of this study was to use a stochastic simulation model to estimate the relative economic value for eleven traits for a general purpose beef production system based on long-term economic and production conditions, and to develop selection indexes based on EPD for traits having EPD available.

Materials and Methods

Source of data and simulation process

Data from the literature were used in the simulation study. A stochastic model was simulated using SAS version 9.3. The effect of calving difficulty (CD) was modeled considering the effect on mortality, subsequent reproduction and cow treatment cost. The relationship between

percentage of calving difficulty and the frequency of score of calving difficulty (1 = no difficulty, no assistance, 2 = minor difficulty, some assistance, 3= major difficulty, mechanical assistance, 4 = caesarian section or other surgery, and 5 = abnormal presentation) was estimated using information reported by Berger et al. (1992), Bennett and Gregory (2001), Colburn et al. (1997), Cervantes et al. (2010), and Mujibi and Crews (2009). Using regression analysis between percentage of calving difficulty and each score of calving difficulty, 5 groups of calving difficulty were defined, which included incidence rates of 0 to 15 %; 15 to 35%; 35 to 65%; 65 to 80%; and 80 % and greater. The frequency of CD score of 2, 3, 4, and 5 for incidence rate of 0 to 15% were 0.8399, 0.1599, 0.0001, and 0.0001; for incidence rate of 15 to 35% were 0.67, 0.25, 0.04, and 0.04; for incidence rate of 35 to 65% were 0.34, 0.54, 0.07, and 0.06; for incidence rate of 65 to 80% were 0.22, 0.518, 0.21, and 0.05; and for incidence rate of 80% of grater were 0.13, 0.50, 0.34, and 0.03, respectively. The effect of CD on calf and cow mortality, reproduction, and cost per cow treatment was estimated using the random multinomial sample mean.

The mortality of different CD scores was estimated using information reported by Laster and Gregory (1973) and Cervantes et al. (2010), where the average mortality for CD score 1, 2, 3, 4, and 5 was 5.6, 6.4, 35.2, 31.8, and 42.8% , respectively. The effect on reproduction was estimated based on Colburn et al. (1997) and Meijering (1984) where the subsequent pregnancy rate in cows experiencing CD decreased, with respect to cow not experiencing CD, in a proportion of 0.94, 0.93, 0.82, and 0.79 for CD score of 2, 3, 4 and 5, respectively. Cost per treatment of cow experiencing CD was calculated following Rusche (2012), assuming 2, 3, 4, and 3 h labor for CD score 2, 3, 4, and 5, respectively; and number of veterinarian calls of 0, 0, 2, and 1 for CD score 2, 3, 4, and 5, respectively; and additional cost (for medicines and producer

labor) of 15, 30, 60, and 45 $/head for CD score 2,3,4,and 5, respectively. The cost per treatment (veterinarian calls and additional costs) of cow for CD score 2, 3, 4, and 5 was estimated at $35, $70, $170, and $130 per event, respectively.

A binomial distribution was assumed to simulate pregnancy rate in cows 2 yr and older ($p = 0.933$), abortion from pregnancy test to calving ($p = 0.023$), calf mortality at birth ($p = 0.064$), cow mortality at calving ($p = 0.005$), calf mortality from birth to weaning ($p = 0.029$), calf mortality from weaning to yearling ($p = 0.01$), annual mortality from 1 to 2 yr of age ($p = 0.02$), and annual mortality from 2 yr and older ($p = 0.015$).

Livestock and feedstuff prices, interest rate, and metabolizable energy cost per metabolic size per day (MEM, kcal. $kg^{-0.75}.d^{-1}$) were simulated following a normal distribution. The livestock and corn prices were simulated considering the correlation of these prices with steer carcass price for March and April, and feedstuffs prices (relative to corn) were simulated considering the correlation of these last prices with corn price. Prices were based on 10-yr period (2003 – 2012) and were adjusted for inflation rate to 2012 basis; the average, standard error, and correlations used are shown in Appendices 9 and 10.

Ranges and increments of the candidate traits for the breeding objective analyzed in the current simulation were based on the peer-reviewed information published since 2000 (Table 1). Eleven traits were considered: milk production (Milk, $kg.205^{-1}$ d), average post weaning daily gain (ADG, kg/d, based on calf-fed steers), mature weight (MW, kg), dressing percentage (DP, %), rib fat thickness (FAT, cm), kidney-pelvic-heart fat (KPH, %), ribeye area (REA, cm^2), marbling score (MS; 5=$Small^0$, 6=$Modest^0$, 7=$Moderate^0$, and so on; Beef Improvement Federation, 2010), calving difficulty (CD, %), heifer pregnancy (HP, %), and gestation length (GL, d); and standard error of 7 was included for the error of the full model.

The simulation was based on 1,000 cows at calving, and profit was calculated on one-bred-cow basis. The herd composition was estimated based on reproduction, survival, and selection parameters (Figures A1, A2, A3, and Appendices 1A through 1J). Retention of cows was based on their reproductive performance and age limit. All cows failing to calve or those that lost a calf within the 15 d after calving were culled; all cows diagnosed as non-pregnant at weaning were culled. All cows over 9 yr of age were culled after weaning (assuming that cow performance decreases when 10 yr of age, (BIF, 2009) and to limit generation interval). Heifers diagnosed as non-pregnant were sent to the yearling finishing system. Calves at weaning were separated to heifers and bulls to be retained for replacement, heifers and steers retained for the calf-fed system, and heifers and steers retained for the yearling system.

CD difficulty was corrected for birth weight and calf sex effect. Calving difficulty was corrected for birth weight based on Berger et al. (1992), the calving difficulty considered in the simulation was multiplied by 0.28, 0.51, 1.00, 1.98, and 2.93 for birth weight lower than 26 kg, from 26 to 30, from 31 to 35, from 36 to 40, and more than 40 kg, respectively. After correcting for birth weight, calving difficulty incidence for sex of calves was considered in proportion of 1.2 and 0.8 for male and female calves, respectively, based on Berger et al. (1992), Gregory et al. (1995b,c), Bennett and Gregory (2001), and Mujibi and Crews (2009). Birth weight was estimated using a regression of birth weight (kg) on gestation length (d), a regression coefficient of 0.33 kg/d was used based on Bourdon and Brinks (1982), Gregory et al. (1995b,c), and Crews (2006), and intercept was simulated assuming normal distribution with mean (-58.6) and SD (1.5 kg). Calf birth weight (BW) for calves from first and second parity cows were adjusted by -3.6 and -2.3 kg, respectively (BIF, 2010).

Numbers of heifers and bulls retained for replacement were estimated in relation to the numbers of heifers at calving and young bulls for replacement at breeding required, maintaining the number of cows at calving constant. Weaned heifers and bulls that were not retained for replacement were split into heifers and steers to the calf-fed system (50%), and heifers and steers to the yearling system (50%). The calf-fed system period was considered 211 d for steers and 240 d for heifers; and yearling system period 405 d for steers and 425 d for heifers, divided into a 315 d growing period for both heifers and steers, and a 90 d and 110 d finishing period for steers and heifers, respectively (Anderson et al., 2005). One season of calving (March and April), ratio 50:50 male:female calves at birth, 205-d weaning age, and 25 cows per breeding bull were assumed. The formula used to estimate the number of animals in each group is shown in the Appendices 1A through 1J.

Milk production was based on Diaz et al. (1992), Mallinckrodt et al. (1993), Meyer et al. (1994), Miller et al. (1999), Brown and Brown (2002), and MacNeil and Mott (2006). Cows were divided in three groups after their second lactation according to the levels of milk production, low milk cows (L; cows with less than 1146 kg of milk/205 d); medium milk cows group (M; cows from 1146 to 1675 kg of milk/ 205 d), and high milk cows group (H; cows with more than 1675 kg milk/205 d). A reduction of milk production of 26 and 12% was considered for first calving cows and for second calving cows, respectively (NRC, 1996).

Weaning weight was estimated using simple regression on milk intake. The regression coefficient of preweaning gain on milk intake was estimated based on Clutter and Nielsen (1987), Diaz et al. (1992), Mallinckrodt et al. (1993), Miller et al. (1999), and Brown and Brown (2002). Regression coefficient of 0.0484, and 0.0271 kg weaning weight gain/ kg of milk produced in 205 d was estimated for calves from cows with milk production lower and equal to

1250 kg, and those greater than 1250 kg, respectively, and an intercept of 143 kg was assumed. To calculate the weaning weight by sex, the weaning obtained by regression was multiplied by 1.00 for steers, 0.95 for heifers and 1.05 for bulls. Postweaning gain (ADG) was estimated as proportion of the ADG for steers in the calf-fed system (Table 2A, B). The proportions for different groups were estimated based on Van Oijen et al. (1993), Adams et al. (2009), and Anderson et al. (2005).

Weights of cows and heifers at breeding were calculated using the exponential equation (Brody, 1945):

$W_t = A\ (1 – be^{-kt})$,

where, W_t is body weight (kg) at time t, A is weight or asymptote, b is “time-scale” parameter, k is “mature-rate” parameter, and t is age in days. The values used in the previous equation were: for A (mature size) was simulated in range showed in Table 1; and for b and k were 0.927 and 0.00205, respectively (Montaño-Bermudez and Nielsen, 1990b). An additional 6 and 20% were added to the weight calculated using the exponential equation for estimate the weight of cows of the L group and the breeding bulls, respectively (Montaño-Bermudez and Nielsen, 1990b).

Feed cost was calculated as the sum of cost for maintenance, cost for growing, cost for lactation, and cost for gestation. These costs were estimated as a function of the metabolizable energy requirement (Kcal) and the cost per energy metabolizable ($/Kcal). The metobolizable energy requirement for maintenance (MEReq) was calculated using the metabolic body weight by the following relationship:

$MEReq\ (Kcal.head^{-1}.period^{-1}) = E_m \int_0^n (IBWT + ADG * n)^{0.75}\, \partial n$, where E_m is the metabolizable energy cost per metabolic size per day (kcal. $Kg^{-0.75}$. d^{-1}), IBWT is the initial body

weight (kg), ADG is average daily gain (kg/d), and n is the total number of days between the final weight and initial weight. Solving the integration,

$MEReq\ (Kcal) = E_m * \frac{1}{ADG*1.75}(FBWT^{1.75} - IBWT^{1.75})$, where, FBWT is final body weight ($FBWT = IBWT + ADG * n$).

Metabolizable energy requirement for maintenance was calculated for calves from birth to weaning; for replacement heifers and bulls from weaning to breeding; for heifers from breeding to pregnancy test; for heifers from pregnancy test to calving; for 1, 2, 3, 4, and 5 or more parity cows from calving to early cull (15 d after calving), from early cull to breeding, from breeding to weaning, and from weaning to next calving; for 1, 2, 3, 4, 5, and 6-yr-old breeding bulls from breeding to culling, and from culling to next breeding; for heifers and steers in yearling system during the growing and finishing period; and for heifer and steers in calf-fed system. A variation of metabolizable energy cost per metabolic size per day (E_m; kcal. $Kg^{-0.75}$. d^{-1}) as a function of milk level was considered using Montaño-Bermudez et al. (1990). In gestating cows, the regression coefficient of 1.6 kcal/d in maintenance coefficient (E_m) per kilogram of milk was used. The energy metabolizable costs in kcal. $Kg^{-0.75}.d^{-1}$ for lactation cows, growing breeding stock, heifers in feedlot, and heifers in feedlot were 1.28, 1.31, 1.44, and 1.34 times the E_m for gestating cows, respectively.

Metabolizable energy requirement for growing (MEGrow) was estimated based on the energy content of the protein and fat in body gain, thus:

$$MEGrow\ (kcal.kg\ of\ EBW^{-1}) = \frac{E_{Pt} * Pt}{K_{Pt}} + \frac{E_{Fat} * Fat}{K_{Fat}}$$

Where, EBW is empty body weight gain, E_{Pt} is the energy in the protein (5.61 kcal/kg of protein), E_{Fat} is the energy in fat (9.39 kcal/kg of fat) (Webster, 1985), Pt and Fat are protein and

fat gain per EBW, respectively (kg/kg), K_{Pt} and K_{Fat} are efficiency of utilization of metabolic energy for growing of protein and fat, respectively. Then,

$$MEGrow\ (kcal.kg\ of\ EBW^{-1}) = \frac{E_{Pt} * EADG * a * b * (IEBW + EADG * n)^{b-1}}{K_{Pt}} + \frac{E_{Fat} * EADG * c * d * (IEBW + EADG * n)^{d-1}}{K_{Fat}}$$

Because, $Pt = EADG * a * b * (IEBW + EADG * d_i)^{b-1}$, and $Fat = EADG * c * d * (IEBW + EADG * d_i)^{d-1}$, where IEBW is initial empty body weight, EADG is Empty average daily gain, a (-0.5037) and c (-2.657) are the intercept of allometric equation for protein and fat, respectively, b (0.8893) and d (1.788) are the coefficient for allometric equation for protein and fat, respectively, and n is the period in days (ARC, 1980).

Then, to estimate the metabolic energy required for an animal in each period, the integration to the previous equation was applied, thus

$$MEGrow\ (kcal.head^{-1}.period^{-1}) = (\frac{E_{Pt} * EADG * a * b}{K_{Pt}}) \int_0^n (IEBW + EADG * n)^{b-1}\, \partial n + (\frac{E_{Fat} * EADG * c * d}{K_{Fat}}) \int_0^n (IEBW + EADG * n)^{d-1}\, \partial n$$

$$= (\frac{E_{Pt} * EADG * a * b}{K_{Pt}})(\frac{FEBW^b - IEBW^b}{b * EADG}) + (\frac{E_{Fat} * EADG * c * d}{K_{Fat}})(\frac{FEBW^d - IEBW^d}{d * EADG})$$

$$= (\frac{E_{Pt} * a}{K_{Pt}})(FEBW^b - IEBW^b) + (\frac{E_{Fat} * c}{K_{Fat}})(FEBW^d - IEBW^d)$$

Finally the formula above was expressed in live body weight, and was corrected by sex, and average daily gain. Thus,

$$MEGrow\ (kcal.head^{-1}.period^{-1}) = C_F[\left(\frac{E_{Pt}*a}{K_{Pt}}\right)\left((\frac{FBW}{1.09})^{b}-(\frac{IBW}{1.09})^{b}\right)+\left(\frac{E_{Fat}*c}{K_{Fat}}\right)\left((\frac{FBW}{1.09})^{d}-(\frac{IBW}{1.09})^{d}\right)]$$

where, FBW and IBW are final and initial live body weight, C_F = (1+e+f*(ADG-0.6)*10), where e is sex correction factor (0.15 for female and -0.15 for intact male), and f is the correction factor for current ADG (for each 0.1 kg of gain/day more than 0.6 kg of gain/day, an additional requirement of 2% was included) (ARC, 1980).

Efficiency of utilization of metabolic energy for growing in protein (K_{Pt}) and fat (K_{Fat}) used was 0.65 and 0.45 for calves before weaning, and 0.7 and 0.2 after weaning, respectively , (ARC, 1980). The metabolizable energy required for growing was estimated for all the groups of animals of the herd indicated previously for energy requirement for maintenance.

The metabolizable energy requirement for lactation was calculated using the total milk production multipled by 1.06 Mcal ME/ kg of milk (NRC, 1996). The metabolizable energy requirement for gestation (MEGestation) was estimated using the following relationship: MEGestation = EC *K_g^{-1}* Q, where, EC is energy content of the gravid uterus, K_g=0.14 is efficiency of energy utilization for gestation, and Q is a factor of correction (Ferrell et al., 1976a,b). $EC\ (kcal) = 69.73\ e^{(0.0323-0.0000275*t)t}$, and $Q = \frac{calf\ birth\ weight}{(0.005839e^{0.0512-0.0000707*t)t})}$ where, t is length of gestation in days. Metabolizable energy requirement for gestation was estimated for age of calving female where calf birth weight and gestation length was varied.

Energy cost per energy metabolized ($/Mcal) was estimated for each group of feeding program based on the price, dry matter, and energy value of each component of the diet. The feeding programs are shown in the Appendices 2 through 8; feedstuff composition was extracted

from Nutrient Requirement of Beef Cattle (NRC, 1996). The metabolizable energy costs ($/ 1000 Mcal) were estimated for heifer from weaning to breeding, and from breeding to calving; for 1, 2, 3 or more parity cows in lactation period; for 1, 2, 3 or more calvings cows in gestation period; for 1, 2, 3, or more calvings cows in dry period; for bulls in breeding; for heifers and steers during the winter and summer in the yearling system, and for the feedlot period.

Feed cost was estimated on basis of the total metabolic energy requirement per animal (Kcal/animal/period), the cost by metabolizable energy ($/Kcal), the number of animals in the period, and interest rate. The number of animals was estimated as the average between the inventory at the beginning and at the end of each period, and interest was included for half of the period. Feed cost was estimated for calves from birth to weaning (205 d), replacement heifers and bulls from weaning to breeding (245 d), replacement heifers from breeding to calving (gestation length, d), cows and bulls (365 d), replacement heifers and bulls to be sold as yearlings (160 d), replacement bulls to be sold at 2 yr (365 d), heifers and steers in growing period in yearling system (315 d), heifers (110 d) and steers (90 d) in finishing period in yearling system, and heifers (240 d) and steers (211 d) in calf-fed system.

To estimate feed cost for calves from birth to weaning, the energy content of milk consumed by the calves was subtracted from the total energy requirement in calves. The total energy on milk was calculated assuming 12.3 of DM in milk, 5.45 Mcal of energy per DM of milk (Chenette and Frahm, 1981), 0.88 of ME per energy gross in milk (Webster, 1985), and 1.06 Mcal ME/kg of milk (NRC, 1996).

Other costs for cow-calf period were those for veterinary and medicine, bedding and litter, custom operation, fuel, lubrication, electricity, repair, and interest. The prices used for estimating these cost were simulated assuming normal distributions (Table 3). Interest was

charged for half period. Other costs for postweaning period included: interest of initial cost of livestock, cost for processing, for drylot yardage, and mineral supplementation in animals in grazing period. The prices used for estimating the cost were simulated assuming normal distributions. Interest was charged for the total period of the initial cost of livestock and for half period for other costs.

Average Effective Interest Rate on Non-Real Estate Bank Loans Made to Farmers was used to calculate interest cost (Federal Reserve Bank of Kansas City, 2003-June 2012). Interest of 3.7% annually (6% minus 2.3% inflation adjusted) was considered; full interest was charged on the replacement-bull and replacement-heifer purchase, and half interest was charged on feed and variable costs incurred during ownership.

Calving difficulty cost was charged on first calving cows as a function of the frequency of calving difficulty and price of CD treatment. Price of CD treatment was estimated using multinomial average sample, assuming the frequency of score of calving difficulty and their respective cost for each score. The total cost was estimated summing the cost in cow-calf and postweaning period, which include interest cost and direct calving difficulty cost.

Income was estimated for heifers and steers sent to slaughter from yearling and calf-fed system, and cow and bulls sent to slaughter from breeding. The income was on base of the total kg of carcass and the price by kg of carcass. The carcass price was calculated using the grid base price adjusted by premium and discount (Appendix 11), heifer carcass price was used for carcass from females and steers carcass price for carcass from males. The prices and premiums and discounts used were for the month when the animal was sent to slaughter, and were based on quality grade, yield grade, carcass weight, and over 30 month age. Quality grade was based on the age and MS, and yield grade was calculated using the following relationship

$YG = 2.5 + 2.5*(FAT (cm) /2.54) + 0.2 * KPH (\%) + 0.0038*(2.2 * CWT (kg)) - 0.32*(REA (cm^2)/6.45)$.

FAT, KPH, REA, MS and DP for steers from calf-fed system were simulated with values shown in Table 1, and for the other groups were based in the proportionality showed in the Appendix 12. Total income was estimated summing the total income for cows, bulls, heifers and steers from calf-fed system, heifers and steers form yearling system, and heifers and bulls sold for replacement. Profit was calculated on cow-bred basis using the following relationship:

Profit per cow ($/ Cow bred) = (total income – total cost)/ total number of cows exposed.

Economic value and relative economic value

The economic value for each trait was estimated using Proc Reg procedures of SAS. The average estimate of the regression coefficient from 1000 simulations was used as a economic value, expressed as an additional profit/loss for each unit of change of the each trait when the others traits were held constant. The standard error for the economic value was estimated based on the variance of the 1000 regression coefficients. The relative economic value of each trait was estimated as a product of their respective economic value and their genetic standard deviation. The genetic standard deviation was based on journal papers published since 1980.

Selection indexes

The selection index weights for the traits and the accuracy of each index were estimated using Proc IML procedure of SAS. Fourteen selection indexes based on breeding value were

estimated using the genetic variances and covariances (Schneeberger et al., 1992). The genetic variances and genetic correlations for the traits in the breeding objective and traits for which EPD are published were extracted from peer reviewed papers published since 1980, and genetic covariances were calculated using the genetic variances and correlations; the average values weighted for the sampling variances are shown in the Table 6. To define the traits to be analyzed in the selection index, complete-linkage cluster analysis was used based on the maximum distance among traits. For each selection index, it was ensured that a positive definite variance-covariance matrix existed (Johnson and Wichern, 2007). Using cluster analysis (Figure 1), twelve indices were developed: Index one (I_1) was based on the traits included in the breeding objective excluding the traits for which the EPD are not reported, and including maternal weaning weight (WWM) for milk production, the traits in the I_1 were: ADG, MW, FAT, REA, MS, CD, HP, and WWM. Index two (I_2) was like I_1, except CD was replaced by birth weight (BWT). Index 3 (I_3) was like I_2, but MWT was replaced by yearling height (YH). Index 4 (I_4) was like I_3, but ADG was replaced by yearling weight (YWT). Index 5 (I_5) like I_3, but ADG was replaced by carcass weight (CWT). Likewise Index 6 (I_6) was like I_3, but ADG was replaced by direct weaning weight (WWT). Index 7 (I_7) was like I_4, but YH was excluded. Index 8 (I_8) was like I_4, but MS was excluded. Index 9 (I_9) was like I_9, but FAT was excluded. Index 10 (I_{10}) was like I_4, but REA was excluded. Index 11 (I_{11}) was like I_9, but both REA and FAT were excluded. Index 12(I_{12}) was the I_{11}, but YH was excluded. Index 13 (I_{13}) was the I_{12}, but HP was excluded. Finally, Index 14 (I_{14}) was based only on BWT and YWT.

Results and Discussion

Economic values

Economic values, expressed as dollars in profit/loss per unit change for the each of the 11 traits, where the other traits were held constant, are given in Table 4. All the traits evaluated showed significant economic importance on profit ($P < 0.001$). The most reliable economic values estimated were for milk, marbling score, mature weight, FAT, and rib eye area, followed by postweaning average daily gain, KPH, and ribeye area, calving difficulty, while dressing percentage, heifer pregnancy, and gestation length were the least reliable. Milk production showed negative economic value being very consistent for all simulations, with relative standard error of 0.50%. This result confirms that the additional weaning weight of calves from high milk cows is offset by the incremental increase of energy required both for production and maintenance (Montaño-Bermudez and Nielsen, 1990a). However, results reported for Miller et al. (1999), and Freking and Marshall (1992) suggested that one should consider an optimal level of milk production. Mature weight had negative economic value and was consistent with relative standard error of 0.69%. These results are in agreement with the economic value of -\$0.10 and -\$0.23/kg of mature weight per head reported by Melton (1995) for U.S. cow-calf producer and integrated beef firm, respectively, and -\$0.11/kg of mature weight per cow reported by MacNeil et al. (1994) for average of three maternal lines for Canadian beef production. This result suggests an agreement in selection for decreasing cow mature weight will increase the profitability of beef industry. Gestation length (GL) had a negative economic value with relative standard error of 2.54%; a similar tendency was reported by Melton (1995) with values of -\$0.78 and -\$8.17/d of GL for cow-calf producer and for an integrated beef firm, respectively, for the U.S. Reduction of gestation length will improve profit not only by reducing direct cost for extra days in gestation, but also for the reduction in birth weight and calving difficulty. Postweaning average daily gain (ADG) showed positive economic value with relative standard error of 1.52%.

This is in agreement with the economic value reported for Aby et al. (2012) of 30 and 24 EUR per kg of ADG per cow in intensive and extensive system, respectively, and had the same tendency to that reported by MacNeil et al. (1994) of 16.27, 4.74, 16.07 Canadian dollars per kg of ADG in maternal lines, sire line on yearling system, and sire line on mature weight, respectively. The numerical differences between studies may be explained in part to the system of finishing, and sources of feed. In this study, ADG was assumed for steers on a finishing diet in calf-fed system. Dressing percentage had positive economic value with relative standard error of 3.51%, showing moderate reliability. Similar results were reported by MacNeil et al. (1994) and MacNeil (1995). MacNeil et al. (1994), for U.S. industry, of 2.78, 0.92 and $2.85/ unit dressing percentage per cowherd in for specialized maternal line, sire line on yearling weight, and sire line on mature weight, respectively; and ranged from 9.53 to 11.18 Canadian dollars / unit dressing percentage per cowherd for as general purpose maternal and sire lines. MacNeil (1995), for U.S. industry, reported positive value for dressing percentage ranging from 1131 to 3319 dollars per unit dressing percentage per enterprise basis. This result suggests that selection for increasing dressing percentage will increase profit in the beef industry. However, in the current study, an interaction of traits associated with final carcass weight and yield grade was noticed. Because increasing carcass weight will increase the yield grade this may reduce the carcass price, especially for large carcasses in a yearling system. This suggests that the period of finishing should be based on avoiding low and high carcass weight.

Carcass traits had significant effects on profit in this study. Rib fat thickness (FAT) and kidney-pelvic-heart fat (KPH) were characterized by negative economic values with relative standard error of 0.47 and 1.57%, respectively. Increasing FAT and KPH will increase yield grade (YG), and thus, increase carcass discount when YG is over 4. In the scenario where the

high carcass weight increase and REA decrease, the economic value for FAT and KPH were more negative, with greater changes in the economic value for KPH than for FAT. Hirooka et al. (1998) reported substantial positive economic value for FAT in Japanese Black cattle for the Japanese industry. This difference in the sign of economic value reported for Hirooka et al. (1998) and that found in this study is explained by the high preference for fat carcasses in Jappaness Back cattle. MacNeil (1995) reported negative value for yield grade for U.S. industry with considerable variation between terminal sire breeds. Marbling score had positive economic value with relative standard error of 0.35%. Similar results were reported by MacNeil (1995) and Melton (1995) for the U.S. industry and Hirooka (1998) for the Japanese industry. Melton (1995) reported economic values for MS of $3.15 and $4.04 /unit of MS per cow for integrated beef firm and cow-calf producer, respectively. MacNeil (1995) reported relative economic values that varied widely for MS across different populations. Horooka (1998) reported economic value for MS of 19,603 Japanese yen per cow. Differences in absolute values may be explained by differences in the traits in each breeding objectives, and the differences of the productions system design for each study.

The economic value for heifer pregnancy was positive with relative standard error of 9.97%. Variation in heifer pregnancy is associated with the variation in profitability of finishing heifers in yearling system. In this study, heifer pregnancy affects the number of weaning heifers retained for replacement and also the portion of heifers sent to finishing from non-pregnant heifers at pregnancy test. When, the finishing period for heifers is highly profitable, the economic value for heifer pregnancy decreases. Calving difficulty had negative economic value for the incidence levels considered in this study (from 0 to 10% of CD) with relative standard

error of 5.57%. The economic value for CD increases slightly when the incidence of calving difficulty increases.

Relative economic value

Table 5 shows the relative economic value (economic value multiplied by genetic standard deviation) for all traits evaluated. Per unit of genetic standard deviation the traits of greater economic importance were marbling score (19.6%), ribeye area (16.6%), and milk production with (16.1%), followed by mature weight (12.5 %), rib fat thickness (12.3%), and postweaning daily gain (8.8%). Traits with the least economic importance per unit of genetic standard deviation were gestation length (5.6%), dressing percentage (3.7%), KPH (4.3%) and calving difficulty (0.4%), and heifer pregnancy (0.1%).

Comparing the relative economic values with economic values, ADG, rib fat thickness, and marbling score had greater economic values. But due to genetic variability of these traits, the economic values per unit of genetic SD decreased. Milk production, mature weight and ribeye area increased in economic importance measured as change per genetic SD than change for a unit of the trait. Similar tendency was reported by Aby et al. (2012), for Norway conditions, for calving difficulty with values of 2.3 and 2.71% for intensive and extensive systems, respectively; and for ADG with values of 6.67 and 7.05% for intensive and extensive systems, respectively. MacNeil (1995), for U.S. industry, reported positive relative economic values that varied very little for ADG between terminal sire breeds. In general, selection based on the traits included in the breeding objective in this study could improve the profitability of beef industry under the conditions used in this simulation.

Selection indexes

Table 7 shows the selection index weights for traits. In general high correlation among the index and breeding objective (shown in the Table 4) was found for all the cases. Index I_1 shows that after excluding 3 traits and replacing milk production by maternal weaning weight from the breeding objective, the correlation between the index I_1 and the breeding objective only is reduced by 6%. Additionally, this high correlation between the I_1 (including maternal weaning weight) and the breeding objective (including milk) confirms that the use of maternal weaning weight, as expected, is a good indicator of milk production. The indexes I_2 and I_3 showed that the inclusion both of BWT for CD and YH for MWT improved slightly the accuracy. This is explained by the higher genetic variance of CD than BWT and of MWT than YH. Similar negative weights for BWT and for MWT were reported by Dickerson et al. (1974) and by MacNeil and Newman (1994), indicating that selection for limiting birth weight and mature weight will increase the efficiency in beef cattle. Indexes I_4, I_5, and I_6 revealed that the substitution of ADG for WWT, YWT or CWT had almost the same accuracy, showing that using WWT, YWT or CWT when EPD for ADG are not available may have the same improvement in the breeding objective. However, an additional advantage of using YWT over CWT may be found in that YWT is easy to measure on all animals and data may be available at earlier age. Similar positive economic weights for YWT were reported by Dickerson et al. (1974) and by Enns and Nicoll (2008). Index I_7 revealed that exclusion of YH did not decrease the accuracy (I_4 vs I_7), showing that YWT will be good indicator for ADG and MW. However, when we excluded YH in indexes I_8, I_9, and I_{10}, a reduction of 3 to 4% in accuracy was found. Due to that we kept YH in indexes I_8, I_9, I_{10}. Indexes I_8, I_9, and I_{10} revealed that, of the carcass traits

analyzed, inclusion of MS had higher accuracy followed by REA, and the inclusion of FAT showed the lowest accuracy. This is a function of heritabilities of these traits where MS has the highest heritability and FAT the lowest. However, using MS as the sole carcass trait, excluding of both REA and FAT, decreased the accuracy of the index by 21% (index I_{11} vs. I_4). The index weight found for FAT is in agreement with that reported by Swiger et al. (1965) and by MacNeil and Newman (1994) where both reported negative weight for FAT in selection indexes for total net merit in terminal sire lines. However, this is in contrast with the positive value reported for FAT in maternal line by MacNeil and Newman (1994). In the present study, FAT was simulated in the breeding objective as a component of yield grade (YG), where high YG is penalized in final carcass price. Index (I_{12}) had a reduction of 4% of accuracy compared with I_{11}, showing that exclusion of YH in the index that included MS as the only carcass trait would not be recommended. Index (I_{13}) showed that exclusion of HP had no major impact in the accuracy in the index (I_{13} vs. I_{12}). Index (I_{14}), based only on BWT and YWT (I_{12} = YWT – 3.03 BWT), had additional 13% reduction of accuracy compared to index I_{13}. Similar index based on phenotypes was reported by Dickerson et al. (1974), I = YWT – 3.2 BWT, for selection to increase the economic efficiency of beef production. MacNeil (2003) has demonstrated the favorable genetic responses for using this index in a composite population. In conclusion, index I_3 would be the recommended index to improve the breeding objective proposed in this study, and if the EPD for ADG are not available, then index I_4, I_5, I_6, or I_7 are recommended.

Implication

For the system of beef production designed for this study, selection based on the traits considered in the breeding program would improve the profitability of the beef industry. From

the relative economic value and the relative standard error selection for decreasing mature weight, milk production, and fat thickness; increasing marbling score, ribeye area, and postweaning average daily gain would increase the profitability of beef industry. Additional profitability, but of less magnitude, may be obtained by selecting to reduce KPH and increasing dressing percentage and heifer pregnancy. Additionally, calving difficulty was economically important, increasing in economic importance when incidence of CD increased. In general, a selection index based on EBV for traits whit EPDs available had high correlation with the breeding objective in this study. For creating selection response to improve economic efficiency of beef production, a selection index including carcass, growth, and maternal traits should be used.

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Table 1. Range and increment of the traits included as independent variables in the model

Traits	Unit	Minimum	Maximum	Increment
Milk production	kg/205d	616	2205	794
Postweaning average daily gain	kg/d	1.4	1.8	0.2
Mature weight	kg	424	692	134
Dressing percentage	Percentage	62	64	1
Rib fat thickness	cm	0.16	2.0	0.96
The internal kidney-pelvic-heart fat	Percentage	1.5	4.5	1.5
Ribeye area	cm^2	59	96	18.5
Marbling score	Score	2.7	7.7	2.5
Calving difficulty	Percentage	0	10	5
Heifer pregnancy	Percentage	75	95	10
Gestation length	Day	275	299	12

Table 2A. Proportion of postweaning average daily gain with respect to steers in the calf-fed system

Group	Proportion[1]
Heifers in growing during the winter period, born from L 1 calving cows	0.27
Heifers in growing during the winter period, born from M 1 calving cows	0.26
Heifers in growing during the winter period, born from H 1 calving cows	0.27
Heifers in growing during the winter period, born from L 2 calving cows	0.31
Heifers in growing during the winter period, born from M 2 calving cows	0.30
Heifers in growing during the winter period, born from H 2 calving cows	0.30
Steers in growing during the winter period, born from L 1 calving cows	0.32
Steers in growing during the winter period, born from M 1 calving cows	0.31
Steers in growing during the winter period, born from H 1 calving cows	0.33
Steers in growing during the winter period, born from L 2 calving cows	0.37
Steers in growing during the winter period, born from M 2 calving cows	0.34
Steers in growing during the winter period, born from H 2 calving cows	0.35
Heifers in growing during the summer period, born from L 1 calving cows	0.48
Heifers in growing during the summer period, born from M 1 calving cows	0.46
Heifers in growing during the summer period, born from H 1 calving cows	0.48
Heifers in growing during the summer period, born from L 2 calving cows	0.54
Heifers in growing during the summer period, born from M 2 calving cows	0.53
Heifers in growing during the summer period, born from H 2 calving cows	0.53
Steers in growing during the summer period, born from L 1 calving cows	0.56
Steers in growing during the summer period, born from M 1 calving cows	0.54
Steers in growing during the summer period, born from H 1 calving cows	0.57
Steers in growing during the summer period, born from L 2 calving cows	0.65
Steers in growing during the summer period, born from M 2 calving cows	0.60
Steers in growing during the summer period, born from H 2 calving cows	0.62

[1] Based on Van Oijen et al. (1993), Anderson et al. (2005), and Adams et al. (2009)

L= Low milk cow groups, M= Medium milk cow groups, H= High milk cow groups, winter = 117 d, summer = 198 d.

Table 2B. Proportion of postweaning average daily gain with respect to steers in the calf-fed system

Group	Proportion[1]
Heifers in finishing in the yearling system, born from L 1 calving cows	1.00
Heifers in finishing in the yearling system, born from M 1 calving cows	0.97
Heifers in finishing in the yearling system, born from H 1 calving cows	0.94
Heifers in finishing in the yearling system, born from L 2 calving cows	1.06
Heifers in finishing in the yearling system, born from M 2 calving cows	1.06
Heifers in finishing in the yearling system, born from H 2 calving cows	1.03
Steers in finishing in the yearling system, born from L 1 calving cows	1.20
Steers in finishing in the yearling system, born from M 1 calving cows	1.17
Steers in finishing in the yearling system, born from H 1 calving cows	1.13
Steers in finishing in the yearling system, born from L 2 calving cows	1.28
Steers in finishing in the yearling system, born from M 2 calving cows	1.22
Steers in finishing in the yearling system, born from H 2 calving cows	1.21
Heifers in the calf-fed system, born from L 1 calving cows	0.81
Heifers in the calf-fed system, born from M 1 calving cows	0.79
Heifers in the calf-fed system, born from H 1 calving cows	0.77
Heifers in the calf-fed system, born from L 2 calving cows	0.87
Heifers in the calf-fed system, born from M 2 calving cows	0.87
Heifers in the calf-fed system, born from H 2 calving cows	0.84
Steers in the calf-fed system, born from L 1 calving cows	0.98
Steers in the calf-fed system, born from M 1 calving cows	0.95
Steers in the calf-fed system, born from H 1 calving cows	0.92
Steers in the calf-fed system, born from L 2 calving cows	1.05
Steers in the calf-fed system, born from M 2 calving cows	1.00
Steers in the calf-fed system, born from H 2 calving cows	0.99

[1] Based on Van Oijen et al. (1993), Anderson et al. (2005), and Adams et al. (2009)

L= Low milk cow groups, M= Medium milk cow groups, H= High milk cow groups, finishing in the yearling system = 90 d for steers and 110 for heifers, calf-fed system = 211 d for steers and 240 for heifers.

Table 3. Adjusted for inflation price of other operation for Nebraska based from 2003 to 2012

Item	Unit	Mean	Standard error[3]
Calf-Period[1]			
Veterinary and Medicine	$\$.cow\ bred^{-1}$	31.86	1.593
Bedding and litter	$\$.cow\ bred^{-1}$	0.62	0.001
Marketing	$\$.cow\ bred^{-1}$	10.41	0.574
Custom Operation	$\$.cow\ bred^{-1}$	30.88	5.741
Fuel, lube, and electricity	$\$.cow\ bred^{-1}$	53.46	8.873
Repair	$\$.cow\ bred^{-1}$	42.19	6.062
Postweaning period[2]			
Processing in growing period in YS	$\$.head^{-1}.period^{-1}$	21.61	1.080
Mineral supplement in growing period in YS	$\$.head^{-1}.period^{-1}$	3.07	0.154
Drylot yardage in growing period in YS	$\$.head^{-1}.period^{-1}$	35.80	1.790
Processing in finishing period in YS	$\$.head^{-1}.period^{-1}$	10.80	0.540
Processing in finishing period in CS	$\$.head^{-1}.period^{-1}$	32.43	1.621
Yardage in feedlot period	$\$.head^{-1}.\ d^{-1}$	0.39	0.019

[1] USDA-2012. Agriculture Service Market

[2] Jordon (2000), YS = yearling system, CS= calf system.

[3] Assuming 30% of variation

Table 4. Economic values per unit of trait per cow exposed[1]

Traits	Mean	SD[2]	SE[3]	Min	Max	Pr > |t|
Milk production, $\$.kg^{-1}.205d^{-1}$	-0.046	0.0002	0.0002	-0.047	-0.046	0.001
Postweaning average daily gain, kg/d	56.195	0.8533	0.9308	54.555	58.085	0.001
Mature weight, kg	-0.207	0.0014	0.0014	-0.211	-0.203	0.001
Dressing percentage, %	1.970	0.0691	0.0750	1.833	2.157	0.001
Rib fat thickness, cm	-39.285	0.1867	0.2037	-39.722	-38.792	0.001
Kidney-pelvic-heart fat, %	-7.944	0.1246	0.1249	-8.273	-7.735	0.001
Ribeye area, cm^2	2.044	0.0086	0.0101	2.031	2.062	0.001
Marbling score, score	21.974	0.0777	0.0749	21.828	22.140	0.001
Calving difficulty, %	-0.168	0.0274	0.0375	-0.220	-0.108	0.001
Heifer pregnancy, %	0.092	0.0177	0.0186	0.049	0.136	0.001
Gestation length, d	-1.177	0.0140	0.0146	-1.207	-1.149	0.001

Adj R-Sq = 0.7691 ± 0.0007

[1] From 1000 Monte Carlo simulations

[2] Sample standard deviation, from Monte Carlo simulations

[3] Average standard error

Table 5: Relative economic value ($) derived as product of economic value and genetic std. dev.

Traits	Relative economic value	Genetic SD[1]
Milk production, $\$.kg^{-1}.205d^{-1}$	-9.068	196.84
Postweaning average daily gain, kg/d	4.957	0.09
Mature weight, kg	-7.042	34.04
Dressing percentage, %	2.065	1.05
Rib fat thickness, cm	-6.904	0.18
Kidney-pelvic-heart fat, %	-2.401	0.30
Ribeye area, cm^2	9.311	4.56
Marbling score, score	11.023	0.50
Calving difficulty, %	-0.200	1.19
Heifer pregnancy, %	0.074	0.80
Gestation length, d	-3.155	2.68

[1] Based on peer review papers published since 1980

Table 6. Genetic variance (on diagonal), genetic correlation (above diagonal) used in calculating selection indixes

Trait[1]	Milk	ADG	MW	DRE	FAT	KPH	REA	MS	CD	HP	GL	BWT	WWT	YWT	CWT	YH	MH	SC	DOC	WWM
Milk[2]	38747	0.16	-0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	-0.11	-0.42	-0.44	0.00	-0.29	-0.10	-0.10	0.00	0.79
ADG		0.008	0.07	0.36	0.03	0.15	0.33	0.18	0.00	0.00	0.03	0.36	0.71	0.85	0.50	0.54	0.10	0.06	-0.23	0.16
MW			1158	0.00	-0.07	-0.01	0.33	-0.16	0.00	0.00	0.00	0.43	0.69	0.85	0.64	0.73	0.83	0.00	0.00	-0.39
DRE				0.76	0.12	0.19	0.66	0.29	0.00	0.00	0.00	-0.57	0.18	0.18	0.37	0.00	0.00	0.00	0.00	0.00
FAT					0.03	0.37	-0.13	0.29	-0.14	0.00	0.00	-0.24	0.18	-0.02	0.12	0.00	0.00	0.00	0.00	0.00
KPH						0.09	-0.05	0.27	0.00	0.00	0.00	-0.59	0.33	0.25	0.14	0.00	0.00	0.00	0.00	0.00
REA							20.8	-0.02	-0.04	0.00	0.00	0.30	0.46	0.51	0.52	0.00	0.00	0.19	0.32	0.00
MS								0.25	-0.09	0.10	0.27	0.18	0.30	0.33	0.34	0.00	0.00	0.01	0.10	0.00
CD									596	0.00	0.44	0.82	0.16	0.27	-0.31	0.00	0.00	-0.10	0.00	0.00
HP										316	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00
GL											7.18	0.47	-0.17	-0.07	0.03	0.00	0.00	-0.34	0.00	0.10
BWT												6.87	0.52	0.53	0.17	0.17	0.10	0.03	0.00	-0.11
WWT													154	0.83	0.88	0.50	0.65	0.33	0.00	-0.42
YWT														407	0.75	0.50	0.50	0.26	0.00	-0.44
CWT															316	0.00	0.00	0.00	-0.54	0.00
YH																8.27	0.50	0.31	0.00	-0.29
MH																	11.2	0.10	0.00	-0.10
SC																		2.48	0.00	-0.10
DOC																			0.11	0.00
WWM																				145

[1] Milk = milk production ($kg.205^{-1}$), ADG = postweaning average daily gain ($kg.d^{-1}$), MW = mature weight (kg), DRE = dressing percentage (%), FAT = rib fat thickness (cm), KPH = the internal kidney-pelvic-heart fat percentage (%), REA = ribeye area (cm^2), MS = marbling score (score), CD = calving difficulty in heifers (%), HP = heifer pregnancy (%), GL = gestation length (d), BWT = birth weight (kg), WWT = direct weaning weight (kg), YWT = yearling weight (kg), CWT = carcass weight (kg), YH = yearling height (cm), MH = mature height (cm), SC = scrotal circumference (cm), DOC = docility (FS, m/s or score), WWM = maternal weaning weight (kg).

[2] Milk production and maternal effect on weaning weight are assumed equivalent but measured on different scales

Table 7. Selection indexes (I_i) for profit for general pourpose beef cattle

Traits[1]	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9	I_{10}	I_{11}	I_{12}	I_{13}	I_{14}
ADG	52.6	71.9	128											
MW	-0.20	-0.11												
FAT	-42.0	-50.0	-53.0	-50.4	-48.9	-60.2	-50.4	-30.2		-53.1				
REA	2.30	2.44	1.92	2.49	2.93	2.03	2.55	1.24	2.63					
MS	20.2	25.1	25.3	27.7	30.2	26.3	28.1		21.9	20.4	13.8	15.8	16.2	
CD	-0.23													
HP	0.10	0.08	0.08	0.08	0.07	0.08	0.07	0.15	0.09	0.10	0.12	0.11		
BWT		-2.83	-3.52	-2.79	-2.71	-3.53	-2.77	-2.76	-1.73	-3.18	-2.08	-1.81	-1.81	-1.82
WWT						0.53								
YWT				0.06			0.04	0.64	0.03	0.63	0.63	0.46	0.46	0.60
CWT					-0.15									
YH			-2.39	-0.18	-0.02	-0.85		-1.83	-0.25	-1.75	-1.91			
WWM	-0.62	-0.60	-0.72	-0.36	-0.39	-0.24	-0.37	-0.05	-0.36	-0.06	-0.04	-0.03	-0.03	
Acc[2]	0.95	0.95	0.97	0.89	0.90	0.91	0.89	0.71	0.80	0.80	0.68	0.64	0.64	0.51

[1] ADG = postweaning average daily gain ($kg.d^{-1}$), MW = mature weight (kg), FAT = rib fat thickness (cm), REA = ribeye area (cm^2), MS = marbling score (score), CD = calving difficulty in heifers (%), HP = heifer pregnancy (%), BWT = birth weight (kg), WWT = direct weaning weight (kg), YWT = yearling weight (kg), CWT = carcass weight (kg), YH = yearling height (cm), WWM = maternal weaning weight (kg).

[2] Acc = Sqrt(Variance of index / variance of breeding objective)

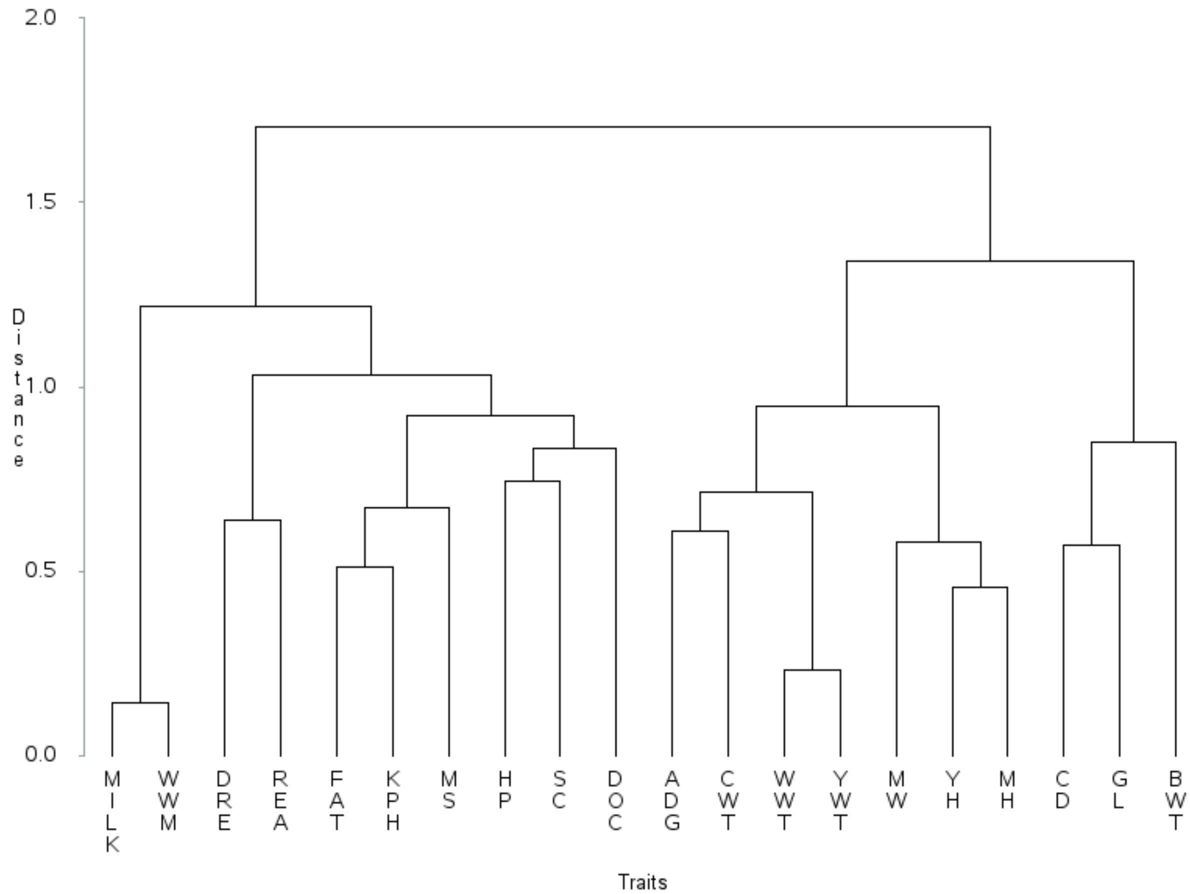

Figure 1. Complete linkage cluster analysis

[1]Milk = milk production ($kg.205^{-1}$), WWM = maternal weaning weight (kg), DRE = dressing percentage (%), REA = ribeye area (cm^2), FAT = rib fat thickness (cm), KPH = the internal kidney-pelvic-heart fat percentage (%), MS = Marbling score (score), HP = heifer pregnancy (%), SC = scrotal circumference (cm), DOC = docility (FS, m/s or score), ADG = postweaning average daily gain ($kg.d^{-1}$), CWT = carcass weight (kg), WWT = direct weaning weight (kg), YWT = yearling weight (kg), MW = mature weight (kg), YH = yearling height (cm), MH = mature height (cm), CD = calving difficulty in heifers (%), GL = gestation length (d), BWT = birth weight (kg).

APPENDICES

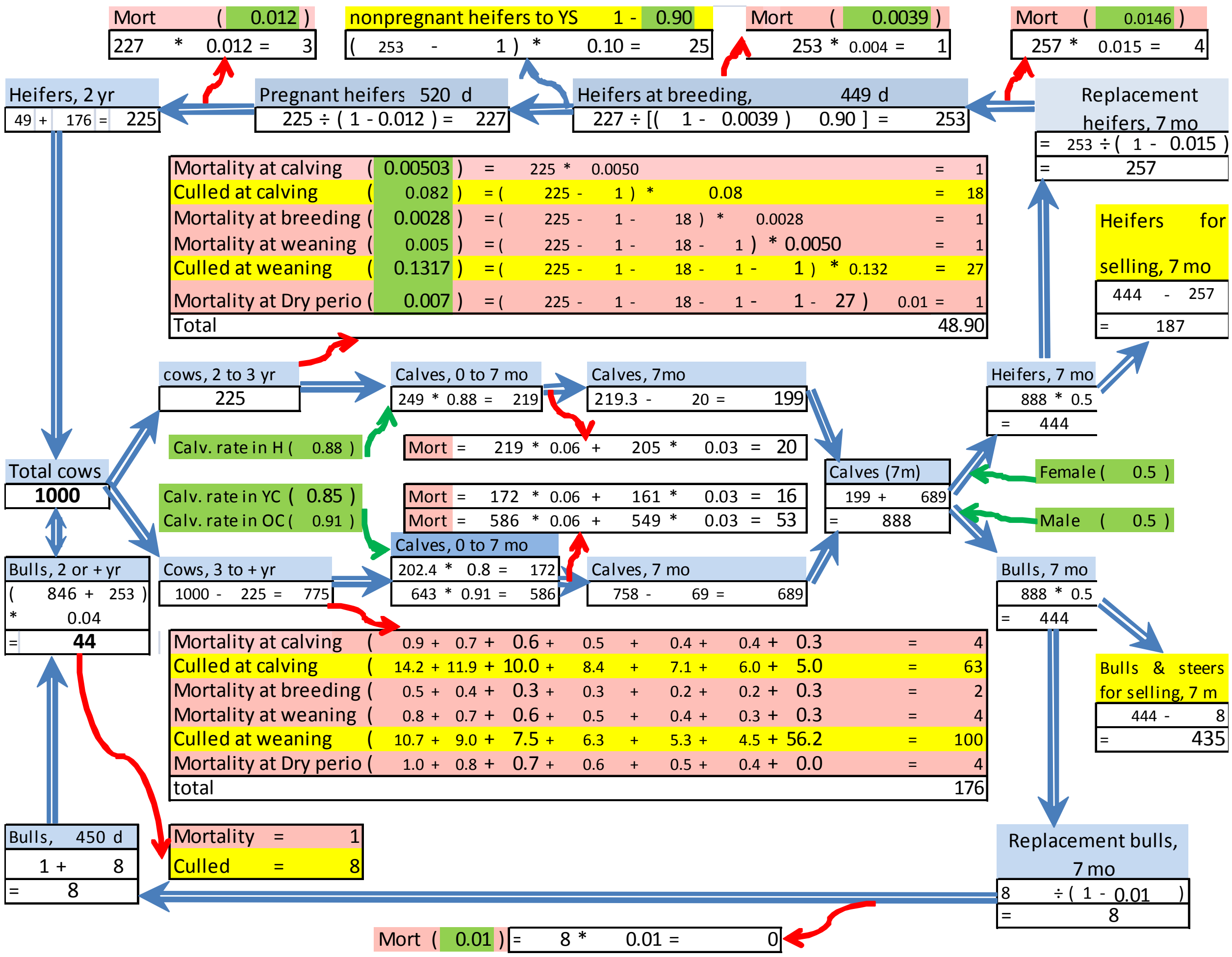

Figure A1. Number of animals in cow-calf phase for beef operation

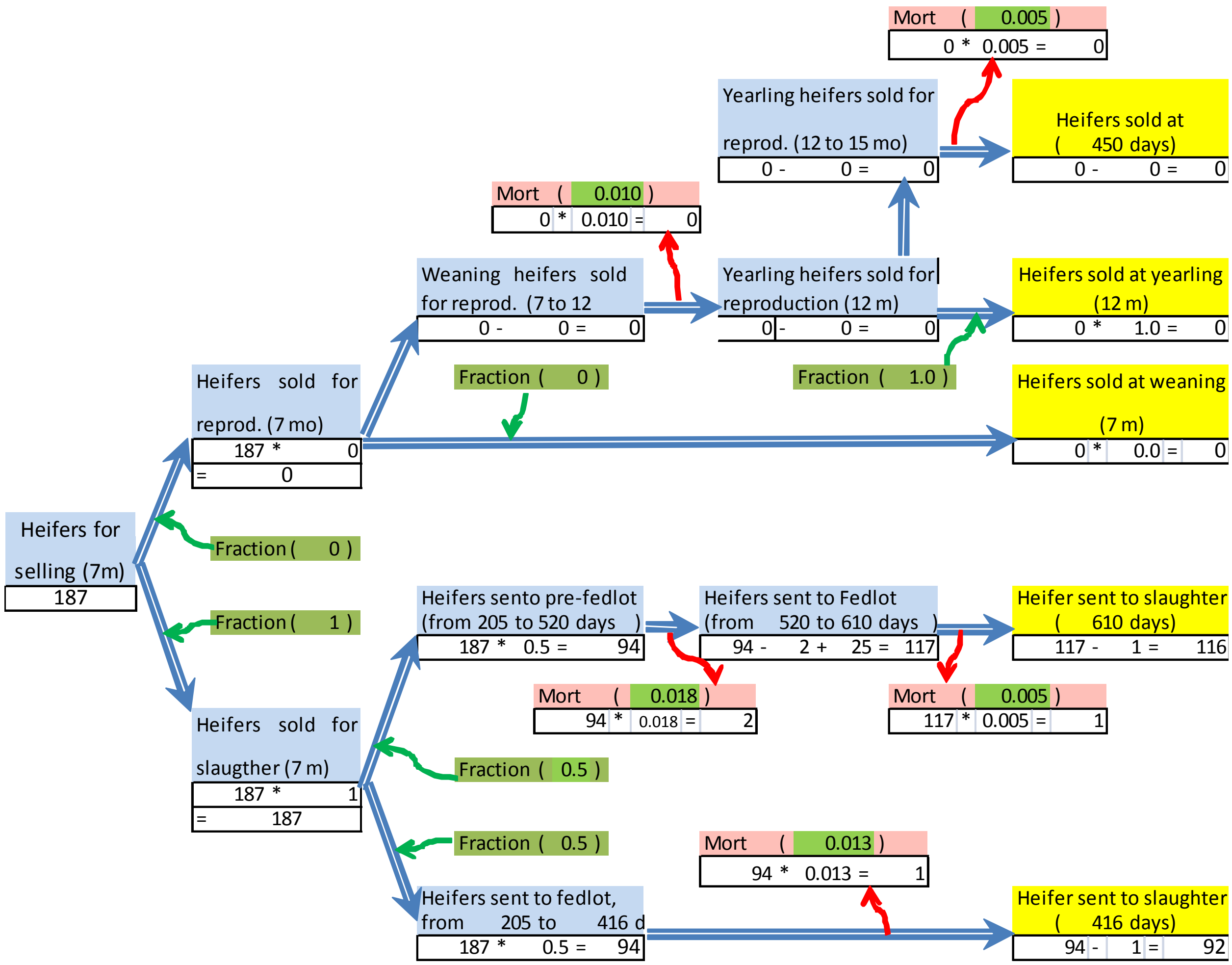

Figure A2. Number of heifers for postweaning phase

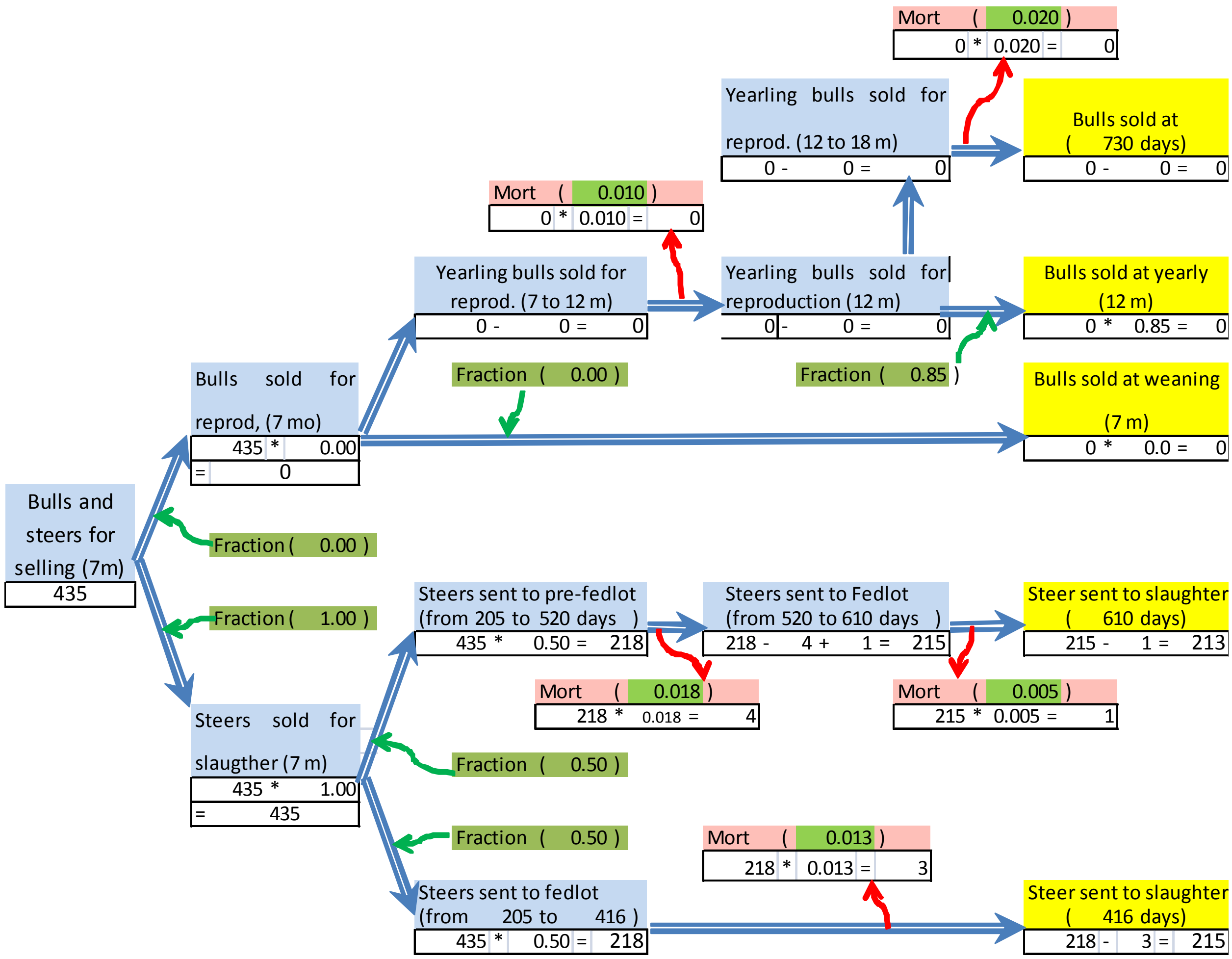

Figure A3. Numbers of steers and bulls for postweaning phase

Appendix 1A. Mortality: notation and formula

Items	Notation	Formula
Abortion, fraction		
In heifers	M_{1A}	0.023 (simulated)
In first calving cows	M_{1B}	0.023 (simulated)
In 2+ calvings cows	M_{1C}	0.023 (simulated)
Mortality at birth, fraction		
In calves born from 1 calving cows	M_{2A}	$M_{2A} = M_{2B}(CD * (CF - 1) + 1)$ CD is in fraction and CF is correction factor
In calves born from 2 calvings cows	M_{2B}	$M_{2B} = 0.064$ (simulated)
In calves born from 3+ calvings cows	M_{2C}	$M_{2C} = 0.064$ (simulated)
Mortality in calves from 0 to 205 d of age		
In calves born from 1 calving cows	M_{3A}	$M_{3A} = 0.029(1 + 0.0 * CD)$
In calves born from 2 calvings cows	M_{3B}	$M_{3B} = 0.029$ (simulated)
In calves born from 3+ calvings cows	M_{3C}	$M_{3C} = 0.029$ (simulated)
Mortality after weaning, fraction		
From 205 d to 365 d of age	M_4	$M_4 = 0.01$ (simulated)
From 1 yr to 2 yr of age	M_5	$M_5 = 0.02$ (simulated)
For 2 + yr age	M_6	$M_6 = 0.015$ (simulated)
In heifers from 205 d to breeding	M_7	$M_7 = M_4 + M_5 * (X - 365)/365$ X=450, age of heifers at breeding, d
In bulls from 205 d to breeding	M_{B7}	$M_{B7} = M_4 + M_5 * (X - 365)/365$ X=450, age of bulls at breeding, d
In heifers at calving or early lactation	M_{F1A}	$M_{F1A} = M_{F1B}(CD * (CF - 1) + 1)$
In cows with 2 + calvings at calving or early lactation	M_{F1B}	$M_{F1B} = 0.005$ (simulated)
In 1 calving cows from culling at calving to breeding	M_{F3A}	$M_{F3A} = M_6(B - C)/365$ B=84, days from calving to breeding and C=15, days from calving to culling.
In 2+ calvings cows from culling at calving to breeding	M_{F3B}	$M_{F3B} = M_6(B - C)/365$ B and C, the same as in M_{F3A}
In heifers from breeding to pregnancy test	M_{F4A}	$M_{F4A} = M_5 * Z/365$ Z=71, days from breeding to pregnancy test
In first calving cows from breeding to weaning	M_{F4B}	$M_{F4B} = M_6(205 - B)/365$ B=84, days from calving to breeding
In 2+ calvings cows from breeding to weaning	M_{F4C}	$M_{F4C} = M_6(205 - B)/365$ B, the same as in M_{F4A}
In heifers from pregnancy test to calving	M_{F6A}	$M_{F6A} = M_5(GL - Z)/365$ GL= gestation length, and Z=71, days from pregnancy-test to calving.
In first calving cows in dry period	M_{F6B}	$M_{F6B} = M_6(GL - Z)/365$ GL and Z the same as in M_{F6A}
In 2+ calvings cows in dry period	M_{F6C}	$M_{F6C} = M_6(GL - Z)/365$ GL and Z the same as in M_{F6A}

Appendix 1B. Mortality: notation and formula

Items	Notation	Formula
Mortality in bulls at breeding age		
In first breeding bulls from breeding to selection	M_{B1A}	$M_{B1A} = M_5(P - S)/365$ where, P=520, age of bull at selection, and S=450 age of bull at breeding
In 2-breeding bulls from breeding to selection	M_{B1B}	$M_{B1B} = M_6 * M/365$ where, M=60 breeding period in bulls, d
Mortality in 1-breeding bulls from selection to second breeding	M_{B3A}	$M_{B3A} = (730 - P)/365$ P=520 is age of 1 yr bull at selection, d
Mortality in 2+ breeding bulls from selection to next breeding	M_{B3B}	$M_{B3B} = M_6(365 - M)/365$ where, M=60 breeding period in bulls, d
Mortality in heifers and bulls for selling		
In heifers sold for reproduction after yearling	M_{F11C}	$M_{F11C} = M_5(D - 365)/365$ where, D=540, age of heifers at selling, d
In bulls sold for reproduction after yearling	M_{F11D}	$M_{F11D} = M_5(E - 365)/365$ E=730, age of bulls at selling, d
In heifers during the feedlot period in calf-fed system	M_{F13A}	$M_{F13A} = M_4 + M_5(A - 365)/365$ where, A=416, age at the end of feedlot, d
In steers during the feedlot period in calf-fed system	M_{S2A}	$M_{S2A} = M_4 + M_5(F - 365)/365$ where, F=416, age at the end of feedlot, d
In heifers during the growing period in yearling system	M_{F12A}	$M_{F12A} = M_4 + M_5(B - 365)/365$ where, B=520, age at the end of growing period in yearling system, d
In heifers during the feedlot period in yearling system	M_{F12B}	$M_{F12B} = M_4 + M_5(C - B)/365$ where, C=610, age at the end of feedlot period, and B=520, age at the beginning of feedlot period, in yearling system, d
In steers during the growing period in yearling system	M_{S1A}	$M_{S1A} = M_4 + M_5(G - 365)/365$ where, G=520, age at the end of growing period in yearling system, d
In steers during the feedlot period in yearling system	M_{S1B}	$M_{S1B} = M_4 + M_5(H - G)/365$ where, H=610, age at the end of feedlot period, and G=520, age at the beginning of feedlot period, in yearling system, d

Appendix 1C. Reproductive parameters: notation and formula

Items	Notation	Formula
Pregnancy rate, fraction		
In heifers	HP	$HP = 0.902$ (simulated)
In first calving cows	R_{1B}	$R_{1B} = R_{1C}(CD * (CF - 1) + 1)$ R_{1C} , pregnancy rate in 2+ parity cows; CD, calving difficulty in fraction; CF, correction factor.
In 2+ calvings cows	R_{1C}	$R_{1C} = 0.933$ (simulated)
Calving rate, fraction		
In first calving cows	R_{2A}	$R_{2A} = \frac{HP(1 - M_{F6A})(1 - M_{1A})}{1 - (1 - C_{F5A})M_{F6A}}$
In second calvings cows	R_{2B}	$R_{2B} = \frac{R_{1B}(1 - M_{F6B})(1 - M_{1B})}{1 - (1 - C_{F5B})M_{F6B}}$
In 3+ calvings cows	R_{2C}	$R_{2C} = \frac{R_{1C}(1 - M_{F6C})(1 - M_{1C})}{1 - (1 - C_{F5C})M_{F6C}}$
Calf crop rate, fraction		
In 1calving cows,	R_{3A}	$R_{3A} = [R_{2A}(1 - (1 - C_{F5A})M_{F6A})(1 - M_{2A})(1 - M_{3A})] \div [1 - (1 - C_{F5A})(M_{F6A} - (1 - M_{F6A})(M_{F1A} - (1 - M_{F1A})(1 - C_{F2A})\left(\frac{205 - W}{365}\right)M_6))]$ Where, W= is number of days from calving to early cull-cows
In 2 calvings cows	R_{3B}	$R_{3B} = [R_{2B}(1 - (1 - C_{F5B})M_{F6B})(1 - M_{2B})(1 - M_{3B})] \div [1 - (1 - C_{F5B})(M_{F6B} - (1 - M_{F6B})(M_{F1B} - (1 - M_{F1B})(1 - C_{F2B})\left(\frac{205 - W}{365}\right)M_6))]$ Where, W= is number of days from calving to early cull-cows
In 3+ calvings cows	R_{3C}	$R_{3C} = [R_{2C}(1 - (1 - C_{F5C})M_{F6C})(1 - M_{2C})(1 - M_{3C})] \div [1 - (1 - C_{F5C})(M_{F6C} - (1 - M_{F6C})(M_{F1B} - (1 - M_{F1B})(1 - C_{F2C})\left(\frac{205 - W}{365}\right)M_6))]$ Where, W= is number of days from calving to early cull-cows
Female:total calves ratio at birth	R_4	$R_4 = 0.5$
Bull:bred cows ratio	R_5	$R_5 = 0.04$
Calving difficulty in heifer	CD	$CD = 0.05$, fraction

Appendix 1D. Cull rate and selection: notation and formula

Items	Notation	Formula
Cull rate in cows and bulls in breeding, fraction		
In heifers at calving or early lactation	C_{F2A}	$C_{F2A} = 1-(\frac{R_{2A}(1-(1-C_{F5A})M_{F6A})(1-M_{2A})}{(1-C_{F5A})(1-M_{F6A})(1-M_{F1A})})$
In 2 calvings cows at calving or early lactation	C_{F2B}	$C_{F2B} = 1-(\frac{R_{2B}(1-(1-C_{F5B})M_{F6B})(1-M_{2B})}{(1-C_{F5B})(1-M_{F6B})(1-M_{F1B})})$
In 3 + calving cows at calving or early lactation	C_{F2C}	$C_{F2C} = 1-(\frac{R_{2C}(1-(1-C_{F5C})M_{F6C})(1-M_{2C})}{(1-C_{F5C})(1-M_{F6C})(1-M_{F1B})})$
In heifers at pregnancy test	C_{F5A}	$C_{F5A} = 1-HP$
In 1 calving cows at weaning	C_{F5B}	$C_{F5B} = 1-R_{1B}$
In 2 to 7 calving cows at weaning	C_{F5C}	$C_{F5C} = 1-R_{1C}$
In 8 calvings cows at weaning	C_{F5I}	$C_{F5I} = 1$
In first breeding bulls	C_{B2A}	$C_{B2A} = 0.1$
In 2 to 5 breeding bulls	C_{B2B}	$C_{B2B} = 0.0$
In 6 breeding bulls	C_{B2F}	$C_{B2F} = 1.0$
Fraction of heifers, bulls, and steers sold for reproduction, feedlot (YS or CF system), slaughter, fraction		
Heifers to be sold for replacement	C_1	$C_1 = 0.0$
Heifer sell at weaning for replacement	C_{F11A}	$C_{F11A} = 0.0$
Heifer sell at 1 yr for replacement	C_{F11C}	$C_{F11C} = 1.0$
Bulls to be sold for replacement	C_2	$C_2 = 0.0$
Bulls sell at weaning for replacement	C_{B8A}	$C_{B8A} = 0.0$
Bulls sell at 1 yr for replacement	C_{B8C}	$C_{B8C} = 0.85$
Bulls sell at 2 yr for replacement	C_{B8E}	$C_{B8E} = 1.0$
In heifers sent to feedlot (calf-fed or yearling system)	C_3	$C_3 = 1-C_1$
Heifers sent to the calf-fed system	C_4	$C_4 = 0.5$
Heifers sent to the yearling system	C_5	$C_5 = 1-C_4$
Steers sent to feedlot (calf-fed or yearling system)	C_6	$C_6 = 1-C_2$
In steers sent to the calf-fed system	C_7	$C_7 = 0.5$
Steers sent to the yearling system	C_8	$C_8 = 1-C_7$

Appendix 1E. Number of cows, notation and formula

Number of heifer at calving, 2 yr old (F1A)

$$FIA = \frac{N * M_{F1B}}{[1 - [-M_{F1B} + Q + (1 - Q)\big[R + (1 - (M_{F1B} + R))\big[P + W[P + W[P + W[P + W[P + W * Z]]]]]]]}$$

Where,

$Q = [M_{F1A} + (1 - M_{F1A})[C_{F2A} + (1 - C_{F2A})[M_{F3A} + (1 - M_{F3A})[M_{F4B} + (1 - M_{F4B})[C_{F5B} + (1 - C_{F5B})M_{F6B}]]]]]$,
$R = (1 - M_{F1B})[C_{F2B} + (1 - C_{F2B})[M_{F3B} + (1 - M_{F3B})[M_{F4C} + (1 - M_{F4C})[C_{F5C} + (1 - C_{F5C})M_{F6C}]]]]$,
$P = (1 - M_{F1B})[C_{F2C} + (1 - C_{F2C})[M_{F3B} + (1 - M_{F3B})[M_{F4C} + (1 - M_{F4C})C_{F5C} + (1 - M_{F4C})(1 - C_{F5C})M_{F6C}]]]$,
$Z = (1 - M_{F1B})[C_{F2C} + (1 - C_{F2C})[M_{F3B} + (1 - M_{F3B})[M_{F4C} + (1 - M_{F4C})[C_{F5I} + (1 - C_{F5I})M_{F6C}]]]]$, and
$W = [1 - (M_{F1B} + P)]$

Items	**Notation**	**Formula**
Total number of cows at calving	N	N = F1A + F1B + F1C + F1D + F1E + F1F + F1G + F1H
Total number of cows at bred	NCB	NB = F4A + F4B +F4C +F4D + F4E + F4F + F4G + F4H
Number of cows at calving		
With 2 lactation, 3 yr old	F1B	$F1B = F6B(1 - M_{F6B})$
With 3 lactation, 4 yr old	F1C	$F1C = F6C(1 - M_{F6C})$
With 4 lactation, 5 yr old	F1D	$F1D = F6D(1 - M_{F6C})$
With 5 lactation, 6 yr old	F1E	$F1E = F6E(1 - M_{F6C})$
With 6 lactation, 7 yr old	F1F	$F1F = F6F(1 - M_{F6C})$
With 7 lactation, 8 yr old	F1G	$F1G = F6G(1 - M_{F6C})$
With 8 lactation, 9 yr old	F1H	$F1H = F6H(1 - M_{F6C})$
Number of cows at calving cull, 15 d after calving		
With 1calving, 2 yr old	F2A	$F2A = F1A(1 - M_{F1A})$
With 2 calving, 3 yr old	F2B	$F2B = F1B(1 - M_{F1B})$
With 3 calving, 4 yr old	F2C	$F2C = F1C(1 - M_{F1B})$
With 4 calving, 5 yr old	F2D	$F2D = F1D(1 - M_{F1B})$
With 5 calving, 6 yr old	F2E	$F2E = F1E(1 - M_{F1B})$
With 6 calving, 7 yr old	F2F	$F2F = F1F(1 - M_{F1B})$
With 7 calving, 8 yr old	F2G	$F2G = F1G(1 - M_{F1B})$
With 8 calving, 9 yr old	F2H	$F2H = F1H(1 - M_{F1B})$

Appendix 1F. Number of cows, notation and formula

Items	Notation	Formula
Number of cows after calving cull, 15 d after calving		
With 1 calving, 2 yr old	F3A	$F3A = F2A(1 - C_{F2A})$
With 2 calving, 3 yr old	F3B	$F3B = F2B(1 - C_{F2B})$
With 3 calving, 4 yr old	F3C	$F3C = F2C(1 - C_{F2C})$
With 4 calving, 5 yr old	F3D	$F3D = F2D(1 - C_{F2C})$
With 5 calving, 6 yr old	F3E	$F3E = F2E(1 - C_{F2C})$
With 6 calving, 7 yr old	F3F	$F3F = F2F(1 - C_{F2C})$
With 7 calving, 8 yr old	F3G	$F3G = F2G(1 - C_{F2C})$
With 8 calving, 9 yr old	F3H	$F3H = F2H(1 - C_{F2C})$
Number of cows at breeding		
Heifers at breeding, 1 yr old	F4A	$F4A = F6A/HP(1 - M_{F4A})$
With 1 calving, 2 yr old	F4B	$F4B = F3A(1 - M_{F3A})$
With 2 calving, 3 yr old	F4C	$F4C = F3B(1 - M_{F3B})$
With 3 calving, 4 yr old	F4D	$F4D = F3C(1 - M_{F3B})$
With 4 calving, 5 yr old	F4E	$F4E = F3D(1 - M_{F3B})$
With 5 calving, 6 yr old	F4F	$F4F = F3E(1 - M_{F3B})$
With 6 calving, 7 yr old	F4G	$F4G = F3F(1 - M_{F3B})$
With 7 calving, 8 yr old	F4H	$F4H = F3G(1 - M_{F3B})$
With 8 calving, 9 yr old	F4I	$F4I = F3H(1 - M_{F3B})$
Number of cows at weaning		
Heifers at pregnancy test, 1 yr old	F5A	$F5A = F4A(1 - M_{F4A})$
With 1 lactation, 2 yr old	F5B	$F5B = F4B(1 - M_{F4B})$
With 2 lactation, 3 yr old	F5C	$F5C = F4C(1 - M_{F4C})$
With 3 lactation, 4 yr old	F5D	$F5D = F4D(1 - L_{F4C})$
With 4 lactation, 5 yr old	F5E	$F5E = F4E(1 - M_{F4C})$
With 5 lactation, 6 yr old	F5F	$F5F = F4F(1 - M_{F4C})$
With 6 lactation, 7 yr old	F5G	$F5G = F4G(1 - M_{F4C})$
With 7 lactation, 8 yr old	F5H	$F5H = F4H(1 - M_{F4C})$
With 8 lactation, 9 yr old	F5I	$F5I = F4I(1 - M_{F4C})$
Number of cows after culling at weaning		
Heifers after pregnancy test, 1 yr old	F6A	$F6A = F1A/(1 - M_{F6A})$
With 1 lactation, 2 yr old	F6B	$F6B = F5B(1 - C_{F5B})$
With 2 lactation, 3 yr old	F6C	$F6C = F5C(1 - C_{F5C})$
With 3 lactation, 4 yr old	F6D	$F6D = F5D(1 - C_{F5C})$
With 4 lactation, 5 yr old	F6E	$F6E = F5E(1 - C_{F5C})$
With 5 lactation, 6 yr old	F6F	$F6F = F5F(1 - C_{F5C})$
With 6 lactation, 7 yr old	F6G	$F6G = F5G(1 - C_{F5C})$
With 7 lactation, 8 yr old	F6H	$F6H = F5H(1 - C_{F5C})$
With 8 lactation, 9 yr old	F6I	$F6I = F5I(1 - C_{F5I})$

Appendix 1G. Females calves and heifers: Number, notation and formula

Items	Notation	Formula
Number of female calves at birth, 0 d old		
Born from 1 calving cows	F7A	$F7A = 0.5 * F1A(1 - M_{1A})$
Born from 2 calvings cows	F7B	$F7B = 0.5 * F1B(1 - M_{1B})$
Born from 3+ calvings cows	F7C	$F7C = 0.5 * (F1C + F1D + F1E + F1F + F1G + F1H)(1 - M_{1C})$
Number of female calves after perinatal death, 15 d old		
Born from 1 calving cows	F8A	$F8A = F7A(1 - M_{2A})$
Born from 2 calvings cows	F8B	$F8B = F7B(1 - M_{2B})$
Born from 3+ calvings cows	F8C	$F8C = F7C(1 - M_{2C})$
Number of heifers at weaning, 205 d old		
Born from 1 calving cows	F9A	$F9A = F8A(1 - M_{3A})$
Born from 2 calvings cows	F9B	$F9B = F8B(1 - M_{3B})$
Born from 3+ calvings cows	F9C	$F9C = F8C(1 - M_{3C})$
Number of female weaning-calf retained for replacement, 205 d old	F10	$F10 = \frac{F4A}{(1 - M_7)}$
Number of heifers for selling for reproduction		
Replacement heifer at weaning, 205 d old	F11A	$F11A = (F7A + F7B + F7C - F10) * C_1$
Replacement heifer after selling at weaning, 205 d old	F11B	$F11B = F11A(1 - C_{F11A})$
Replacement heifers 1 yr, 365 d old	F11C	$F11C = F11B(1 - M_4)$
Number of heifers sent to the yearling system		
Weaning heifers sent to pre-feedlot, 205 d old	F12A	$F12A = (F7A + F7B + F7C - F10) * C_3 * C_5$
Heifers sent to feedlot, 520 d old	F12B	$F12B = (F12A(1 - M_{F12A})) + I_{F5A}$
Heifers sent to slaughter, 610 d old	F12C	$F12C = F12B(1 - M_{F12B})$
Number of heifers sent to the calf-fed system		
Weaning heifers sent to feedlot, 205 d old	F13A	$F13A = (F7A + F7B + F7C - F10) * C_3 * C_4$
Heifers sent to slaughter, 416 d old	F13B	$F13B = F13A(1 - M_{F13A})$

Appendix 1H. Bulls: Number, notation and formula

Number of 1 yr breeding bulls at breeding, 450 d old (B1A) $B1A = M_{B1B} * NB \div \{1 - [-M_{B1B} + M_{B1A} + (1 - M_{B1A})[C_{B2A} + (1 - C_{B2A})[M_{B3A} + (1 - M_{B1B})(1 - M_{B3A})[C_{B2B} + (1 - C_{B2B})[M_{B3B} + (1 - M_{B1B})(1 - M_{B3B})[C_{B2B} + (1 - C_{B2B})[M_{B3B} + (1 - M_{B1B})(1 - M_{B3B})[C_{B2B} + (1 - C_{B2B})[M_{B3B} + (1 - M_{B1B})(1 - M_{B3B})[C_{B2B} + (1 - C_{B2B})[M_{B3B} + (1 - M_{B1B})(1 - M_{B3B})\ [C_{B2F} + (1 - C_{B2F})M_{B3B}]]]]]]]]]]]]\}$		
Items	**Notation**	**Formula**
Number of bulls at breeding		
2 yr breeding bull, 815 d old	B1B	$B1B = B3A(1 - M_{B3A})$
3 yr breeding bulls, 1,180 d old	B1C	$B1C = B3B(1 - M_{B3B})$
4 yr breeding bulls, 1,545 d old	B1D	$B1D = B3C(1 - M_{B3B}$
5 yr breeding bulls, 1,910 d old	B1E	$B1E = B3D(1 - M_{B3B})$
6 yr breeding bulls, 2,275 d old	B1F	$B1F = B3E(1 - M_{B3B})$
Number of bulls at cull, after breeding season		
1yr breeding bulls, 510 d old	B2A	$B2A = B1A(1 - M_{B1A})$
2 yr breeding bulls, 875 d old	B2B	$B2B = B1B(1 - M_{B1B})$
3 yr breeding bulls, 1,240 d old	B2C	$B2C = B1C(1 - M_{B1B})$
4 yr breeding bulls, 1,605 d old	B2D	$B2D = B1D(1 - M_{B1B})$
5 yr breeding bulls, 1,970 d old	B2E	$B2E = B1E(1 - M_{B1B})$
6 yr breeding bulls, 2,335 d old	B2F	$B2F = B1F(1 - M_{B1B})$
Number of bulls after culling		
1yr breeding bulls, 510 d old	B3A	$B3A = B2A(1 - C_{B2A})$
2 yr breeding bulls, 875 d old	B3B	$B3B = B2B(1 - C_{B2B})$
3 yr breeding bulls, 1,240 d old	B3C	$B3C = B2C(1 - C_{B2B})$
4 yr breeding bulls, 1,605 d old	B3D	$B3D = B2D(1 - C_{B2B})$
5 yr breeding bulls, 1,970 d old	B3E	$B3E = B2E(1 - C_{B2B})$
6 yr breeding bulls, 2,335 d old	B3F	$B3F = B2F(1 - C_{B2F})$
Number of male calves at birth, 0 d old		
Born from 1 calving cows	B4A	$B4A = 0.5 * F1A(1 - M_{1A})$
Born from 2 calvings cows	B4B	$B4B = 0.5 * F1B(1 - M_{1B})$
Born from 3+ calvings cows	B4C	$B4C = 0.5 * (F1C + F1D + F1E + F1F + F1G + F1H)(1 - M_{1C})$
Number of males calves after perinatal death, 15 d old		
Born from 1 calving cows	B5A	$B5A = B4A(1 - M_{2A})$
Born from 2 calvings cows	B5B	$B5B = B4B(1 - M_{2B})$
Born from 3+ calvings cows	B5C	$B5C = B4C(1 - M_{2C})$
Number of male calves at weaning, 205 d		
Born from 1 calving cows	B6A	$B6A = B5A(1 - M_{3A})$
Born from 2 calvings cows	B6B	$B6B = B5B(1 - M_{3B})$
Born from 3+ calvings cows	B6C	$B6C = B5C(1 - M_{3C})$
Weaning bulls retained for replacement, 205-d old	B7	$B7 = \frac{B1A}{(1 - M_{B7})}$

Appendix 1I. Males calves, bulls and steers for selling: Number, notation and formula		
Items	Notation	Formula
Number of bulls for selling for replacement		
Replacement bulls at weaning, 205 d old	B8A	$B8A = (B6A + B6B + B6C - B7) * C_2$
Replacement bulls after selling at weaning, 205 d old	B8B	$B8B = B8A(1 - C_{B8A})$
Replacement bulls at 1 yr, 365 d old	B8C	$B8C = B8B(1 - M_4)$
Replacement bulls after selling at 1 yr, 365-d old	B8D	$B8D = B8C(1 - C_{B8C})$
Replacement bulls at 2 yr, 730 d old	B8E	$B8E = B8D(1 - M_5)$
Number of steers sent to the yearling system		
Weaning steers sent to pre feedlot, 205 d old	S1A	$S1A = (B6A + B6B + B6C - B7) * C_6 * C_8$
Steers sent to feedlot, 520 d old	S1B	$S1B = S1A(1 - M_{S1A}) + I_{B2A}$
Steers sent to slaughter 610 d old	S1C	$S1C = S1B(1 - M_{S1B})$
Number of steer sent to calf-fed system		
Weaning steers sent to feedlot, 205 d old	S2A	$S2A = (B6A + B6B + B6C - B7) * C_6 * C_7$
Steers sent to slaughter, 416 d old	S2B	$S2B = S2A(1 - M_{S2A})$

Appendix 1J. Income: Number, notation and formula		
Items	Notation	Formula
Number of cows cull at calving, 15 d after calving		
With 1 calving, 2 yr old	I_{F2A}	$I_{F2A} = F2A * C_{F2A}$
With 2 calving, 3 yr old	I_{F2B}	$I_{F2B} = F2B * C_{F2B}$
With 3 calving, 4 yr old	I_{F2C}	$I_{F2C} = F2C * C_{F2C}$
With 4 calving, 5 yr old	I_{F2D}	$I_{F2D} = F2D * C_{F2C}$
With 5 calving, 6 yr old	I_{F2E}	$I_{F2E} = F2E * C_{F2C}$
With 6 calving, 7 yr old	I_{F2F}	$I_{F2F} = F2F * C_{F2C}$
With 7 calving, 8 yr old	I_{F2G}	$I_{F2G} = F2G * C_{F2C}$
With 8 calving, 9 yr old	I_{F2H}	$I_{F2H} = F2H * C_{F2C}$
Number of cows cull at weaning		
Heifers sent to the yearling system at pregnancy test, 1 yr old	I_{F5A}	$I_{F5A} = F5A - F6A$
With 1 calving, 2 yr old	I_{F5B}	$I_{F5B} = F5B * C_{F5B}$
With 2 calving, 3 yr old	I_{F5C}	$I_{F5C} = F5C * C_{F5C}$
With 3 calving, 4 yr old	I_{F5D}	$I_{F5D} = F5D * C_{F5C}$
With 4 calving, 5 yr old	I_{F5E}	$I_{F5E} = F5E * C_{F5C}$
With 5 calving, 6 yr old	I_{F5F}	$I_{F5F} = F5F * C_{F5C}$
With 6 calving, 7 yr old	I_{F5G}	$I_{F5G} = F5G * C_{F5C}$
With 7 calving, 8 yr old	I_{F5H}	$I_{F5H} = F5H * C_{F5C}$
With 8 calving, 9 yr old	I_{F5I}	$I_{F5I} = F5I * C_{F5I}$
Number of breeding bulls cull		
1 yr bulls *sent to the yearling system*, 510 d old	I_{B2A}	$I_{B2A} = B2A * C_{B2A}$
2 yr bulls, 875 d old	I_{B2B}	$I_{B2B} = B2B * C_{B2B}$
3 yr bulls, 1,240 d old	I_{B2C}	$I_{B2C} = B2C * C_{B2B}$
4 yr bulls, 1,605 d old	I_{B2D}	$I_{B2D} = B2D * C_{B2B}$
5 yr bulls, 1,970 d old	I_{B2E}	$I_{B2E} = B2E * C_{B2B}$
6 yr breeding bull *culls*, 2,335 d old	I_{B2F}	$I_{B2F} = B2F * C_{B2F}$
Number of heifers and bulls sold for reproduction		
Weaning replacement heifers, 205 d old	I_{F11A}	$I_{F11A} = F11A * C_{F11A}$
Yearling replacement heifers, 365 d old	I_{F11C}	$I_{F11C} = F11C * C_{F11C}$
Weaning replacement bulls, 205 d old	I_{B8A}	$I_{B8A} = B8A * C_{B8A}$
Yearling replacement bulls, 365 d old	I_{B8C}	$I_{B8C} = B8C * C_{B8C}$
Two yr replacement bulls, 730 d old	I_{B8E}	$I_{B8E} = B8E * C_{B8E}$
Number of heifers and steers sold to slaughter from the yearling system (YS) and calf-fed system (CS)		
Heifers from YS, 610 d old	I_{F12C}	$I_{F12C} = F12B(1 - M_{F12B})$
Heifers from CS, 416 d	I_{F13B}	$I_{F13B} = F13A(1 - M_{F13A})$
Steers from YS, 610 d old	I_{S1C}	$I_{S1C} = S1B(1 - M_{S1B})$
Steers from CS, 416 d	I_{S2B}	$I_{S2B} = S2A(1 - M_{S2A})$

Appendix 2. Heifer feeding program from weaning to first calving (205 d to 730 d of age)

Period			Summer grazing[1],	Winter grazing[2],	Prairie hay[4],	Corn[4],	44% Pt supplement[4],
Begin	End	Days	AUM[3]	AUM	$kg.hd^{-1}.d^{-1}$	$kg.hd^{-1}.d^{-1}$	$kg.hd^{-1}.d^{-1}$
From weaning to breeding							
15-Oct	30-Apr	198	0.00	0.00	4.42	1.19	0.34
1-May	31-May	31	0.00	0.00	5.13	1.42	0.27
1-Jun	15-Jun	15	0.70	0.00	0.00	0.00	0.00
From breeding to calving							
16-un	31-Aug	77	0.70	0.00	0.00	0.00	0.00
1-Sep	31-Oct	61	0.80	0.00	0.00	0.00	0.00
1-Nov	31-Dec	61	0.00	0.80	0.00	0.00	0.83
1-Jan	23-Mar	82	0.00	0.00	7.15	1.24	0.40
Total per period		525	3.77	1.63	1620.49	381.32	159.12

[1] From June 1 to October 31

[2] From November 1 to December 31

[3] One AUM equal to 309 kg of dry matter of pasture, Werth, (1990)

[4] As fed base equivalent

Appendix 3. Feeding program for 2 yr old Cows

Period		Number of days	Summer grazing[1], AUM[3]	Winter grazing[2], AUM	Prairie hay[4], $kg.hd^{-1}.d^{-1}$	Corn[4], $kg.hd^{-1}.d^{-1}$	44% Pt supplement[4], $kg.hd^{-1}.d^{-1}$
Begin	end						
Lactation period							
24-Mar	31-May	69	0.00	0.00	6.59	1.89	0.82
1-Jun	12-Jun	12	1.30	0.00	0.00	0.00	0.00
13-Jun	15-Oct	124	1.30	0.00	0.00	0.00	0.00
Gestation period							
13-Jun	15-Oct	124	1.30	0.00	0.00	0.00	0.00
16-Oct	31-Oct	16	1.00	0.00	0.00	0.00	0.00
1-Nov	31-Dec	61	0.00	1.00	0.00	0.00	0.49
1-Jan	24-Mar	83	0.00	0.00	7.95	1.28	0.36
Total per period		365	6.43	2.03	1114.56	236.65	116.35

[1] From June 1 to October 31

[2] From November 1 to December 31

[3] One AUM equal to 309 kg of dry matter of pasture, Werth, (1990)

[4] As fed base equivalent

Appendix 4. Feeding program for 3 yr old Cows

Period Begin	Period end	Number of days	Summer grazing[1], AUM[3]	Winter grazing[2], AUM	Prairie hay[4], $kg.hd^{-1}.d^{-1}$	Corn[4], $kg.hd^{-1}.d^{-1}$	44% Pt supplement[4], $kg.hd^{-1}.d^{-1}$
Lactation period							
24-Mar	31-May	69	0.00	0.00	7.84	1.89	0.78
1-Jun	12-Jun	12	1.30	0.00	0.00	0.00	0.00
13-Jun	15-Oct	124	1.30	0.00	0.00	0.00	0.00
Gestation period							
13-Jun	15-Oct	124	1.30	0.00	0.00	0.00	0.00
16-Oct	31-Oct	16	1.00	0.00	0.00	0.00	0.00
1-Nov	31-Dec	61	0.00	1.00	0.00	0.00	0.40
1-Jan	24-Mar	83	0.00	0.00	7.95	1.28	0.36
Total per period		365	6.43	2.03	1200.81	236.65	108.10

[1] From June 1 to October 31

[2] From November 1 to December 31

[3] One AUM equal to 309 kg of dry matter of pasture, Werth (1990)

[4] As fed base equivalent

Appendix 5. Feeding program for 4+ yr old Cows

Period		Number of days	Summer grazing[1], AUM[3]	Winter grazing[2], AUM	Prairie hay[4], kg.hd^{-1}.d^{-1}	Corn[4], kg.hd^{-1}.d^{-1}	44% Pt supplement[4], kg.hd^{-1}.d^{-1}
Begin	End						
Lactation period							
24-Mar	31-May	69	0.00	0.00	8.89	0.00	0.80
1-Jun	12-Jun	12	1.30	0.00	0.00	0.00	0.00
13-Jun	15-Oct	124	1.30	0.00	0.00	0.00	0.00
Gestation period							
13-Jun	15-Oct	124	1.30	0.00	0.00	0.00	0.00
16-Oct	31-Oct	16	1.00	0.00	0.00	0.00	0.00
1-Nov	31-Dec	61	0.00	1.00	0.00	0.00	0.33
1-Jan	24-Mar	83	0.00	0.00	10.12	0.00	0.33
Total per period		365	6.43	2.03	1453.37	0.00	102.72

[1] From June 1 to October 31

[2] From November 1 to December 31

[3] One AUM equal to 309 kg of dry matter of pasture, Werth, (1990)

[4] As fed base equivalent

Appendix 6. Feeding program for bulls

Period			Summer	Winter	Prairie		44% Pt
		Number	grazing[1],	grazing[2],	hay[4],	Corn[4],	supplement[4],
Begin	end	of days	AUM[3]	AUM	$kg.hd^{-1}.d^{-1}$	$kg.hd^{-1}.d^{-1}$	$kg.hd^{-1}.d^{-1}$
24-Mar	19-May	57	0.00	0.00	11.4	2.3	0.45
20-May	31-May	12	0.00	0.00	8.89	0.00	1.45
1-Jun	31-Oct	153	1.35	0.00	0.00	0.00	0.00
1-Nov	31-Dec	61	0.00	1.35	0.00	0.00	0.00
1-Jan	24-Mar	82	0.00	0.00	11.40	2.30	0.45
Total per period		365	6.89	2.75	1691.28	319.70	79.95

[1] From June 1 to October 31

[2] From November 1 to December 31

[3] One AUM equal to 309 kg of dry matter of pasture, Werth (1990)

[4] As fed basis equivalent

Appendix 7. Composition of calf-fed and yearling finishing diet

Ingredient	Inclusion (% DM)[3]
Dry-rolled corn	43.80
WDGS[1]	43.80
Alfalfa hay	7.50
Supplement[2]	4.90
Urea	1.10
Limestone	1.90
Potassium	0.80
Salt	0.60
Trace minerals	0.43
Rumensin	0.03
Tylan	0.02
Vitamin premix	0.02
Total	100.00

[1] Wet distillers grains plus solubles, (value was assumed in 95% of corn price in Dry Matter)

[2] Based on Wilken et al. (2009)

Appendix 8. Feeding program for yearling system (205 d to 610 days of age)

Period		Number of days	Summer grazing[1], AUM[3]	Winter grazing[2], AUM	Prairie hay[4], kg.hd^{-1}.d^{-1}	Corn[4], kg.hd^{-1}.d^{-1}	44% Pt supplement[4], kg.hd^{-1}.d^{-1}
Begin	End						
Winter period							
15-Oct	30-Apr	198	0.00	0.00	4.42	1.19	0.34
Summer period							
1-May	31-May	31	0.00	0.00	5.13	1.42	0.27
1-Jun	25-Aug	86	0.70	0.00	0.00	0.00	0.00
Feedlot							
26-Aug	24-Nov	90[5]	Same as calf-fed system (Appendix 7)				
Total per period		405	2.01	0.00	1034.19	279.64	75.69

[1] From June 1 to October 31

[2] From November 1 to December 31

[3] One AUM equal to 309 kg of dry matter of pasture, Werth, (1990)

[4] As fed base equivalent

[5] 90 d for steers, 110 d for heifers

Appendix 9. Inflation-adjusted Market Prices, and Correlation For Livestock Sales Based on Average 10-yr Period (2003-2012) In Nebraska.

Class of Livestock	Unit	Price	SE	Correlation[d]
Steer calves: 181 - 204 kg[a]	$.kg-1	3.46	0.26	0.85
Steer calves: 204 - 227 kg[a]	$.kg-1	3.28	0.24	0.87
Steer calves: 227 - 250 kg[a]	$.kg-1	3.12	0.22	0.88
Steer calves: 250 - 273 kg[a]	$.kg-1	2.98	0.21	0.88
Steer calves: 273 - 295 kg[a]	$.kg-1	2.92	0.20	0.88
Steer calves: 454-476 kg[b]	$.kg-1	2.55	0.12	0.53
Heifer calves: 181 - 204 kg[a]	$.kg-1	3.08	0.24	0.81
Heifer calves: 204 - 227 kg[a]	$.kg-1	2.95	0.22	0.84
Heifer calves: 227 - 250 kg[a]	$.kg-1	2.83	0.22	0.85
Heifer calves: 250 - 273 kg[a]	$.kg-1	2.75	0.20	0.85
Heifer calves: 273 - 295 kg[a]	$.kg-1	2.68	0.20	0.85
Heifer calves: 408 - 431 kg[b]	$.kg-1	2.56	0.12	0.80
Heifer for replacement: 250 - 273 kg[c]	$.kg-1	2.91	0.27	0.80
Heifer for replacement: 273 - 295 kg[c]	$.kg-1	2.85	0.26	0.81
Heifer for replacement: 295 - 318 kg[c]	$.kg-1	2.75	0.24	0.84
Heifer for replacement: 318 - 341 kg[c]	$.kg-1	2.75	0.24	0.81
Heifer for replacement: 341 - 364 kg[c]	$.kg-1	2.68	0.23	0.82
Heifer for replacement: 364 - 386 kg[c]	$.kg-1	2.60	0.22	0.82
Bull for replacement: 1-yr	Bull	4096.82	520.31	0.91
Bull for replacement: 2-yr	Bull	4998.03	962.51	0.62
Steer Carcass: Mar- Apr	$.kg-1	3.73	0.23	1.00
Steer Carcass: May - Jun	$.kg-1	3.59	0.21	0.93
Steer Carcass: Oct - Nov	$.kg-1	3.65	0.28	0.41
Steer Carcass: Nov - Dec	$.kg-1	3.69	0.29	0.54
Heifer Carcass: Mar- Apr	$.kg-1	3.73	0.23	1.00
Heifer Carcass: May - Jun	$.kg-1	3.59	0.20	0.93
Heifer Carcass: Oct - Nov	$.kg-1	3.66	0.25	0.70
Heifer Carcass: Nov - Dec	$.kg-1	3.69	0.26	0.79

[a] USDA Agricultural Marketing Service, Nebraska (October and November Sales)

[b] USDA Agricultural Marketing Service, Nebraska (August and September Sales)

[c] USDA Agricultural Marketing Service, Nebraska (February, March and April Sales)

[d] Correlation with steers carcass price, for average March-April

Table 10. Inflation-adjusted Price and Correlation For Feedstuffs based On Average of 10-yr Period (2003 - 2012) In Nebraska

Feedstuffs	Unit	Price	SE	Correlation[6]
Corn[1]	$.kg^{-1}	0.165	0.0103	1.00
Soybean meal[1], 44.00%	$.kg^{-1}	0.449	0.0166	0.87
Trace mineral blocks[1]	$.kg^{-1}	0.282	0.0069	0.80
Stock salt[1]	$.kg^{-1}	0.191	0.0047	0.84
Urea[1] 44-46%	$.kg^{-1}	0.447	0.0167	0.72
Muriate of Potash[1] 60-62% K20	$.kg^{-1}	0.468	0.0418	0.69
Limestone[1]	$.kg^{-1}	0.021	0.0003	0.92
Hay, Excluded Alfalfa[1]	$.kg^{-1}	0.076	0.0029	0.66
Hay, Alfalfa[1]	$.kg^{-1}	0.087	0.0040	0.84
Summer pasture[2]	$.kg^{-1} of DM	0.105	0.0039	0.90
Winter pasture[3]	$.kg-1of DM	0.053	0.0020	
WDGS[4]	$.kg^{-1} of DM	0.157	0.010	
Rumensin[5]	$.kg^{-1}	19.575	1.223	0.40
Tylan[5]	$.kg^{-1}	17.775	1.111	0.40
Vitamin premix[5]	$.kg^{-1}	1.400	0.088	0.40

[1] USDA-2012. Agriculture Service Market.

[2] Johnson and Van Newkirk (2012)

[3] Half price of summer pasture was assume, Werth (1990)

[4] Wet distiller grains plus soluble, (value was assumed in 95% of corn price in Dry Matter, Wilken et al. 2009)

[5] Based on Wilken et al. (2009)

[6] Correlation with corn price

Appendix 11. Inflation-adjusted Premium and Discount For Carcass Sales Based On Average of 10-yr (2003 -2012) For 5 Area.

	Mar-Apr		May-Jun		Oct-Nov		Nov-Dec	
Value Adjustments[1]	Average	SE	Average	SE	Average	SE	Average	SE
Quality:								
Prime	0.362	0.095	0.354	0.095	0.377	0.075	0.368	0.101
Choice	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Select	-0.163	0.128	-0.235	0.143	-0.274	0.132	-0.277	0.103
Standard	-0.365	0.133	-0.450	0.147	-0.474	0.152	-0.477	0.130
CAB	0.043	0.027	0.051	0.035	0.049	0.034	0.051	0.036
Dairy - Type	0.000	0.000	-0.001	0.000	0.000	0.000	0.000	0.000
Bullock/Stag	-0.945	0.091	-0.929	0.095	-0.951	0.098	-0.963	0.096
Hardbone	-0.763	0.061	-0.775	0.072	-0.809	0.102	-0.815	0.090
Dark Cutter	-0.883	0.049	-0.874	0.048	-0.893	0.080	-0.902	0.868
Over 30 Months	-0.343	0.007	-0.348	0.007	-0.335	0.026	-0.336	0.024
Yield Grade								
1.0-2.0	0.096	0.010	0.095	0.009	0.099	0.010	0.099	0.009
2.0-2.5	0.050	0.002	0.050	0.002	0.051	0.002	0.051	0.002
2.5-3.0	0.048	0.002	0.047	0.002	0.049	0.003	0.049	0.003
3.0-3.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3.5-4.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4.0-5.0	-0.344	0.078	-0.337	0.076	-0.365	0.082	-0.362	0.086
5.0/up	-0.531	0.060	-0.525	0.060	-0.544	0.060	-0.544	0.063
Weight (kg)								
181-227	-0.797	0.100	-0.782	0.112	-0.792	0.099	-0.785	0.100
227-249	-0.571	0.041	-0.557	0.033	-0.593	0.074	-0.586	0.057
249-272	-0.029	0.019	-0.031	0.021	-0.028	0.019	-0.028	0.019
272-408	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
408-430	-0.002	0.002	-0.002	0.002	-0.001	0.002	-0.001	0.002
430-454	-0.033	0.043	-0.025	0.033	-0.067	0.067	-0.063	0.063
Over 454	-0.521	0.069	-0.509	0.080	-0.531	0.067	-0.537	0.064

[1] USDA Agriculture Market Service (2012). Based on individual packer's quality, yield, and weight buying programs. Values reflect adjustments to base prices, dollars per/kg., on a carcass basis.

Appendix 12. Proportion for carcass from different groups based on carcass of steers from calf-fed system.

Group	DP	FAT	KPH	REA	MS
Steers from calf-fed system	1	1	1	1	1
Heifers from calf-system	0.99	1.16	1.10	0.93	1.00
Steers from yearling system	1.05	0.90	1.05	1.13	0.89
Heifer from yearling system	1.03	1.04	1.15	1.05	0.89
Heifers cull at calving	0.75	0.70	0.91	0.91	0.64
Two calving cows cull at calving	0.75	0.80	1.05	1.02	0.64
Three or more calving cows cull at calving	0.75	0.80	1.05	1.02	0.67
First calving cows cull at weaning	0.75	0.70	0.99	0.97	0.54
Two or more calving cows cull at weaning	0.75	0.70	0.99	0.97	0.58
First breeding bulls cull	0.90	0.80	0.95	1.02	0.70
Second breeding bulls cull	0.95	0.85	0.98	1.10	0.70
Three or more breeding bulls cull	0.95	0.90	1.16	1.24	-

DP =Dressing percentage, FAT=Rib fat thickness, KPH=The internal kidney-pelvic-heart fat, REA= Ribeye area, and MS=Marbling score.

Appendix 13. Energy cost for gestation, lactation, growing, and maintenance, \$/1000 Mcal of ME[1]

Item	Period, d	Unit	Price	SE
From weaning to breeding	244	\$.1000 $Mcal^{-1}$	58.23	14.54
Gestation (breeding to calving)		\$.1000 $Mcal^{-1}$		
Heifer	281	\$.1000 $Mcal^{-1}$	47.50	10.46
2-yr cows	284	\$.1000 $Mcal^{-1}$	44.73	9.75
3-r cows	284	\$.1000 $Mcal^{-1}$	44.48	9.70
4+ yr cows	284	\$.1000 $Mcal^{-1}$	43.78	9.22
Lactation (calving to weaning)		\$.1000 $Mcal^{-1}$		
2-yr cows	205	\$.1000 $Mcal^{-1}$	48.21	10.66
3-r cows	205	\$.1000 $Mcal^{-1}$	48.05	10.62
4+ yr cows	205	\$.1000 $Mcal^{-1}$	47.54	10.00
Growing and maintenance		\$.1000 $Mcal^{-1}$		
Heifer	525	\$.1000 $Mcal^{-1}$	51.47	12.36
2-yr cows	365	\$.1000 $Mcal^{-1}$	47.56	10.63
3-r cows	365	\$.1000 $Mcal^{-1}$	47.27	10.57
4+ yr cows	365	\$.1000 $Mcal^{-1}$	46.36	9.78
Bulls in breeding	365	\$.1000 $Mcal^{-1}$	45.77	10.35
Heifers and steers in calf-fed system	211	\$.1000 $Mcal^{-1}$	59.66	19.88
Heifers and steers in yearling system				
Winter, growing period	198	\$.1000 $Mcal^{-1}$	60.11	15.15
Summer, growing period	117	\$.1000 $Mcal^{-1}$	46.38	10.29
Total growing period	315	\$.1000 $Mcal^{-1}$	53.83	12.92
Finishing period	90	\$.1000 $Mcal^{-1}$	59.66	19.88

[1] ME, Metabolizable energy

"OBJETIVO DE SELECTION PARA EL MEJORAMIENTO DE LA EFFICIENCIA DEL GANADO VACUNO"

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Estudios de simulación basados en 1000 vacas en lactación se utilizaron para evaluar el efecto de la producción del nivel de producción de leche y dos sistemas de producción en la eficiencia biológica y económica, y estimar los valores económicos para un objetivo de producción e índices de selección para vacunos de carne. Los datos para este estudio fueron tomados de la literatura. Precios promedios de 10 años, características reproductivas, supervivencia, crecimiento, y calidad carne así como parámetros genéticos fueron obtenidos de revistas indexadas publicadas desde 1990.   En el primer estudio, vacas con baja (L), media (M), y alta (H) producción, y dos sistemas de manejo post-destete fueron analizados, eficiencias biológica y económica fueron estimados por terneros vendidos al destete y al camal. En el segundo estudio, valores económicos para un objetivo de selección basado en once características e índices de selección usando valores genéticos estimados fueron estimados para a un sistema de producción integrado. Las eficiencias biológicas fueron 29.77, 27.29, and 27.39 g de peso destetado and 21.76, 19.92, y 19.81 g carcasa por Mcal para L, M, y H vacunos, respectivamente. Eficiencias económicas (%) al destete y al camal fueron 98.9, 94.2, y 94.6 y 105.8, 99.0, y 98.8 para L, M, y H vacunos, respectivamente. Valores económicos y valores económicos relativos ($/genética DS) para producción de leche, promedio de ganancia diaria post-destete (ADG), peso adulto, porcentaje de carcasa, grosor de grasa en la 12va costilla (FAT), grasa en el área del riñón, pelvis, y corazón (KPH), área del ojo de lomo (REA,),

marmóreo (MS), dificultad al parto, preñez en vaquillas (HP), y longitud de gestación fueron -0.046 $/kg·205 d^{-1} y -9.068; 56.195 ($/kg·d^{-1}) y 4.957; -0.207 ($/kg) y -7.042; 1.970 ($/%) y 2.065; -39.285 ($/cm) y -6.904; -7.944 ($/%) y -2.401; 2.044 ($/cm^{2}) y 9.311; 21.974 ($/escore) y 11.023; -0.168 ($/%) y -4.095; 0.092 ($/%) y 1.633; y -1.177 ($/d) y -3.155, respectivamente. El índice de selección con la mas alta correlación con el objetivo de selección incluyo ADG, FAT, REA, MS, HP, peso al nacimiento (BWT, kg), altura al año (cm), y peso al destete materno (WWM, kg) con pesos del índice de 128, -53.0, 1.92, 25.3, 0.08, -3.52, -2.39, -0.72, respectivamente. Las características con mayor consistencia a ser incluidos en un índice fueron, en orden de importancia, MS, WWM, peso al año, and BWT.