Relationships among lifetime measures of growth and frame size for commercial beef females in a pasture-based production system in the Appalachian region of the United States

Allison Clare Echols

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
In
Animal and Poultry Sciences

Scott P. Greiner, Co-Chair
Mark L. Wahlberg, Co-Chair
William S. Swecker Jr.

September 9, 2011
Blacksburg, VA

Keywords: beef cow, body weight, frame score, mature size

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ABSTRACT

The beef cattle industry has placed increased focus on mature cow size as a result of its influence on production efficiency and profitability. The objectives of this study were to evaluate relationships among lifetime measures of body weight (**BW**) and frame score (**FS**) in commercial beef females, and to assess the value of immature measures as predictors of mature cow size. Measurements of BW, hip height (**HH**), body condition score (**BCS**), and calculated FS were recorded at weaning (**WN**), breeding at 13 mo age (**BR**), and 8 subsequent periods, ceasing at approximately 5 yr of age for 232 Angus-cross females born 2004 through 2008. Correlation analysis revealed significant ($P <$ 0.001) relationships among BW taken at WN and BR with BW measurements taken at 2.5, 3.8, and 4.8 yr of age (WN r = 0.70, 0.51, 0.61; BR r = 0.65, 0.57, 0.64, respectively). Significant relationships ($P < 0.001$) existed between FS collected at WN and BR, and FS at 2.5 and 3.8 yr (WN= 0.70, 0.72; BR= 0.79, 0.82, respectively). Repeatability of lifetime FS measures was 0.73. BCS was a significant ($P < 0.001$) source of variation in mature BW, with a unit change in BCS accounting for 41 kg BW change at 4.8 yr ($P < 0.001$). BW and FS were moderately to strongly related ($P < 0.001$) at WN, BR, 2.5, 3.8, and 4.8 yr (r = 0.62, 0.49, 0.62, 0.62, and 0.47 respectively). Prediction models for BW at 4.8 yr were similar using weaning BW alone, or with inclusion of both weaning BW and HH ($R^2 = 0.57$ and 0.56). Similarly, breeding BW and HH were non-additive for prediction of 4.8 yr BW ($R^2 = 0.68$, 0.58, and 0.68 for BW, HH, and BW +HH respectively). Performance at immature ages proves to be a satisfactory indicator of mature size, supporting continued incorporation of immature BW and HH and/or FS measurements into selection practices.

Keywords: beef cow, body weight, frame score, mature size

ACKNOWLEDGEMENTS

As two great years of graduate studies draws to a close, I owe a great deal of thanks to the faculty and colleagues who assisted me while pursuing a master's degree.

Even though I sometimes left his office thinking that he was too laid back, I came to really appreciate Dr. Greiner's calm nature and understanding as I proceeded further into my research. He prompted me to think harder, and always provided valuable guidance and feedback. I appreciate the opportunities presented to me to become involved in extension and outreach activities. Heart-felt thanks go out to him and his family for all they have done for me.

Thanks to Dr. Swecker and Dr. Wahlberg for agreeing to serve on my committee. With Dr. Wahlberg's retirement, and Dr. Swecker located in the vet school, I did not meet one on one as much, but greatly do appreciate their expertise and input. I consider each a valuable asset in the development and completion of this project and degree.

Mr. David Fiske proved to be very helpful in providing the abundant records needed to create the dataset I utilized for my project. It always amazed me how fast he was to respond to my questions and requests.

There is no way I could go without acknowledging the assistance of Dr. McGilliard (a.k.a. SAS King). I probably would still be conducting analysis if it was not for his excellent courses and numerous hours spent getting my data and models in shape. I credit him not only for his expertise with statistics, but also his willingness to share his love of golf.

Much time was spent in Dr. McCann's office. I often popped my head in with what I thought to be a question that could be quickly answered; I was continually mistaken.   One question would lead to conversation about his time spent in Georgia, the ins and outs of the sheep business, or the best way to prepare a brisket. I enjoyed the conversations and guidance and found them to be very stimulating whether insight was solicited or not.

One of the most rewarding components of my time at Virginia Tech was my involvement in teaching under Dr. Beal, Dr. Wood, and Dr. Eversole. I grew as an educator and professional during my time spent with each of them. I had no idea how much I enjoyed teaching until I became a teaching assistant for Dr. Beal’s Introduction to Animal and Poultry Science course in the fall of 2009.

I consider myself very fortunate to be raised in a rural area with strong ties to agriculture. It is to the credit of my parents, Larry and Pam that I have grown into the person I am. I am grateful for my father’s dedication to our family and the farm.   I know this may have not always been easy given the challenges of his chosen vocation. Mom has always been extremely supportive of me, and I appreciate all the times she set me straight, and even more the times she said nothing as I learned from my own mistakes. I am so glad I have been able to share so many special moments with my brother Andrew. It is great to have a brother that looks out for his older sister.

Much gratitude is owed to my friends in and out of Blacksburg. Their friendship means the world to me. I anticipated coming to graduate school and meeting some interesting people, but I never thought I would have developed as many lasting friendships as I have.

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Chapter I

Introduction

Selection practices in the United States beef industry have placed a large emphasis on increased growth in recent decades. Selection pressure for weaning and post-weaning growth coupled with moderate to high correlations of these weights and associated frame size to the same measures at maturity have resulted in heavier body weight (**BW**) in the mature cow herd (McMurray, 2008; Dib et al., 2010). With diverse management practices and increased feed costs, larger cows may not be the best alternative for all operations in regard to overall cow herd efficiency.

Body weight and frame score (**FS**) are commonly used to describe size, and there is a direct relationship between these measures. The concept of using linear skeletal measurements to describe cattle has been a part of standard beef industry practices for many years. In 1986, the Beef Improvement Federation (**BIF**) developed and published a standardized FS system that has been adopted by breed associations and commercial cattlemen. A FS (1-9) is determined by hip height at a given age, and is intended to serve as supplemental information to other selection tools such as weight at a given age or EPDs. The FS system has not been altered since its recognition by BIF.

Evaluation of skeletal size is one of the most important traits for beef cattle given reported high heritability of frame score (0.60-0.64; Minish and Fox, 1979; Dib et al., 2010). Estimates of direct heritability of mature weight and mature height have been generally moderate to high (Berg and Butterfield, 1976; Petty and Cartwright, 1966; Dib et al., 2010), with correlations between the two traits also high. The nature of the relationship between one trait measured early (e.g. weaning or yearling) and another trait at a later age would aid in the facilitation of the decision making process when selecting replacement females.

Industry advancements have promoted increased performance at earlier ages, consequently resulting in increased cow size. This may not be desirable for the breeding herd as cattle with larger weights have greater maintenance costs (Fiss and Wilton, 1992). Feed energy consumption during the cow calf component of the production cycle represent approximately 72% of metabolizable energy consumed during period from conception to slaughter (Ferrell and Jenkins, 1982). This makes matching feed resources to growth and milk potential crucial. The commercial cattleman is continually looking for management practices that will add consistency to their calf crop and improve profitability. Optimizing cow size for a particular herd requires understanding and management of the genetic potential of cattle, the environment, and marketing objectives.

In the current study, relationships of lifetime measures of BW and FS for commercial beef females in a pasture-based production system were examined. Objectives of this research project were: 1) characterize and evaluate growth of BW and skeletal size over the lifetime of beef females, 2) identify the relationship among immature measurements of weight and skeletal size to the same measures at mature ages in beef females, 3) develop strategies for assessment and change of mature size to be utilized by the commercial cow-calf sector utilizing within-herd records.

Chapter II

Literature Review

Overview of Growth

Obtaining measurements of growth at early ages provides opportunity to develop uniformity in the commercial cow herd during selection of replacement heifers. Increased interest among animal scientists and producers in life-time weight-height relationships has been stimulated by the recognition of the economic importance of mature size. Selection practices in the United States beef industry have placed a large emphasis on increased growth in previous years. As a result, the nation's average cow size has increased. Many researchers have reported mature weight and height heritability to be moderate to high (Brinks et al., 1964; Smith et al., 1976; DeNise and Brinks, 1985), which indicates that these traits could be altered genetically by selection. The concept of cooperative beef production systems emphasizes the need for understanding the fundamental relationships of growth and development during the life of cattle.

Basics of growth and development

Growth is defined in many different ways, and no one definition is universal to all applications. Growth is commonly defined as the production of new cells. Growth not only includes increase of body size, but also biological phenomena at the cellular level through increase number (hyperplasia) and size of cells (hypertrophy) and in changes of form and chemical composition of cells resulting from differential growth of various components of the body, especially in muscle and fat (Berg and Butterfield, 1976). As mammals mature, specialized cells (e.g., nerves, skeletal muscle cells) lose their ability to replicate and grow only by hypertrophy or incorporation of satellite cells. Other tissues such as blood cell precursors, hair follicles, gastrointestinal epithelia, digestive tract organs, and ectoderm continue to divide throughout life.

Tissues, bones, and organs do not mature simultaneously (Owens et al., 1993). There is a general gradient in organ/muscle formation from head to tail and from extremities to the core based on relative growth rates. Body shape changes over time; deposition of certain internal muscle components occurs more extensively later in life.

Body growth is determined by genetic and non-genetic factors (Arango and Van Vleck, 2002) with the genetic makeup of an individual including additive and non-additive genetic combinations impacting growth. These combinations interact with environmental conditions such as management, nutrition, climate, and intrinsic factors such as sex, age, and physiological status. Extrinsic factors such as maternal effects and random environmental factors also impact the phenotypic expression of growth.

Post-natal growth generally follows a sigmoid or S-shaped curve through which the rate of growth varies with age until the rate slowly declines reaching a plateau when the animal achieves mature weight. This curve is composed the prepubertal, self-accelerating and the postpubertal, self-inhibiting phases (Owens et al., 1993). The point of inflection is the meeting point of these two phases (Goonewardene, 1981). Deceleration of growth postpubertally is not well understood despite years of study. Owens et al. (1993) disclosed two suggestions for growth inhibition, one due to limitation of resources (nutrient supply and growth factors), the other resulting from the accumulation of products or inhibitory factors that restrict cell division. Growth rate is retarded when energy or protein supply is limited, influencing some researchers to speculate that growth deceleration is simply due to reduced intake of energy above maintenance. If this was true, forced feeding should increase lean body mass of maturing animals; however, most force-feeding studies have found no increase in protein deposition (Owens et al., 1993). Excess nutrients from force feeding were converted to lipid, excreted, or catabolized. Mature size (weight) generally is defined when maximum protein mass is achieved despite the increased fat deposition that can occur beyond this point (Owens et al., 1993). If maximum lean body mass indicates mature weight, additional weight gain is fat. This means that weight of mature animals may not reflect mature weight as a result of varying body condition.

Maximum body size is genetically determined, but can be altered by nutritional and hormonal factors. Breed differences are due to variations in size of skeleton and the number of muscle cells (Hammond, 1961). Growth rate before maturity can be influenced greatly by plane of nutrition, hormonal status, and environment (Widdowson, 1980; Gluckman, 1986). These factors may inhibit cell division to the extent that mature body size is less than the genetically determined maximum. Alteration of mature size by nutritional restrictions continues to be debated. Depending on the severity of the restriction and the specific nutrient involved, size of an animal when it becomes mature has been reported to be decreased, increased, or unchanged (Owens et al., 1993). Variations in studies may be related to the timing or severity of deprivation or the nutrient involved. Very severe nutrient reduction, particularly protein, reduces mature size of swine and cattle (Berg and Butterfield, 1976; Pond et al., 1990; Widdowson and Lister, 1991). A moderate degree of restricted feeding during growth did not alter composition of rib sections of the carcass (Winchester and Howe, 1955). This agrees with conclusions of Long (1988) that genetic potential of cattle governs carcass composition at any weight regardless of when that weight is reached.

Growth is sometimes measured as the size or stature (bone length or height). Long bones cease to increase in length after epiphyseal closure, presumably stopping linear bone growth when closure occurs (Owens et al., 1993). Oberbauer et al. (1989) concluded that hormones and nutrient uptake can influence the age at epiphyseal closure. Hence, closure need not correspond to a specific animal age even though closure is used commercially as an index of maturity in slaughter lambs and beef.

Factors influencing growth

Certain tissues grow and mature before others, with growth starting with neural tissue and proceeds to bone, muscle tissue, and finally adipose tissue. Depending on anatomical location, development of each of these tissues can be early, medium, or late. An example of this would be deposition of fat near the kidneys preceding deposition at intermuscular, subcutaneous, and intramuscular sites, supporting body shape and composition changes as an animal matures (Owens et al., 1993).

Specific hormones or growth factors alter growth rate or body composition. Endogenous and exogenous hormones promote translation, transcription, and amino acid uptake (Owens et al., 1993). Hormone administration responses can differ with species and organ of the body. Administration of growth hormone, somatotropin, has increased the growth rate and gain: feed ratio of swine, sheep, and cattle. In steers, administration of exogenous growth hormone expanded the size of internal organs and increased feed intake (Early et al., 1990). Effects of growth hormone effects seem to be indirect and dependent on locally produced somatomedins (IGF-I and II). IGF response to growth hormone is reduced when nutrient status or insulin levels are low. Beta-adrenergic agonists are another class of compounds that can alter tissue growth and composition (Owens et al., 1993). Structurally, these compounds are related to epinephrine and norepinephrine. Upon activations, beta-receptors in adipose tissue stimulate lipolysis (Muir, 1988). In muscle tissue they decrease protein degradation (Morgan et al., 1989) either transiently or continuously. Decreased fat deposition and increased net protein deposition may occur in poultry, swine, sheep, and, to a lesser extent, in cattle when given beta agonists.

Selection for rapid growth rate or low fat content often results in increased mature body weight (Owens et al., 1993). Rapid growth can be desirable for enhancement of production efficiency of lean tissue and reduced fat content at a specific slaughter weight (Greathouse, 1986). Conversely, larger skeletal mass and weight increases both birth weight and the cost of maintenance. Because maintenance energy requirements and age at puberty both increase with mature weight (Koch et al., 1988), growth restriction rather than stimulation might be preferable for heifers intended for use as replacements. Whether mature size of cattle can be altered readily by nutritional restriction is still debated. Restricted growth may result in adverse effects such as delayed puberty and first parturition, thereby reducing lifetime cow productivity. Delayed puberty is more prevalent in very large frame or Bos indicus cattle (Owens et al., 1993). Growth rate is subnormal when nutrient uptake of growing animals is restricted. Rate of weight gain during realimentation usually is greater than for those animals that were never restricted. Supplemental feeding of postpubertal heifers generally can resolve previous restricted growth. Called compensatory growth, this growth rebound presumably represents rapid hypertrophy of muscle tissue. Extent of compensatory growth is greater when it follows energy restriction rather than restriction of protein (Drouillard et al., 1991). Moran and Holmes (1978) reported that the magnitude of compensatory growth depends on a number of factors, including age when restriction begins; the severity, duration, and nature of low plane of nutrition; the realimentation diet and time; and breed type.

Assessing Mature Cow Size

The United States beef cow herd inventory has decreased 12 of the last 14 years, dropping from a cyclic peak of 35.3 million head in 1996 to 31.3 million head in 2010, the smallest inventory since 1963 (USDA-NASS, 2011a). Cow inventory for 2011 has dropped below 31 million head, while total kg of beef produced annually has been maintained at almost 23 billion kg (USDA-NASS, 2011b), providing evidence that cattle have steadily increased growth potential and size. The trend of increasing size poses an important task for the industry to address how big the modern cow really is. McMurray (2008) reported a 146 kg increase in cow weight from 1975 to 2005, estimating slaughter cows at body condition score 5.0 weighed 475 kg in 1975 and 621 kg by 2005. In addition to thinking specifically at phenotypic observations, there are indicators of shifts of cow size are noticed in expected progeny difference (EPD) genetic trends for cattle weights. Dib et al. (2010) documented a trend of increasing mature weight in registered Angus cows from 1979 to 2005. Recent estimated breeding values indicate cow mature weight beginning to plateau. From 1979 to 1990, the regression coefficient for estimated breeding value was 2.5 kg/year, and after the apparent plateau the estimated breeding value was 0.29 kg/year. From 1979 to 1992 there was a continuous increase in mature height (0.21 cm/yr). From 1992 to 2005 there was a decline in mature height at a rate of -0.089 cm/yr.

Weight

Typically there is a direct relationship between frame size and mature weight, but variations in muscling characteristics prevent a perfect relationship. Frame size or skeletal size is typically measured as length of specific bones or height at the withers or hip (Owens et al., 1993). Fox and Black (1984) estimated the fat content for animals with different FS and different weights. Fat content at the point of maximum protein mass was 34 to 37% of empty body weight for all classes examined. This indicates that mature weight for animals of different frame sizes might be defined as the weight at which fat content of the empty body reaches 34 to 37%.

Expression of body size can be represented by a set of size-age points (representing weights, heights, etc.) that gradually change until reaching a plateau at maturity (Arango and Van Vleck, 2002). The points represent a typical longitudinal process and results in sets of many, typically highly correlated measurements (Meyer, 1998). Arango and Van Vleck (2002) define maturity as the only period in the life of an animal when growth is normally in an unchanging state. The most obvious procedure to estimate mature weight would be an average of all weights taken after the animal has ceased growing. Although this procedure may give an accurate assessment of mature weight, it can be difficult to determine when an animal has ceased lean tissue growth. Smith et al., (1976) defined mature weight as fat-constant, asymptotic weight at 6 to 9 yr of age adjusted for body condition score. When derived from growth curves, mature weight begins to be reliable only when data extend beyond 4.5 yr (Morrow et al, 1978; Johnson et al., 1990).

Describing growth

Curves that relate weight or stature with age have been used to describe growth. Growth parameters such as mature weight and maturity rate, estimated from weights taken throughout the life of the animal, can be used to evaluate the development of animals. Several approaches have been proposed to deal with growth data, ranging from a basic repeatability model to full multivariate models. Observations of a single measure of size, such as height, yields univariate data while multiple measures of size (weight, height, width, etc.) represents multivariate data. The dataset can be considered longitudinal when a complete set of measurements is available for all individuals at all ages (stages). Even when longitudinal data is partitioned into subsets for static or cross-sectional analyses, confidence in the interpretations is increased because the individuals contribute to all levels of the analysis (Brown et al., 1973). The repeatability model approach is simplistic assuming that different weights of the same animal represent the same trait with constant variance during the animal's life. The so-called repeatability model considers sequential weights of an animal as repeated measures of a single trait (Arango and Van Vleck, 2002). A multivariate approach would consider each measurement of an age-size point as a different trait. This method requires subjective subdivision of age segments to represent different traits. Traditional growth functions would explain the curve using a small set of parameters defined by a deterministic equation (Arango and Van Vleck, 2002). Growth curves have been a standard approach to fit growth data with mathematical functions that are known as biologically based curves (growth curves) (Sandland and McGilchrist, 1979). Growth equations are significant in estimating parameters that are biologically uninterpretable, such as age at point of inflection of the growth curve, mature weight and maturity rate (Richards, 1959). Consolidation of information of weight-age data into interpretable parameters is one of the main advantages of using mathematical models to describe growth. Other approaches have utilized covariance functions and random regression models. There are several procedures by which mature weight can be estimated. Richards, Brody, Von Bertalanffy and Logistic are four exponential equations that have been used for describing beef cattle growth. One that has been used in many studies (Fitzhugh and Taylor, 1971; DeNise and Brinks, 1985) is the growth curve as described by Brody (1945):

$$W_t = A(1 - Be^{-kt})$$

Where W_t is weight at time t, A is the asymptotic weight, B is the integration constant, and k is the relative growth rate. Brody's model is often chosen because of the simplicity of interpretation and ease of estimation. Bullock et al. (1993) found that to fit Brody's curve it is necessary to have records on the animal to a point when the animal is no longer growing (approximately 5 yr of age). When viewing individual growth curves, the weights seem to increase in a quadratic manner from birth to 4 yr of age, plateauing thereafter (Bullock et al., 1993). Another way to estimate mature weight is to fit a quadratic with a plateau:

$$MWP = A + B*MAGE + C*(MAGE)^2$$

Where MWP is the predicted mature weight, A is the intercept, B is the linear coefficient, C is the quadratic coefficient, and MAGE is the age at which the plateau is reached for each cow (Bullock et al., 1993). The two methods discussed (Brody and quadratic) necessitate actual determination of a mature weight. Fitting the quadratic is advantageous from the perspective that the point at which growth stops can easily be estimated as the age at which the curve reaches a plateau. Brody's method uses an arbitrary percentage of the asymptotic weight to calculate the age at maturity (typically 98%). Bullock et al. (1993) concluded that with these two methods for determining mature weight, only animals with records extending past approximately 5 yr of age can be used. Therefore, a strategy that includes animals that do not have actual mature records to be included in the analysis would be advantageous.

Frame/Skeletal Size

Most studies report heritability for HH to be moderate to high. Vargas et al. (2000) reported a heritability estimate for HH for Brahman cattle at 18 mo of age of 0.87. In Angus, Polled Hereford, and Santa Gertrudis cattle, Neville et al. (1978) reported a relatively high heritability estimate of 0.75 for HH measured at 15 mo of age in replacement heifers. In Hereford cattle, Bourdon and Brinks (1986) reported a heritability estimate of 0.55± 0.08 for 365 d HH. Similarly in Angus, a heritability of 0.62 for mature HH was reported (Choy et al., 1996).

Minish and Fox (1979) suggested evaluation of skeletal size was one the most important traits for beef cattle in the late 1970s. At this time, researchers concluded that visual appraisal of frame size was highly heritable (0.6) and repeatability of scoring cattle for frame was the highest (0.8-0.9) of any trait measurements taken with physical appraisal. With consideration of breed type, frame size was intended as a tool to predict mature cow size in addition to the optimum slaughter end point (Minish and Fox, 1979). Linear skeletal measurement to describe cattle has been a part of the beef industry for many years. Over the years, FS has been identified as a convenient way of numerically describing skeletal size and is often reported as supplemental information to weight and other performance data.

The BIF describes FS as a suitable way of describing the skeletal size of cattle (BIF, 2002). Because an animal is expected to maintain the same FS throughout life, the system accepts variable timing of FS evaluation. The 1 to 9 scoring system has become the standard in the beef industry for describing cattle skeletal size. The BIF guidelines recommend that height measurement for FS be taken at the point directly over the hooks (hips) while the animal's legs are set squarely. Smaller numeric FS are associated with cattle that are shorter in stature for their age, and tend to be earlier maturing. Acknowledgement should be made that environmental factors and nutrition level can alter the growth rate from an animal's genetic potential. Cattle fed on a lower plane of nutrition will grow slower than the FS tables indicate while cattle fed at an extremely high plane of nutrition may accelerate their growth pattern.

Frame score assessment information was first included in beef publications in the late 1970's. Beef Production and Management (1979) used specific HH to designate the minimum height for a particular FS, allowing cattle to be assigned to one of nine FS (1-9). Rather than providing a table or equation for calculating FS, it described a base point, FS 3 as a bull or steer with a hip height of 45 inches at 12 mo of age. Two inch deviations between FS were allowed for animals of the same age. To account for variation in age, this system allowed for 1 inch increase in HH per month from 5 to 12 mo of age, then 0.50 inch per mo from 12 to 18 mo of age, and 0.25 inch/mo change from 18-24 mo. It was disclosed that heights for heifers are generally two inches less at the same age than aforementioned bull/steer scale. An example of this would be a heifer measuring 42 inches at 8 mo of age. For the heifer, there would be a 4 inch adjustment for age, and a 2 inch adjustment for sex. A FS 3 heifer at 8 mo of age would have a HH ranging from 39-41 inches. Since this heifer is 42, she would be categorized as a FS 4. When the FS system was included in the BIF Guidelines for Uniform Beef Improvement Programs (1986) released equations for calculation of FS on cattle 5-21 mo of age. The following equation should only be used for heifers between the ages of 5 and 21 mo:

Frame Score = -11.7086 + (0.4723 x HH) - (0.0239 x Age) + (0.0000146 x Age x Age) + (0.0000759 x HH x Age), where Age = days of age.

A separate equation for calculation of FS is used for bulls. After an animal exceeds 21 mo, there is an extrapolation table to determine FS for bulls and cows. This table includes hip heights for respective FS at 24, 30, 36, and 48 mo of age.

University of Missouri professor John Massey has been credited with the development of the first frame scoring system. The Missouri frame system was based on seven frame sizes (1 to 7), with smaller numbers indicating smaller frame size (Massey, 1979). Massey was a coordinator of the Missouri Beef Cattle Improvement Programs that initiated the Missouri Performance- Tested Bull Sale Program (Univ. of Missouri, 2006). Funds for erecting bull test facilities were appropriated in 1959. Frame score was just one measurement collected by the testing program, but increased availability of information impacted the Missouri beef industry, with FS of feeder cattle transitioning from 3.5 in the early 1970s to nearly 6.0, 20 yr later (Univ. of Missouri, 2006). This increase in height resulted in an increase of 68 kg in live weight.

Relationships between weight and frame

Mature cow weight impacts the profitability of beef enterprises making it a fundamental consideration in selection programs. Ideally, mature weight prediction should be based on all available information; however, mature weight can also be predicted from immature body weight and/or other measures of body size. Weights of contemporary animals reared under the same environment also increases accuracy of prediction (Taylor, 1985).

Many management steps and decisions must be made during the process of selecting and raising replacement heifers. Replacement heifers must pass a number of production challenges, two key examples being selection at weaning; and development from weaning to first breeding. The ability to make early selection decisions for replacement breeding animals can be favorable, as selection of the right heifers can have a long-term positive impact on cow herd production and profitability. For early predictions to be effective, reliable estimates of parameters for associated traits measured at young and older ages and their relationships is necessary. The nature of the relationship between estimated breeding values for one trait measured early (e.g. weaning) and another trait measured at a later age would aid in the facilitation of the decision making process (Vargas et al., 2000). Early estimates of direct heritability of mature weight and mature height have been generally moderate to high (Berg and Butterfield, 1976; Petty and Cartwright, 1966; Dib et al., 2010). Northcutt and Wilson (1993) found mature height to be a highly heritable trait, as indicated by the estimate of 0.83 for analyses both with and without weight adjustments for body condition. Bourdon and Brinks (1986) reported a yearling HH heritability of .61 ± .06 for Hereford bulls. Similarly, Kriese et al. (1991) estimated a direct heritability of .66 for heights taken from field records on yearling Hereford bulls. Recent work by Dib et al. (2010) using data compiled by the American Angus Association supports high heritabilities for both traits. Heritability for mature weight was estimated to range from 0.44 to 0.47, and mature height heritability estimate of 0.62 for the sample groups included in this study by Dib et al. (2010). Strong, positive estimates of genetic correlation between mature weight and height were found to range from 0.80 to 0.83. Selection for either trait would lead to a correlated response in the other. Selection for mature height would be more accurate than for mature weight because of higher heritability and less variation due to permanent environmental effects.

Postweaning body weight gain and mature weight were discovered to have a high, positive relationship of 0.48 to 0.59 (Williams et al., 2009). Evans et al. (2000) reported an average estimate of 0.68 between mature weight observed at 2 to 9 yr of age and post weaning gain. Other estimates include 0.76 (Bullock et al., 1993) and 0.35 (Brinks et al., 1964). This suggests that calves sired by bulls with a greater rate of increase in body weight gain will likely have heavier mature weights.

Cow-calf producers that do not routinely collect and document cow weights do not know the actual weight of the cow herd. Increase in cow weight over time is likely a result of greater emphasis placed on calf weaning weight, yearling weight, and necessary increase in milk production needed to support desired calf performance. Increased size is supported by the moderate correlations of such traits to mature weight (Northcutt and Wilson, 1993). Depending on targeted marketing endpoint, either weaning weight, yearling weight, or carcass weight becomes a source of revenue and all are correlated to mature cow weight. Northcutt and Wilson (1993) estimated genetic correlations between mature weight and weaning weight and yearling weight of 0.62 and 0.45, respectively. The genetic correlation between mature weight and carcass weight was estimated at 0.81 (Nephawe et al., 2004). Other research included similar estimates concluding that of immature traits, weaning weight has the highest genetic correlation with mature cow weight. Williams et al. (2009) estimates weaning weight genetic correlations with mature cow weight ranging from 0.65 to 0.82 in Red Angus data. Bullock et al. (1993) found mature weight to have a positive genetic correlation with weaning weight and yearling weight (0.80 and 0.76). Genetic trends for increased growth over time expose a corresponding increase in mature cow size. Vargas et al. (1998) reported a positive relationship of height with scrotal circumference and negative relationship of height with age at puberty.

Tools for selection

Replacement heifers represent the next generation of genetic progress for the cow herd. Since calving season and breed is established by the producer, weaning weight becomes the primary selection parameter in initial selection of replacement animals. Retaining replacement heifers out of the same breeding intended for producing larger feeder cattle would likely result in larger cows, increasing feed costs or decreasing the herd's reproductive performance if feed resources were not adequate.

Body size characteristics have been used by breeders to implement strategies for the genetic improvement of beef cattle (Jenkins et al., 1991). Weight and (or) weight gains have been the basis of consideration for size of cowherds. Hip height has also been used to change stature of cows, which ultimately results in heavier cows. Neither weight nor hip height alone can account for all genetic differences in size (BIF, 2002). Evaluation including both weight and height may be a superior option during selection. Breeding system objectives which capture genetic potential in a given environment and market is important. Genetic prediction of mature size could allow cattle breeders to make directional changes in mature size of their herd, promoting uniformity of cow size for their production environment. Until recently, EPDs were absent of selection tools for traits controlling inputs. The first selection tool for mature size was made available by the American Angus Association in the 1992 American Angus Association Sire Evaluation Report (Wilson and Northcutt, 1992). The beef industry now has a limited number of tools for decreasing input costs, available to producers through maintenance EPDs and some selection index EPDs. The first mature cow maintenance energy EPD was published by the Red Angus Association of America in the spring of 2004. It is predicted from mature weight of the cow adjusted for BCS and from milk production (Enns et al, 2003) because of the impacts of these traits on maintenance requirements (Montano-Bermudez et al., 1990). Selection indices are a collection of EPDs that are relevant to a particular breeding objective, where each EPD is multiplied by an associated economic weight (Spangler, 2010). Breed association have published EPDs for mature weight and maintenance energy, and continue to work on the development of tools to accommodate varying market interests and production systems (Spangler, 2010).

Importance of Cow Size

Producers constantly evaluate grain prices and other costs of production receive constant considerations by producers in an attempt to maintain profitability and efficiency. Defining and assessing optimum cow size and efficiency has been debated for years, and has proven challenging as differing biological types of cattle vary in performance and adaptation in different environments and production systems. Production of economically efficient cattle is of major emphasis for commercial cow-calf enterprises. Myers et al. (1999) reported that feed accounts for 54-75% of annual variable costs on a per cow basis, solidifying that an efficient cow herd is vital to the profitability of a producer. To address questions on size and efficiency, there must be consideration of the complex influences of biological and economic efficiencies on the different segments of the beef industry. The location, market, resources, producer skills, and breeding systems are quite variable and matching cow size to these conditions does affect production efficiency.

Efficiency in production of different types of cows is not a new area of interest. Armsby and Fries (1911) addressed biological type and age of cattle on feed utilization 100 years ago. Others concerned with the impact of cattle type on biological and economic efficiency released reports in the early half of the 20th century (Brody and Cunningham, 1936; Kleiber, 1936). This proved to just be the start of numerous research efforts focusing on cow efficiency not only from an output, but also input perspective.

Efficiency is frequently a goal for businesses. In food animal production, Dickerson (1970) defined efficiency as best measured by the ratio of total costs to the total animal product from females and their offspring over a specified time period. This definition established a standard for overall efficiency without delineating between biological efficiency, defined as conversion of physical inputs into marketable product, and economic efficiency, which relates financial expenditures to gross receipts. Factors impacting biological efficiency include cow maintenance, gestation, and lactation requirements, along with reproductive performance, and calf maintenance and growth requirements (Dickerson, 1970). The number of calves weaned per cow exposed most clearly reflects biological efficiency in the cow herd (Notter, 1979). Biological and economic efficiency are related, but may not be the same (Johnson et al., 2010). Johnson et al. (2010) emphasized the complexity of optimizing the relationship between biological and economic efficiency, which requires considerations of the genetic potential of cattle, the environment, and objectives for products produced and marketed. Defining efficiency in the beef industry is further complicated by economic issues regarding the definition of biological efficiency, a key example being utilization of grazed forages compared to harvested forages and/or concentrates.

Differing interpretations of efficiency arise from terminal and maternal production settings, making it difficult to develop a single definition. Genetic improvement of cow-herd productivity has promoted increased weights of leaner progeny for marketing at specific times in the production cycle (Notter et al., 1979; Humes and Munyakazi, 1989). By selection for increased performance at earlier ages, cow size has also increased. This may not be desirable for the breeding herd as animals with larger mature weight have greater maintenance costs (Fiss and Wilton, 1992). Dickerson (1970) reported that an efficient cowherd exhibits early sexual maturity, high reproductive rates, longevity, minimum maintenance requirements, and the ability to convert available energy from forage into maximum pounds of calf weaned. He reported that a cow's ability to reproduce is the most important factor promoting efficiency. In contrast, cattle excelling in production of retail product have heavier birth weights, later onset of puberty, decreased marbling scores, and have higher maintenance requirements due to heavier mature weights (Cundiff et al., 1993). Historically, low feed costs in the feedlot industry have favored heavier slaughter weights. Industry acceptance of larger, heavier carcasses promoted a market to reward cattle with the genetic potential to maximize output (Ferrell and Jenkins, 2006). Efficiency in the feedlot and processing plants has been a powerful influence on the creation of incentives for cattle producers to select for increased growth traits and carcass weight. Traditionally, farmers and ranchers have effectively mitigated the increased costs of larger cows with low costs of supplemental feed. When input costs are high, this may not be a reasonable management practice.

Breed implications

Consistent differences among breeds or breed crosses for efficiency of converting food energy resources to weight of calf at weaning are difficult to document. Klosterman and Parker (1976), Marshall et al., (1976), Bowden (1980), Brown and Dinkel (1982), and McMorris and Wilton (1986) provide evidence suggesting breed or breed crosses were similar in biological efficiency. Researchers at the U.S. Meat Animal Research Center have reported differences among diverse biological types for biological efficiency (Ferrell and Jenkins, 1984; Green et al., 1991). Jenkins and Ferrell (1994) compared the biological efficiencies of 9 pure breeds of mature cows provided 4 differing levels of feed energy intake over a 5 yr period. These breeds varied in genetic potential for weight at maturity, observed peak daily milk yield, post weaning gain and fat deposition potential (Gregory et al., 1994 a, b; Jenkins and Ferrell, 1992). Jenkins and Ferrell (1992) defined biological efficiency as the ability of a cow to convert feed resources to calf weight at weaning. Ranking of the breeds for efficiency depended on dry matter intake. At low feed availability, breeds that were more moderate in genetic potential for growth and milk production were most efficient because of their ability to convert limited resources into salable product, supporting the importance of reproduction on efficiency. With lower feed availability, Red Poll and Angus were the most efficient breeds, but were ranked comparatively lower for efficiency when feed availability was high. At high feed availability, the Continental breeds with greater genetic potential for milk production and growth excelled over British breeds because feed availability was sufficient to support their higher genetic potential. The Continental breeds excelled because of their ability to reproduce and convert excess energy into additional milk, resulting in heavier calves. Breeds with lower genetic potential for growth and milk production were unable to take advantage of high energy availability resulting in cows' inability to convert additional energy into milk, thereby increasing cow body condition. In a similar study, Brinks and Miller (1990) reported that when feed resources were not limited, large cows with a high level of milk production and low management-labor requirements displayed optimum net return. Seifert and Rudder (1975) concluded that in a nutritionally stressful Australian environment, small, fertile cows were considered more efficient as they reared calves of similar weight as heavy, lowly fertile cows. Varying genetic potential in cattle require different levels of dry matter for maximum production efficiency, requiring producers to identify the level of genetic potential of their cow herd. Different requirements support the concept of defined mating systems to match the biological type of cow to feed resources for the herd. Use of breeds with high genetic potential with limited feed resources can have a negative effect on production efficiency, primarily through reproduction. In environments where feed resources are less limiting on reproduction, higher production efficiency would be realized using genetics with greater potential for growth and milk production. A logical response to environmental variation is to utilize cattle with different genetic potentials for production.

Biological efficiency is dependent on the interaction between environment and genetic potential, and is most effectively assessed when measured in this context. Cow size is phenotypically important because of effects on maturing rate and weight, and, therefore, on maintenance and growth requirements at various ages (Cartwright, 1979). Dickerson (1978) maintains that mature cow size, as a component of efficiency, is more important in beef cattle than in other meat livestock because of the low rate of reproduction and high maintenance cost of cows. Of energy consumed by the cow herd, 70-75% is used for cow maintenance (Ferrell and Jenkins, 1985). Fifty percent of the total energy expended in producing beef is used for maintenance of the cow (Ritchie, 1995). Cows use the nutrients provided to them for bodily processes, first allocating to maintenance, then partitioning to growth, followed by lactation, and finally reproduction (NRC, 1996). Ferrell and Jenkins (1985) concluded that about three-fourths of the energy requirement for a life cycle is needed for maintenance.

High maintenance cows have been described as those tending to have high milk production, high visceral organ weight, high body lean mass, and low body fat mass (Ritchie, 1995). In contrast, Ritchie (1995) characterizes low maintenance cows as those with lower propensities for milk production, low visceral organ weight, low body lean mass, and high body fat mass. Cows with a higher milk yield tend to have increased visceral organ mass thus increasing energy requirements even when a cow is not lactating (Solis et al., 1988). It is important to recognize the difference between maintenance requirements and efficiency. As previously defined, efficiency is the ratio of input to output, whereas maintenance energy is a proxy for input and not a direct measure of efficiency. Accurate economic projections are dependent on accurate performance predictions, which is reliant on the ability to describe and account for variables that influence requirements of cattle (Fox et al., 1988).

Frame size is only one factor influencing weight gain and body composition. Other factors include stage of growth, rate of gain, breed type, sex, growth stimulants, nutritional management system and special dietary effects (Fox and Black, 1984; NRC, 1996). Maintenance requirements are heavily influenced by weight, previous nutritional treatment, and level of production (NRC, 1996; Ferrell et al., 1986). Over 250 cattle breeds of varying frame sizes are recognized around the world (Field, 2007). With cattle raised in every environmental and management extreme, difficulty arises in developing nutrient requirement guidelines for each production scenario. Weight, therefore, is commonly used when identifying requirements under standardized conditions that have minimal adjustments for variations in biological type.

Matching feed resources to growth and milk production is crucial to creating efficient cows (Spangler, 2010). Moderating cow size and milk production is beneficial to controlling costs, regardless of environment, given that milk production has been estimated to explain 23% of variation in maintenance requirements (Montano-Bermudez et al., 1990). Coupling large mature size and increased per unit cost associated with milk production potential creates a major constraint on the production efficiency of the cow herd (Jenkins and Ferrell, 2002).

Nutrition and management of different biological types of cattle play an important role in reproductive performance (Wiltbank et al., 1962; Short and Bellows, 1971; Short and Adams, 1988). Persistent restrictions in nutrient intake impact not only body condition, but rebreeding success. Jenkins and Ferrell (2002) affirmed that maximum efficiency within breeds occurred at energy intake levels that did not limit reproduction. High maintenance females in limited feed environments may have difficulty maintaining an acceptable body condition score and could experience longer anestrous periods which lead to lower conception rates during a fixed breeding season (Nugent et al., 1993).

Summary

Genetic and non-genetic factors determine body growth. Genetic potential interacts with environmental conditions such as management, nutrition, climate, and intrinsic factors such as age and physiological status. Even as growth rate may vary; post-natal growth generally follows a sigmoid curve, plateauing at maturity. Mature weight is generally considered the point when maximum protein mass is achieved despite increased fat deposition. Growth is typically documented through collection of body weight and stature measurements.

Noticeable increases in mature cow size over the past 30 years have directed attention to selection for a more efficient cow herd. Even as cow size (weight or height) is only one component of efficiency, size is a major factor when determining cow maintenance costs. Cow size is important phenotypically because of effects on maturing rate and weight, and therefore on maintenance and growth requirements at all ages. It appears that two of the traits that are typically selected for, high weaning and yearling weight, increase mature weight. Optimal values for cow size and milk production may vary as future industry profitability, competitiveness, and sustainability will necessitate prioritization on efficiency. With highly variable and dynamic physical and economic environments, one may consider variability of cow size as an asset to cow-calf producers. More consideration must be given to optimal size(s) with respect to achieving the best strategy to cope with dynamics of location, producer skills, markets, resources, breeding systems, and environment. Continued understanding of the relationships among lifetime measures of body weight and height in cattle is essential, as reliable predictions of mature cow size are important for the commercial cow-calf segment.

Chapter III

Relationships among lifetime measures of growth and frame size for commercial beef females in a pasture-based production system in the Appalachian region of the United States

A paper to be submitted to the Professional Animal Scientist

A. C. Echols[1], M. L. Wahlberg[1], W. S. Swecker Jr.[2], S. P. Greiner[1]

ABSTRACT: The beef cattle industry has placed increased focus on mature cow size as a result of its influence on production efficiency and profitability. The objectives of this study were to evaluate relationships among lifetime measures of body weight (**BW**) and frame score (**FS**) for commercial beef females, and to assess the value of immature measures as predictors of mature cow size. Measurements of BW, hip height (**HH**), body condition score (**BCS**), and calculated FS were recorded at weaning (**WN**), breeding at 13 mo age (**BR**), and 8 subsequent periods, ceasing at approximately 5 yr of age for 232 Angus-cross females born 2004 through 2008. Correlation analysis revealed significant ($P < 0.001$) relationships among BW taken at WN and BR with BW measurements taken at 2.5, 3.8, and 4.8 yr of age (WN r = 0.70, 0.51, 0.61; BR r = 0.65, 0.57, 0.64 respectively). Significant relationships ($P < 0.001$) existed between FS collected at WN and BR and FS at 2.5 and 3.8 yr (WN= 0.70, 0.72; BR= 0.79, 0.82 respectively). Repeatability of lifetime FS measures was 0.73. BCS was a significant ($P < 0.001$) source of variation in mature BW, with a unit change in BCS accounting for 41 kg BW change at 4.8 yr ($P < 0.001$). BW and FS were moderately to strongly related ($P < 0.001$) at WN, BR, 2.5, 3.8, and 4.8 yr (r = 0.62, 0.49, 0.62, 0.62, and 0.47 respectively). Prediction models for BW at 4.8 yr were similar using weaning BW alone, or with inclusion of both weaning BW and HH (R^2 = 0.57

[1]Department of Animal and Poultry Science, Virginia Polytechnic Institute and State University, Blacksburg, VA 24060.
[2]Virginia-Maryland Regional College of Veterinary Medicine, Blacksburg, VA 24060.

and 0.56). Similarly, breeding BW and HH were non-additive for prediction of 4.8 yr BW (R^2 = 0.68, 0.58, and 0.68 for BW, HH, and BW and HH respectively). Performance at immature ages proves to be a satisfactory indicator of mature size, supporting continued incorporation of immature BW and HH/FS measurements into selection practices.

Keywords: beef cow, body weight, frame score, mature size

Introduction

Selection pressure for weaning and post-weaning growth coupled with moderate to high correlations of these weights and associated frame score (**FS**) to the same measures at maturity have resulted in heavier body weight (**BW**) in the mature cow herd (McMurray, 2008; Dib et al., 2010). Increased cow size may not be desirable for the breeding herd as cattle with larger weights have greater maintenance costs (Fiss and Wilton, 1992).

Skeletal size has been considered one of the most important traits for beef cattle given reported high heritability of FS (0.60-0.64; Minish and Fox, 1979; Dib et al., 2010). Estimates of direct heritability of mature BW and mature height have been generally moderate to high (Berg and Butterfield, 1976; Petty and Cartwright, 1966; Dib et al., 2010), with correlations between the two traits also high. Body weight and FS have been commonly used to describe size for many years, and even though the relationship is not perfect, there is a direct relationship between FS and mature BW (Owens et al., 1993).

Acquiring or raising quality replacement heifers is an essential and major investment for the cow-calf producer, as the replacement female becomes the building block for the cow herd. The commercial cattleman is continually looking for management practices that will add consistency to their calf crop and improve profitability; however, their selection methods may be limited to phenotypic information. It is imperative that there is continued efficacy in selection practices utilizing BW and FS in selection decisions.

Objectives of this research project were: 1) characterize and evaluate lifetime BW and skeletal size changes for beef females, 2) identify the relationship among immature measurements of BW and skeletal size to the same measures at mature ages in beef females, and 3) develop strategies for assessment and change of mature size to be utilized by the commercial cow-calf sector utilizing within-herd records.

Materials and Methods

Phenotypic observations were compiled from Angus-cross females that were born and raised at the Shenandoah Valley Agricultural Research and Extension Center (**SVAREC**) in Raphine, Virginia (37^0 56`N; $79^0$ 13` W; elevation 537.4 m). The cow herd at SVAREC is maintained exclusively on grazing and forage systems. A total of 232 females were utilized, including 51, 49, 36, 47, and 48 born in 2004 through 2008, respectively. Pedigree information (sire, dam, and maternal grandsire), along with repeated measures of BW, HH, and BCS from weaning (**WN**) to oldest age or approximately 4.8 yr of age were evaluated.

During initial compilation of data, all observations for BW, HH, and BCS were included when organizing data by birth year. Weaning HH was not measured on calves born in 2005. To account for variation of BCS, BW measurements not accompanied by a BCS were removed from further analysis when females exceeded 2 yr of age. Using days of age (**DOA**), observations were grouped for each birth year into 10 periods (Table A.1). Considerations for the number of observations on a particular date and average age for the respective period dictated what observations were included when animals had multiple observations within the same period.

Observations for period 1 were taken at weaning (mean DOA= 230) and period 10 contains information on cows just under 5 yr (mean DOA= 1745). Animals born prior to 2004 were not utilized due to limited weight and hip height collections.

Forage composition of SVAREC pastures was representative of that of cow-calf operations common to the Appalachian region. Tall fescue (*Festuca arundinacea*) was the dominant forage available for grazing and stockpiling. Cows were maintained on rotationally grazed paddocks until stockpiled forages diminish, typically in January or February. After all stockpiled grass had been consumed, cows were fed free-choice fescue (*Festuca arundinacea)*/orchardgrass (*Dactylis glomerata)* hay placed in round hay feeders. A mineral and vitamin supplement was provided ad libitum, but no other supplements were provided to the cow herd. The year-round forage systems provided for the changing nutritional demands of the beef cows and allowed calves to have continuous access to high-nutritive value forages through creep grazing of adjacent paddocks within the system during the grazing season. First calf heifers were managed similarly in separate paddocks. In addition to orchardgrass hay, heifers received some orchardgrass baleage. Weaning measurements were collected on 12/16/2004, 10/20/2005, 10/13/2006, 09/07/2007, and 09/10/2008. Heifers retained post-weaning were developed on stockpiled fescue followed by either orchardgrass baleage (2006-2008) or orchardgrass baleage supplemented with 75% corn gluten and 25% wheat midds at 1% of bodyweight every other day (2004-2005). Approximately April 1 each yr, heifers were rotationally grazed on fescue pastures until calving.

Cows were synchronized and artificially inseminated once prior to exposure to Hereford or Angus bulls for a 63 d breeding season. Semen (AI) from commercial companies, and cleanup bulls (leased from seedstock producers in Virginia) were used. Within 45 to 60 d after the end of the breeding, cows were rectally palpated for pregnancy diagnosis, and open cows were culled. Calves were born in January through March. Sires of females in the dataset were Angus (N=51), Hereford (N=6), and Red Angus (N=1).

The number of replacements annually was determined by the number of females needed to populate research trials in addition to replacement of open females. An average of 46 (SD= 5.6) heifers were kept as replacements. The selection process began at weaning by first eliminating any heifers with low weaning weights or heifers born late in the calving season. Disposition was a secondary consideration. Heifers were ranked on weight per day of age, providing additional information for final selection. Females kept through 1 yr of age were bred.

Body weight and HH measurements were collected periodically throughout the year when cattle were gathered for vaccinations, synchronization and breeding (**BR**), pregnancy diagnosis, and WN. Body weights and/or HH were not collected at every handling; therefore, the database was limited to observation dates when BW, HH, and BCS (when appropriate) were documented. An adjusted weaning BW was calculated adjusting age to 205 d and additionally adjusted for age of dam using BIF Guidelines (2002). Mean adjusted weaning weight was 224 kg (SD = 22.54). Hip heights and FS were measured and calculated according to BIF Guidelines (2002). A FS was calculated using HH adjusted to 205 d of age and further adjusted for dam age using adjustments included in the BIF Guidelines (1986). No subsequent observations were adjusted for dam age. Body condition score was based on a subjective, 9-point classification scale, from extremely thin (1= very emaciated) to extremely fat (9= very obese) (Richards et al., 1986). Cows were assigned physiological codes for pregnancy (1= open under 2 yr of age, 2= bred 13-24 mo of age, 3= open over 2 yr of age, 4= bred over 2 yr of age) and lactation (1= not lactating, 2= lactating). Technicians determining HH and assigning BCS varied, but were not documented.

Statistical analyses were conducted using SAS 9.2 (SAS Institute Inc., Cary, NC). Pearson correlation coefficients were used to evaluate the relationships between BW and FS at all 10 periods. Since the BW could be influenced by BCS, a partial correlation was conducted when BW was of interest. Repeated measurements were analyzed using GLIMMIX procedure.

Models fitted for repeated measurements of BW, HH, and FS, respectively are presented in Tables A.2-A.4. Quadratic estimates were not significant for HH (Table A.3). Differences in least squares means were evaluated using the Tukey adjustment.

Multivariate analyses were conducted to determine traits contributing to prediction of BW at specific ages. The GLM procedure of SAS was used to determine the effects of birth yr, lactation, BCS, along with combinations of WN and BR observations on BW at 2.8, 3.8, 4.5, and 4.8 yr.

Results and Discussion

Means and standard deviations for BW, HH, FS, and BCS of all cows included in this study are presented in Table 3.1. The information was further organized in the same format for each birth yr in Table A.5 - A.9 to better describe the observations collected for each birth yr.

Correlation values for lifetime measures of BW are presented in Table 3.2. Correlations were similar between BW taken at both WN and BR to those taken at mature ages. The correlations of BW at WN and BW at 2.5 yr, 3.8 yr and 4.8 yr were 0.70, 0.51, and 0.61, respectively ($P < 0.001$). The correlations of breeding BW to BW at the same ages were 0.65, 0.57, and 0.64 ($P < 0.001$) respectively. Additional correlations are included in Table 3.2.

Correlations reported in the current study are higher than those reported by Northcutt and Wilson (1993) who found correlation between 205 d BW and mature BW of 0.37 ($P < 0.001$) and a correlation between 365 d BW and mature BW of 0.41 ($P < 0.001$). Differences may be attributed to the variation in management and environment of the 28,391 head, multiple herd database studied by Northcutt and Wilson (1993). Brinks et al. (1964) reported similar correlations to Northcutt and Wilson (1993) in Hereford cattle, with r = 0.45 between weaning BW and mature BW. Mature BW in the Brinks et al. (1964) study was collected on 5-, 6-, and 7-yr-old Angus cows.

Klosterman et al. (1968) reported that mature weight is greatly influenced by body condition. Accounting for 16% of the total variation in weight (Northcutt et al., 1992), BCS was found to be a significant source of variation in weight (P < 0.001). While inclusion of BCS as a covariate had no effect on HH or FS in the present study, BCS was a significant source or variation of mature cow BW ($P < 0.001$); therefore, it was included as a variable when weight was included in correlations. The mean BCS was 5.81 (N= 399). There is apparent merit in adjusted weights for body condition, as measures of cow maintenance requirements are based on weight at an identified condition. Bensyhek and Marlow (1973) suggested that adjusting weight for body condition removes environmental variation. Additionally, adjusting for BCS removes some genetic variation in BW as genetic variation in BW includes genetic variation in body composition (Choy, 1996).

Strong genetic and phenotypic correlations between BW and height traits have been documented in previous studies. Bourdon and Brinks (1986) reported genetic and phenotypic correlations of 0.77 and 0.62 respectively, between yearling weight and height. Phenotypic correlation between yearling BW and FS in the current study was 0.48 ($P < 0.001$, Table 3.3).

Phenotypic relationships between BW and FS at 3.8, 4.2, and 4.8 yr were 0.62 (P < 0.001), 0.58 (P < 0.05), and 0.47 (P < 0.001), included in Table 3.3. Northcutt and Wilson (1993) reported a phenotypic correlation between mature weight and height of 0.58 when weight was adjusted for BCS, which is similar to correlations reported by Bourdon and Brinks (1986).

Correlation coefficients among FS at different age periods are presented in Table 3.4. Some of the coefficients lacked significance, likely attributed to the limited number of observations. As expected, some of the highest correlations existed between observations in subsequent periods. Breeding FS tended to be more highly correlated than weaning FS as compared to measurements taken at maturity. Weaning FS was significantly related to FS at 2.5, 2.8, 3.8, and 4.2 yr (r = 0.70, 0.60, 0.72, and 0.60 (P < .001)), but not at 4.5 or 4.8 yr. The limited number of observations at 4.5 and 4.8 yr (n=25 and 22), likely contributed to lack of relationship. Breeding FS had r = 0.79, 0.71, 0.82, and 0.58 (P < .001) at 2.5 yr, 2.8 yr, 3.8 yr, and 4.8 yr respectively. These relationships suggest selection on FS at an early age will be related with mature FS.

Depending on the targeted marketing endpoint (weaning or yearling), weights become a source of revenue but are also a major factor influencing the cost of production through correlations to mature cow weight. These correlations are relevant especially when producers sell some portion of calves but also retain their own replacement females. Body weight and/or FS taken on heifers prior to maturity may be a useful component of evaluation for replacement females, especially as commercial cow-calf producers may not have extensive genetic information available for decision-making. Selection based on phenotypic values may lead to satisfactory responses in mature size of replacements.

A subsample of the dataset was used to compare collected HH measurements of the SVAREC herd to BIF FS guidelines (BIF, 2002). The 47 cows included in the subsample had HH observations at 4.8 yr. The average of all FS collected on this group was 5.25. The mean HH of subsample group at each period was compared to the BIF (2002) HH standard for a female with a FS of 5.25 (Figure 3.1). The mean HH on the Angus-cross females closely mimicked the HH values of the BIF standard,. The largest difference between the observed and the standard occurred at 8 mo, when collected HH exceeded that of the standard by 2.25 cm. At 26 mo, the standard was 1 cm taller than the observed mean HH. By 3.8 yr, there was only a 0.07 cm difference between the observed and standard. The subsample continued to increase in HH after 3.8 yr, and exceeded the standard no more than 1.00 cm after 3.8 yr. The changes in HH over time of collected HH followed very closely with the HH derived from the BIF heifer FS equation and extrapolation table for ages exceeding 21 mo (BIF, 2002). Current research supports validity of continued application of the BIF FS system.

In four of the five birth years, FS remained the same or increased no more than 0.4 of a FS from WN to 4.8 yr of age ($P < 0.001$, Figure 3.2). A significant increase in FS from WN to 4.8 yr occurred for cattle born in 2004 ($P < 0.001$) and 2006 ($P = 0.038$). In contrast, FS least squares means for cattle born in 2008 significantly decreased from 4.28 at weaning to 3.88 at their final measurement at 2.8 yr of age ($P < 0.001$). Inconsistencies in FS may be partially attributed to measurement error in addition to existing management and environmental variation. Even with slight changes in FS over time, FS measurements taken on the same animal over its lifetime were found to be repeatable (0.73). This supports BIF Guidelines (2002) statement that most animals should maintain the same FS throughout their life. Selection for uniformity in replacement females can be accomplished through incorporation of FS as a selection tool. The relationship between an immature FS measurement and mature frame should assist producers in identifying the FS that will match their specific environment and feed resources.

An increase in one unit of frame size results in a 25 kg ($P < 0.001$) increase in BW, while increasing BCS one unit increases BW 30 kg ($P < 0.001$) at 4.8 yr of age, shown in Figure 3.3. Wilson (1996) reported 38 kg increase in BW for every unit increase in FS. The average increase in BW as a result of a unit increase in BCS reported by Northcutt et al. (1992) was 34 kg for collection of American Angus Association cow records. The BW adjustment for each unit increase in BCS varied, as the smallest adjustment was 22 kg going from BCS 3 to BCS 4, and the largest adjustment found was increasing from a BCS 7 to BCS 8 accounting for 46 kg increase in BW (Northcutt et al., 1992).

Body condition score was more highly correlated with BW (r = 0.66; $P > 0.001$) than HH (r = 0.12; $P = 0.015$). Nelsen et al. (1985) reported a similar BW-BCS correlation of 0.61. Northcutt et al. (1992) reported a stronger relationship of BCS with BW (0.48) than with height (0.10). Williams et al. (1979) found similar correlations of 0.56 and 0.18. Thompson et al. (1983) reported a BW and BCS correlation of 0.75 in Angus and Angus-Hereford cows.

Because of selection emphasis on weight per day of age when determining herd replacements, one may have anticipated an increase in BW of cows born in subsequent years. Table 3.5 contains least squares means estimates for BW. From weaning through 2.5 yrs least squares means estimates for BW were heavier ($P < 0.05$) for females born in 2004 and 2005 compared to those born 2006, 2007, and 2008. There was no significant difference in BW across birth years from 522 d to 4.8 yr. At 4.8 yr, 2006-born females were significantly heavier than cows born in 2004 and 2005 ($P < 0.01$). Table 3.6 presents least squares means estimates for

HH. While there were some birth year effects observed for BW and HH, the differences were small in magnitude and were not consistent across ages.

A void in previous research prompted the interest in determining the value of using both immature BW and HH to predict mature size. Models for prediction of 4.8 yr BW are included in Table 3.7. Using a multivariate analysis that included birth year, BCS, and weaning BW to predict 4.8 yr BW resulted in a $R^2 = 0.57$, shown in Table 3.7. When weaning HH was exchanged for weaning BW in the analysis, $R^2 = 0.52$. Frame score had the same predictive power as HH. Including both weaning BW and HH does not enhance prediction of 4.8 yr BW (R^2=0.56), as compared to BW or HH alone, as the r-squared value is not increased and the effects of weaning BW and HH are non-significant (P =0.205 and P = 0.903). Conclusions from the r-squared values are that these traits are non-additive. Evaluating the effects of birth year, BCS, and breeding BW on 4.8 yr BW, BW without HH yielded an R^2 of 0.68, where a 1 kg increase in breeding BW ($P < 0.001$) resulted in 1.1 kg increase in BW at 4.8 yr (Table 3.7). In this same analysis, increasing BCS 1 unit increased 4.8 yr weight by 41.3 kg ($P < 0.001$). Evaluation of the effects of breeding HH independent of breeding BW, HH was a significant source of variation contributing to 4.8 yr BW ($P < 0.001$). Models revealed an 8.1 kg increase in 4.8 yr BW for each cm increase in HH. Estimates for increased BW due to BCS were similar to previous model, with estimates of one unit increase in BCS resulting in 42.4 kg increase in 4.8 yr BW ($P < 0.001$). When both breeding BW and HH were incorporated into the analysis to predict 4.8 yr BW, R^2= 0.68 where only birth year ($P = 0.003$), BCS ($P < 0.001$), and breeding BW ($P = 0.001$) were significant effects. This indicates that BW is superior to HH as a predictor of future mature cow BW. Using the two traits collectively does not provide substantial additional information to further enhance prediction efforts.

Beef Improvement Federation has recommended adjusting weaning HH to constant age of 205 d, as well as for age of dam (BIF, 1986). As one would expect, there is a strong relationship between raw weaning HH and adjusted weaning HH ($r = 0.95$, $P < 0.001$). Dam age is significant in explaining differences in weaning HH ($P = 0.0166$); however this influence is very small based on the correlation between the two HH and the subtle difference in predictive power of mature BW (Table 3.7).

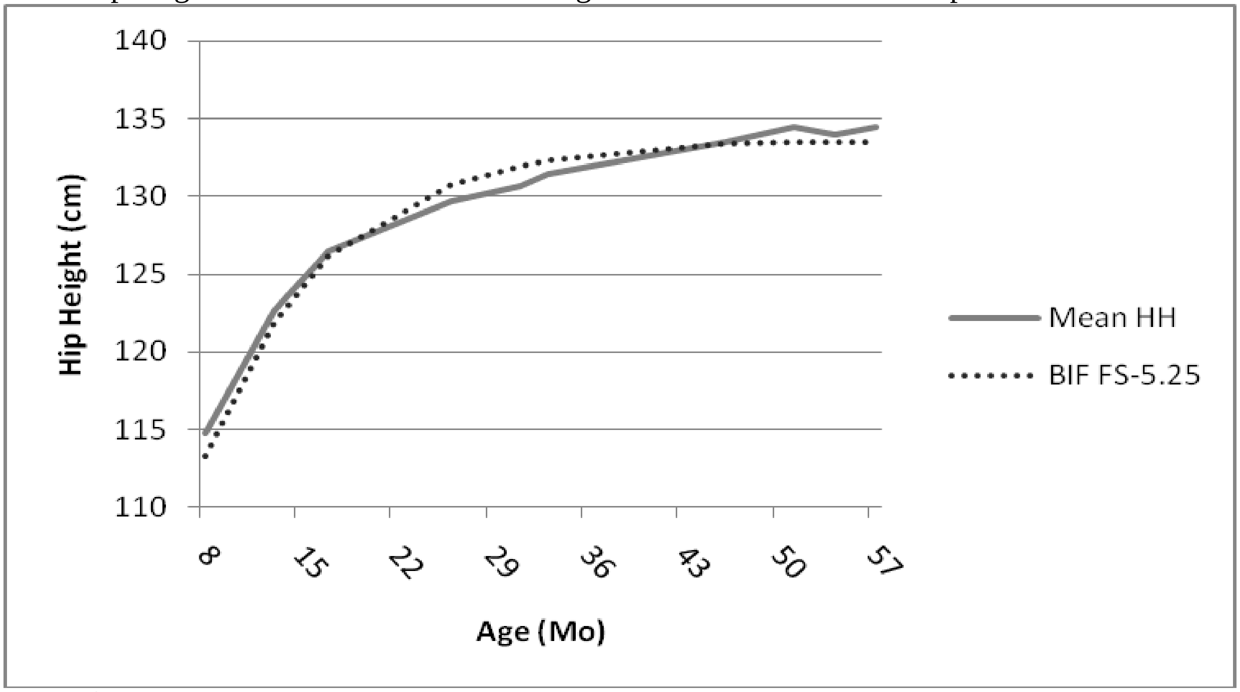
The effects of birth year and weaning BW and HH measurements proved to be non-significant indicators of mature BCS. It can be concluded that BW of calf at weaning is not a useful indicator of the future ability of the cow to maintain flesh. Selection based on weaning BW and/or HH will not comprise the fleshing ability of the cow herd. Interestingly, breeding BW proved to have a significant effect on BCS at 2.8 ($P = 0.017$), 3.8 ($P = 0.006$), and 4.5 ($P = 0.011$) yr of age, but not at 4.8 ($P = 0.9013$) yr of age. At 4.5 yr of age, for every 1.0 kg increase in BW at breeding, BCS increased 0.02 of a unit. Results were similar for 2.8 and 3.8 yr BCS. For every 1.0 kg increase in breeding BW, BCS at 2.8 and 3.8 yr increased 0.01 units.

Implications

Commercial cattle producers and those involved with other segments of the beef industry are constantly discussing size of beef cattle. The beef industry has addressed these concerns through development of mature size expected progeny differences and breed selection index EPDs. The commercial cow-calf producer can use these genetic tools to make bull selection decisions, but frequently this information is not available on the cow herd, emphasizing the continued need of tools utilizing phenotypic evaluation. Estimates of phenotypic traits of economic importance are needed for producers to formulate effective breeding plans. For cowherd efficiency, producers need to match cattle type and size to production and management environment.

Producers selecting for a particular size and/or uniformity in replacement females can use FS as one of the selection tools. Knowing the relationship between an immature BW and FS measurement and mature BW and FS will assist producers in identifying and selecting for the mature size that will match their specific environment and feed resources.

Figure 3.1 Mean hip height (cm) of Angus-cross females in the herd at 4.8 yrs (N= 47) compared to BIF hip height measurements for the average frame score of the subsample of cows[a]



[a] Mean frame score was 5.25. Average based on all frame score measurements collected on the 47 cows.

Figure 3.2. The relationship of frame score with age in Angus-cross females born 2004-2008

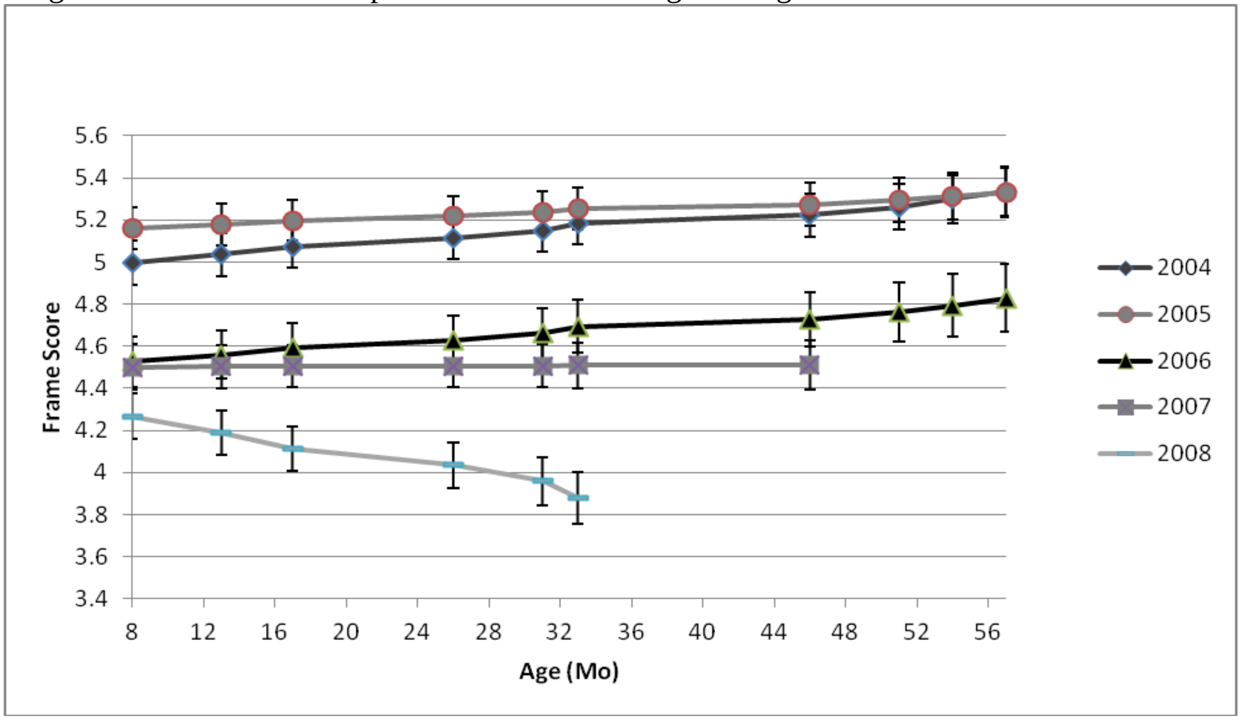


Figure 3.3. Body weight (kg) of 4.8 yr Angus-cross females at different frame scores with body condition scores 4,5, or 6

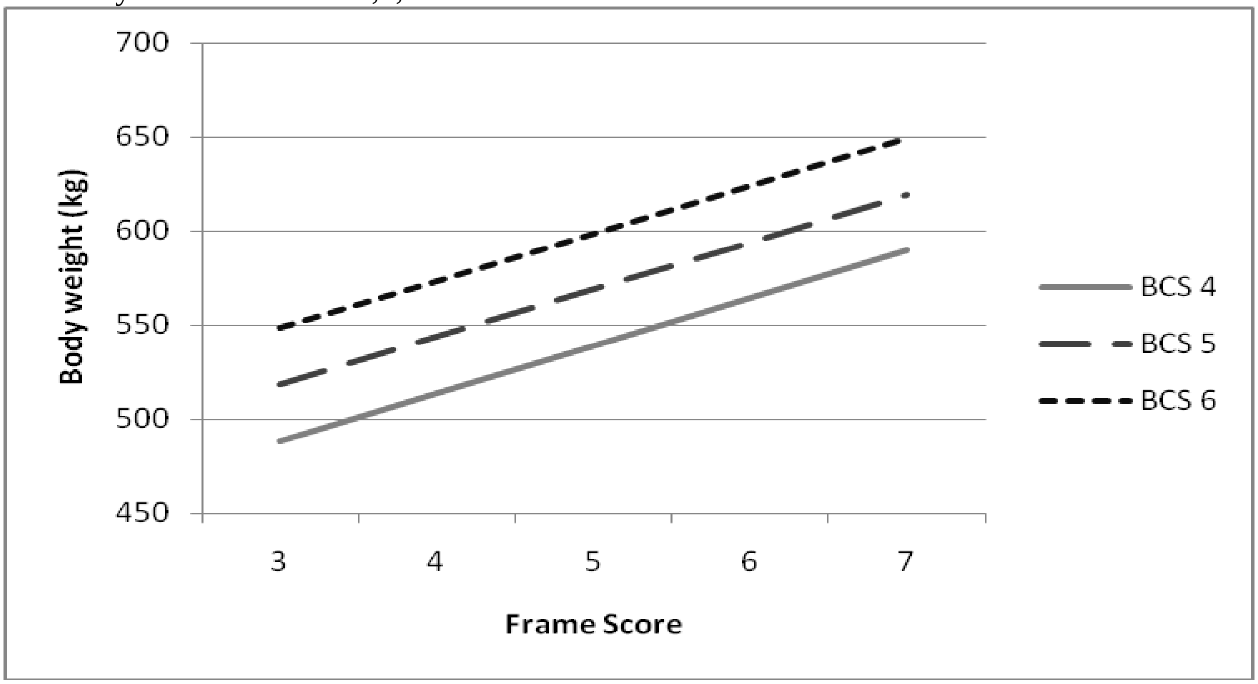


Table 3.1. Numbers of measurements (n), and unadjusted means (±SD) by period for age (d), body weight (kg), hip height (cm), and body condition score for beef females born 2004-2008

	Age		Weight		Height		Frame Score		Condition Score	
Period	N	Mean	n	Mean	n	Mean	n	Mean	n	Mean
1	231	230 ± 44	231	235 ± 36	171	110.08 ± 5.31	171	4.77 ± 0.72		
2	228	394 ± 25	228	308 ± 44	228	119.58 ± 4.80	228	4.79 ± 0.84		
3	229	522 ± 20	226	376 ± 42	229	123.90 ± 4.52	229	4.78 ± 0.91		
4	93	805 ± 19	92	446 ± 41	93	129.57 ± 3.66	93	5.08 ± 0.79	93	5.57 ± 1.05
5	86	929 ± 17	86	446 ± 45	86	129.44 ± 4.22	86	4.84 ± 0.86	86	5.13 ± 1.02
6	72	1015 ± 15	72	494 ± 46	72	128.96 ± 3.94	72	4.60 ± 0.81	72	5.75 ± 0.62
7	61	1386 ± 19	61	574 ± 59	61	131.90 ± 4.09	61	4.99 ± 0.84	61	6.36 ± 0.93
8	15	1547 ± 13	15	567 ± 42	15	133.17 ± 3.78	15	5.23 ± 0.77	15	6.00 ± 1.13
9	25	1656 ± 16	25	542 ± 64	25	133.60 ± 3.48	25	5.31 ± 0.71	25	5.84 ± 1.10
10	47	1745 ± 20	47	629 ± 65	46	134.44 ± 3.07	46	5.45 ± 0.63	47	6.83 ± 0.87

Table 3.2. Correlation coefficients among measurements of body weight[a]

Variable		Adj. 205 d BW	BW1 230 d	Adj. 365 d BW	BW2 394 d	BW3 522 d	BW4 2.2 yr	BW5 2.5 yr	BW6 2.8 yr	BW7 3.8 yr	BW8 4.2 yr	BW9 4.5 yr	BW10 4.8 yr
Adj. 205-d BW		1.00	0.70***	0.65***	0.52***	0.56***	0.67***	0.61***	0.46***	0.49***	0.56*	0.47*	0.42*
	N		231	228	228	226	92	85	71	60	15	25	46
BW1	230 d		1.00	0.38***	0.57***	0.51***	0.77***	0.70***	0.43***	0.51***	0.47	0.30	0.61***
	N			228	228	226	92	85	71	60	15	25	46
Adj. 365-d BW				1.00	0.89***	0.81***	0.55***	0.53***	0.33*	0.54***	0.70*	0.24	0.61***
	N				228	225	91	84	71	59	15	25	45
BW2	394 d				1.00	0.86***	0.71***	0.65***	0.24*	0.57***	0.70*	0.22	0.64***
	N					225	91	84	71	59	15	25	45
BW3	522 d					1.00	0.70***	0.74***	0.44***	0.62***	0.51	0.15	0.69***
	N						89	82	71	59	15	25	45
BW4	2.2 yr						1.00	0.90***	-	0.65***	0.47	0.16	0.66***
	N							44		26	15	25	40
BW5	2.5 yr							1.00	0.87***	0.64***	-	-	0.64***
	N								36	56			31
BW6	2.8 yr								1.00	0.76***	-	-	0.23
	N									34			7
BW7	3.8 yr									1.00	-	-	0.91***
	N												28
BW8	4.2 yr										1.00	0.53	0.93*
	N											15	8
BW9	4.5 yr											1.00	0.95***
	N												16
BW10	4.8 yr												1.00
	N												

* Values different from zero ($P < 0.05$). *** Values different from zero ($P < 0.001$). [a] Body weight adjusted for BCS.

Table 3.3. Correlation coefficients among body weight and frame score measurements[a]

Variable		Adj. 205 d FS	FS1 230 d	Adj. 365 d FS	FS2 394 d	FS3 522 d	FS4 2.2 yr	FS5 2.5 yr	FS6 2.8 yr	FS7 3.8 yr	FS8 4.2 yr	FS9 4.5 yr	FS10 4.8 yr
Adj. 205-d BW		0.67***	0.64***	0.63***	0.58***	0.52***	0.31***	0.42***	0.53***	0.52***	0.37	0.24	0.26
	N	171	171	171	228	229	93	85	71	60	15	25	45
BW1	230 d	0.56***	0.62***	0.48***	0.49***	0.42***	0.41***	0.43***	0.41***	0.50***	0.33	0.21	0.2
	N	171	171	171	228	229	93	85	71	60	15	25	45
Adj. 365-d BW		0.40***	0.27***	0.52***	0.48***	0.48***	0.22*	0.44***	0.44***	0.52***	0.48	0.28***	0.47***
	N	171	171	171	228	228	92	84	71	59	15	25	44
BW2	394 d	0.35***	0.26***	.47***	0.49***	0.49***	0.35***	0.45***	0.34***	0.48***	0.47	0.27	0.43***
	N	171	171	171	228	228	92	84	71	59	15	25	44
BW3	522 d	0.40***	0.31***	0.54***	0.53***	0.58***	0.35***	0.50***	0.47***	0.54***	-0.03	0.18	0.42***
	N	171	171	171	225	226	90	82	71	59	15	25	44
BW4	2.2 yr	0.52***	0.47***	0.47***	0.62***	0.64***	0.59***	0.66***	-	0.089***	0.58*	0.53*	0.48***
	N	48	48	48	91	92	92	44		26	15	25	39
BW5	2.5 yr	0.52***	0.57***	0.61***	0.63***	0.72***	0.65***	0.62***	0.76***	0.67***	-	-	0.48***
	N	40	40	40	84	85	45	86	36	56			30
BW6	2.8 yr	0.44***	0.43***	0.48***	0.42***	0.43***	-	0.69***	0.60***	0.49***	-	-	0.08
	N	66	66	66	71	71		36	72	34			7
BW7	3.8 yr	0.51***	0.53***	0.38*	0.52***	0.56***	0.57***	0.65***	0.56***	0.62***	-	-	0.53*
	N	34	34	34	59	60	26	56	34	61			27
BW8	4.2 yr	0.91***	0.75***	0.39	0.46	0.16	0.61*	-	-	-	0.58*	0.68***	0.91***
	N	8	15	15	15		15				15	15	8
BW9	4.5 yr	0.42*	0.44*	0.24	0.29	0.07	0.22	-	-	-	0.62*	0.20	0.08
	N	25	25	25	25	25	25				15	25	16
BW10	4.8 yr	0.23	0.19	0.05	0.41***	0.35*	0.61***	0.59***	0.31	0.85***	0.72	0.48	0.47***
	N	22	22	22	45	46	40	31	7	28	8	16	46

* Values different from zero ($P < 0.05$). *** Values different from zero ($P < 0.001$). [a] Body weight adjusted for BCS.

Table 3.4. Correlation coefficients among frame scores

Variable		Adj. 205 d FS	FS1 230 d	Adj. 365 d FS	FS2 394 d	FS3 522 d	FS4 2.2 yr	FS5 2.5 yr	FS6 2.8 yr	FS7 3.8 yr	FS8 4.2 yr	FS9 4.5 yr	FS10 4.8 yr
Adj. 205-d FS		1.00	0.96***	0.70***	0.70***	0.68***	0.43*	0.69***	0.60***	0.68***	0.60*	0.37	0.21
	N		171	171	171	171	48	40	66	34	15	25	22
FS1	230 d		1.00	0.65***	0.71***	0.69***	0.47***	0.70***	0.60***	0.72***	0.60***	0.38	0.17
	N			171	171	171	48	40	66	34	15	25	22
Adj. 365-d FS				1.00	0.96***	0.74***	0.57***	0.82***	0.73***	0.80***	0.60***	0.43*	0.49*
	N				228	228	92	84	71	59	15	25	44
FS2	394 d				1.00	0.78***	0.71***	0.79***	0.71***	0.82***	0.37	0.46*	0.58***
	N					228	92	84	71	59	15	25	44
FS3	522 d					1.00	0.71***	0.79***	0.74***	0.83***	0.21	0.44*	0.42*
	N						93	85	71	60	15	25	45
FS4	2.2 yr						1.00	0.88***	-	0.86***	0.81***	0.82***	0.80***
	N							45		26	15	25	39
FS5	2.5 yr							1.00	0.79***	0.86***	-	-	0.67
	N								36	56			30
FS6	2.8 yr								1.00	0.85***	-	-	0.86*
	N									34			7
FS7	3.8 yr									1.00	-	-	0.71***
	N												27
FS8	4.2 yr										1.00	0.78***	0.76*
	N											15	8
FS9	4.5 yr											1.00	0.83***
	N												16
FS10	4.8 yr												1.00
	N												

* Values different from zero (*P* < 0.05). *** Values different from zero (*P* < 0.001).

Table 3.5. Least squares means estimates for body weight (kg)

		Period[c]									
		230 d	394 d	522 d	2.2 yr	2.5 yr	2.8 yr	3.8 yr	4.2 yr	4.5 yr	4.8 yr
Birth Year[d]	2004	422.38[a]	439.60[a]	456.82	474.04	491.26	508.49	525.71	542.93[b]	560.15[b]	577.37[b]
	2005	421.00[a]	436.71[a]	452.42	468.13	483.85	499.56	515.27	530.98[b]	546.69[b]	562.41[b]
	2006	358.54[b]	387.84[b]	417.13	446.42	475.72	505.01	534.30	563.59[a]	592.89[a]	622.18[a]
	2007	362.90[ab]	390.15[ab]	417.39	444.64	471.89	499.13	526.38	553.63[ab]	580.87[ab]	608.12[ab]

[a, b] Means within a column with unlike superscripts differ (*P* < 0.05).

[c] Body weight adjusted for BCS.

[d] No least squares means estimates were generated for 2008.

Table 3.6. Least squares means estimates for hip height (cm)

		Period									
		230 d	394 d	522 d	2.2 yr	2.5 yr	2.8 yr	3.8 yr	4.2 yr	4.5 yr	4.8 yr
	2004	121.03[b]	122.72[b]	124.41[b]	126.09[b]	127.78[b]	129.40	131.15[b]	132.83[b]	134.52[b]	136.20[b]
Birth	2005	123.69[a]	125.20[a]	126.72[a]	128.23[a]	129.74[a]	131.25	132.76[ab]	134.27[ab]	137.78[ab]	137.29[b]
Year	2006	115.67[c]	118.58[c]	122.29[c]	124.39[bc]	127.30[b]	130.21	133.12[ab]	136.03[a]	138.94[a]	141.85[a]
	2007	113.32[d]	116.80[c]	120.29[cd]	123.78[c]	127.26[b]	130.75	134.24[a]			
	2008	110.60[e]	114.60[d]	118.61[d]	122.51[c]	126.62[b]	130.63				

[a, b, c, d, e] Means within a column with unlike superscripts differ ($P < 0.05$).

Table 3.7. Prediction models for 4.8 yr body weight including combinations of weaning and breeding body weight and hip height

	Variable[a]	Parameter Estimate	*P*	R^2	RMSE
Model A	WN BW	1.04	< 0.001	0.57	45.07
Model B	WN HH	2.85	0.440	0.52	40.99
Model C	WN FS	16.71	0.420	0.52	40.90
Model D	WN BW	0.66	0.205	0.56	40.18
	WN HH	-0.54	0.903		
Model E	Adj. WN BW	1.17	0.003	0.55	46.48
Model F	Adj. WN HH	3.29	0.338	0.53	40.62
Model G	BR BW	1.08	<0.001	0.68	39.36
Model H	BR HH	8.09	0.001	0.58	45.26
Model I	BR BW	1.03	0.001	0.68	39.85
	BR HH	0.58	0.845		
Model J	WN BW	-0.36	0.446	0.69	39.57
	BR BW	1.32	0.001		
Model K	WN HH	3.00	0.460	0.52	42.17
	BR HH	-0.41	0.917		

[a] All models contain birth year and BCS variables

Appendix

Table A.1. Age range of periods.

Period	Age	
	Minimum	Maximum
1	124	321
2	321	446
3	445	562
4	753	846
5	859	960
6	972	1049
7	1313	1424
8	1518	1570
9	1619	1683
10	1683	1776

Table A.2. Significant sources of variation for trait BW

Source	df	Type	ddfm	Error Term
Birth yr	3	Class	165	Calf (Birth yr)
FS	1	Continuous	220	Residual
Lactation code	1	Class	220	Residual
BCS	1	Continuous	220	Residual
Period*Birth yr	4	Continuous	220	Residual
Total	396			

Random Terms: Calf (Birth yr), Residual

Table A.3. Significant sources of variation for trait HH

Source	df	Type	ddfm	Error Term
Birth yr	4	Class	225	Calf (Birth yr)
Lactation Code	1	Class	789	Residual
Per*Birth yr	5	Continuous	789	Residual
Total	1024			

Random Terms: Calf (Birth yr), Residual

Table A.4. Significant sources of variation for trait FS

Source	df	Type	ddfm	Error Term
Birth yr	4	Class	225	Calf (Birth yr)
Lactation Code	1	Class	789	Residual
Period*Birth yr	5	Continuous	789	Residual
Total	1024			

Random Terms: Calf (Birth yr), Residual

Table A.5. Numbers of measurements (n), and unadjusted means (±SD) by period for age (d), weight (kg), hip height (cm), and body condition score for beef females born 2004

	Age		Weight		Height		Frame Score		Condition Score	
Period	N	Mean	n	Mean	n	Mean	n	Mean	n	Mean
1	51	294 ± 15	51	278 ± 21	51	115.87 ± 2.54	51	5.09 ± 0.48	-	
2	51	417 ± 15	51	333 ± 26	51	122.78 ± 2.97	51	5.23 ± 0.57	-	
3	51	518 ± 14	51	397 ± 32	51	126.14 ± 3.07	51	5.24 ± 0.61	-	
4	48	796 ± 14	48	430 ± 32	48	128.47 ± 2.82	48	4.84 ± 0.61	48	5.02 ± 0.81
5	-									
6	-									
7	-									
8	15	1547 ± 13	15	567 ± 42	15	133.17 ± 3.78	15	5.23 ± 0.77	15	6.00 ± 1.13
9	25	1656 ± 16	25	542 ± 64	25	133.60 ± 3.48	25	5.31 ± 0.71	25	5.84 ± 1.11
10	16	1741 ± 19	16	647 ± 63	16	134.85 ± 2.54	16	5.56 ± 0.54	16	6.94 ± 0.93

Table A.6. Numbers of measurements (n), and unadjusted means (±SD) by period for age (d), weight (kg), hip height (cm), and body condition score for beef females born 2005

	Age		Weight		Height		Frame Score		Condition Score	
Period	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean
1	49	236 ± 19	49	240 ± 26						
2	48	414 ± 19	48	328 ± 30	48	122.56 ± 3.73	48	5.23 ± 0.69		
3	49	507 ± 19	46	394 ± 32	49	126.01 ± 3.81	49	5.27 ± 0.74		
4	45	816 ± 18	44	463 ± 43	45	130.71 ± 4.09	45	5.33 ± 0.89	45	6.16 ± 0.95
5	45	922 ± 18	45	446 ± 50	45	130.56 ± 3.71	45	5.07 ± 0.80	45	4.91 ± 1.12
6	-									
7	26	1376 ± 21	26	582 ± 75	26	133.38 ± 3.71	26	5.31 ± 0.79	26	6.35 ± 1.02
8	-									
9	-									
10	24	1745 ± 22	24	607 ± 69	24	134.44 ± 3.38	24	5.44 ± 0.70	24	6.88 ± 0.90

Table A.7. Numbers of measurements (n), and unadjusted means (±SD) by period for age (d), weight (kg), hip height (cm), and body condition score for beef females born 2006

	Age		Weight		Height		Frame Score		Condition Score	
Period	N	Mean	n	Mean	n	Mean	n	Mean	n	Mean
1	36	239 ± 11	36	234 ± 21	36	110.13 ± 3.66	36	4.67 ± 0.78	-	
2	36	391 ± 11	36	318 ± 25	36	118.75 ± 3.20	36	4.64 ± 0.67	-	
3	36	544 ± 11	36	375 ± 32	36	123.55 ± 3.94	36	4.59 ± 0.82	-	
4	-									
5	16	934 ± 12	16	445 ± 42	16	130.23 ± 2.06	16	4.95 ± 0.46	16	5.44 ± 1.03
6	14	1014 ± 11	14	515 ± 46	14	130.28 ± 2.79	14	4.86 ± 0.56	14	5.57 ± 0.76
7	12	1385 ± 13	12	579 ± 52	12	133.40 ± 2.21	12	5.27 ± 0.46	12	6.42 ± 0.79
8	-									
9	-									
10	7	1757 ± 10	7	665 ± 11	7	133.53 ± 3.25	7	5.29 ± 0.64	7	6.43 ± 0.53

Table A.8. Numbers of measurements (n), and unadjusted means (±SD) by period for age (d), weight (kg), hip height (cm), and body condition score for beef females born 2007

	Age		Weight		Height		Frame Score		Condition Score	
Period	N	Mean	n	Mean	n	Mean	n	Mean	n	Mean
1	47	202 ± 13	47	222 ± 22	47	107.09 ± 3.58	47	4.55 ± 0.73	-	
2	47	382 ± 13	47	318 ± 30	47	118.16 ± 4.24	47	4.62 ± 0.86	-	
3	47	535 ± 13	47	387 ± 38	47	123.77 ± 4.52	47	4.68 ± 0.93	-	
4	-									
5	25	939 ± 10	25	446 ± 38	25	126.90 ± 5.05	25	4.38 ± 1.00	25	5.32 ± 0.69
6	29	1023 ± 12	29	473 ± 44	29	129.72 ± 4.14	29	4.78 ± 0.85	29	5.59 ± 0.68
7	23	1399 ± 13	23	565 ± 41	23	129.44 ± 4.22	23	4.49 ± 0.84	23	6.35 ± 0.93
8	-									
9	-									
10	-									

Table A.9. Numbers of measurements (n), and unadjusted means (±SD) by period for age (d), weight (kg), hip height (cm), and body condition score for beef females born 2008

	Age		Weight		Height		Frame Score		Condition Score	
Period	N	Mean	n	Mean	n	Mean	n	Mean	n	Mean
1	48	176 ± 17	48	197 ± 26	37	105.82 ± 4.06	37	4.69 ± 0.81		
2	46	367 ± 15	46	241 ± 24	46	114.96 ± 4.37	46	4.13 ± 0.84		
3	46	512 ± 15	46	324 ± 31	46	119.81 ± 4.06	46	4.00 ± 0.82		
4	-									
5	-									
6	29	1007 ± 14	29	505 ± 39	29	127.56 ± 3.91	29	4.29 ± 0.80	29	6.00 ± 0.38
7	-									
8	-									
9	-									
10	-									

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