

THE RELATIONSHIP BETWEEN MARBLING AND OTHER EPDs
WITH IMPLICATIONS WHEN MAKING BEEF COW HERD
BREEDING AND MANAGEMENT DECISIONS

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Introduction Definitions and Heritability

Value-based marketing and the advent of industry alliances have increased the awareness and profitability of beef carcass quality. Pricing cattle on an individual animal basis rather than on the average of a group makes those traits related to the end product more valuable to the cattle feeder and breeder. Hopefully, demand for high quality beef will increase interest and support for source verification from the different segments of the beef industry. Identification of producers possessing high quality cattle will continue to increase their bargaining power and profits. Net profits will rise only if a balance between product quality/value and cowherd production costs can be achieved. Major factors in cowherd profitability will continue to be greatly influenced by reproductive rates, calf growth, and cow maintenance costs. Even though the quality of beef has been a major concern of cattle producers for decades, the lack of real premiums has forced most selection pressures to be put on growth and reproduction traits. Through these selection efforts, producers have substantially reduced their cost of production. These advances in animal breeding can not be abandoned (Siegfried, 1998). But, the decrease in consumer demand for commodity beef (Purcell, 1998) has renewed the emphasis cattle breeders and feeders need to place on beef quality.

Beginning in 1928 with the publication of USDA standards for beef carcass quality, the United States cattle industry has had a system of grades to classify their products. Over the years, modifications and additions have been implemented to update and improve the applications of those standards. However, three carcass characteristics (marbling, lean texture and color, and physiological age) have controlled the quality grading standards. Most notably marbling and muscle characteristics have been the major factors in quality grade separation (USDA, 1979 and 1996).

Marbling is defined as the specks of intramuscular fat distributed in muscular tissue and is usually evaluated in the ribeye between the 12th and 13th rib (BIF, 1996). Prior to the advent of ultrasonography the only way to estimate or measure the amount of marbling was to visually examine a cross-section of the ribeye surface. To establish breeding value estimates for the marbling trait, extensive progeny testing is required. Even though progeny testing is a slow, time consuming, tedious methodology, it has and will continue to be the main source of definitive EPD information. However, with the addition of ultrasound the collection of carcass trait data and hence genetic progress should be greatly enhanced (Houghton and Turlington, 1992; Brethour, 1994; Moser et al., 1998). Within the last five years genetic markers have been found that identify some genes associated with marbling. This technology shows great promise, but to date only a limited number of marbling genes have been discovered and reported. Results comparing gene frequency with marbling have been variable with genes explaining from 0 to nearly 33% of the variance in slaughter groups.

Studies have measured the differences in marbling both between and within breed populations. Numerous trials (Urick et al. 1991; DeRouen et al., 1992; Marshall, 1994; Gregory et al., 1995; Wheeler et al., 1996; O'Connor et al., 1997; Sprinkle et al., 1998; Cundiff et al., 1998) have reported differences among the major breeds of cattle. From

these trials it is can be concluded that *Bos indicus* breeds do not have the genetic capability to marble like *Bos taurus* breeds. Among the *Bos taurus* breeds it appears that British breeds are superior to continental breeds in marbling ability (Cundiff et al., 1993). Furthermore, adequate differences in breeding values for marbling exist within breeds (Vieselmeyer et al., 1996; AAA, 1999) so that cattle producers can change the marbling potential of their cattle irrespective of breed.

Average heritabilities for marbling have been estimated in many genetic trials. Table 1 is a partial listing of those results. Heritability is defined as the proportion of phenotypic variation that is due to additive gene effects (Buchanan and Clutter, 1989). In laymen terms, heritability is the proportion of what you measure that is caused by genetics and not by environment. Reproduction traits are low, growth traits are usually moderate and carcass and mature traits are generally high in heritability. This means that genetic greatly influences traits like marbling much more than pregnancy rates. It also means that heterosis will be more effective in improving reproductive and growth traits than carcass traits. There are no free rides in carcass genetics; either the genes are present for marbling or they are absent. No amount of feed will express more marbling than is genetically possible (Urlick et al., 1991; May et al., 1992).

Using Correlation Coefficients to Explain Relationships

Relationships between cattle selections traits have been a major factor in improving the efficiency of beef production. Today, with modern sire summaries and ranch records, cattle producers can fine tune and make faster, more precise genetic progress in those traits that will sustain profits throughout the lifetime of their operations. But, even with these new and powerful selection tools, time honored genetic and animal breeding principles hold true. Single or specific trait selection can have a detrimental or complimentary effect on traits which have been taken for granted in the selection process.

Correlations are used to measure the strength of the relationship between two variables or traits. Generally, relationships can be categorized into three correlations: positive – as one or the other trait increases or decreases in value the other traits performs in a similar manner; negative – as one trait changes in value in a particular direction the other trait moves in a corresponding opposite direction, and none – where there is no associations between the two variables. Therefore, correlation coefficients will range in value for -1 (strong negative relationship) to 0 (no relationship) to +1 (strong positive relationship). The square of the correlation coefficient measures the proportion of the variance in one variable that can be accounted for by variation in the related variable. Making the difference between 1 and the squared correlation coefficient an estimate of the amount of variation due to other factors.

When a correlation is found between two variables, a cause-and-effect relationship is assumed. This is not always the case. A correlation coefficient also does not provide information as to which is the cause and which is the effect. Selection trials would be needed to determine the biological relationships between the traits.

Marbling and Reproduction

One question often asked by cattle producers is: Does selection for marbling affect reproductive efficiency of the cowherd? No scientific studies can be found that

directly address this question, but several studies do exist that provide guidance.

Bergfeld and coworkers (1995) examined the age at puberty in heifers sired by Angus bulls considered high or low in marbling EPD. They found no difference in the age of puberty onset between the different sire groups. Gregory et al. (1993) and Cundiff et al. (1993) reported breed differences in puberty age, scrotal circumference, reproductive traits, maternal and marbling scores of cattle used in the MARC germplasm projects. These data indicate that breed or biotype has more influence on reproductive ability than marbling potential. Recently, the American Angus Association has developed heifer pregnancy (HP) EPDs. The final analysis represented 320 contemporary groups of 10,913 heifers. Using sires with accuracy of $>.50$ for HP EPD, no correlations were found between HP EPD and scrotal circumference, percent intramuscular fat, marbling, calving ease, milk, carcass fat or any growth trait. Thus, it appears that selection for HP EPD will have no effects on other reported traits (Northcutt, 2007).

Frazier and coworker (1999) compared reproductive performance of daughters of bulls with various EPDs for marbling and milk. Their conclusions were that marbling EPDs did not affect either the age of first calving or the length of the next three calving intervals. The average genetic correlation between preweaning gain and marbling score has been reported to be $.39$ (Ritchie, 1999) and $.21$ (Splan et al 1998). This is quite favorable if genetic selection for weaning weight and marbling are desired in the same direction. Because of the direct, positive relationship of weaning weight and dam's milk production (Knapp and Black, 1941; Neville et al., 1960; Wyatt et al., 1977; Boggs et al., 1980; Marston et al., 1992) one would speculate that increased milk production would also be positively associated with greater of marbling potential. Kuhlert and Jungst (1992) reported that breeding lines of swine selected for increased 70-day litter weight produced market hogs that had greater marbling scores. To achieve greater 70-day litter weights, sows were selected for increased milk production, increased litter size and increased pig survivability. This would indicate that selecting for increased milk production genetically drags along increased ability to marble. The question then becomes: Is the inverse true? Generally speaking, I would suggest that it does. However, Fiss and Wilton (1993) uncovered no relationship between dam's milk yield and any feedlot or marketing trait measured in their progeny. Arnold et al. (1991) reported a positive genetic relationship between post weaning rate of gain and marbling. This would indicate that the environmental conditions during the finishing phase would be able to limit the expression of marbling but not enhance it past the animal's genetic potential.

Because milk production is highly related to preweaning weight gain, producers often wonder if overall milk yield or milk composition is important. There are documented differences in milk composition among beef and dairy breeds (Marston et al., 1992; Boweditswe et al., 1992). The Jersey breed is noted for high milk fat concentration and total production, and according to MARC data (Cundiff et al., 1988) it is one of the highest breeds for marbling. A correlation between the ability to produce greater amounts of butterfat and marbling may exist, but presently no data is available that can substantiate this interesting hypothesis. Table 2 shows the levels of milk, marbling and growth of sire breed groups in MARC studies (Cundiff et al., 1988). Beal et al. (1989) machine milked Angus and Angus x Holstein crossbred cows and found that the milk fat content varied by the genetic makeup of the cows and by the day of lactation. Totusek et al. (1973) reported butterfat content had no influence on calf growth rates or

weaning weight. If milk composition can not be shown to influence growth rate during the suckling period, the question then becomes where would a relationship between butterfat and marbling take place? If not in calf performance then it would have to occur within a basic metabolic pathways which influence partitioning of energy within the body and among differing fat stores.

Marbling and Body Type

Conversations with producers of various breeds have noted a concern that pregnancy rates of virgin heifers and subsequent breedings are lower in heifers of higher marbling parentage. The present review of data does not substantiate this review. Since reproduction is a lowly heritable trait and marbling is a moderate to highly heritable trait, this review would suggest that the genes controlling reproduction and marbling would have to overlap and affect multiple traits for this to be true genetic relationship. However, evidence exists, and field observations note, that those progeny of higher marbling parents seem to also have a higher propensity to produce milk. If this is indeed the case and if multiple trait selection is not practiced to select those individuals that excel in marbling yet are only moderate for milk, then the increased nutrient demand for milk production would definitely limit reproduction in environments with limited nutritional resources (Rawlings, 1998). Therefore, it is important for cattle producers to monitor multiple traits so that genetic selection does not impede reproductive performance.

Vizcarra and coworkers (1995) at Oklahoma State University indicated that heifers that reach puberty first in both age and weight have the ability to cycle and maintain fertility with less weight gain after severe nutritional challenges. This would suggest that if cattle were simultaneously selected for high marbling and for puberty age and (or) scrotal circumference, then reproductive efficiency could be maintained even in less than ideal environments. Yelich et al. (1992) reported that puberty age in heifers is controlled by the rate of gain and body composition. He concluded that puberty is partially controlled by fat deposition. Gaughan et al. (1997) studied gilts and agreed with Yelich that age of puberty is influenced by the rate of fat and protein deposition. Therefore, cowherd managers must provide an environment conducive to proper heifer development and cow maintenance to maintain reproductive efficiency.

Because of the relationship between marbling and overall fat accumulation, there appears to be an antagonistic relationship between marbling and cutability across breeds and within breeds (Marshall, 1994). The American Angus Association (1999) reported only a minimal correlation (-.04) between marbling and percent retail product. In contrast, Gregory et al. (1995) reported a positive phenotypic and genetic correlation ($n = .04$) between marbling and 12th rib fat covering (.28 and .44, respectively). This should be comforting to Angus breeders as it allows them to more freely select for the both quality and quantity of red meat. Many cattlemen and cattle evaluators assume that the ability of cows to fatten and their "do ability" are positively correlated. Furthermore, the ability of cattle to accumulate back fat and to marble (AAA, 1999; genetic correlation between marbling and fat thickness = .02) is not correlated, implying that Angus breeders have the ability to match both marbling ability and do-ability to their particular management systems. Berg and Butterfield (1976) reported that Angus steers tend to deposit a fairly fixed proportion of internal and external fat at early stages of fattening and these proportions persist to high levels of fattening. This would allow reproduction and

sustainability of a cowherd to be maintained while selecting for high quality beef production. However, when producers try to lower backfat and increase marbling simultaneously, slower progress will be made in both traits than if only one trait is emphasized. These two traits appear to be antagonistic in most studies (Urick et al., 1991; DeRouen et al., 1992; Gregory et al., 1995; USDA, 1996). After reviewing the American Angus Association Sire Summary (1999) and research using Angus bulls, it appears that EPDs can be used for genetic selection and trait movement that would normally be thought antagonistic. MacNeil (1984) predicted that selection for reduced back fat (or increased percentage of retail product) would be associated with increased mature weight, increased age and weight at puberty, and reduced fertility of females. No studies can be found to confirm or contradict these predictions of increased mature weight and reduced female fertility. MacNeil did not examine the direct consequences of increased marbling selection.

Has the change in body type altered the ability to marble over the last several decades? One breeder and cattle evaluator was asked if any physical differences were noted among the high marbling population. His reply: "The heifers seem to reach puberty about the same age as their counterparts, the cattle as a whole are flatter muscled, growth may be slightly compromised, and they reach mature weights [that are] slightly less than the rest of the population". This appears to be supported by several research reports. Sapp and co-workers (2002) used bulls classified as high or low ultrasound marbling measurements to compare genetic selection for marbling on other carcass traits. Progeny from high marbling bulls did have greater marbling and carcass quality grades ($P < .05$) and had smaller age-adjusted ribeye area ($P < .05$) than the steer progeny of low marbling bulls. This supported the finding of Gregory et al. (1995) when they analyzed MARC data. Vieselmeyer et al. (1996) bred cows to high and low marbling Angus bulls and collected data on their offspring until slaughter. They found no differences in birthweight or dystocia, post-weaning weight gain or feed efficiency while in the feed yard. He did note that the calves in the low marbling group weighed more at weaning than their sire EPDs would have predicted, but the weight advantage was lost during the finishing phase. Hopper et al. (1993) noted no significant difference in puberty age of heifers that differed in marbling score potential. Bergfeld et al. (1993) reported no difference in the puberty age of heifers from the same sires used in the Vieselmeyer experiment and this conclusion was substantiated by Span et al. (1998). Numerous reports have indicated that higher marbling cattle have compromised rib-eye area (Gwartney et al., 1996; Hammack, 1997; Pariacote et al., 1998). Fiss and Wilton (1993) noted that calves expressing greater marbling scores tended to be the offspring of lighter weight cows.

An interesting study by May and coworkers (1995) examined the results of breeding crossbred cows to Angus bulls born in either the 1960's or 1980's. No EPD criteria were used in bull selection; their use was based only on semen availability. The results were as expected for many of the growth traits when genetic trends were taken into account (AAA, 1999). Newer generation-sired calves were heavier and larger framed throughout life. Carcass data analysis noted no differences in fat (adjusted fat thickness, KPH, or marbling scores) or muscle measurements but there was a difference in USDA yield grade. Smaller ribeye areas per hundredweight of carcass appeared to cause the decline in cutability of the calves sired by 1980's bulls. They also noted differences in characteristics of the marbling fat cells. Detailed analysis found that the 1980's sire calves

required more adipocytes to achieve those same amounts of marbling. Others (Jacobi and Miner, 1999) are seeking ways to manipulate the expression of marbling but this research is in its infancy. Cattle breeders must rely on genetic selection to make changes in marbling potential.

Unfortunately, breeding experiments have not been completed to address the relationship between marbling, milk production, and reproduction with a particular biotype or breed. Correlation coefficients between Marbling EPD, IMP EPD, and \$EN were calculated using the Spring 2007 AAA Main Sire Summary. Marbling EPD (number of sires = 762) and IMF EPD (number of sires = 2,163) were found to be little related to \$EN. The \$EN Selection index was developed to estimate animal feed cost savings of an animal's maintenance needs. Therefore, cattle with the most feed cost savings would be characterized as smaller in weight, stature, and milk production. Nephew and coworkers (2004) reported genetic correlations of -.15 and -.17 between marbling and cow mature weight and height, respectively. The magnitude of the coefficients indicate one or more other traits account for more of the variation in cow mature weight and height than marbling, but marbling would be expected to be favored with small statured, lighter weight cows (see Table 10).

Correlation between Marbling EPD Other Performance EPDs

The author determined the correlation between marbling EPD and other performance trait EPDs on the high accuracy marbling bulls listed in the Fall 2006 and Spring 2007 Angus Sire Summaries. Only the results from the Spring 2007 Sire Summary will be presented because little disagreement was noted between the analysis. One hundred twenty-four were listed in the summary with accuracies for ultrasound marbling EPD greater than or equal to .60. The results are listed in Tables 3 - 6. These tables show that regardless of marbling EPDs genetic selection for other production, carcass or selection indexes is not compromised. With that said, cattle breeders should be cognizant that there are relationships between marbling and other traits that should be monitored and considered when mating cattle. Examples follow. One relationship found was a positive correlation between marbling EPD and the sire's year of birth. This is probably best explained by the fact that over the last decade the selection for greater marbling has placed more young bulls into the higher marbling category. Unless these young bulls are used quite heavily in proper contemporary groups other genetic information may not be as reliable as older, higher accuracy bulls. As with the 1999 analysis, the mild correlations exist between lighter birth weights, easier calving, and heavier milk production to greater marbling. These are not large in magnitude making single trait selection slowly pulling other traits along instead of a rapid rate of change in only one or two generation intervals. The data also found a negative relationship between marbling and mature height, but not mature weight. It would appear that selection for greater marbling without regard to other traits over many years could result in a cowherd that would drift toward light birth weight, easy calving offspring from smaller framed cows that weigh nearly the same as their lower marbling contemporaries. However, because these cows milk as much or more than the lower marbling cows and weigh nearly the same, these high marbling cows may not be as energy efficient in converting calories into weaning weight as their counterparts (as noted by the negative relationship between marbling and \$EN). As expected selecting for greater marbling will

dramatically increase ultrasound IMF EPDs as well as increase the \$G and \$B values of the herd. Selecting for marbling would be expected to increase the grid marketing value of the offspring.

The database was expanded to include all bulls (n = 304) listed with ultrasound IMF EPD accuracies of greater than or equal to .80 (Tables 8 and 9). From the analysis, expectations were reaffirm the relationship between daughter's milk production potential and offspring birth weights. Most of the outliers on the enlarged ultrasound IMF data set were nested within the first marbling EPD analysis. Significant correlation coefficients between marbling and birth weight, calving ease, mature height, marbling, \$G and \$B EPDs and selection indexes appeared again in the analysis.

Conclusions and Closing Thoughts

Marbling is an economically important trait in today's beef cattle industry. For several decades there has been a movement toward value-based marketing. This will allow cattle producers to financially benefit from incorporating superior genetics into their programs. For producers to maximize returns from tomorrow's marketing systems they will have to meet consumer demands in an efficient manner. Great genetic strides have been made in the improvement of efficient growth; now is the time for producers to maintain growth advantages and increase carcass quality.

Most pricing grids reward cattle feeders with premiums for high quality carcasses. These premiums will have the potential to add \$20 to \$250 per head to gross income. It is common for 500 or more pounds of growth to be added in the finishing phase and this growth can cost 50 to 85¢ per pound to produce. Cow maintenance will consume about 70% of the total calories used by beef production. With these facts in mind, simple arithmetic indicates that the most profitable cattle will be those that do everything well. Hard-doing, non-production cows; poor feedlot performing offspring; nor inferior carcasses (both quality and quantity) will not be tolerated in the future. The beef production systems must maintain profitability throughout all production phases to sustain and flourish. This may be why advancing in beef production traits, like carcass quality, cowherd efficiency, and overall animal health, has suffered over the previous fifty to sixty years. During that period more profits have been made by setting the different production phases against each other than by then working together in harmony. In the future, as the different segments (seedstock, cow/calf, stocker, feedlot, packing and retail) work together to insure that all segments remained profitable, each phase will then have the confidence to advance and improve the beef that goes the ultimate consumer

Marbling is the major contributor to determining carcass quality. Like other production traits, marbling is controlled by genetics and environment. Research indicates that the heritability of marbling is moderate to high. Producers need to realize that genetics is more influential on the expression of marbling than on traits like weaning weight or calving percentage. Marbling has to be bred into the offspring; it can not be fabricated from a special environment. Today, we do not have an implant, injection or feed additive that enhances marbling score. Instead, quite to the contrary, most growth stimulants utilized in today's modern finishing programs hinder marbling expression (Duckett et al., 1997).

Producers are questioning the wisdom of selecting strictly for marbling. This is well advised, as single trait selection has been shown to be detrimental to other important production traits. For example, if yearling weight is the only selection criteria, birth weights will increase and eventually dystocia would hinder overall production of the cow herd. Because of known relationships between marbling and other carcass traits, selecting cattle to increase marbling will result in finished cattle that will have greater grid premiums and overall feedlot and carcass value under the current finished cattle marketing system.

Age of puberty does not seem to be affected by marbling potential. Several experiments have shown no difference in pubertal age; however, differences in fertility were not reported. Fortunately, heifers and cows that exhibit estrus are usually fertile. Along with changes in carcass characteristics one would expect high marbling cattle to be higher in milk production which would promote heavier weaning weights. Direct growth for weaning weight would not be expected to change; therefore, weaned calves may be expected to be carrying additional condition or flesh. Cows with greater genetic potential to milk have metabolic rates that demand more energy for maintenance than lower milking contemporaries (Andersen, 1978; Lemenager et al., 1980).

All too often, cow-calf producers do not adequately consider the ramifications of increasing production parameters such as milk production and weaning weight. Greater demands on body energy reserves may cause reductions in reproductive performance. If management does not properly match genotype to environment the cowherd will begin to experience lower reproductive rates caused by decreased body condition scores. Actually, we know little about the peculiarities of dams that possess high marbling genes.

The solution is to use selection indexes and multi-trait selection based on EPDs. Considering multiple traits simultaneously would minimize many of the unfortunate scenarios being reported from field observations. Breeders need to rely heavily on the American Angus Association Sire Summary publication and visual observations of type and kind. Accurate data collection is the cornerstone to the system. Assembly of the data into organized information and turning that information into concrete knowledge is the most efficient system to improve cattle breeding and meet the demands of our consumers.

Commercial cow-calf producers appear to be segmenting themselves into three general categories or paradigms: 1) Heavy work load, time restricted, high risk; 2) data collection and recordkeeping, low-cost, commodity driven; and 3) food producer, consumer orientated, management by knowing where the operation is and anticipating future marketing opportunities. The first group love their work and life style, but oftentimes go unrewarded financially because of the changes in market and production environments. They are often steeped in tradition and do things over and over because that's the way they have always been done. The second category will be the low cost producer so survival is highly possible. As long as there is a commodity market for beef this producer will have an outlet for their produce, margins (profits) will vary with cattle cycles and production costs. And finally, there is the third group, the food producers. They understand how the beef industry works and how the production segments can build on each other. They truly care about the consumer's wants and find ways to fill those needs. They are rewarded financially for their efforts and for their management decisions. They encounter risk but not so much at the whim of the weather or cattle cycle, but by anticipating and building the acceptance and demand for beef.

Table 1. Heritability estimates of marbling in beef cattle.

Study	Year	Heritability estimate
Benyshek	1981	.47
Wilson & Rouse	1987	.31 (light steers)
Wilson & Rouse	1987	.26 (heavy steers)
Lamp et. al.	1990	.33
Arnold	1991	.35
Woodard	1992	.23 (Simmental)
Veseth et al.	1993	.31 (Herefords)
Wilson et al.	1993	.27 (Angus)
Gregory et al.	1994	.52
Gregory et al.	1995	.48 (all breeds)
Gregory et al.	1995	.45 (purebreds)
Gregory et al.	1995	.55 (composites)
Wulf et al.	1996	.51
O'Conner et al.	1997	.37
Pariacote et al.	1998	.88 (Shorthorn)
Robinson et al.	1998	.30 & .15 (tropical and temperate)
Splan et. al.	1998	.71 (1 st 4 MARC cycles)
American Angus Association	1999	.36
Davis and Simmen	2000	.27
Marquez et al.	2000	.36 (6 breeds)
Stelzleni et al.	2002	.16 (Brangus)
Crews et al.	2003	.38 (Charolais X steers)
Crews et al.	2003	.54 (Simmental)
Riley et al.	2003	.44 (Brahman)
Minick et al.	2004	.43 (several breeds)
Nephawe et al.	2004	.46 (MARC)
Utrera and Van Vleck	2004	.37 (Review paper)
Dikeman et al.	2005	.68 (14 breeds)
Rumph et al.	2007	.27 (Simmental)
<i>Average</i>		.36

Table 2. Breed crosses grouped into seven biological types on the basis of four major criteria and marbling score^{a,b}

Sire Breed Group	Growth Rate	Lean to Fat	Puberty Age	Milk Production	Marbling Score
Jersey	X	X	X	XXXXXX	13.2
Hereford-Angus	XX	XX	XXX	XX	11.3
Red Poll	XX	XX	XX	XXX	11.5
Devon	XX	XX	XXX	XX	
South Devon	XXX	XXX	XX	XXX	11.3
Tarentaise	XXX	XXX	XX	XXX	10.2
Pinzgauer	XXX	XXX	XX	XXX	10.8
Brangus	XXX	XX	XXXX	XX	
Santa Gertrudis	XXX	XX	XXXX	XX	
Sahiwal	XX	XXX	XXXXX	XXX	9.7
Brahman	XXXX	XXX	XXXXX	XXX	9.3
Brown Swiss	XXXX	XXXX	XX	XXXX	10.4
Gelbvieh	XXXX	XXXX	XX	XXXX	9.6
Holstein	XXXX	XXXX	XX	XXXXX	
Simmental	XXXXX	XXXX	XXX	XXXX	9.9
Maine-Anjou	XXXXX	XXXX	XXX	XXX	10.1
Limousin	XXX	XXXXX	XXXX	X	9.0
Charolais	XXXXX	XXXXX	XXXX	X	10.3
Chianina	XXXXX	XXXXX	XXXX	X	8.3

^a Increasing number of X's indicate relatively higher levels of performance and older age at puberty.

^b Marbling: 8 = slight, 11 = small, 14 = modest.

Adapted from Cundiff et al., 1988.

Table 3. Statistics of the high marbling Angus bulls (n = 31, marbling accuracy \geq .60) used in correlation analysis^a.

	Mean	SD	Minimum	Maximum
Year of birth	1993	5.2	1981	2002
<i>Production trait EPDs</i>				
Birth weight	2.1	2.2	-2.2	6.9
Calving ease direct	6.2	5.3	-11	16
Calving ease maternal	7.0	3.3	-3	14
Weaning weight	34.9	9.0	16	51
Milk	22.5	6.5	6	32
Yearling weight	68.8	16.3	25	97
Mature weight	30.1	28.3	-13	104
Mature height	.56	.37	-.1	1.5
Scrotal circumference	.23	.63	-1.17	1.42
<i>Carcass trait EPDs</i>				
Carcass weight	5.5	11.4	-12	37
Marbling	.52	.10	.39	.76
Ribeye	.19	.32	-.44	.79
Fat	.002	.03	-.06	.06
UIMF	.32	.17	.11	.75
URibeye	.19	.32	-.41	.86
UFat	.001	.02	-.03	.03
<i>Selection Indexes</i>				
\$F	15.05	12.92	-19.65	37.43
\$G	26.99	6.84	16.12	40.05
\$B	39.004	11.51	15.29	62.12
\$W	22.48	6.16	5.83	35.82
\$EN	6.31	6.85	-7.27	21.46

^aData from Angus Sire Summary, Spring 2007.

Table 4. Statistics of the moderately high marbling Angus bulls (n = 31, marbling accuracy \geq .60) used in correlation analysis^a.

	Mean	SD	Minimum	Maximum
Year of birth	1993	4.1	1986	2001
<i>Production trait EPDs</i>				
Birth weight	2.2	1.9	-1.2	5.9
Calving ease direct	6.8	3.6	-3	12
Calving ease maternal	7.4	4.2	-1	14
Weaning weight	39.8	8.6	21	55
Milk	20.1	8.5	4	35
Yearling weight	77.0	14.4	47	104
Mature weight	42	31.6	-32	131
Mature height	.70	.48	-.30	1.8
Scrotal circumference	.40	.68	-.99	1.49
<i>Carcass trait EPDs</i>				
Carcass weight	10.8	13.8	-23	33
Marbling	.27	.05	.21	.35
Ribeye	.14	.27	-.40	.60
Fat	.007	.03	-.06	.05
UIMF	.16	.15	-.18	.50
URibeye	.13	.26	-.39	.63
UFat	.006	.02	-.03	.04
<i>Selection Indexes</i>				
\$F	21.37	11.59	-1.19	43.26
\$G	17.59	4.48	9.11	29.98
\$B	35.59	13.62	3.13	56.62
\$W	22.81	7.09	4.54	35.55
\$EN	5.99	6.33	-7.04	15.24

^aData from Angus Sire Summary, Spring 2007.

Table 5. Statistics of the moderately low marbling Angus bulls (n=31, marbling EPD accuracy $\geq .60$) used in correlation analysis^a.

	Mean	SD	Minimum	Maximum
Year of birth	1989	5.1	1978	1996
<i>Production trait EPDs</i>				
Birth weight	1.9	2.3	-2.3	5.7
Calving ease direct	5.7	4.7	-6	15
Calving ease maternal	7.3	3.7	-4	12
Weaning weight	38.3	8.1	17	51
Milk	21.2	7.1	6	34
Yearling weight	72.2	14.2	40	98
Mature weight	31.9	22.3	-6	100
Mature height	.43	.40	-.2	1.4
Scrotal circumference	.30	.80	-.89	2.07
<i>Carcass trait EPDs</i>				
Carcass weight	6.1	13.0	-26	27
Marbling	.13	.05	.07	.21
Ribeye	.13	.28	-.57	.81
Fat	.007	.02	-.038	.055
UIMF	.07	.13	-.21	.38
URibeye	.12	.27	-.44	.60
UFat	.002	.02	-.03	.06
<i>Selection Indexes</i>				
\$F	17.04	11.29	-6.32	40.15
\$G	13.93	5.05	4.99	22.95
\$B	27.82	11.10	.93	46.47
\$W	24.62	5.68	12.13	35.82
\$EN	7.43	6.83	-5.23	21.87

^aData from Angus Sire Summary, Spring 2007.

Table 6. Statistics of the low marbling Angus bulls (n=31, marbling EPD accuracy \geq .60) used in correlation analysis^a.

	Mean	SD	Minimum	Maximum
Year of birth	1990	5.3	1973	1998
<i>Production trait EPDs</i>				
Birth weight	2.5	1.8	-.8	5.9
Calving ease direct	4.3	5.2	-10	11
Calving ease maternal	5.6	5.3	-7	15
Weaning weight	37.1	9.1	20	69
Milk	18.9	7.2	4	38
Yearling weight	71.4	16.0	45	122
Mature weight	37	27.3	-12	85
Mature height	.48	.48	-.40	1.5
Scrotal circumference	.08	.48	-.96	.93
<i>Carcass trait EPDs</i>				
Carcass weight	7.8	10.2	-12	29
Marbling	-.06	.10	-.33	.07
Ribeye	.13	.23	-.28	.64
Fat	-.001	.03	-.28	.64
UIMF	-.07	.12	-.34	.13
URibeye	.09	.27	-.45	.81
UFat	.002	.02	-.03	.03
<i>Selection Indexes</i>				
\$F	16.81	12.88	-4.18	57.07
\$G	7.05	5.20	-5.12	16.02
\$B	21.67	10.81	-2.74	50.33
\$W	21.33	7.07	3.88	40.14
\$EN	8.06	6.29	-6.52	26.16

^aData from Angus Sire Summary, Spring 2007.

Table 7. Correlation coefficients^a between marbling EPD and other traits of Angus bulls (n = 124; marbling EPD \geq .60) used in tables 3, 4, 5, and 6^b.

EPD or Index	Marbling EPD Rank Groupings				
	Low	Mod. Low	Mod. High	High	All
	$\leq .07$.07 to .21	.21 to .35	.39 to .76	
No. of bulls	31	31	31	31	124
Year of birth	.30 (.10)	-.23 (.21)	.01 (.97)	.02 (.90)	.26 (.003)
<i>Production trait EPDs</i>					
Birth weight	-.30 (.10)	.04 (.84)	.16 (.39)	-.17 (.38)	-.09 (.32)
CED	.43 (.02)	-.27 (.14)	-.38 (.03)	.02 (.92)	.17 (.06)
CEM	.27 (.14)	.07 (.69)	-.31 (.09)	-.07 (.70)	.12 (.19)
Weaning weight	.16 (.38)	-.05 (.77)	.26 (.16)	-.05 (.79)	-.05 (.55)
Milk	.25 (.18)	-.05 (.80)	-.04 (.83)	-.06 (.74)	.16 (.07)
Yearling weight	.24 (.20)	-.13 (.48)	.28 (.13)	-.11 (.57)	-.02 (.84)
Yearling height	.02 (.92)	.01 (.97)	.28 (.13)	.09 (.64)	.08 (.36)
Mature weight	.18 (.33)	-.18 (.34)	.28 (.12)	.18 (.33)	-.01 (.91)
Mature height	.14 (.46)	-.09 (.65)	.25 (.18)	.37 (.04)	.16 (.07)
Scrotal circ.	-.13 (.49)	.02 (.89)	-.17 (.35)	-.02 (.91)	.06 (.53)
<i>Carcass trait EPDs</i>					
Carcass weight	-.16 (.38)	-.01 (.97)	.26 (.15)	.06 (.76)	-.03 (.72)
Ribeye	-.14 (.44)	-.13 (.50)	.04 (.82)	.26 (.15)	.10 (.27)
Fat	.14 (.44)	.15 (.43)	.05 (.77)	-.15 (.43)	.04 (.65)
U_IMF	.09 (.63)	.36 (.04)	.07 (.72)	.41 (.02)	.72 (.001)
U_Rib	.11 (.55)	.02 (.92)	.20 (.27)	.10 (.58)	.16 (.09)
U_Fat	.04 (.81)	-.01 (.94)	.03 (.86)	.03 (.85)	.01 (.88)
<i>Selection Indexes</i>					
\$F	.26 (.16)	-.15 (.43)	.26 (.15)	-.12 (.53)	-.01 (.95)
\$G	.37 (.04)	.38 (.06)	.17 (.37)	.46 (.01)	.83 (.001)
\$B	.22 (.24)	.08 (.67)	.34 (.06)	.22 (.23)	.52 (.001)
\$W	.20 (.28)	.05 (.80)	-.14 (.44)	-.05 (.77)	.04 (.66)
\$EN	-.36 (.05)	.14 (.44)	-.27 (.14)	.05 (.80)	-.15 (.10)

^aTabular values are Pearson Product correlation coefficients followed by P values within parenthesis.

^bData from Angus Sire Summary, Spring 2007.

Table 8. Simple statistics of Angus bulls (n = 304) with U-IMF accuracies greater than .80^a.

	Mean	SD	Minimum	Maximum
Year of birth	1995	4.3	1978	2002
<i>Production trait EPDs</i>				
Birth weight	2.3	2.1	-4.2	8.0
Calving ease direct	5.7	4.6	-9	16
Calving ease maternal	7.0	3.7	-7	15
Weaning weight	44.5	10.0	16	72
Milk	21.3	7.9	-1	48
Yearling weight	84.2	16.5	40	128
Mature weight	39	28	-72	144
Mature height	.55	.46	-1	2.7
Scrotal circumference	.39	.61	-1.17	2.16
<i>Carcass trait EPDs</i>				
Carcass weight	7.9	10.1	-26	38
Marbling	.18	.21	-.36	.86
Ribeye	.17	.21	-.57	.81
Fat	.002	.03	-.07	.09
UIMF	.12	.22	-.5	.75
URibeye	.20	.29	-.68	1.21
UFat	.004	.02	-.04	.07
<i>Selection indexes</i>				
\$F	26.93	13.49	-6.32	65.51
\$G	14.43	8.69	-9.75	40.05
\$B	35.24	11.32	.93	62.12
\$W	25.37	6.39	5.83	11.58
\$EN	4.43	7.54	-17.14	30.97

^aData from Angus Sire Summary, Spring 2007.

Table 9. Correlation coefficients between U_IMF EPD and other traits of Angus bulls (n = 304 with an U_IMF EPD accuracy \geq .80) ^a.

	Pearson correlation	
	coefficient	P value
Year of birth	.22	.0001
<i>Production trait EPDs</i>		
Birth weight	-.19	.001
CED	.15	.01
CEM	.11	.05
Weaning weight	-.08	.19
Milk	.17	.002
Yearling weight	-.04	.50
Yearling height	-.14	.02
Scrotal circumference	-.08	.18
Mature weight	-.07	.04
Mature height	-.05	.38
<i>Carcass trait EPDs</i>		
Carcass weight	-.08	.17
Marbling	.63	.0001
Ribeye area	.06	.33
Fat	.11	.05
U_Ribeye	.16	.007
U_Fat	.24	.0001
<i>Selection indexes</i>		
\$F	-.03	.65
\$G	.80	.0001
\$B	.56	.0001
\$W	.11	.06
\$EN	-.12	.04

^aData from Angus Sire Summary, Spring 2007.

Table 10. Estimates of genetic correlations of carcass traits of steers and mature weight, height, and body condition score of cows (adapted from Nephawe et al., 2004, MARC).

Steer carcass traits	Cow parameters		
	Weight	Height	BCS
Hot carcass weight	0.81	0.69	0.23
Percent retail product	-0.05	0.03	-0.12
Ribeye area	0.34	0.32	0.24
Marbling	-0.15	-0.17	-0.03
Warner-Bratzler shear force	0.15	0.22	0.08