RELATIONSHIP OF MILK PRODUCTION, MILK EXPECTED PROGENY DIFFERENCE, AND CALF WEANING WEIGHT IN ANGUS AND SIMMENTAL COW-CALF PAIRS

by

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The Great Clock

The clock of life is wound but once
and no man has the power,
To tell just when the hands will stop
at a late or early hour.

Now is the only time you own,
Live, love, toil with a will.
Place no faith in tomorrow
for the hands may then be still.

L. S. Barngrover
(neighbor and friend)

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CHAPTER I

GENERAL INTRODUCTION

Reproductive efficiency and weaning weight are traits that directly affect the profitability of a beef cow herd. Milk production directly affects these traits, thus indirectly influencing the profitability of cow/calf operations. The ability to predict the milking potential of an individual beef cow or a herd of beef cows can be used by producers to optimize the potential for profit from their operations. Milk production (a part of maternal ability of beef cattle) is a moderately heritable quantitative trait with moderate variation and indirect economic value (Van Vleck, et al., 1987). The relationship between milk production and calf preweaning growth, as expressed by weaning weight has been evaluated in many studies. Optimum milk production is a biological objective that is heavily dependent upon the factors of genetic ability, feed resources, and marketing situations (Ritchie, 1982). Therefore, producers need selection tools available to manipulate and manage the level of milk production in their cow herds. Prior to the development of National Cattle Evaluation (NCE) programs reported by breed associations, the only means of predicting milking ability was within herd comparison of weaning weights. Through NCE programs, milk expected progeny differences (EPDs), provide comparisons of progeny genetic potential expressed in units of calf weaning weight, to predict the milking potential of progeny.

The following literature review examines the characteristics of lactation curves, the techniques used to measure milk production, the factors that affect beef cow milk production (both fluid and components), the prediction of milk production, the procedure used to calculate EPDs, and compare EPDs to cattle performance.

CHAPTER II

LITERATURE REVIEW

Lactation curves. Lactation curves are important in determining the potential milk production of a cow or herd of cows. The area under the curve is of primary importance since it is a measure of total milk production during the lactation. This area depends on the shape as well as the height of the curve. It is generally accepted that during lactation, daily milk yield increases in a nonlinear fashion from the onset of lactation until milk yield peaks and then steadily decreases until lactation ceases (Appendix, Figure 1). Furthermore, the level of production during early lactation is limited by the capacity of the calf to consume milk as well as the cow's potential to produce milk. A mathematical equation can be used to describe an animal's lactation with the average of the parameters of the equation used to compare groups of animals.

Beef cow lactation curves were first described by Cole and Johansson (1933) for Aberdeen-Angus cattle. Since then, studies by Woods (1967); Gleddie and Berg (1968); Melton et al. (1967); Abadia and Brinks (1972); Totusek et al. (1973); Kress and Anderson (1974); Cobby and LeDu (1978); Notter et al. (1978); Neidhardt et al. (1979); Gaskins and Anderson (1980); Rowlands et al. (1982); Casebolt et al. (1983); and Clutter and Nielsen (1987) have provided information on the shape of lactation curves for both beef and dairy cows, along with the amount of milk produced (Appendix Table 1).

Several approaches have been used to convert daily and hourly measurements of milk production into estimates of total milk production during lactation. Some scientists have merely averaged the daily milk yields (Gleddie and Berg, 1968; Melton et al., 1967; Belcher and Frahm, 1979; and Cranwell et al., 1987) and then multiplied by the number of days of lactation or the number of days between the first and last sampling dates. Beal et al. (1990) calculated milk production by averaging estimated daily milk production by the number of samples taken per cow. In another approach, Clutter and Nielsen (1987) employed a method proposed for economic models by Fuller (1969) to approximate production surfaces and time series trends. This technique combined functions that best approximated segments of the entire data range. Since daily milk production estimates increased to the peak of lactation in a nonlinear fashion and then decreased linearly, a quadratic function was joined with a linear function to adequately describe milk production. The R-square values were used to determine the day of peak lactation and the point at which the quadratic and linear functions joined. Peak lactation at 70 d gave the highest R-square value. Individual cow milk production was estimated using specific parameters for their respective milk-group lactations. Estimates of 24-h and 205-d milk yields mirrored the results of Cundiff et al. (1982) for cows of similar breed groups.

Using a different approach, Woods (1967) estimated parameters of algebraic models, after a transformation of data, by linear least squares estimation. This method was developed by fitting curves to 859 British Frisian lactation records. It accounted for 82.3% of the variation in the logarithm of milk yields. This technique was later applied to data from the Grassland Research Institute where it accounted for 92% of the variation; however, some of the curves did not fit the data as well as expected. It was discovered that the proposed lactation curve $y = A\, n^{b}\, e^{-cn}$ (where y=daily milk yield (kg) in the n^{th} week of lactation and A, b and c are positive parameters which determine the shape of the lactation curve) consistently overestimated the daily milk yields from week 2 through 10 but underestimated milk production from week 11 until lactation ceased. Woods (1967) contended the most important features of a lactation curve are the peak daily milk yield and the persistency of lactation (which is defined as the persistence with which peak yield is maintained).

Jenkins and Ferrell (1984) used the empirical equation: $Y(n) = n/ae^{kn}$ (where $Y(n)$ was the daily milk yield of the n^{th} week postpartum and a and k define the shape of the lactation curve) to describe the lactation curves of several beef breeds and their crosses. Parameters were estimated by expressing the equation in logarithms, i.e., $log_e[Y(n)/n] = log_e 1/a - kn$. The reciprocal of the k parameter determined the time to peak lactation and the a parameter determined the milk yield. The parameter k did, however, affect the general shape of the curve and could therefore be used as an indirect measure of persistency of lactation.

Pre-peak milk production. Pre-peak milk production is highly influenced by the genetic ability of the cow, the environment, and the capacity of her offspring to consume milk. Using two daily milk production estimates during early lactation, Williams et al. (1979b) concluded that milk production increased between days 7 and 56 of lactation, resulting in increased average daily gains of the calves during the corresponding period. Neville (1962) noted that some calves had the ability to consume as much as 10.0 kg milk per suckling early in lactation without any noticeable reduction in subsequent months.

Holloway and Worley (1983) concluded that milk production during early lactation (less than 30 d postpartum) was determined by the capacity of the calf to consume milk, which is a function of calf metabolic body weight. Therefore, to estimate milk production, Holloway and Worley used calf weights to calculate net energy requirements during this period. This method produced satisfactory results to develop the early segment of the lactation curve. Gifford (1953) reported "udder spoilage" caused by excessive milk production above calf consumption which greatly affected milk production during later stages of lactation.

Peak milk production. Most cows reach peak milk production 2-3 mo following calving, which coincides with normal breeding seasons and rapid calf growth. In general, producers try to time peak lactation with optimum forage growth so that nutrition does not limit productivity and reproduction since approximately 60 to 70% of the variation in weaning weight is accounted for by milk production of the cow (Taylor, 1984).

While numerous research trials have attempted to identified the day of peak lactation, the results have been inconsistent. For example, Kress and Anderson (1974) and Gaskins and Anderson (1980) reported that peak lactation occurred at 20 to 28 d for purebred Hereford and crossbred cows, while Abadia and Brinks (1972) reported peak lactation at 28 to 35 d in two-yr-old Herefords. Furthermore, Cole and Johansson (1933) along with Neidhardt et al. (1979) reported that peak milk yields occurred around 30 d postpartum for Angus and Brahman cattle, respectively. Dawson et al. (1960), Gleddie and Berg (1968), and Totusek et al. (1973) determined that peak lactation occurred in the second mo postpartum for British, British cross and British × dairy cross cows. High producing milk cows were found to reach peak daily milk yields from 28 to 49 d in a study by Butler et al. (1981). Jenkins and Ferrell (1984) reported that peak lactation occurred from 49 to 64 d post-calving depending on breed groups, whereas Melton et al. (1967) reported peak milk production occurred at 77 d postpartum with cows five yr of age and older. Green et al. (1988) reported peak milk yield estimates (8.15 to 11.35 kg) occurred 55 to 64 d postpartum, independent of breed. Similar results were reported by Mallinckrodt et al. (1990). Cundiff et al. (1974) noted that British and British cross cows reached peak lactation from 6 to 14 wk after calving. Variation in time of peak lactation reported by these researchers may reflect both biological phemonena and analytical models.

Several studies have attempted to identify factors affecting the variability in time of peak lactation. For instance, time of peak lactation was slightly affected by the quality of grass pastures in a study by Worley (1981). Cows on high quality pastures (fescue and legume mixture) had peak milk production 80 d postpartum while cows grazing low quality pastures (fescue) had peak lactation 68 d postpartum. Diets had a marked affect on the time and amount of peak milk production in spring calving crossbred cows in a study by Chenette and Frahm (1981) in which peak milk production occurred in early to mid lactation which corresponded to improved pasture conditions in May and June.

Jenkins and Ferrell (1984) noted that low quality diets had little effect on time of peak lactation ($P < .05$) but had a substantial effect on the persistency of lactation. Other environmental factors related to nutrition, such as season of calving, have been found to influence the time from parturition to peak milk production. Oklahoma work, conducted by McCarter et al. (1987), revealed that spring calving cows took approximately 30 d longer to reach peak production compared to fall calving cows; however, total milk yields were similar between the groups. Furthermore, McCarter et al. (1987) found that the level of nutrition, supplied prior to calving, influenced the development of tissues in the mammary glands. Therefore, nutrition prior to calving, especially the 6-wk period prior to parturition, was extremely important to peak milk production and persistency.

Actual level of milk production at peak lactation reported in the literature is variable. Breed, age, nutritional plane, and genetic potential have been shown to impact the levels reported. Multiparous Simmental and Polled Hereford cows averaged peak milk production levels of 11 and 8 kg/d, respectively, in a study by Mallinckrodt et al., 1990. Similar results were reported by Gaskins and Anderson (1980) using Angus × Hereford, Angus × Simmental, and Angus × Jersey cows. Lower peak milk yields were noted by Notter et al.

(1978) using various combinations of crossbred 2-yr-old cows, with estimates primarily in the range of 5 to 6.5 kg/d. Three- and 4-yr-old herd mates in the same study had peak milk yields of 5 to 12 kg/d. Boggs et al. (1980) reported that the peak milk production level of Polled Hereford cows during April and May exceeded 6 kg/d, which were similar to levels reported by Lamond et al. (1969), and slightly higher than the 5 kg/d reported by Robison et al. (1978). Cow age had a definite effect on peak milk production level in a study conducted by Pope et al. (1963) in which 2-yr-old cows averaged less than 4-yr-old cows (4.5 vs. 5.5 kg/d, respectively) at peak lactation.

Post-peak milk production. All studies have shown a continuous decrease in daily milk production after peak lactation. Neville (1962) found that daily milk production declined only .54 kg/d when the first 4-mo average was compared to the last 4 mo. Gaskins and Anderson (1980), and Rutledge et al. (1971) concluded that the decline in milk production after peak lactation is nonlinear. However, a linear decrease in daily milk production following peak lactation was reported by Abadia and Brinks (1972), Kress and Anderson (1974) and Clutter and Nielsen (1987).

Whether the decline is nonlinear or linear may depend on environmental factors such as nutrition, climate, and(or) calf stimulation. Also, the amount of milk produced at peak milk yield can partially determine the persistency of the lactation. Linear declines in milk production following peak lactation have been generally associated with high milk producing cows (Notter et al., 1978; and Mallinckrodt et al., 1990). A linear decline of milk production and a decrease in the correlation between daily milk yields and calf average daily gain from 1-8 mo of lactation was reported by Gifford (1949).

Notter et al. (1978) noted that, with the exception of the Charolais breed, breeds with the highest milk production possessed the highest peak milk yields which corresponded with the lowest persistency of milk production. Therefore, their increase in overall production of milk came from obtaining higher milk daily yields at peak lactation, not from sustained high levels of milk production. Classified as high milking, the Jersey- and South Devon-crosses declined linearly from peak lactation until weaning by 53 and 41%, respectively, while low milking, purebred Hereford and Angus cows declined only 22% during the same period. Jenkins and Ferrell (1984) reported comparable results while studying other breed combinations.

Chenette and Frahm (1981) also noted that daily milk production differences between groups of high and low milk producing cows were maximized at peak lactation. They, however, concluded that deteriorating pasture condition, not genetic difference, was the primary factor governing the difference in rate of change in milk production following peak yields. Taylor (1984) reported that milk production was sustained longer if cows received lush, green pasture at the time of peak milk production.

Cow age was shown to affect the persistency of lactation in a study by Christian et al. (1965) who noted that first calf heifers produced a higher percentage of their milk after peak lactation than did older cows. Spike and Freeman (1967) reported this same result using data from dairy cattle.

Methods of measuring milk production. Most studies measuring milk production in beef cows have used one of two methods: weigh-suckle-weigh or machine milking. Additionally, some researchers have used teat cannulation and hand milking methods with or without an injection of oxytocin to stimulate milk letdown.

The advantages of weigh-suckle-weigh over machine milking include: less stress on the cows, more accurate measurement of the amount of milk consumed by the calf, and less time required to take the measurement. However, using a machine causes less stress on the calves, measures milking potential of the cows, eliminates the need for repeated animal handling, and allows measurement of milk constituents.

Several studies have been conducted to compare methods of measuring milk production. For example, Belcher et al. (1980) reported that average milk estimates were consistently higher for machine milking than for weigh-suckle-weigh. An average difference of 1.5 ± .14 kg/d was reported for eight different genotypes. The largest difference between methods occurred at peak lactation and was attributed to the inability of the calves to consume all available milk. When measuring milk production in ewe lambs, Henry and Benson (1990) reported daily milk estimates between weigh-suckle-weigh and milking machine were similar and highly correlated.

In a study comparing three methods for estimating milk production in beef cows, Lam et al. (1970) concluded that ranking of cows was unaffected by method of measurement even though different methods gave different milk production estimates. Weigh-suckle-weigh resulted in the lowest estimates of daily milk production compared to two methods involving oxytocin injection, one with teat cannulation and the other with weigh-suckle-weigh and removal of residual milk using teat catheters. They noted that more cows could be measured per d with the oxytocin and teat catheters than with the other two methods.

Totusek and Arnett (1965) used 24 beef cows to compare weigh-suckle-weigh, hand milking, and cow weight as methods to estimate milk production and early calf growth. Milk estimates were taken daily, but regardless of method, estimates taken at 70-, 112-, and 210-d postpartum accurately predicted total lactation milk production. The weigh-suckle-weigh method provided estimates of higher daily milk production (by 1.31 kg) than did hand milking. However, oxytocin was not used to elicit milk letdown with the hand milking method. Interestingly, they reported a high positive correlation of cow weight to milk production.

In a direct comparison of weigh-suckle-weigh and machine milking, Hardt et al. (1988) reported a higher correlation between calf weights and milk estimates taken by weigh-suckle-weigh than by machine (.75 vs. .57). However, the design of the experiment could have influenced the results since oxytocin was not used with the machine milking method.

Beal et al. (1990) compared weigh-suckle-weigh to machine milking to determine the most repeatable technique and to investigate the relationship between total lactation yield and postpartum reproduction. The average weigh-suckle-weigh estimate and the average machine milking estimate of milk production were highly correlated with each other and preweaning weight gains of calves (r = 0.76 and 0.75, respectively). The residual correlation between individual machine milkings taken at 66-, 123-, or 187-d of lactation, respectively, were equally correlated with calf weight gain. However, when individual weigh-suckle-weigh estimates were compared to calf weight gains, the correlations were lower than the correlation of calf gain with the average of four weigh-suckle-weigh estimates. At each milking date, machine milking gave larger correlations between kg of milk and calf weight gain than did weigh-suckle-weigh. Weigh-suckle-weigh was associated with dramatic re-ranking of cows based on repeated estimates of milk production. This result could be partially explained by the design of the study, in which they permitted nearly 20 h of calf removal prior to measurement of milk. At all test times, machine milking produced higher estimates of daily milk production than weigh-suckle-weigh. However, the milking machine method was preferred due to the precision, consistency and strong relationship of estimated milk production and calf gain. Machine milking during two successive lactations had a much higher correlation to calf gain (r = .73,

$P < .02$) than did weigh-suckle-weigh ($r = -.14$, nonsignificant). This correlation of weigh-suckle-weigh to calf gain is surprising, especially since Pope et al. (1963) reported a strong correlation ($r = .6$) using the same technique.

Oxytocin use to elicit milk letdown. Administration of exogenous oxytocin causes contraction of myoepithelial cells surrounding alveoli and small ducts in the mammary gland to elicit milk letdown (Sagi et al., 1980). Sagi and coworkers reported that small amounts (i.e., less than .5 IU) of exogenous oxytocin given i.v. promoted milk ejection. Schwulst et al. (1966) found that oxytocin did not change the estimates of milk production and the percentages of milk constituents, but did decrease the amount of residual milk left in the udder after sampling. Lamond et al. (1969) determined that oxytocin was necessary to totally evacuate the udder and eliminate variation due to residual milk. They suggested an i.v. dosage of 20 IU was adequate. The dosage of oxytocin used in previous research has varied from 10 to 40 IU, given i.v. or i.m., with the higher dosages normally given i.m. (see Appendix Table 2).

Some concern regarding possible side effects caused by the administration of oxytocin for milk elicitation has been expressed. Stewart and Stevenson (1987), however, reported no detrimental effects on reproductive performance when oxytocin was used to enhance milk production.

Number of daily milk estimates needed to accurately predict total lactation output. Totusek et al. (1973) concluded that two to four well timed, daily milk yield estimates could be used to predict 210-d milk yield. Using milk measurements from 30, 70, 112, 140 and 210 d postpartum, they were able to accurately predict the total amount of milk produced in a 210-d lactation. Two estimates, one at mid-lactation and the other in late-lactation (90- and 180-d, respectively) also had a high positive correlation with 210-d total milk yield ($P < .01$; $r = 0.87$) and when averaged they approximated average daily milk yield for the entire lactation. An additional sampling shortly after parturition (d 10) did not increase the accuracy of predicting 210-d milk production, which was attributed to the limited capacity of the calf at this age.

Normal calf suckling behavior. Day et al. (1987) studied the relationship of milk production to calf nursing frequency and intensity. The level of milk production and stage of lactation both significantly affected suckling behavior of the calves. During early lactation, calves nursing low milk producers tended to suckle more frequently for a shorter period of time; however, on a 24-h basis they suckled more min/d than calves nursing high milk producing dams. On a daily basis, as lactation continued, the number of times calves suckled and the total min spent suckling were not related to milk production level. Thus, they concluded that if calf nursing behavior was to affect milk production, it must happen in the early stages of lactation.

Odde et al. (1985) reported normal suckling patterns showed three peak periods per d; the highest peak coincided with the onset of daylight, the next highest peak occurred around dusk, and the smallest peak occurred around noon. Calves nursed an average of 5 times/d predominantly during daylight. High milk production increased the interval between nursing as did increased calf weight. This is in agreement with Williams et al. (1979a) who found that calves nurse 3.2 to 3.5 times/d during early lactation and that most calf suckling occurred during daylight hours with major intensity immediately after daybreak and before darkness.

Effect of length of calf separation on milk yield estimates. In studies using both machine milking and weigh-suckle-weigh, shorter intervals of calf removal increased daily milk yield estimates (Totusek et al., 1973 and Belcher et al., 1980). It appears that the rate of milk production is greatest shortly after nursing or milk extraction, then becomes a linear function until the capacity of the udder cells is reached. Nonetheless, after calf removal, milk production in beef cows is normally considered to be linear for 16 h (Williams et al., 1979a).

Williams et al. (1979a) compared 4-, 8-, and 16-h separation periods to milk production yield and calf daily gain. The 8-h period was preferred over the other treatments because it: 1) reduced the amount of discomfort to the cows, 2) had smaller measurement error and a higher correlation to calf gain, 3) simulated the length of the natural interval between calf nursings and 4) reduced udder distention. Lamond (1969) used a 6-h separation interval on the premise that rate of milk production is only constant for a few h after the alveoli cells begin filling with milk. Anthony et al. (1959) recommended the use of 12-h intervals of calf removal when machine milking to standardize procedures for future research.

Factors influencing milk production. Age of dam has been shown to influence the amount of milk produced during lactation with a plateau at 5 to 10 yr of age (Boggs et al., 1980). The Beef Improvement Federation (1986) recommendations for adjustment of calf weaning weights based on the age of dam parallel the differences expected in milk production at different ages.

Breed has been shown to be a major factor in milk yield. For example, Gleddie and Berg (1968) reported that 82.5% of the variation in milk production in their trial was due to breed differences. Significant breed differences were also reported by Melton et al. (1967), Wyatt et al. (1977), Notter et al. (1978), Gaskins et al. (1980), Lawson (1981), Chenette and

Frahm (1981), Cundiff et al. (1982), Cundiff et al. (1985), McCuskey et al. (1986), McGaughey and Nelson (1986), McMorris and Wilton (1986), Clutter and Nielsen (1987), Green et al. (1988), Healy et al. (1989), and Marston et al. (1989).

Fixed effects of herd, season, and year have a definite influence on milk production of dairy cows. Approximately 40% of the variance in milk and fat yields was accounted for by these three factors and their interactions in a study by Chauhan (1987). He concluded that direct comparisons within and between herds should be limited to dams calving within a period of four mo or less to reduce variation caused by season and year.

Maternal environment and offspring milk production. Several studies have shown a negative relationship between milk production of a cow and subsequent milk production by her daughter, a phenomenon commonly referred to as "fat calf syndrome" (Koch, 1972; Gregory et al., 1978a and 1978b; Koch et al., 1985; Dearborn et al., 1987; and Green et al., 1988). Mangus and Brink (1970) noted a detrimental affect upon cow productivity resulted from higher levels of nutrition during the preweaning growth period of beef heifers and suggested that the heifer's weaning weight is a poor criterion for selections to increase cow productivity. These research trials have indicated that heifers suckling high milk producing dams have a higher percentage of body fat at weaning, some of which is deposited within the mammary glands. These fat deposits hinder subsequent production of milk. A high nutritional plane during early stages of life has been shown to be detrimental to subsequent milk production in dairy cattle (Wallace, 1953; Swanson and Spann, 1954; Hanson, 1956; and Swanson, 1957). Furthermore, Kress et al. (1988) and Reed et al. (1988) reported a decrease in milk production ($P<.05$) from the first generation to the second, which appeared to be caused by high levels of milk production. When the third generation was analyzed, milk production returned to the same level as the first generation. Therefore, they too suggested that high milk production, both in early and mid lactation can be detrimental to subsequent milk production of female offspring.

Calf influences on milk production. Numerous studies have been conducted to investigate the affect calves have on their dam's milk production. Both size (either as birth weight or weights taken at milking) and calf sex have been examined. Robison et al. (1978) reported that birth weight was associated ($P < .01$) with milk production estimates taken early in lactation but decreased in importance as lactation progressed. Furthermore, correlations between birth weight and three bi-monthly daily milk yield estimates and predicted 7-mo lactation yield were higher than the correlations between calf sex and the milk measurements ($P < .01$). In a study involving Holsteins, calf birth weight was positively correlated to dam's milk yield, butterfat, and other milk solids (Chew et al., 1981). This relationship was explained by the fact that as prenatal calf size increased the levels of blood estrogen, prolactin and placental lactogen (along with other hormones) increased, which subsequently increased prepartum mammary gland development and milk yield.

An investigation by Hohenboken et al. (1973) found that birth weight was positively correlated to total milk yield but was negatively correlated to percent butterfat. He contended that heavier calves suckled more aggressively and induced greater milk secretion. This theory was supported by Reynolds et al. (1978) who found that larger crossbred calves challenged their dams more than smaller straightbred calves.

Research by Gifford (1953), Drewry et al. (1959), Schwulst et al. (1966), Jeffery and Berg (1971), and Rutledge et al.(1971) reported a positive relationship between birth weight and milk production. However, birth weight was not always a major factor influencing milk yield since early lactation milk yields were dependent on a balance between the capacity and aggressiveness of the calf and the dam's genetic and physical potential to produce milk. Pope et al. (1963) and Christian et al. (1965) found a weak correlation between birth weight and milk yield but concluded that heavier birth weights did not increase milk production of the dam.

Mixed results have been reported on the effect of sex of calf on milk production. Rutledge et al. (1971) reported that heifer calves consumed more milk on a daily basis than their bull counterparts. Several studies, however, have shown just the opposite. Drewry et al. (1959), Gifford (1953), Cartwright and Carpenter (1961), Pope et al. (1963), and McCuskey et al. (1986) all concluded that bull calves stimulated their dams to produce higher milk yields, particularly during early lactation. Melton et al. (1967) and Daley et al. (1987) also reported that cows nursing bull calves gave more milk/d than cows nursing heifer calves during the first part of their studies. The sex difference diminished progressively during lactation, especially in late lactation as calves matured, at which time the effect became nonsignificant (Daley et al., 1987). Christian et al. (1965), Wilson et al. (1969), Reynolds et al. (1978), Chew et al. (1981), Chenette and Frahm (1981), Lawson (1981), and Goehring (1987) found sex had no affect on milk yield or the production of milk components. Jeffery et al. (1971) reported cows suckling bull calves gave more milk than cows nursing heifer calves during the first yr of the study but less the next yr.

In summary, it certainly is logical that the calf can have an affect on its dam's milk production with large calves stimulating milk production more than small calves. Since bull calves have heavier average birth weights and faster growth rates than heifer calves, bulls should stimulate their dams to produce more milk than their heifer counterparts.

Relationship between milk and calf performance. Increased milk production in beef cows has been shown to increase weaning weight of calves (Knapp and Black, 1941; Neville et al., 1960; and Wyatt et al., 1977). Weaning weight is a reflection of both the milking and mothering ability of the cow and the preweaning growth rate of the calf (Taylor, 1984). Numerous studies have shown positive correlations (.4 to .6) between milk production and calf weaning weight (Howes et al., 1958; Neville, 1962; Pope et al., 1963; Christian et al., 1965; Schwulst et al., 1966; Melton et al., 1967; Todd et al., 1968; Wilson et al., 1969; Rutledge et al., 1971; Koch, 1972; Kress and Anderson, 1974; Reynolds et al., 1978; Robison et al., 1978; Neidhardt et al., 1979; Williams et al., 1979b; McGauhey and Nelson, 1986; Clutter and Nielsen, 1987; Beal et al., 1988; and Marston et al., 1989). While Hohenboken et al., 1973; Belcher et al., 1980; and Chenette and Frahm, 1981 reported lower correlations (.09 to .20), all correlations have been positive with their magnitude partially dependent upon levels of supplemental feed available to the calves. A complete list of research trials evaluating this relationship is presented in Appendix Table 3.

Howes et al. (1958) reported that calf growth and milk yield were highly correlated through the first four mo of lactation but declined as lactation persisted. Howes and coworkers, therefore, concluded that the daily dry matter and protein supply from milk became inadequate to maintain calf growth past the second or third mo of lactation in all experimental groups. Pope et al. (1963) reported correlations much higher during early lactation, with values up to .8 prior to three mo postpartum. Neville (1962) and Melton et al. (1967) also noted that correlations between daily milk yield and calf gain declined as lactation progressed, primarily due to the increasing importance of other feed sources.

The amount and quality of forage available to calves has been shown to influence the relationship between the amount of milk and calf weight gains. Consequently, season of yr must be considered in interpreting research on this relationship, since fall-born calves typically have lower quality feed supplies (other than milk) unless a high quality creep feed is available. In addition, as milk production increases, the conversion of milk into calf weight becomes less efficient (Mallinckrodt et al., 1990). Boggs et al. (1980), using Polled Herefords, reported that a daily increase of 1 kg of milk would increase weaning weight 7.2 kg. Beal et al. (1988) determined that 13.7 kg of milk produced one kg of weaning weight in Angus and Angus cross cow-calf pairs. Neville (1962) reported ratios of 12.5 and 23.5 to one of milk to calf gain depending on cow nutritional regimes which also agrees with the findings of Wistrand and Riggs (1966) and is only slightly higher than the 11.2 to one ratio reported by Wilson et al. (1969). Williams (1979a) reported that it took 16.8 and 12.3 units of milk to produce a unit of calf weight, depending upon the year of the trial. It took more milk to produce calf weight as calf age increased which agrees with Gifford (1953), Drewry et al. (1959) and Klett et al. (1965). Research trials examining the relationship between milk and calf gain are summarized in Appendix Table 4.

It has been shown that the ratio of milk production to calf weight gains can be influenced by the technique used to estimate milk yields, the availability of other feed sources for the calf, and the maintenance requirements of the calf. The use of oxytocin and shorter periods of calf removal decreases the amount of milk necessary to produce weaning weight by increasing the estimates of milk production. Lusby et al. (1976) reported that calves suckling dams with low milk production were more efficient than calves suckling high milk producing dams.

Relationship between milk components, milk yield, and calf performance. Milk is intended by nature to be utilized specifically for the growth and development of offspring in mammalian species. Altogether, over 250 chemical components have been identified in milk; typically only fat, protein, lactose, and total solids or solids-not-fat have been measured to characterize the composition of milk (Campbell and Marshall, 1975). The average time for calves to double their weight from birth is 47 d, primarily because cow's milk averages 3.3% protein, 5.0% lactose and 4.0% fat (Campbell and Lasley, 1969). Milk is approximately 88% water, and on a dry matter basis milk has 130% TDN, 4.60 Mcal/kg of NEm, 1.00 Mcal/kg of NEg and is 25.8% crude protein (Taylor, 1984).

Percentages of milk constituents have been measured in numerous breeds of beef and dairy cattle (see Appendix Table 5). Melton et al. (1967) reported differences in the percentage of milk constituents between Angus, Charolais and Hereford as follows: butterfat, 2.68, 2.87, 2.83; and total solids 11.31, 11.73, 11.76, respectively. Not only did they find that cows 5-yr old and older gave considerably more milk than younger cows, but older cow's milk contained lower percentages of butterfat and total solids. Breed averages revealed that lower milk production was partially compensated for by higher percentages of milk components. However, Wyatt et al. (1977) reported that butterfat, total solids, and non-fat-solids concentrations were unchanged as beef cows matured from 2- to 5 yr of age. Humes and Taylor (1983) found no difference in butterfat content of milk from three breeds of Continental and Brahman cows, but did report differences in total solids in the first and last periods of their trial. Conversely McMorris and Wilton (1986) reported differences in beef breeds in composition and quantity of milk.

Melton et al. (1967) reported correlations between total calf gain and percent butterfat, solids-not-fat and total solids were near zero (-.01, .03, .01; respectively). However, total estimated yield of butterfat, solids-not-fat and total solids were significantly correlated to calf gains (.82 to .99). Similar results were shown by Totusek et al. (1973) who also found no increase in the correlation between milk yield and calf weight by substituting fat-corrected-milk for uncorrected milk. Therefore, they concluded that total production of milk (volume) was the major factor influencing calf growth and development rather than constituent concentration.

Abadia and Brinks (1972) and Hohenboken et al. (1973) reported positive correlations between milk production (240-d lactation yield), 240-d butterfat production and butterfat percentage which is somewhat different than dairy cows which have a negative correlation between total lactation yield and butterfat test. Belcher and Frahm (1979) reported that butterfat percentage and calf growth were negatively correlated, possibly because calves that were on a higher nutritional plane were less efficient than calves on lower nutritional diets.

Beal et al. (1990) reported that total quantities of protein and lactose were correlated closely with the variation in the fluid portion of the milk and were highly correlated with calf gain. Milk fat was less closely related to variation in the fluid portion of the milk, but it remained highly correlated with calf gain. Similar conclusions were observed in studies by Rutledge et al. (1971).

Healy et al. (1989) reported differences within and between Charolais and Angus cows in the amount of energy produced per unit of milk. While there was no difference in percent protein, lactose, non-fat-solids and total solids, they found significant differences in energy (kcal/kg) levels of milk caused by differences in percent butterfat.

Using eight different crosses of cows, Chenette and Frahm (1981) found that genotypic groups produced different amounts of milk, percent protein and total solids, but there were no significant differences in percent butterfat. They also reported that 2-yr-old cows produced lower amounts and lower percentages of butterfat than did 4-yr-old cows. Protein levels ranged from 2.75 to 3.44% among different crossbred groups, with total solid content rankings following protein levels. Higher correlations were realized between 24-h milk yield and daily production of butterfat, protein and total solids (.93, .98, and .96, respectively) than 24-h milk yield and percentage of milk constituents (.23, .22, and .30, respectively). They concluded that total intake of butterfat, protein, and total solids influenced calf growth and weaning weights; while percent of constituents had no influence. Cundiff et al. (1974) reported differences in percent butterfat and non-fat-solids between different crosses and straightbred British cows.

It appears that milk composition changes with the stage of lactation. Laben (1963) along with Rook and Campling (1965) found that the fat content of milk at the beginning of lactation was high (4.5%) then drifted lower to approximately 3.5% during most of lactation. Shortly before lactation terminated it increased to 4.5%. Solids-not-fat (SNF) and protein followed the same trend as butterfat. Lactose behaved differently in that it increased during the first wk of lactation and remained at nearly 5.0% until very late in lactation. The concentration of all major milk constituents tended to decrease from the second to the fifth lactation. This last conclusion was substantiated by Barta et al. (1969) and Spike and Freeman (1967) when they concluded that older cows gave more total milk but of lower quality.

Canadian work by Lawson (1981) reported increases in the percentage of butterfat, protein and solids-not-fat as lactation persisted thus increasing total energy/kg of milk near the end of lactation. He further stated that age of dam had no affect on the percentage of milk constituents but did influence total milk produced. Franke et al. (1983) also reported that milk component concentrations changed as lactation persisted. They noted that percent protein increased (2.6 to 3.2%); while solids-non-fat and total solids decreased (13 to 7.5% and 20 to 13%, respectively) from d 50 to 200 of lactation. Percent butterfat decreased in three and four breed rotation cows, increased in two breed rotation cows, and remained the same in straightbred cows. Cundiff et al. (1974) reported a slight increase in percent butterfat and non-fat-solids from wk six of location to d 200.

Beal et al. (1990) used machine milking on Angus and Angus X Holstein crossbred cows to obtain milk samples for analysis of milk components. They reported that the levels of fat, lactose, and protein, and solids-not-fat declined as lactation persisted. Average milk composition was reported as 4.1 ± .07% fat, 8.8 ± .04% solids-not-fat, 4.7 ± .03% lactose and 3.32 ± .02% protein. Taylor and Humes (1983) reported, that as lactation persisted, differences between breeds in butterfat percent decreased, protein differences remained the same, and solids-non-fat differences showed little variation.

Somatic cell count (indicating the presence of mastitis) has been studied for its effect on milk production and subsequent calf growth. Mollett and Leighton (1987) and Mollett et al. (1988) reported that increased values had a negative relationship with the percentage of lactose in the milk while the protein percentage did not vary with cell count. The inverse relationship of the Total California Mastitis Test (a standard mastitis test) score for the dam and calf weaning weight indicates that lower than expected weaning weights could be caused by subclinical mastitis. Mollett et al. (1988) concluded that the relationship between mastitis and somatic cell count was linear and associated with *Staphylococcus*, *Micrococcus*, *Corynebacterium*, *Bacillus*, and *Pseudomonas* from the mammary gland. Furthermore, sex of calf influenced the magnitude of the inverse relationship of mastitis and calf weaning weight. In another study, Daley et al. (1987) reported mastitis in beef cows did not affect daily milk production; but increased the percent butterfat and protein while decreasing the percent lactose.

Diet of the cow has been shown to affect the composition of milk. Bowden (1981) reported that increasing protein in the cow ration produced milk with higher contents of protein and ash. However, the level of protein in the diet did not affect the levels of butterfat or total solids in milk produced throughout the lactation. Lamond et al. (1969) reported no difference in the percentage of any milk components when comparing cows fed different quality forages. Restricting the diet immediately before milking had no effect on the percent of milk components but did slightly reduce the amount of milk in a study by Munford et al. (1964).

Milk energy. The milk production of cows can be quantified by expressing the output in terms of gross energy. This takes into consideration not only the volume of fluid milk but also the percentage of milk components. The gross energy (or heat of combustion) value represents the most common basis to which the energy content of all organic substances can be reduced.

Using an array of milk samples that differed in percentage of milk constituents, Tyrrell and Reid (1965) developed a formula to estimate the gross energy of milk. They found that fat and total solids had the highest correlation to gross energy (.93 and .96, respectively). The most applicable equation for the accurate prediction of energy in milk samples having a wide range of chemical composition was:

$$\text{Energy (kcal/lb)} = 41.48 \times (\%\text{Fat}) + 22.29 \times (\%\text{SNF}) - 25.58.$$

$$\text{(conversion to kj/kg)} = 386 \times (\%\text{Fat}) + 206 \times (\%\text{SNF}) - 236.$$

From this equation it was determined that solid-corrected milk contained 748 kcal/kg.

Lamond et al. (1969) used the formula:

$$\text{Energy (kcal)} = \text{fat} \times 9 + \text{milk} \times (\text{SNF\%} - .07\%) \times 4.$$

The energy content of fat was assumed to be 2.25 times that of SNF, with fat and milk weighed in g. The mean energy content (kcal) using this formula was closely related to total milk yield. Marston et al. (1989) used gross energy values reported by Atwater and Bryant (1899) and a lactation curve equation by Jenkins and Ferrell (1984) to determine the milk energy produced during lactation.

Crovetto and van der Honing (1984) found that the equation of Tyrrell and Reid overestimated the energy content of milk which contained a high percent of butterfat and underestimated the energy content of milk that contained 3 to 4% butterfat. Therefore, using milk samples from Jersey and Holstein cows (that varied from 1.96 to 11.01% butterfat), they derived the following equation that was more accurate for butterfat levels less than 6.4%: Energy (kj/kg) = 458 × (% Fat) + 1222. They reported a high correlation (r = .994) between the content of fat and the energy of milk.

Alvarez et al. (1985) developed an equation to predict the energy in ewe's milk. They determined that total solids was the most accurate single predictor of milk energy and developed the equation: Energy (Mcal/kg) = .0915 × (% Total Solids) - .5391. This, however did not give as precise an estimate of milk energy as: Energy (Mcal/kg) = .0202 × (%Fat) + .0721 × (%Total Solid) - .3236.

Relationship between phenotypic traits and milk production. Hohenboken et al. (1973) using Hereford cows reported that early size (measurements taken from 8 to 15 mo of age) was not associated with milk production (both 240-d fluid and 240-d butterfat yield); however, weight gain of the cow during lactation and milk production were antagonistic. Beal et al. (1990) also indicated that high producing cows tended to lose more weight (or to gain less weight) than lower producing cows. However, McGinty and Frerichs (1971) noted that cow weight loss was not related to milk production in their study. Changes in cow body weight can be monitored by changes in body condition score. Dunn et al. (1983) and Wagner (1984) showed that body condition score accurately predicts body fat (the principle tissue in cow weight changes). Whitman (1975) and Richards et al. (1986) found that changes in body condition score affect reproductive efficiency and calf weaning weight.

Williams et al. (1979b) studied height (wither and hip), weight, ratios of weight to height, body condition score and calf average daily gain as related to milk production. Measurements of physical traits were highly repeatable, but none of them were useful in estimating or predicting lactation yields with the exception of calf daily gain, which was only slightly effective. A negative, nonsignificant relationship was reported between height at the withers and 240-d total milk yields by Christian et al. (1965). No significant correlations between cow measurements and milk production were found by Pope et al (1963).

Cole and Johansson (1933) used body measurements along with live weights to arrive at a dimension index. Drawing from a small but random sample of the Angus breed, different body types were chosen for the experiment. The "longest-bodied, highest-legged" cow was the highest milk producing cow, while the poorest milking cow was rather "blocky" (as indicated by her dimension-weight index). The correlation between body type and production was not as obvious in the intermediate milkers. They concluded no correlation existed between phenotype and milk production, which was later confirmed by Jeffery et al. (1971). Wilson et al. (1969) indicated cow size did not affect milk production, even though larger cows tended to produce less total milk and total milk energy. Rutledge et al. (1971) also reported that heavier dams produced more milk, although they dismissed it as of minor importance.

Irgang et al. (1985) found that selecting for birth weight, weaning weight or yearling weight caused little change in milk production but noticeable change in calf growth rate and size. Measures of feed efficiency early in the heifer's life were not closely related to her subsequent lactation efficiency in a study by Hohenboken et al. (1973). Jeffery et al. (1971) implied that the fastest way to increase milk yield was to introduce breeds known for high milk production and select calves with the highest daily gain from birth to weaning. If calf weights are to be used to select for milk production, Pope et al. (1963) suggested selecting calves with high early weight gains, since the correlation of milk yield and calf gain decreases with age of the calf.

Positive correlations have been found between udder size and milk production in dairy cows by White and Vinson (1975) and in beef cows by Doornbos et al. (1981). White and Vinson (1975) also found that all direct udder measurements (udder size) were positively correlated with daily milk yield ($P < .01$). However, none of the correlations were high enough to be useful as phenotypic predictors of milk yield, and udder conformation scores were unrelated to udder measurements. Rundle and DeNise (1986) assigned udder capacity scores to cows at 2 mo postpartum. Udder scores were positively associated with increased weaning weights, but udder score was not correlated with milk production. DeNise et al. (1987) reported that subjective udder capacity scores or udder shape scores, assigned at 70 to 80 d postpartum in Hereford cows, were poor indicators of calf weights at either time of scoring or at weaning. There was no relationship between udder capacity and the incidence of udder defects; however, cows with unbalanced udders (shapes) had more udder defects.

Relationship between expected progeny differences to milk production and maternal traits. Expected progeny differences (EPDs) can be simply defined as one half of an animal's breeding value, with breeding value being the genetic value of an individual as a parent (Buchanan and Clutter, 1988). One half of the breeding value is used because each parent contributes one half of the offspring's genetic makeup; therefore, an individual's genetic worth can be expressed as the sum of the additive genetic contribution from both of its parents along with Mendelian sampling effect (Wilson and Willham, 1988). Mendelian sampling effect is the reason that even full-sibs can be considerably different. With this in mind, an interim EPD for individuals can be calculated by adding one half EPD of the sire to one half EPD of the dam and taking into account one half of the Mendelian sampling effect.

Expected progeny differences, as calculated for the breed associations, are one half the breeding value of the individual derived by using the Best Linear Unbiased Predictor (BLUP) procedure (Benyshek et al., 1988). The performance record of the individual along with performance records of its relatives are used to determine the breeding value. Adjustments and corrections for environmental effects must be made to calculate an accurate breeding value. The records of relatives are essential for determination of the breeding values for traits that cannot be observed in the individual (such as milk production in males) and traits that are lowly heritable (Henderson and Quass, 1976). Information available from progeny, relatives, mates, the individual, and Wright's numerator relationship matrix (which helps account for genetic trends) is incorporated into BLUP equations, allowing animals to be compared within each breed (Benyshek, 1987).

Milk production is the maternal trait of primary importance because it is positively correlated to calf weaning weight. Since milk production is not directly measured in beef cattle, weaning weights must be used to determine milking ability. Weaning weight, however, is influenced by both direct and maternal components. These components are: the growth genes received from the parent (sire and dam) and the milking ability of the dam. The milking ability of cows is the combined result of the dam's genes for maternal ability, her permanent maternal environmental effect determined by the environment in which she was raised and the temporary environment in which she expresses that ability (Bruckner and Slanger, 1986a).

Benyshek et al. (1988) noted that when using multiple-trait Reduced Animal Models to generate breeding values (or EPDs), using the relationship between two or more traits will enhance the accuracy of the prediction. Consequently, this technique is used to increase the accuracy of milk EPDs.

Since weaning weights of offspring are used to predict maternal genetic value, weaning weight can be described as

$y_{ijk} = h_i + d_j + m_k + e_{ijk}$,

where h_i is the mean for the herd-year i, d_j is the direct additive genetic value of individual j, m_k is the maternal additive genetic value of individual k influencing her offspring j's weaning weight y_{ijk}. Maternal breeding values are based on field data and calculated by using the average weaning weight ratios of calves of the daughters of the sires in the pedigree (Willham, 1979).

Milk or maternal EPDs are reported by many breed associations and defined as the milking ability of an individual's daughters measured in lb of calf weaned. They are expressed in units of calf weaning weight (American Shorthorn Association, 1988; American Polled Hereford Association, 1989; American Angus Association, 1990; and the American Simmental Association, 1990). Even though EPDs can be compared only within breeds, their usage has become wide spread in the beef industry.

An individual milk EPD is computed using the following formula:

Milking Ability Breeding Value =

Regression Coefficient × [Cow's calves' weaning records - contemporary group effect - calves' growth breeding value - permanent environmental effect of the cow]

+

Regression Coefficient × [Sum of the milk breeding values for relatives of the individual]

-

Regression Coefficient × ½[Sum of the milk breeding values for mates of the individual]

+

[Adjustment for the relationship between growth and milking ability]. (Benyshek, 1988).

For females, the first part of the equation adjusts the records of her calves to reflect her milk production. Contemporary group effect is removed from the record by fitting fixed effects in the model. This should eliminate any environmental factors that could influence the comparison with other calves' records in a specific contemporary group. The calves' growth breeding values are subtracted which removes the effect of the calves' natural ability to grow. The remainder of the weaning weight reflects the milking ability of the cow regardless of the genetic potential for growth the calf possesses. The last step is used to adjust for the cow's genetic milking ability, having the permanent environmental effect subtracted from the record.

Regression coefficients are used to adjust for the heritability of the trait and the relationships between pieces of information. The second part of the equation is used to bring all known pedigree information into the computation. The third part of the equation adjusts for mates of the individual removing any bias caused by non-random mating. The final component adjusts for any genetic relationship between growth and milking ability (Benyshek, 1988). Milk EPDs for sires are computed in the same manner except the first part of the equation is omitted.

A negative correlation has been found between direct and maternal genetic effects by Bertrand and Benyshek (1987), Bruckner and Slanger (1986b) and Quass et al. (1985). However Koch (1972) and Skaar (1985) reported that correlations are near zero or slightly positive. The genetic correlation between maternal milk and weaning weight used to calculate milk EPDs for Simmentals is -.32 (American Simmental Association, 1990). However, at the present time zero is used for the genetic correlation in Angus (Benyshek, personnel communication). This is unusual because most breeds calculating EPDs use a negative correlation.

Limited reports are available on the use of EPDs for predicting maternal characteristics. A review of the trials reported indicates that the response of weaning weight to selection for milk EPD has shown EPDs to be conservative in representing genetic differences. For example, greater weaning weights were realized by Mallinckrodt et al. (1990) using Polled Hereford and Simmental cow-calf pairs than were expected. Mahrt et al. (1987) reported that maternal EPDs and yearling EPDs can be used to influence calf weights. Marshall and Freking (1988) noted that crossbred daughters out of high milk EPD bulls produced more milk than daughters out of low milk EPD bulls. In addition, weaning weight differences in their calves were greater than predicted which indicates that EPDs are conservative in predicting differences in calf weaning weight.

Milk or maternal EPDs were correlated to dam milk production and calf weaning weights for Angus and Simmental in a study by Marston et. al., (1989). Both fluid milk and milk energy production were moderately correlated to the milk EPDs of the dams. The correlations between milk production and milk EPDs were higher than between calf weaning weight and milk EPDs (.41 and .55 vs. .30 and .47, respectively) for spring calving Angus and Simmental cows. Diaz et al. (1990) using Polled Hereford X Angus cows reported that milk EPDs were positively associated ($P < .01$) with milk production, with each kg increase in milk EPD of the sire producing an increase of $.176 \pm .066$ kg in 24-h milk production. Thus, the few studies which have evaluated the relationship between milk production and milk EPDs indicate that they are at least positively correlated.

Relationship between milk production and reproduction. Limited research has been reported involving milk production and its effect on reproductive performance. Whitman (1975) found that suckled cows had longer intervals to estrus than those cows that did not raise a calf. However, this result could be due to the stimulation of nursing and companionship of the calf and not actual milk production. Goehring (1987) found that milk production did not effect the time to first estrus with first calf heifers unless daily milk yields were over 5.6 kg at 60 d postpartum. In addition, calving difficulty and condition score influenced the level of milk production which could be detrimental to subsequent reproductive performance. Wiltbank and Cook (1958) stated that level of milk production was not related to reproductive efficiency (-0.06; nonsignificant) of multiparous cows, but was correlated in primiparous cows.

The period of time from parturition to first ovulation is probably extended due to the negative energy state caused by the onset of lactation. Milk production is negatively related to the length of this period only when it is great enough to cause an energy imbalance (Bulter et al., 1981). These findings could explain the "threshold" of milk production in Goehring's study in which high milk production extended first ovulation.

LITERATURE CITED

Abadia, D. and J. S. Brinks. 1972. Milk production of Hereford heifers. J. Anim. Sci. 34:886(Abstr.).

Alvarez, P. J., F. J. Ovejero and J. A. Guada. 1985. Estimacion del contenido energetico de la leche de oveja a partir de los datos de su composicion. Anales del Instituto Nacional de Investigaciones Agrarias. Series Ganadera. 22:39.

American Angus Association. 1990. 1990 Spring American Angus Association Sire Evaluation Report. Angus Publications, Inc. St. Joseph, MO.(Suppl.).

American Polled Hereford Association. 1989. 1989 Polled Hereford Sire Summary. Kansas City, MO.

American Simmental Association. 1990. Sire Summary. Bozeman, MT.

American Shorthorn Association. 1988. 1988 Shorthorn Sire Summary. Omaha, NE.

Anthony, W.B., P. F. Parks, E. L. Mayton, L. V. Brown, J. G. Starling and T. B. Patterson. 1959. A new technique for securing milk production data for beef cows nursing in nutritional studies. J. Anim. Sci. 18:1541(Abstr.).

Barta, T. R., H. W. Norton and R. W. Touchberry. 1969. Genetic study of milk constituents in purebred and crossbred dairy cattle. J. Anim. Sci. 29:671.

Beal, W. E., R. M. Akers and D. R. Notter. 1988. Milk production in beef cows: methods of measurement and relationship to cow and calf performance. J. Anim. Sci. 66(Suppl. 1):454(Abstr.).

Beal, W. E., D. R. Notter and R. M. Akers. 1990. Techniques for estimation of milk yield in beef cows and relationships of milk yield to calf weight gain and postpartum reproduction. J. Anim. Sci. 68:937.

Beef Improvement Federation. 1986. Guidelines for Uniform Beef Programs. (5th Ed.) Beef Improvement Federation, North Carolina State Univ., Raleigh.

Bertrand, J. K. and L. L. Benyshek. 1987. Variance and covariance estimates for maternally influenced beef growth traits. J. Anim. Sci. 64:728.

Belcher, C. G. and R. R. Frahm. 1979. Productivity of two-year-old crossbred cows producing three-breed cross calves. J. Anim. Sci. 49:1195.

Belcher, C. G., R. R. Frahm, D. R. Belcher and E. N. Bennett. 1980. Comparison of machine milkout and calf nursing techniques for estimating milk yields of various two-breed cross range cows. Okla. Agric. Exp. Sta. The Station. p.6.

Benyshek, L. 1987. Reduced animal model predictions and back solutions--an overview of currently used methodology for genetic prediction. In: Frank H. Baker (Ed.) Prediction of Genetic Values for Beef Cattle: Proc. of Workshop II. March 10-11, 1987, Kansas City, MO. Winrock International, Morrilton, AR.

Benyshek, L. L. 1988. Performance programs: What we know about cattle today. Proc. Nat. Beef Cattle Conf. 1988 Blueprint for the Right Kind. May 24-25. Oklahoma State Univ., Stillwater.

Benyshek, L. L., M. H. Johnson, D. E. Little, J. K. Bertrand and L. A. Kriese. 1988. Applications of an animal model in the United States beef cattle industry. J. Dairy Sci. 71(Suppl. 2):35.

Boggs, D. L., E. F. Smith, R. R. Schalles, B. E. Brent, L. R. Corah and R. J. Pruitt. 1980. Effects of milk and forage intake on calf performance. J. Anim. Sci. 51:550.

Bowden, D. M. 1981. Feed utilization of calf production in the lactation by two-year-old F_1 crossbred beef cows. J. Anim. Sci. 51:304.

Bruckner, C. M. and W. D. Slanger. 1986a. Symmetric differences squared and analysis of variance procedures for estimating genetic and environmental variances and covariances for beef cattle weaning weight: I. Comparison via simulation. J. Anim. Sci. 63:1779.

Bruckner, C. M. and W. D. Slanger. 1986b. Symmetric differences squared and analysis of variance procedures for estimating genetic and environmental variances and covariances for beef cattle weaning weight: II. Estimates from a data set. J. Anim. Sci. 63:1794.

Buchanan, D. S. and A. C. Clutter. 1988. Beef cattle improvement. Animal Breeding: Principles of Applications (2nd Ed.) Chapter M.

Butler, W. R., R. W. Everett and C. E. Coppock. 1981. The relationships between energy balance, milk production and ovulation in postpartum Holstein cows. J. Anim. Sci. 53:742.

Campbell, J. R. and J. F. Lasley. 1969. The Science of Animals That Serve Mankind. McGraw-Hill Book Co., New York.

Campbell, J. R. and R. T. Marshall. 1975. The Science of Providing Milk for Man. McGraw-Hill, Inc. St. Louis, MO. p.2.

Cartwright, T. C. and J. A. Carpenter, Jr. 1961. Effect of nursing habits on calf weights. J. Anim. Sci. 20:904(Abstr.).

Casebolt, D., D. Kress, D. Anderson and D. Doornbos. 1983. Lactation curves for different breed groups of beef cattle. Res. Rep. Mont. Agric. Exp. Sta. (213):p47. Montana State Univ, Bozeman.

Chauhan, V. P. S. 1987. Partitioning of herd, year and season variation in milk production. Livest. Prod. Sci. 16:107.

Chenette, C. G. and R. R. Frahm. 1981. Yield and composition of milk from various two-breed cross cows. J. Anim. Sci. 52:483.

Chew, B. P., L. C. Maier, J. K. Hillers and A. S. Hodgson. 1981. Relationship between calf birth weight and dam's subsequent 200- and 305-day yields of milk, fat, and total solids in Holsteins. J. Dairy Sci. 64:2401.

Christian, L. L., E. R. Hauser and A. B. Chapman. 1965. Association of preweaning and postweaning traits with weaning weight in cattle. J. Anim. Sci. 24:652.

Clutter, A. C. and M. K. Nielsen. 1987. Effect of level of beef cow milk production on pre- and postweaning calf growth. J. Anim. Sci. 64:1313.

Cobby, J. M. and Y. L. P. LeDu. 1978. On fitting curves to lactation data. Anim. Prod. 28:127.

Cole, L. J. and I. Johansson. 1933. The yield and composition of milk from Aberdeen-Angus cows. J. Dairy Sci. 16:665.

Cranwell, C. C., G. E. Nelms, H. D. Radloff, M. L. Riley, W. C. Russell, D. L. Hixon and D. W. Moore. 1987. Performance of beef calves from dams of different genotypes. Proc. West. Sec. Am. Soc. Anim. Sci. 38:11.

Crovetto, G. M. and Y. van der Honing. 1984. Prediction of the energy of milk from Frisian and Jersey cows with normal and high fat concentration. Zeitschrift fur Tierphysiologie, Tierernahrung und Futtermittelkunde. 51:88.

Cundiff, L. V., K. E. Gregory and R. M. Koch. 1982. Cattle Germ Plasma Evaluation Program. Progress Rep. no. 10. U. S. Meat Anim. Res. Center. ARM-NC-24, pp1-11.

Cundiff, L. V., K. E. Gregory and R. M. Koch. 1985. Characterization of beef breeds representing diverse biological types: reproductive and maternal performance of F_1 cows. Beef Res. Progress Rep. no. 2. U. S. Meat Anim. Res. Center. Agric. Res. Service. ARS-42, pp6-9.

Cundiff, L. V., K. E. Gregory, F. J. Schwulst and R. M. Koch. 1974. Effects of heterosis on maternal performance and milk production in Hereford, Angus and Shorthorn cattle. J. Anim. Sci. 38:728.

Daley, D. R., A. McCuskey and C. M. Bailey. 1987. Composition and yield of milk from beef-type *Bos taurus* and *Bos indicus* × *Bos taurus* dams. J. Anim. Sci. 64:373.

Dawson, W. M., A. C. Cook and Bradford Knapp, Jr. 1960. Milk production of beef Shorthorn cows. J. Animal Sci. 19:502.

Day, M. L., K. Imakawa, A. C. Clutter, P. L. Wolfe, D. D. Zalesky, M. K. Nielsen and J. E. Kinder. 1987. Suckling behavior of calves with dams varying in milk production. J. Anim. Sci. 65:1207.

Dearborn,D. D., K. E. Gregory, L. V. Cundiff and R. M. Koch. 1987. Maternal heterosis and grandmaternal effects in beef cattle: preweaning traits. J. Anim. Sci. 65:33.

DeNise, R. S. Kersey, D. E. Ray, A. M. Lane, V. L. Rundle and M. Torabi. 1987. Relationships among udder shape, udder capacity, cow longevity and calf weights. J. Anim. Sci. 65:366.

Diaz, C. J., D. R. Notter and W. E. Beal. 1990. Is milk EPD a good predictor of actual milk production in Polled Hereford × Angus crossbred cows? J. Anim. Sci.68(Suppl. 1):23(Abstr.).

Doornbos, D. E., D. C. Anderson and D. D. Kress. 1981. Milk production, udder size and calf growth in beef cattle. Proc. West. Sec. Amer. Soc. Anim. Sci. 32:317.

Drewry, K. J., C. J. Brown and R. S. Honea. 1959. Relationships among factors associated with mothering ability in beef cattle. J. Anim. Sci. 18:938.

Dunn, T. G., M. L. Riley, W. J. Murdock and R. A. Field. 1983. Body condition and carcass energy content in postpartum beef cows. J. Anim. Sci. 57(Suppl. 1):341(Abstr.).

Franke, D. E., S. E. Martin, T. O. McRae. 1983. Beef cow milk yield, milk composition and calf growth. Louisiana Agric. Exp. Sta. Livest. Producer's Day Rep. 24:pp74-79. Louisiana State Univ., Baton Rouge.

Fuller, Wayne A.. 1969. Grafted polynomials as approximating functions. Australian J. Agric. Econ. 13:35.

Furr, R. D. and A. B. Nelson. 1964. Effect of level of supplemental winter feed on calf weight and on milk production of fall-calving range beef cows. J. Anim. Sci. 23:775.

Gaskins, C. T. and D. C. Anderson. 1980. Comparison of lactation curves in Angus-Hereford, Jersey-Angus and Simmental-Angus cows. J. Anim. Sci. 50:828.

Gifford. W. 1949. Importance of high milk production in beef cows over estimated. J. Anim. Sci. 8:605(Abstr.).

Gifford, W. 1953. Records-of-performance tests for beef cattle in breeding herds, milk production: milk production of dams and growth of calves. Ark. Agric. Exp. Sta. Bul. 531.

Gleddie, V. M. and R. T. Berg. 1968. Milk production in range beef cows and its relationship to calf gains. Can. J. Anim. Sci. 48:323.

Goehring, T. B. 1987. Effects of Energy and Lasalocid on Productivity of Primiparous Beef Cows. Ph.D. Dissertation. Kansas State Univ., Manhattan.

Green, R. D., L. V. Cundiff and G. E. Dickerson. 1988. Estimates of lactation yield in four beef breed crosses. J. Anim. Sci. 66(Suppl. 1):106(Abstr.).

Gregory, K. E., L. V. Cundiff, R. M. Koch, D. B. Laster and G. M. Smith. 1978a. Heterosis and breed maternal and transmitted effects in beef cattle. I. Preweaning traits. J. Anim. Sci. 47:1031.

Gregory, K. E., D. B. Laster, L. V. Cundiff, R. M. Koch and G. M. Smith. 1978b. Heterosis and breed maternal and transmitted effects in beef cattle. II. Growth rate and puberty in females. J. Anim. Sci. 47:1042.

Hanson, A. 1956. Influence of rearing intensity on body development and milk production. Proc. British Soc. Anim. Prod. 51.

Hardt, P. F., L. W. Greene and J. F. Baker. 1988. Machine milking versus weigh-suckle-weigh estimates of milk production in beef cows of three breed types. J. Anim. Sci. 66 (Suppl. 1):437(Abstr.).

Healy, T. L., M. E. Boyd, C. E. Cantrell and J. E. Tomlinson. 1989. Milk yield, composition and energy in Angus and Charolais cows. J. Anim. Sci. 67(Suppl. 2):12(Abstr).

Henderson, C. R. and R. L. Quass. 1976. Multiple trait evaluation using relatives' records. J. Anim. Sci. 43:1188.

Henry, M. J. and M. E. Benson. 1990. A comparison of weigh-suckle-weigh and machine milking methods for estimating milk production in ewe lambs. J. Anim. Sci. 68(Suppl. 1):137. (Abstr.).

Hohenboken, W. D., E. R. Hauser, A. B. Chapman and L. V. Cundiff. 1973. Phenotypic correlations between dam traits expressed during development and lactation and traits of progeny in cattle. J. Anim. Sci. 37:1.

Holloway, J. W. and T. L. Worley. 1983. Pattern of milk intake as related to weaning traits of Angus calves grazing fescue-legume or fescue pastures. Livest. Prod. Sci. 10:351.

Howes, J. R., J. F. Hentges, A. C. Warnick and T. J. Cunha. 1958. Yield and composition of milk from Brahman and Hereford heifers fed two levels of protein, and the correlated calf growth. J. Anim. Sci. 17:1222.

Humes, P. E. and H. E. Taylor. 1983. Yield and composition of milk from Brahman and continental sired crossbred cows. J. Anim. Sci. 57(Suppl. 1):152(Abstr.).

Irgang, R., E. U. Dillard, M. W. Tess and O. W. Robison. 1985. Selection for weaning weight and postweaning gain in Hereford cattle. III. Correlated responses to selection in milk yield, preweaning and postweaning traits. J. Anim. Sci. 60:1156.

Jeffery, H. B. and R. T. Berg. 1971. Evaluation of milk variables as measures of milk effect on preweaning performance of beef cattle. Can J. Anim. Sci. 51:551.

Jeffery, H. B., R. T. Berg and R. T. Hardin. 1971. Factors influencing milk yield of beef cattle. Can. J. Anim. Sci. 51:551.

Jenkins, T. G. and C. L. Ferrell. 1984. A note on lactation curves of crossbred cows. Anim. Prod. 39:479.

Klett, R. H., T. R. Mason and J. K. Riggs. 1965. Milk production of beef cows and its relationship to weaning weight of their calves. J. Anim. Sci. 24:586(Abstr.).

Knapp, B., Jr. and W. H. Black. 1941. Factors influencing rate of gain of beef calves during the suckling period. J. Agric. Res. 63:249.

Koch, R. M. 1972. The role of maternal effects in animal breeding: VI. Maternal effects in beef cattle. J. Anim. Sci. 35:1316.

Koch, R. M., G. E. Dickerson, L. V. Cundiff and K. E. Gregory. 1985. Heterosis retained in advanced generations of crosses among Angus and Hereford cattle. J. Anim. Sci. 60:1117.

Kress, D. D. and D. C. Anderson. 1974. Milk production in Hereford cattle. J. Anim. Sci. 38:1320(Abstr.).

Kress, D. D., D. E. Doornbos and D. C. Anderson. 1988. Effect of dam milk production on daughter and granddaughter maternal ability. J. Anim. Sci. 66(Suppl. 1):174(Abstr.).

Laben, R. C. 1963. Factors responsible for variation in milk composition. J. Dairy Sci. 46:1293.

Lam, C. F., D. R. Lamond, J. R. Hill, Jr. and C. B. Loadholt. 1970. Three methods for estimating milk production of beef cows. South Carolina Agric. Exp. Sta. Techn. Bull. 1036. Clemson Univ., Clemson.

Lamond, D. R., J. H. G. Holmes and K. P. Haylock. 1969. Estimation of yield and composition of milk produced by grazing beef cows. J. Anim. Sci. 29:606.

Lawson, J. E. 1981. Milk production and weight of cows of the Hereford and Highland breeds and their reciprocal crosses. Can. J. Anim. Sci. 61:861.

Lusby, K. S., D. F. Stephens and R. Totusek. 1976. Effects of milk intake by nursing calves on forage intake on range and creep intake and digestibility in drylots. J. Anim. Sci. 43:1066.

Mahrt, G. S., D. R. Notter, W. E. Beal and W. H. McClure. 1987. Effects of sire breeding value on growth of Polled Hereford × Angus calves. J. Anim. Sci. 65(Suppl. 1):190(Abstr.).

Mallinckrodt, C. H., R. M. Bourdon, R. R. Schalles and K. G. Odde. 1990. Relationship of milk expected progeny differences to actual milk production and calf weaning weight. 1990 Beef Program Rep. pp33-37. Colorado State Univ., Fort Collins.

Mangus, W. L. and J. S. Brinks. 1970. Relationship between direct and maternal effects on growth in Herefords: I. environmental factors during preweaning growth. J. Anim. Sci. 32:17.

Marshall, D. M. and B. A. Freking. 1988. Relationship of sire and expected progeny differences to maternal performance of first-calf daughters in a commercial herd. SDSU Beef Rep.88-19. pp 73-76. South Dakota State Univ., Brookings.

Marston, T. T., D. D. Simms, R. R. Schalles, L. S. Clarke and K. O. Zoellner. 1989. Relationship of milk expected progeny differences to total milk production and calf weaning weight. J. Anim. Sci. 67:(Suppl. 1):466(Abstr.).

McCarter, M. N., R. R. Frahm, E. D. Tinker, J. W. Castree, and S. W. Coleman. 1987. Milk production of crossbred cows with 0, ¼ and ½ Brahman breeding in spring and fall calving systems. Agric. Exp. Sta. Res. Rep. MP-119. pp1-5. Oklahoma State Univ., Stillwater.

McCuskey, A., D. R. Daley and C. M. Bailey. 1986. Milk yield of beef-type *Bos taurus* and *Bos indicus* × *Bos taurus* dams. J. Anim. Sci. 63(Suppl. 1):177(Abstr.).

McGaughey, A. M. and L. A. Nelson. 1986. First-lactation milk yields of Angus, Hereford and Simmental purebred and crossbred cows. J. Anim. Sci. 63(Suppl. 1):178(Abstr.).

McGinty, D. D. and W. G. Frerichs. 1971. Milk yields and calf performance from crossbred and Hereford cows. J. Anim. Sci. 33:210(Abstr.).

McMorris, M. R. and J. W. Wilton. 1986. Breeding system, cow weight and milk yield effects on various biological variables in beef production. J. Anim. Sci. 63:1361.

Melton, A. A., J. K. Riggs, L. A. Nelson and T. C. Cartwright. 1967. Milk production, composition and calf gain of Angus, Charolais and Hereford cows. J. Anim. Sci. 26:804.

Mollett, T. A., C. B. Brooks and E. A. Leighton. 1988. Milk quality, composition and isolation of microorganisms from the mammary gland of the dam associated with reduced calf weaning weight in beef cattle. J. Anim. Sci.(Suppl. 1):448(Abstr.).

Mollett, T. A. and E. A. Leighton. 1987. Relationship among total CMT score of dam, milk composition and calf weaning weight in beef cattle. J. Anim. Sci. 65(Suppl. 1):437(Abstr.).

Munford, R. E., I. L. Campbell, F. H McDowall and A. W. F. Davey. 1964. The effect of restricted grazing during a single day upon milk yield, milk composition and butterfat characteristics. J. Dairy Res. 31:59.

Neidhardt, R., D. Plasse, J. H. Weniger, O. Verde, J. Beltran and A. Benavides. 1979. Milk yield of Brahman cows in a tropical beef production system. J. Anim. Sci. 48:1.

Neville, W. E., Jr., D. M. Baird and O. E. Sell. 1960. Influence of sire, dam's milk production, three levels of nutrition and other factors on 120- and 240-day weight of Hereford Calves. J. Anim. Sci. 19:1223(Abstr.).

Neville, W. E., Jr. 1962. Influence of dam's milk production and other factors in 120- and 240-day weight of Hereford calves. J. Anim. Sci. 21:315.

Notter, D. R., L. V. Cundiff, G. M. Smith, D. B. Laster and K. E. Gregory. 1978. Characterization of biological types of cattle VII. Milk production in young cows and transmitted and maternal effects on preweaning growth of progeny. J. Anim. Sci. 46:908.

Odde, K. G., G. H. Kiracofe and R. R. Schalles. 1985. Suckling behavior in range beef calves. J. Anim. Sci. 61:607.

Pope, L. S., L. Smithson, D. F. Stephens, D. O. Pinney and M. Velasco. 1963. Factors affecting milk production of range beef cows. Oklahoma Agric. Exp. Sta. Misc. Pub. 70:69. Oklahoma State Univ., Stillwater.

Quass, R. L., M. A. Dizo and E. J. Pollack. 1985. Analysis of Simmental data: estimation of direct and maternal (co)variances. J. Anim. Sci. 61(Suppl. 1):221(Abstr.).

Reed, W. A., D. D. Kress, D. E. Doornbos and D. C. Anderson. 1988. Effect of dam milk production on daughter and granddaughter maternal ability. J. Anim. Sci. 66(Suppl. 1):174(Abstr.).

Reynolds, W. L., T. M. Derouen and R. A. Bellows. 1978. Relationships of milk yield of dam to early growth rate of straightbred and crossbred calves. J. Anim. Sci. 47:584.

Richards, M. W., J. C. Spitzer and M. B. Warner. 1986. Effects of varying levels of postpartum nutrition and body condition at calving on subsequent reproductive performance in beef cattle. J. Anim. Sci. 62:300.

Ritchie, H. D. 1982. Future direction of the U.S. beef industry. Proc. National Assc. of Anim. Breeders Conf. Jan. 16, 1982. Denver, CO.

Robison, O. W., M. K. M. Yusuff and E. U. Dillard. 1978. Milk production in Hereford cows. I. Means and correlations. J. Anim. Sci. 47:131.

Rook, J. A. F. and R. C. Campling. 1965. Effect of stage and number of lactations on the yield and composition of cow's milk. J. Dairy Res. 32:45.

Rowlands, G. J., S. Lucey and A. M. Russel. 1982. A comparison of different models of the lactation curve in dairy cattle. Anim. Prod. 35:135.

Rundle, V. L. and S. K. DeNise. 1986. Effects of range cow udder capacity and shape on calf weights. J. Anim. Sci. 63(Suppl. 1):186(Abstr.).

Rutledge, J. J., O. W. Robison, W. T. Ahlschwede and J. E. Legates. 1971. Milk yield and its influence on 205-day weight of beef calves. J. Anim. Sci. 33:563.

Sagi, R., R. C. Gorewit and D. B. Wilson. 1980. Role of exogenous oxytocin in eliciting milk injection in dairy cows. J. Dairy Sci. 63:2006.

Schwulst, F. J., L. J. Sumption, L. A. Swiger and V. H. Arthaud. 1966. Use of oxytocin for estimating milk production of beef cows. J. Anim. Sci. 25:1045.

Skaar, B. R. 1985. Direct Genetic and Maternal Variances and Covariance Component Estimates from Angus and Hereford Field Data. Ph.D. Dissertation. Iowa State Univ., Ames.

Spike, P. W. and A. W. Freeman. 1967. Environmental influences on monthly variation in milk constituents. J. Dairy Sci. 50:1897.

Stewart, R. E. and J. S. Stevenson. 1987. Hormonal, estrual, ovulatory and milk traits in postpartum dairy cows following multiple daily injections of oxytocin. J. Anim. Sci. 65:1987.

Swanson, E. W. 1957. The effect of fattening dairy heifers upon their growth and lactation. J. Dairy Sci. 40:611 (Abstr.).

Swanson, E. W. and T. R. Spann. 1954. The effect of rapid growth with fattening upon lactation in cattle and rats. J. Anim. Sci. 13:1032.

Taylor, H. E. and P. E. Humes. 1983. Milk yield and composition from Brahman and continental sired crossbred cow. Louisiana Agric. Exp. Sta. Livest. Producer's Day Rep. 24:pp67-73. Louisiana State Univ., Baton Rouge.

Taylor, R. E. 1984. Beef Production and the Beef Industry. Burgess Publishing Co. Minneapolis, MN.

Todd, J. C., J. K. Riggs and J. C. Smith. 1968. Milk yields and calf weights from Brahman, Hereford and crossbred cows in the gulf coast prairie. J. Anim. Sci. 27:286(Abstr.).

Totusek, R. and D. Arnett. 1965. Estimators of milk production in beef cows. J. Anim. Sci. 24:906(Abstr.).

Totusek, R., D. W. Arnett, G. L. Holland and J. V. Whiteman. 1973. Relation of estimation method, sampling interval and milk composition to milk yield of beef cows and calf gain. J. Anim. Sci. 37:153.

Tyrrell, H. F. and J. T. Reid. 1965. Prediction of the energy value of cow's milk. J. Dairy Sci. 48:1215.

Van Vleck, L. D., E. J. Pollak and E. A. Oltenacu. 1987. Genetics for the Animal Sciences. W. H. Freeman and Co., New York.

Wagner, J. J. 1984. Carcass Composition in Mature Hereford Cows: Estimation and Influences on Metabolized Energy Requirements for Maintenance During Winter. Ph.D. Dissertation, Oklahoma State Univ., Stillwater.

Wallace, C. 1953. Observations on mammary development in calves and lambs. J. Agric. Sci. 43:413.

White, J. M. and W. E. Vinson. 1975. Relationships among udder characteristics, milk yield, and nonyield traits. J. Dairy Sci. 58:729.

Willham, R. L. 1979. Evaluation and direction of beef sire evaluation programs. J. Anim. Sci. 49:592.

Williams, J. H., D. C. Anderson and D. D. Kress. 1979a. Milk production in Hereford cattle. I. Effects of separation interval on weigh-suckle-weigh milk production estimates. J. Anim. Sci. 49:1438.

Williams, J. H., D. C. Anderson and D. D. Kress. 1979b. Milk production in Hereford cattle. II. Physical measurements: repeatabilities and relationships with milk production. J. Anim. Sci. 46:1443.

Wilson, D. E. and R. L. Willham. 1988. Interim expected progeny differences for young animals not included in National Cattle Evaluations. J. Anim. Sci. 66:618.

Wilson, L. L., J. E. Gillooly, M. C. Rugh, C. E. Thompson and H. R. Prudy. 1969. Effects of energy intake, cow body size and calf sex on composition and yield of milk by Angus-Holstein cows and preweaning growth rate of progeny. J. Anim. Sci. 28:789.

Wiltbank, J. N. and A. C. Cook. 1958. The comparative reproductive performance of nursed and milked cows. J. Anim. Sci. 17:640.

Wistrand, G. C. and J. K. Riggs. 1966. Milk production of Santa Gertrudis cows as measured by calf nursing and machine milking. J. Anim. Sci. 25:263(Abstr.)

Whitman, R. W. 1975. Weight Change, Body Condition and Beef-Cow Reproduction. Ph.D. Dissertation. Colorado State Univ., Fort Collins.

Woods. P. D. P.. 1967. Algebraic model of the lactation curve in cattle. Nature, Lond. 216:164.

Worley, T. L. 1981. Patterns of Forage and Milk Intake by Angus Calves Grazing High and Low Quality Pastures. Masters Thesis. Univ. of Tennessee, Knoxville.

Wyatt, R. D., K. S. Lusby, J. V. Whiteman, M. B. Gould, and R. Totusek. 1977. Performance of 4- and 5-year-old Hereford, Hereford × Holstein and Holstein cows on range and in drylot. J. Anim. Sci. 45:1120.

CHAPTER III

RELATIONSHIP OF MILK PRODUCTION, MILK EXPECTED PROGENY DIFFERENCE AND CALF WEANING WEIGHT IN ANGUS AND SIMMENTAL COW-CALF PAIRS

ABSTRACT

Milk expected progeny differences (EPDs), used to predict the milk production potential of a parent's daughters, have been reported by all major breed associations. The objectives of this experiment were to determine the relationship of milk EPDs to offspring weaning weight and dam's milk production (both fluid and components). Angus (AN; n = 114) and Simmental (SM; n=82) cows were milked via machine at an average of 60, 104, and 196 d postpartum following overnight calf removal. These measurements were fitted to a lactation curve to calculate total milk production during lactation. Simple correlations between 205 d milk yields (TMY) and adjusted calf weaning weight (WW) were .33 ($P < .0001$) and .56 ($P < .004$) for AN and SM, respectively. Furthermore, milk EPD was positively correlated to adjusted WW ($r = .41$, $r = .39$; $P < .02$) and TMY ($r = .32$, $r = .33$; $P < .06$) for AN and SM cows, respectively. Regression coefficients for AN and SM showed a change of .015 ± .006 kg ($P < .0001$) and .025 ± .005 kg ($P < .0001$) of adjusted WW resulted from each kg change in TMY, respectively. Additionally, one kg change in milk EPD resulted in 4.82 ± 1.01 ($P < .0001$) or 2.90 ± .99 ($P < .003$) change in calf weaning weight, and 42.5 ± 16.6 kg ($P < .01$) or 69.3 ± 16.0 kg ($P < .01$) change in TMY for AN and SM, respectively. Correlations between percent milk fat, protein, lactose, or total solids and adjusted WW were not significant ($P < .20$). However, correlations between amount of milk components and adjusted WW were significant ($P < .01$). These data indicate that milk EPDs predict milk

production and appear to be conservative in their estimates of genetic differences. These data confirm that milk EPDs should be useful tools as breeders attempt to change milk production.

(Keywords: Beef Cattle, Lactation, Machine Milking, Weaning Weight, EPD, Milk Yield.)

INTRODUCTION

Since weaning weight of the calf is influenced by the milk production of its dam (Neville, 1962; Melton et al., 1967; Rutledge et al., 1971; Notter et al., 1978; Reynolds et al., 1978; and Boggs et al., 1980), the ability to change the genetic potential of a herd for milk production could be beneficial to cow/calf producers. Milk expected progeny differences (Milk EPDs) have been developed to account for the genetic differences in milking ability of beef cattle (Benyshek et al., 1988). If milk EPDs predict milk production potential, producers could use them to change the milking ability of their herds.

Past studies have shown that using sires with different levels of milk EPDs result in offspring of varying levels of milk production (Mahrt et al., 1987; Marshall and Freking, 1988). However, the relationship between a cow's milk EPD and her milk production has not been delineated. The objective of this study was to find the relationship between the milk EPD of the dam, the offspring's weaning weight, and milk production.

EXPERIMENTAL PROCEDURE

Data were collected from two herds of purebred Angus (AN) and three herds of Simmental (SM) cows in 1988 and(or) 1989. One hundred forty-six lactations from 114 AN and 94 lactations from 82 SM were estimated by 899 individual machine milkings. Animals used in the study calved in a 65 d period within their respective herds. Calving occurred between February 26 and April 15 in the spring or August 20 and October 10 in the fall. Herds were selected which had a wide range in milk EPDs.

Cow Management. The herds used are shown in Tables 1 and 2. They differed by location, calving season, management, breed, and year. Cows were grouped by age using Beef Improvement Federation (BIF) Uniform Guidelines (BIF, 1986).

Herd A1 calved in the fall of 1988. When maintained in drylot, cows were given access to alfalfa hay ad libitum and group fed 2.27 kg $\cdot$ head^{-1} $\cdot$ d^{-1} of dry rolled grain sorghum. All cows in A1 group were primiparous two-year-old heifers. Between the fourth and fifth milking, cows were removed from the dry lot and allowed to graze winter wheat pasture as one group. Angus herds A2 and A3 represent cows in the same location in consecutive years (1988 and 1989). Various age groups were represented and several of the cows were milked in consecutive lactations. Management was similar for both years with cows fed supplemental alfalfa hay and dry rolled grain sorghum from calving to May 1, at which time they were moved to native grass (predominantly bluestem) pastures. Throughout the trial, trace mineralized salt was supplied ad libitum.

Simmental cows in herds S1, S2, and S4 were managed alike with all cows calving during the spring on dormant native grass (predominantly bluestem) pastures. Supplemental feed

TABLE 1. LACTATION CURVE PARAMETERS, MILK PRODUCTION, EPDs, AND CALF PERFORMANCE FOR ANGUS

Angus	Herd			
Item	A1	A2	A3	Total
No. of cows	60	42	44	146
Milk curve parameter and milk estimates				
A	.53 ± .03	.51 ± .11	.65 ± .06	.56 ± .04
K	.10 ± .003	.10 ± .005	.07 ± .003	.09 ± .002
Days to peak milk yield, d	76 ± 2.3	85 ± 11.4	105 ± 4.4	88 ± 3.8
Total milk yield, kg/205-d lactation	1263 ± 43	1556 ± 43	1617 ± 77	1454 ± 37
Peak milk yield, kg/d	8.5 ± .3	10.7 ± .5	10.1 ± .6	9.6 ± .3
Cow and calf data				
Milk EPD, kg[a]	7.3 ± .2	.4 ± .4	1.3 ± .3	3.5 ± .3
Calf weaning EPD, kg[a]	7.3 ± .2	12.0 ± .3	8.8 ± .5	9.1 ± .3
Birth weight, kg	34.0 ± .5	40.3 ± .7	40.7 ± .6	37.9 ± .4
Weaning age, d	222 ± 2	202 ± 2	196 ± 3	209 ± 2
Weaning weight, kg	244 ± 3.6	254 ± 4.5	260 ± 4.8	252 ± 2.5
Adjusted weaning weight, kg[b]	239 ± 3.4	259 ± 4.1	268 ± 7.0	254 ± 3.0
Calf average daily gain, kg/d	.94 ± .01	1.06 ± .02	1.13 ± .03	1.03 ± .01
Age group	2	2 to > 10	3 to > 10	2 to 10

[a]Supplied by American Angus Association, St. Joseph, MO.
[b]Calf weaning weights adjusted to common age (205 d).

TABLE 2. LACTATION CURVE PARAMETERS, MILK PRODUCTION, EPDs, AND CALF PERFORMANCE FOR SIMMENTAL

Simmental	Herd				
Item	S1	S2	S3	S4	Total
No. of cows	25	11	33	25	94
Milk curve parameter and milk estimates					
A	.34 ± .06	.33 ± .05	.51 ± .04	.31 ± .02	.41 ± .02
K	.09 ± .004	.11 ± .008	.09 ± .003	.10 ± .002	.09 ± .002
Days to peak milk yield	86 ± 12	69 ± 6	84 ± 64	75 ± 3	80 ± 3.7
Total milk yield, kg/205-d lactation	1848 ± 80	1668 ± 65	1419 ± 52	2027 ± 104	1724 ± 47
Peak milk yield, kg/d	12.4 ± .6	11.7 ± .7	9.1 ± .3	13.4 ± .7	11.4 ± .3
Cow and calf data					
Milk EPD, kg[a]	2.4 ± .5	.4 ± .7	.9 ± .3	.9 ± .5	1.2 ± .2
Calf weaning, EPD, kg[a]	4.4 ± 1.0	1.0 ± .5	2.9 ± .7	2.9 ± .8	3.1 ± .4
Birth weight, kg	43.9 ± 1.2	38.3 ± .6	38.6 ± .8	46.3 ± 1.3	41.9 ± .6
Weaning age, d	187 ± 3	180 ± 6	194 ± 2	195 ± 2	191 ± 2
Weaning weight, kg	281 ± 6.2	252 ± 8.4	257 ± 4.8	295 ± 6.3	272 ± 3.4
Adjusted weaning weight, kg[b]	314 ± 5.8	312 ± 15.5	291 ± 5.8	337 ± 8.6	311 ± 4.2
Calf average daily gain, kg/d	1.27 ± .02	1.19 ± .04	1.12 ± .02	1.27 ± .03	1.21 ± .01
Age group	3 to 5-10	4 to 10	2	3 to 10	2 to 10

[a]Supplied by American Simmental Association, Bozeman, MT.
[b]Calf weaning weights adjusted to common age (205 d).

(alfalfa hay and dry rolled grain sorghum) were supplied ad libitum until May 1, at which time cows were moved to native grass pastures (similar to AN herds A2 and A3). Trace mineralized salt was fed ad libitum. Herds S1 and S4 represented essentially the same group of cows milked in consecutive years (1988 and 1989).

Herd S3 consisted of primiparous two-year-old heifers. Allowed to graze dormant native grass (buffalo grass, bluestem, and gramma) pastures from calving to weaning, they were supplemented ad libitum with sudan grass hay and 2.27 kg $\cdot$ head^{-1} $\cdot$ d^{-1} of dry rolled grain sorghum.

Calf management. All calves were allowed to suckle their dams at will from birth to weaning, except for the day prior to and the day of milk estimation. During separation periods, water was supplied ad libitum. No supplemental feed was provided for any of the spring born AN or SM calves. Fall born calves in herd S3 were allowed a high energy creep feed from December 1, 1988 until weaning, while fall born calves in group A1 had excess to the alfalfa hay fed to their dams. Average age of calves at weaning is shown in Tables 1 and 2. Spring born AN and SM calves from groups A2, S1, and S2 were weighed at birth and weaning only. All other calves were weighed at birth, at each milk estimation, and at weaning. Weaning weights (WW) were adjusted for d of age using the formula:

$$\text{Adjusted WW} = (((\text{WW} - \text{BW})/\text{WNAGE}) \times 205) + \text{BW}$$

where WW is actual weaning weight, BW is birth weight, and WNAGE is the calf's age at weaning. Age of dam adjustments were not included since they are confounded with milk production. All male calves were left intact and no growth stimulants were used to enhance preweaning calf growth.

Milking procedure and data collection. Milk estimations were made via machine milking at an average of 60, 108 and 194 d postpartum for all herds. Additionally, herd A1 had additional milkings at 35 and 145 d postcalving. The day prior to milk estimation, pairs were gathered between 1500 and 1800, at which time calves were isolated from their dams until approximately 2200. At this time, pairs were reunited and calves allowed to nurse their dams until satiety. Suckling periods did not exceed 45 min. Cows and calves were then separated until machine milking was completed. Milking was initiated at 0700 and completed by 1200 with a mean time of calf separation of 10.7 ± .07 h for AN and 11.3 ± .12 h for SM.

On the day of milk estimation, cows were restrained in a chute, injected with 40 IU (i.m.) of oxytocin with immediate attachment of the milking apparatus. Milking machines consisted of a portable vacuum pump connected to a Bowman claw. During milking, (mean time = 9.31 ±.14 min for AN and 9.50 ± .23 min for SM) udders were massaged. Upon completion of milk flow from all quarters, machines were removed and udders hand stripped of residual milk. All cows were weighed, given a body condition score of 1 to 9 (1 = emaciated, 9 = obese; Whitman, 1975), and allowed to reunite with their calf.

Milk obtained from the machine and hand stripping was combined and weighed. Before disposal, milk was stirred and sampled (approximately 56g). Each sample was preserved with 2-Bromo-2-nitropropane -1,3 -diol and delivered to the Kansas Dairy Herd Improvement Association for milk component analysis. Fat, total solids, protein, and lactose percentages were determined using standard automated methods[1] described by Akers and Thompson (1987). In addition, somatic cell count was determined using a Fossomatic 215[2].

[1]Infrared Dairy Product Analyzer, Berroin Instr. Group, North Hollywood, CA.

[2]Foss Electric, Hillerod, Denmark.

Estimation of lactation yield. To determine the rate of milk production over the time of calf removal, the data was pooled and analyzed by a least squares regression model. Since it was determined that cows produced milk linearly over the time of calf removal, daily milk yields [$Y(n)$] were adjusted to 24 h production by the formula:

$$Y(n) = (M + M \times (12 - CR) \times .0417) \times 2$$

Where M is the amount of milk weighed (kg), and CR is the h of calf removal.

Individual animal daily milk yields were used to estimate parameters for the lactation curve defined by the empirical equation:

$$Y(n) = n/ae^{kn}$$

where $Y(n)$ is the daily milk yield of the n^{th} week postpartum and a and k define the shape of the lactation curve. Parameters were estimated by expressing the equation in logarithms:

$$log_e[Y(n)/n] = (log_e 1/a) - kn$$

and regressing the value $log_e[Y(n)/n]$ on n for individual animals (as proposed by Jenkins and Ferrell, 1984). Total yields of milk components were calculated using the same protocol.

These estimates were adjusted for levels of somatic cell count as reported by the Kansas Dairy Herd Improvement Association using adjustment coefficients for dairy cattle since adjustments haven't been determined for beef cattle (Kansas Dairy Herd Improvement Association, personal communication). However, the low somatic cell counts observed in this study resulted in high correlations between unadjusted and adjusted yields ($r = .91$); consequently, unadjusted yields was used in all analyses.

Statistical analysis. Data were analyzed by breeds. The data were analyzed for TMY using a least squares procedure to fit a linear regression with unequal subclass numbers. Non-significant interactions ($P > .20$) were eliminated from the models described below.

$$Y_{ijklm} = HERD_i + SEX_j + AGEGRP_k + \beta_1 BW_l$$

$$+ \beta_2\text{MILK EPD}_m + e_{ijklm}$$

where Y_{ijklm} is TMY, $HERD_i$ is the i^{th} breed, SEX_j is the j^{th} sex, $AGEGRP_k$ is the k^{th} age group of the dam, $\beta_1 BW_l$ is the regression of TMY on birth weight_l, $\beta_2\text{MILK EPD}_m$ is the regression of TMY on milk EPD_m, and e_{ijklm} is the sampling error. A similar procedure was used to analyze the data for adjusted calf weaning weight. The model is as follows:

$$Y_{ijklm} = HERD_i + \beta_1 BW_j + \beta_2 TMY_l + \beta_3\text{Weaning EPD}_m + e_{ijklm}$$

Where Y_{ijklm} is the adjusted WW, $HERD_i$ is the i^{th} herd, $\beta_1 BW_j$ is the regression of WW on BW_j, $\beta_2 TMY_l$ is the regression of WW on TMY_l, $\beta_3\text{Weaning EPD}_m$ is the regression of WW on Weaning EPD_m, and e_{ijklm} is the sampling error. $\beta_2 TMY_l$ was replaced with $\beta_2\text{MILK EPD}_l$ to determine the relationship of adjusted WW to milk EPD.

In addition to using linear regression coefficients to measure the relationships between the variables of TMY, WW, and milk EPD, Pearson product-moment correlations were computed using herd as a classification variable to define the groups of observations. Since the Chi-Square value was significant ($P < .0001$), the within group covariance matrix was used for calculating the Pearson correlation coefficients. The repeatability of milk production between consecutive lactations was estimated using cows with milking records ($n = 51$) from 1988 and 1989.

All statistical analyses were conducted using the procedures described by SAS (1985).

RESULTS AND DISCUSSION

Condition and Body Weight of Cows. Both breeds tended to increase in BCS and weight during lactation. Cow weights averaged 554.0 ± 2.5 kg and 556.4 ± 4.6 kg, while BCS averaged 5.73 ± .03 and 5.21 ± .02, respectively, for AN and SM during lactation.

Angus cow's BCS were dependent on herd, d postpartum, and TMY ($P < .01$) but not age group ($P < .21$). However, there was a tendency for cows with higher milk production to have lower BCS. Simmental BCS were not dependent on d postpartum, but were influenced by herd, age group, and TMY ($P < .01$). Both AN and SM cows' BCS tended to decrease as TMY increased.

Angus cow weight was significantly influenced by herd, d postpartum, TMY, and age group ($P < .01$). Higher milk producing AN cows tended to be lighter in weight ($P = .27$). Simmental cow weight was not influenced by d postpartum or TMY, but was influenced by herd and age group ($P < .01$)

Milk Traits by Breed. Adjusted means and standard errors for milk curve parameters, milk estimates, and cow and calf EPDs and calf growth are presented in Tables 1 and 2. Parameters of the curve forced milk production to follow a nonlinear rise until peak lactation ($1/k$), a somewhat linear decline from peak lactation until weaning, and set the height of the curve (Jenkins and Ferrell, 1984). In agreement with Belcher and Frahm (1979), differences in daily milk production between breeds and cows within breeds were maximum during peak lactation and declined in magnitude as lactation persisted.

Least square means for TMY of AN and SM were 1454 ± 36.4 and 1724 ± 47.1 kg/lactation, respectively, while milk yield at time of peak lactation for AN and SM were 9.6 ± .3 and 11.4 ± .3 kg/d, respectively. Peak milk production was reached at 67 ± 1.8 and 80 ± 3.7 d for AN and SM, respectively. These results indicate more d to peak lactation than those reported by Totusek et al. (1973) and Jenkins and Ferrell (1984), but similar to those reported by Clutter and Nielsen (1987). Movement of spring calving cows to summer pastures preceded the mean d to peak lactation.

Milk components averaged 3.59 ± .05% fat, 3.38 ± .02% protein, 4.95 ± .01% lactose, and 12.58 ± .05% total solids for AN, while SM cows averaged 3.62 ± .05% fat, 3.17 ± .02% protein, 4.85 ± .02% lactose, and 12.33 ± .05% total solids. Levels for these components are similar to results reported by Jeffery and Berg (1971), Belcher and Frahm (1979), and Beal et al. (1990). Least square mean percentages of milk constituents during lactation are displayed in Figures 1 and 2. The percent of fat decreased as lactation persisted ($P < .01$). Protein increased from mid- to late-lactation ($P < .01$), while lactose rose throughout lactation ($P < .01$) for both breeds. Total solids decreased as lactation persisted ($P < .01$) for AN but remained the same ($P > .20$) for SM. In AN, comparisons of least square means indicated that somatic cell count (SCC) gradually decreased as lactation continued, but for SM the SCC declined only between early- and mid-lactation.

Thirty-three AN and 18 SM ($n = 51$) were milked in successive lactations. Most of these cows were in their third and fourth or later lactation (31 of 51) while eight animals were in the first and second lactation and 12 animals were in their second and third lactation. The repeatability of TMY was .76 ($n = 51$; $P < .0001$). Beal et al. (1990) reported similar results ($r = .73$; $P < .02$) using machine milked cows approaching maturity, while Butcher and Freeman (1968) reported lower values for early lactations with Holstein cows. The consistency of milk production between successive lactations suggests that the genetic potential for milk production can be based upon the measurement of a single lactation.

Factors Influencing Milk Production. Milk EPD of AN and SM cows influenced ($P < .01$) TMY, while herd ($P < .03$) and cow age ($P < .02$) influenced the SM TMY, but not the AN TMY. A one kg change in dam's milk EPD resulted in a direct change of 42.5 ± 16.6 kg in

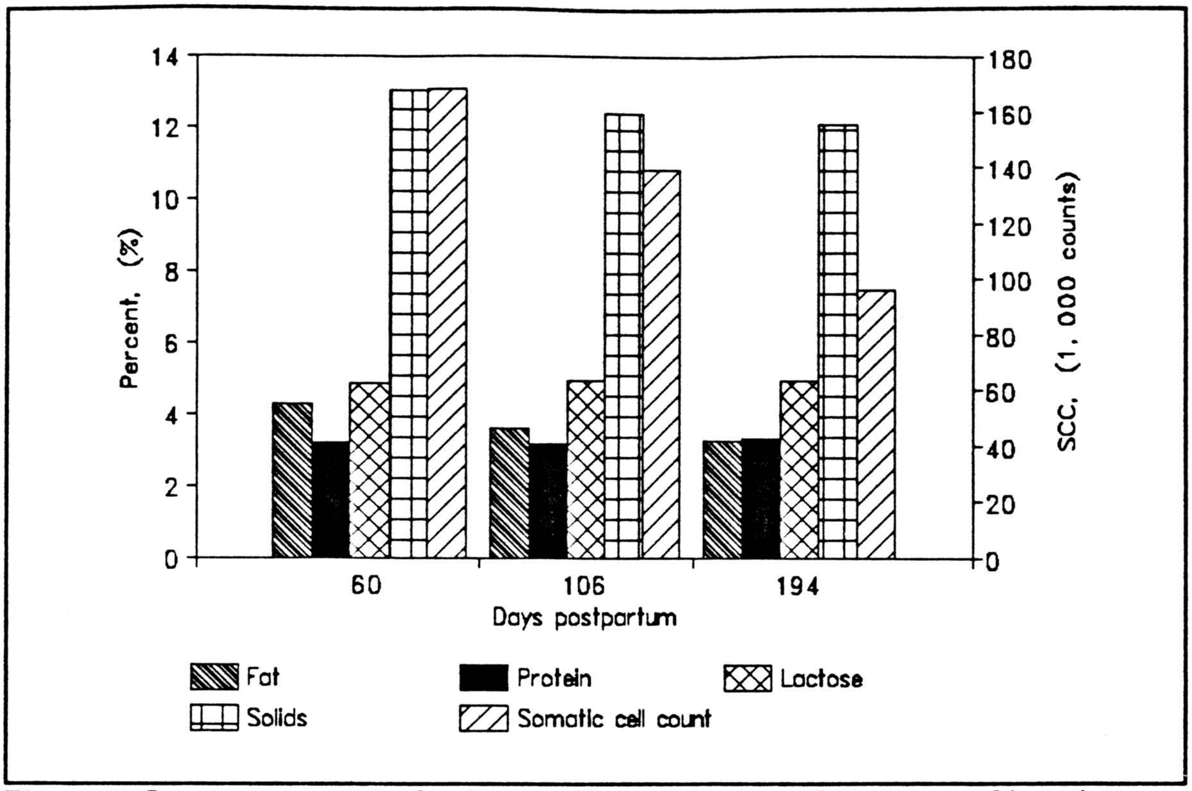


Figure 1. Least square means for Angus milk components at three stages of lactation.

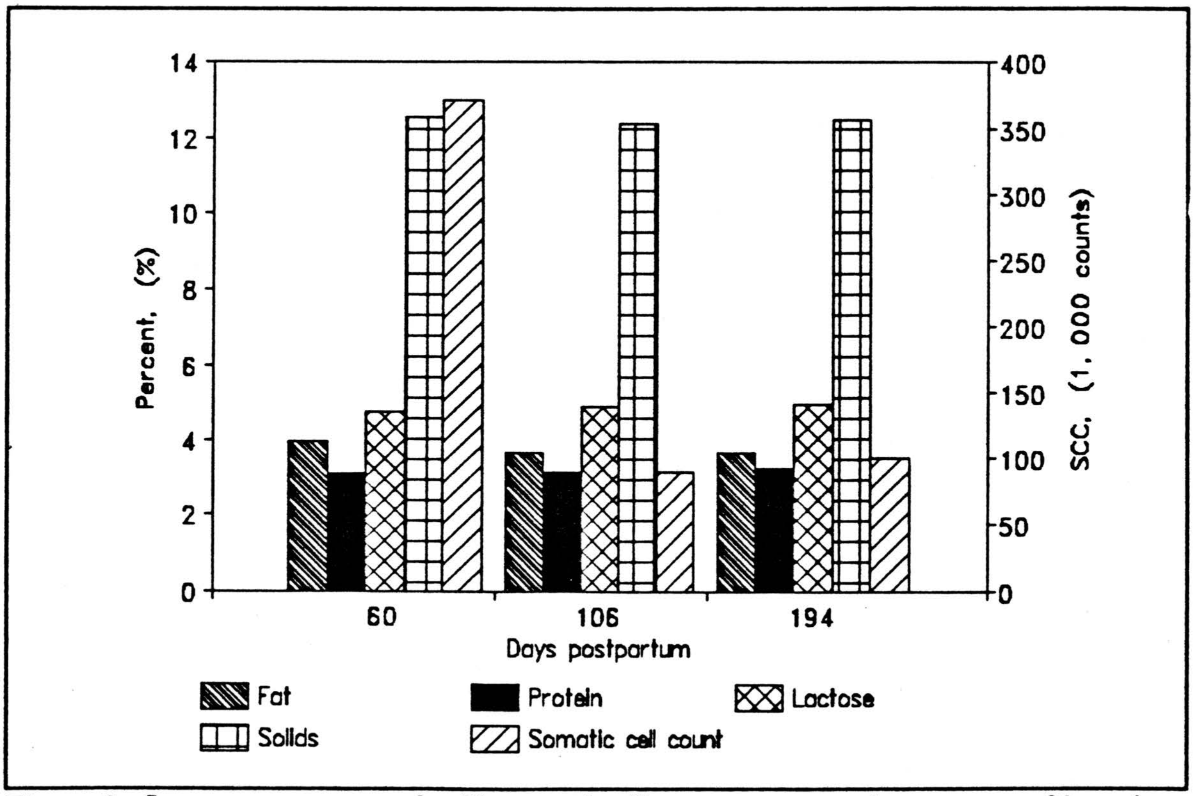


Figure 2. Least square means for Simmental milk components at three stages of lactation.

TMY for AN or a 69.3 ± 16.0 kg change in TMY for SM (Table 3). The birth weight of the calf influenced AN TMY ($P < .03$), but not SM TMY. Additionally, calf sex had little influence on TMY for either AN or SM. In AN there was a tendency for dams of heifer calves to produce more TMY (81.9 ± 69.2 kg), but in SM the dams of bull calves had a very slight advantage in TMY (61.5 ± 77.5 kg). Several other studies (Reynolds et al., 1978; Chenette and Frahm, 1981; and Daley, 1987) reported little or no effect of calf sex on dam's milk production. Rutledge et al. (1971) reports an advantage for heifers; however, Pope et al. (1963), McCuskey et al. (1986) and Daley et al. (1987) reported dams of bull calves produced more milk. In AN, a one kg change in birth weight corresponded to a change in TMY of 19.2 ± 8.6 kg, while in SM a one kg change in birth weight corresponded to a 8.6 ± 6.9 kg change. Gifford (1953), Rutledge et al. (1971), and Boggs et al. (1980) also reported that larger calves stimulated their dams to produce more milk.

TABLE 3. REGRESSION COEFFICIENTS BETWEEN TOTAL MILK YIELD, ADJUSTED CALF WEANING WEIGHT, AND MILK EPD BY BREED

Comparison	Angus coefficient	Simmental coefficient
Milk EPD effect on total milk yield	42.1 ± 16.6**	69.3 ± 16.0***
Total milk yield effect on adjusted calf weaning weight[a]	.0137 ± .0137***	.032 ± .009***
Milk EPD effect on calf weaning weight[a]	4.85 ± 1.14***	3.74 ± 1.73*

[a]Adjusted for calf age.
*$P < .05$. **$P < .01$. ***$P < .001$.

Progeny Performance. Performance parameters for AN and SM calves are shown in Tables 1 and 2. The genetic predictors, weaning weight EPD and dam's milk EPD, had direct affect on adjusted weaning weight (WW) for both breeds ($P < .0001$). A one kg change in weaning weight EPD resulted in a 4.37 ± 9.4 kg change in adjusted WW for AN, while in SM it caused a 2.65 ± .94 kg change in adjusted WW. This is larger than the one to one relationship that was expected (Mahrt et al., 1987). For dam's milk EPDs, a one kg change produced 4.82 ± 1.01 and 2.90 ± .99 kg changes in adjusted WW (Table 3) for AN and SM, respectively, which is larger than the two kg change expected. These results agree, however, with findings of Mahrt et al. (1987), Marshall and Freking (1988), and Mallinckrodt et al. (1990), who also found milk EPDs to be conservative in predicting calf WW differences.

Herd and TMY also influenced calf's adjusted WW ($P < .0001$). As shown in Table 3, a one kg change in TMY of the dam resulted in .015 ± .006 kg and .025 ± .005 kg of adjusted WW for AN and SM calves, respectively. Put on a daily milk production basis, an additional kg of milk added 2.9 or 6.7 kg of adjusted WW for AN or SM, respectively. Boggs et al. (1980) reported results similar to the SM data. However, these data indicate that more milk was used to produce additional weaning weight than reported by Neville (1962) or Beal (1988).

Least squares means for adjusted WW revealed no difference between bull calves and heifer calves in AN (251.4 ± 3.3 vs. 248.7 ± 3.1 kg, respectively). Angus adjusted WW was influenced by birth weight ($P < .001$) where one kg change in birth weight resulted in 1.89 ± .58 kg change in adjusted WW. Conversely, in SM, birth weight had no effect on adjusted WW but calf sex was a significant factor ($P < .0001$) with bull calves 23.42 ± 3.70 kg heavier than their heifer counterparts.

The percentage of milk components measured, i.e., fat, protein, lactose, and total solids, had no affect on adjusted WW of the calves of either breed. However, the quantity of milk fat and milk protein did influence adjusted WW in both breeds ($P < .0001$). In AN, Pearson product moment correlation coefficients between amounts of milk fat and protein and adjusted WW were .33 and .50, respectively, while for SM the coefficients were .14 and .30.

These correlation coefficients are higher than those reported by Hardt et al. (1988). Additionally, Melton et al. (1967), Jeffery and Berg (1971), and Chenette and Frahm (1981) also concluded that total intake of milk fat and protein influenced preweaning calf growth and weaning weight while percent of constituents had little or no influence.

Relationship Between Total Milk Yield, Calf Performance, and Milk Expected Progeny Differences. The relationships between WW, TMY, and milk EPD for each breed are displayed in Table 4. The correlation of TMY and adjusted WW ($r = .30$, $P < .0001$; $r = .47$, $P < .001$) indicate that milk production had a major influence on calf performance. These data are within the range of .16 (Belcher and Frahm, 1979) to .81 (Neville, 1962) reported in previous studies.

The pooled within class correlation coefficients between adjusted WW and milk EPD was .38 ($P < .0001$) and .39 ($P < .001$) for AN and SM, respectively. Furthermore, correlation coefficients between TMY and milk EPD were .32 ($P < .0001$) and .44 ($P < .001$) for AN and SM, respectively. Since milk EPDs are reported in terms of calf weaning weight, these positive relationships mean that milk EPDs are related to both WW and milk production. These correlation coefficients, along with the regression coefficients, suggest that milk EPDs underestimate true genetic differences and thus are conservative in nature. Similar correlations between milk EPD and peak milk yield/d ($r =.30$, $P < .0001$, AN; and $r = .31$, $P < .05$, SM) indicate that milk EPDs can assist producers in predicting nutritional requirements during peak lactation.

TABLE 4. PEARSON PRODUCT MOMENT CORRELATIONS BETWEEN TOTAL MILK YIELD, ADJUSTED CALF WEANING WEIGHT, AND MILK EPD BY HERD AND BREED

	Angus				Simmental				
Comparison	A1	A2	A3	Total	S1	S2	S3	S4	Total
No. of cows	60	42	44	146	25	11	33	25	94
Total milk yield to adjusted calf weaning weight[a]	.12	.75***	.19	.30***	.46*	.54	.60***	.45*	.47***
Milk EPD to adjusted calf weaning weight[a]	.43***	.52***	.30*	.38***	.58***	.26	.16	.52**	.39***
Milk EPD to total milk yield	.16	.42**	.33*	.32***	.41*	.49	.33	.55**	.44***

[a]Adjusted for calf age (205 d).
P < .10 * P < .05 ** P < .01 *** P < .001

IMPLICATIONS

This study shows a positive relationship between milk EPDs, actual milk production, and calf weaning weights. Furthermore, it appears that milk EPDs are conservative in estimating genetic differences. Consequently, these findings indicate that milk EPDs should be a useful tool in changing the potential for milk production in the beef cattle industry. However, milk EPD probably does not reflect only differences in milk production but includes other factors that make up the maternal environment. Measurement of milk production in consecutive years in the same cows indicates that milk production is highly repeatable. Since milk production at peak lactation in this study exceeded the highest level currently listed in the National Research Council, Nutrient Requirements of Beef Cattle (NRC, 1984) tables, it appears that these requirements should be revised to reflect the milking ability of the current beef cattle population.

LITERATURE CITED

Akers, R. M. and W. Thompson. 1987. Effects of induced leucocyte migration on mammary cell morphology and milk component biosynthesis. J. Dairy Sci. 70:1685.

Beal, W. E., R. M. Akers and D. R. Notter. 1988. Milk production in beef cows: methods of measurement and relationship to cow and calf performance. J. Anim. Sci. 66(Suppl. 1):454(Abstr.).

Beal, W. E., D. R. Notter and R. M. Akers. 1990. Techniques for estimation of milk yield in beef cows and relationships of milk yield to calf weight gain and postpartum reproduction. J. Anim. Sci. 68:937.

Belcher, C. G. and R. R. Frahm. 1979. Productivity of two-year-old crossbred cows producing three-breed cross calves. J. Anim. Sci. 49:1195.

Benyshek, L. L., M. H. Johnson, D. E. Little, J. K. Bertrand and L. A. Kriese. 1988. Applications of an animal model in the United States beef cattle industry. J. Dairy Sci. 71(Suppl. 2):35.

BIF. 1986. Guidelines for Uniform Beef Programs. (5th Ed.) Beef Improvement Federation, North Carolina State Univ., Raleigh.

Boggs, D. L., E. F. Smith, R. R. Schalles, B. E. Brent, L. R. Corah and R. J. Pruitt. 1980. Effects of milk and forage intake on calf performance. J. Anim. Sci. 51:550.

Butcher, D. F. and A. E. Freeman. 1968. Estimations of heritability and repeatability of milk and milk fat. J. Dairy Sci. 52:1259.

Chenette, C. G. and R. R. Frahm. 1981. Yield and composition of milk from various two-breed cross cows. J. Anim. Sci. 52:483.

Clutter, A. C. and M. K. Nielsen. 1987. Effect of level of beef cow milk production on pre- and postweaning calf growth. J. Anim. Sci. 64:1313.

Daley, D. R., A. McCuskey and C. M. Bailey. 1987. Composition and yield of milk from beef-type *Bos taurus* and *Bos indicus* × *Bos taurus* dams. J. Anim. Sci. 64:373.

Gifford, W. 1953. Records-of-performance tests for beef cattle in breeding herds, milk production: milk production of dams and growth of calves. Ark. Agric. Exp. Sta. Bul. 531.

Hardt, P. F., L. W. Greene and J. F. Baker. 1988. Milk production in lactating cows of three breed types and calf growth in a forage production system. J. Anim. Sci. 66 (Suppl. 1):454(Abstr.).

Jeffery, H. B. and R. T. Berg. 1971. Evaluation of milk variables as measures of milk effect on preweaning performance of beef cattle. Can J. Anim. Sci. 51:551.

Jenkins, T. G. and C. L. Ferrell. 1984. A note on lactation curves of crossbred cows. Anim. Prod. 39:479.

Mahrt, G. S., D. R. Notter, W. E. Beal and W. H. McClure. 1987. Effects of sire breeding value on growth of Polled Hereford X Angus calves. J. Anim. Sci. 65(Suppl. 1):190(Abstr.).

Mallinckrodt, C. H., R. M. Bourdon, R. R. Schalles and K. G. Odde. 1990. Relationship of milk expected progeny differences to actual milk production and calf weaning weight. J. Anim. Sci. 68(Suppl. 1):245(Abstr.).

Marshall, D. M. and B. A. Freking. 1988. Relationship of sire expected progeny differences to maternal performance of first-calf daughters in a commercial herd. SDSU Beef Report 88-19. pp 73-76. South Dakota State Univ., Brookings.

McCuskey, A., D. R. Daley and C. M. Bailey. 1986. Milk yield of beef-type *Bos taurus* and *Bos indicus* × *Bos taurus* dams. J. Anim. Sci. 63(Suppl. 1):177(Abstr.).

Melton, A. A., J. K. Riggs, L. A. Nelson and T. C. Cartwright. 1967. Milk production, composition and calf gain of Angus, Charolais and Hereford cows. J. Anim. Sci. 26:804.

NRC. 1984. Nutrient Requirements of Beef Cattle (6th Ed.). National Academy Press, Washington, DC.

Neville, W. E., Jr. 1962. Influence of dam's milk production and other factors in 120- and 240-day weight of Hereford calves. J. Anim. Sci. 21:315.

Notter, D. R., L. V. Cundiff, G. M. Smith, D. B. Laster and K. E. Gregory. 1978. Characterization of biological types of cattle VII. Milk production in young cows and transmitted and maternal effects on preweaning growth of progeny. J. Anim. Sci. 46:908.

Pope, L. S., L. Smithson, D. F. Stephens, D. O. Pinney and M. Velasco. 1963. Factors affecting milk production of range beef cows. Oklahoma Agric. Exp. Sta. Misc. Pub. 70:69. Oklahoma State Univ., Stillwater.

Reynolds, W. L., T. M. Derouen and R. A. Bellows. 1978. Relationships of milk yield of dam to early growth rate of straightbred and crossbred calves. J. Anim. Sci. 47:584.

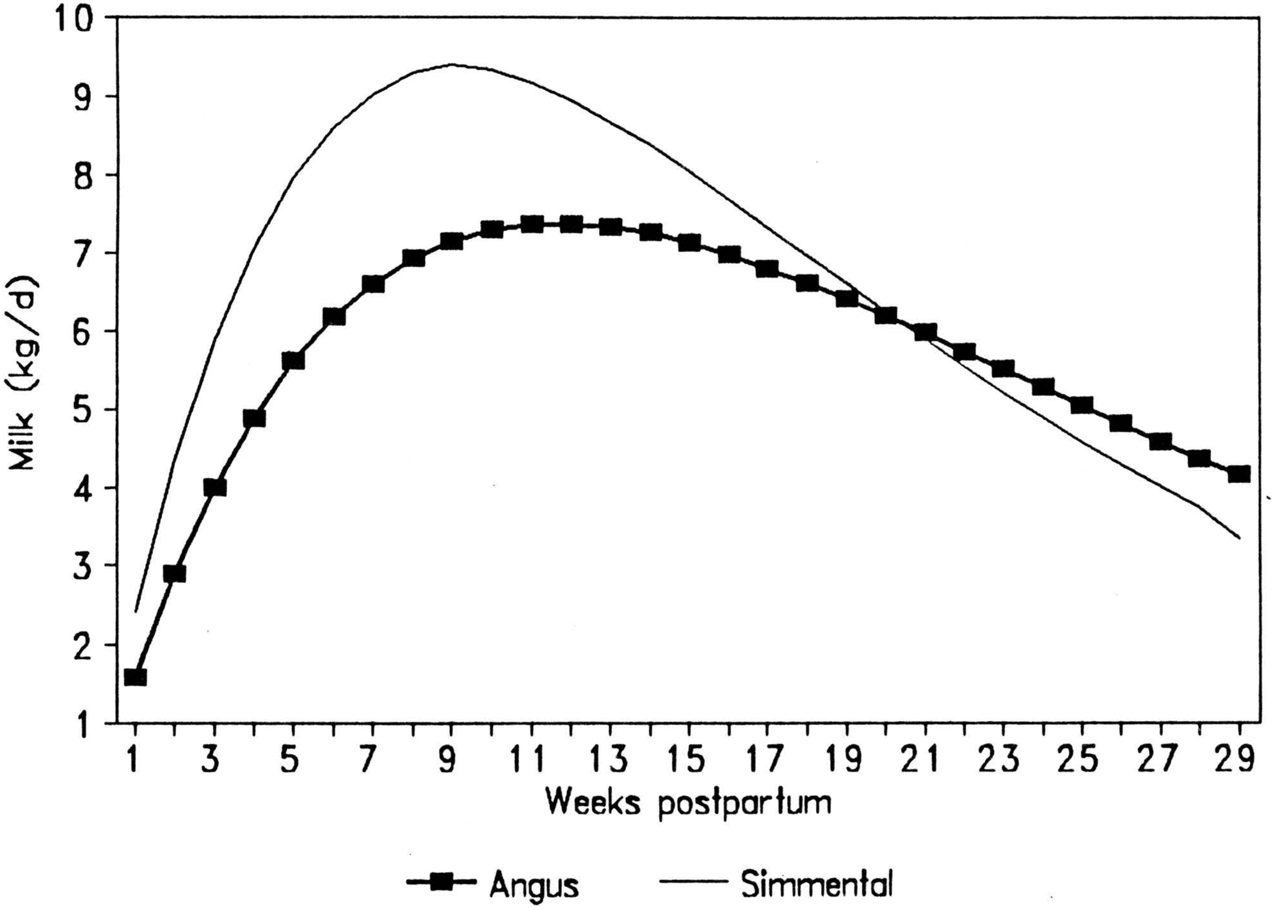
Rutledge, J. J., O. W. Robison, W. T. Ahlschwede and J. E. Legates. 1971. Milk yield and its influence on 205-day weight of beef calves. J. Anim. Sci. 33:563.

SAS. 1985. SAS User's Guide: Statistics. SAS Inst., Inc., Cary, NC.

Totusek, R., D. W. Arnett, G. L. Holland and J. V. Whiteman. 1973. Relation of estimation method, sampling interval and milk composition to milk yield of beef cows and calf gain. J. Anim. Sci. 37:153.

Whitman, R. W. 1975. Weight Change, Body Condition and Beef-Cow Reproduction. Ph.D. Dissertation. Colorado State Univ., Fort Collins.

Figure 1. Typical lactation curves for
Angus and Simmeantal cows.



APPENDIX

APPENDIX TABLE 1. MILK PRODUCTION ESTIMATES FROM PREVIOUS STUDIES

Study	Year	Method[1]	Breed[2]	Cow age (yr)	Daily aver. (kg/d)	Max milk (kg/d)	Total 205-d lactation (kg)
Cole & Johansson	1933	MM	AN	M[a]	4.6		1397
Gifford	1953						681
Dawson et al.	1960	MM	SS	M[a]	7.9	10.3	2000
Pope et al.	1963	WSW		2	3.8	4.45	779
				3	4.49	5.32	920
				4	4.67	5.55	957
Totusek & Arnett	1965	HM	XX		4.55		
		WSW	XX		5.86		
Wistrand & Riggs	1966	WSW			5.6-		
		&MM	SG		7.9		
Gleddie & Berg	1968	MM	XX	4-5	3.8-6.1		
Wilson et al.	1969	HM	XB	M[a]	4.7		
Jeffery & Berg	1971	TC		4-5	3.8		
Rutledge et al.	1971	WSW		V[b]	5.04		
McGinty & Frerichs	1971	WSW	BSXHH		6.6	8.6	1353
Abadia & Brink	1972	MM	H	2	4.08		
Totusek et al.	1973	WSW		M	5.85		
		HM		M	4.54		
Cundiff et al.	1974	WSW	XX		5.68		
		MM	XX		5.10		
Kress & Anderson	1974	WSW	HH	4-5	6.1	7.3	1250
Lusby et al.	1976	WSW	HH		6.7		
			HXHH		9.0		
			HH		10.9		
Marshall et al.	1976	WSW	XX		5.0		
Wyatt et al.	1977	WSW	ANXHH		5.2		
			CHXH		10.0		
Notter et al.	1978	WSW	HHXAN	2	4.4		
			JX	2	5.2		
			DS	2	4.8		
			SMX	2	4.7		
			LMX	2	3.8		
			CHX	2	4.1		
			HHXAN	3-4	6.0		
			JX	3-4	8.8		
			DSX	3-4	6.4		
			SMX	3-4	8.0		
			LMX	3-4	5.4		
			CHX	3-4	5.4		

APPENDIX TABLE 1 (continued). MILK PRODUCTION ESTIMATES FROM PREVIOUS STUDIES

Study	Year	Method[1]	Breed[2]	Cow age	Daily aver.	Max milk	Total 205-d lactation
Robison et al.	1978	WSW	HH	V[b]	5.41	5.85	
Belcher & Frahm	1979	MM	XX	2	6.43		
Neidhardt et al.	1979	WSW	BRX		6.2		1271
Williams et al.	1979a	WSW	HH	2-8	7.6		
Boggs et al.	1980	WSW	HP		4.56	6.14	935
Gaskin & Anderson	1980	WSW	AN	2	5.65	7.51	
				3	6.09	8.38	
				4	6.85	9.5	
Lawson	1980	HM	HHX		3.05		
Chennette & Frahm	1981	MM	ANX	4	7.81		
			HH	4	7.44		
			HHXAN	4	6.35		
Franke et al.	1983	MM	BR		6.36		
			AN		4.77		
			CH		5.32		
			HH		3.68		
			2XX		7.09		
			3-4X		6.59		
Holloway & Worley	1983	WSW	AN	M[a]	5.77	7.74	1397
Jenkins & Ferrell	1984	WSW	ANXHH	8-9		9.7	1218
			CHX	8-9		11.5	1298
			JX	8-9		12.1	1503
			SMX	8-9		13.1	1564
			XX	8-9	6.2		1266
Cundiff et al.	1985	WSW	JX		8.4		
			HHXAN		5.6		
			RPX		6.8		
			DS		3.0		
			TA		7.2		
			PZ		7.2		
			SAX		7.8		
			BRX		8.2		
			BX		7.6		
			GV		7.6		
			SMX		7.6		
			MAX		5.8		
			LMX		5.0		
			CHX		5.0		
			CAX		5.6		

APPENDIX TABLE 1 (continued). MILK PRODUCTION ESTIMATES FROM PREVIOUS STUDIES

Study	Year	Method[1]	Breed[2]	Cow age	Daily aver.	Max milk	Total 205-d lactation
Humes & Taylor	1983	MM	BRXAN	5-7	11.2		
			BRXHH	5-7	9.3		
			CAXAN	5-7	7.4		
			CAXHH	5-7	6.9		
			MAXAN	5-7	9.3		
			MAXHH	5-7	8.4		
			SMXAN	5-7	8.4		
			SMXHH	5-7	8.4		
Clutter & Nielsen	1987	WSW	HHXAN	2-5		7.04	1157
			RPXAN	2-5		8.75	1532
			MXAN	2-5		9.66	1718
Cranwell et al.	1987	MM	JXHH	3-6	8.0		
			SGX	3-6	7.6		
			CHX	3-6	7.2		
Daley et al.	1987	WSW	BRX		8.5		
Dearborn et al.	1987	WSW		2	6.8		
McCarter et al.	1987	WSW	XX		6.11		
Marshall & Freking	1988	WSW	PHX	2	5.8		
			ANX	2	7.0		
			TAX	2	8.1		
Diaz	1990	MM	XX		7.4		
Mallinckrodt et al.	1990	WSW	SM				1531
			HP				1090

[1]Refers to the method of milk extraction: MM = machine milk; WSW= weigh=suckle=weigh; and TC = teat cannulation.
[2]Breeds are listed by Uniform Breed Codes--National Association of Animal Breeders--August 1989.
[a]Study reported cow age as mature.
[b]Study reported cow age as various.

APPENDIX TABLE 2. AMOUNT AND SITE OF OXYTOCIN USED

Study	Date	Amount (IU)	Injection Site
Anthony et al.	1959	40	i.m.
Klett et al.	1965	40	
Schwulst et al.	1966	40	i.m.
Wistrand and Riggs	1966	40	
Melton et al.	1967	40	i.m.
Gleddie and Berg	1968	20	i.v.
Lamond et al.	1969	20	i.v.
Wilson et al.	1969	40	i.v.
Jeffery and Berg	1970	20	
Lam et al.	1970	20	i.v.
Rutledge	1971	40	i.m.
Cundiff et al.	1974	40	i.m.
Neidhardt et al.	1979	20 + 10	
Lawson	1980	10	i.v.
Chenette and Frahm	1981	30	i.v.
McMorris and Wilton	1986	60	
Cranwell et al.	1987	40	i.v.
Daley et al.	1987	30	i.m.
Marston et al.	1989	40	i.m.
Beal et al.	1990	20	i.v.
Diaz et al.	1990	20	i.v.

APPENDIX TABLE 3. CORRELATION BETWEEN MILK PRODUCTION AND CALF AVERAGE DAILY GAIN OR WEANING WEIGHT

Study	Date	Method[1]	Simple correlation ADG	Simple correlation Weaning weight
Knapp and Black	1941		.52	
Gifford	1953		.60	
Neville	1962			.81
Pope et al.	1963	WSW	.6-.7	
Christian et al.	1965		.50	.48
Klett et al.	1965		.74	
Totusek and Arnett	1965		.87	
Schwulst et al.	1966		.58	
Wistrand and Riggs	1966	WSW & MM		.68
Melton et al.	1967		.72	
Gleddie and Berg	1968		.713	
Todd et al.	1968	MM	.14	
Wilson et al.	1969	HM	.49	
Jeffery and Berg	1970		.73-.78	
Jeffery et al.	1971		.33	
Rutledge et al.	1971			.60
Hohenboken et al.	1973		.34	.33
Totusek et al.	1973	WSW		.81
Marshall et al.	1976			.44
Reynolds et al.	1978		.54	
Robison et al.	1978			.63
Williams et al.	1979a	WSW	.46 & .61	
Belcher et al.	1980	MM	.291	.204
		WSW	.157	.086
Chenette and Frahm	1981	MM	.29	.20
Franke et al.	1983		.45	
Holloway and Worley	1983	WSW		.69
McCuskey et al.	1986	WSW	.41	
McGaughey and Nelson	1986	WSW	.40	
Clutter and Nielsen	1987	WSW	.60	.42
Beal et al.	1988	WSW		.34
		MM		.71
Marston et al.	1989	MM		.62
Beal et al.	1990	MM	.76	
Diaz et al.	1990			.65

[1]Refers to the method of milk extraction: MM = machine milk; WSW= weigh=suckle=weigh; and TC = teat cannulation.

APPENDIX TABLE 4. RATIO OF MILK TO CALF WEIGHT GAIN

Study	Date	Method[1]	Ratio of milk to calf weight gain
Neville	1962	WSW	12.5:1
Wistrand and Riggs	1966	WSW & MM	11.1 & 20:1
Melton et al.	1967	HM	5.2:1
Wyatt et al.	1977	WSW	6.5 to 10.1:1
Williams et al.	1979a	WSW	11.2:1
Boggs et al.	1980	WSW	28.4:1
Clutter and Nielsen	1987	WSW	31.25:1
Beal et al.	1988	MM	13.7:1
Marston et al.	1989	MM	26.8:1

[1]Refers to the method of milk extraction: MM = machine milk; WSW= weigh=suckle=weigh; and TC = teat cannulation.

APPENDIX TABLE 5. STUDIES OF MILK COMPOSITION

		Milk Components				
Study	Date	% BF	% Prot	% Lact	% SNF	% TS
Cole and Johansson	1933	4.06	3.56	4.95		
Gifford	1953	3.08				
Dawson et al.	1960	3.98				
Klett et al.	1965	3.51				
Schwulst et al.	1966	4.16	3.0		8.58	12.73
Melton et al.	1967	2.79			8.81	11.6
Gleddie and Berg	1968	3.9	3.5		9.1	13.0
Todd et al.	1968	3.8			8.7	12.5
Jeffery and Berg	1970	4.93	3.61		9.09	
Abadia and Brink	1972	3.8			8.7	
Totusek et al.	1973	3.2				12.2
Cundiff et al.	1974	4.92			8.95	13.86
		5.18			9.04	14.21
Lamond et al.	1978	4.0				
Lawson	1980	5.4	3.92		9.66	
Chenette and Frahm	1981	4.89	3.31			13.33
		4.85	3.28			13.26
		4.90	3.34			13.31
Franke et al.	1883	4.9	3.1		8.9	13.8
McMorris and Wilton	1986	2.77	3.45	5.01		
Daley et al.	1987	5.95	3.16	5.06	8.95	
Mollett and Leighton	1987		3.7	4.0		
Beal et al.	1990	4.1	3.32	4.7	8.8	

RELATIONSHIP OF MILK PRODUCTION, MILK EXPECTED PROGENY DIFFERENCE, AND CALF WEANING WEIGHT IN ANGUS AND SIMMENTAL COW-CALF PAIRS

by

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ABSTRACT

Milk expected progeny differences (Milk EPDs) have been reported by all the major beef cattle breed associations to predict the genetic milk production potential of a parent's daughters. These values are actually one-half of the breeding value for the trait. The objectives of this trial were to determine the relationship between a cow's milk EPD and her milk production and offspring weaning weight. One hundred and fourteen Angus (AN) and eighty-two Simmental (SM) cows were milked via machine at 60, 104, and 196 d postpartum following overnight calf removal. Milk production measurements ($n = 899$) were fitted to lactation curves to determine individual's total milk yields. Milk samples from each milking were analyzed for fat, protein, lactose, and solids. Calf weaning weights were adjusted for weaning age. Simple correlations between 205-d total milk yield (TMY) and calf weaning weight (WW) were .30 ($P < .0001$) and .47 ($P < .001$) for AN and SM, respectively. Milk EPD was correlated to WW ($r = .38$, $r = .39$, $P < .001$) and TMY ($r = .32$, $r = .44$; $P < .001$) for AN and SM, respectively. Regression coefficients for AN and SM showed that $.015 \pm .006$ kg ($P < .0001$) and $.025 \pm .005$ kg ($P < .0001$) of WW resulted from each addition of one kg of TMY, respectively. One kg change in milk EPD resulted in 4.82 ± 1.01 ($P < .0001$) or $2.90 \pm .99$ ($P < .003$) change in WW and 42.5 ± 16.6 kg ($P < .01$) or 69.3 ± 16.0 kg ($P < .01$) change in TMY for AN and SM. respectively. Additionally, correlations between quantity of specific milk components and WW were higher than correlations between percent of milk components and WW in both breeds. These data confirm that milk EPDs do predict milk production and

differences in calf weaning weights and confirm that milk EPDs can be useful tools for beef cattle breeders.