EVALUATION OF MILK YIELD AND UDDER CHARACTERISTICS IN BEEF COWS SIRED BY HIGH AND LOW MILK EPD BULLS

By

KYLE JEFFREY STUTTS

Bachelor of Science

Texas A&M University

College Station, Texas

1999

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
August, 2001

EVALUATION OF MILK YIELD AND UDDER

CHARACTERISTICS IN BEEF COWS SIRED

BY HIGH AND LOW MILK EPD BULLS

Thesis Approved:

Thesis Advisor

Dean of the Graduate College

ACKNOWLEDGEMENTS

I would like to begin by thanking Dr. David Buchanan for this opportunity and for his support and guidance with this study and throughout my time here at Oklahoma State University. I feel privileged to have been given the opportunity to work with someone whom I have come to admire due to his sincerity, fairness, and concern for students.

I would also like to thank the other members of my graduate committee, Dr. Jerry Fitch and Dr. David Lalman. I greatly appreciate their input and their willingness to help, and I thank them for giving up their time to assist me with this project.

To the guys out at the Lake Carl Blackwell North Range, Leon Knori, Jory Bailey, Matt Fullbright, and Joe Steele, your help is greatly appreciated. I really appreciate all of the effort you put into the research projects and for being such good people to work with. In addition, I would like to thank fellow graduate student Serkan Erat for the countless hours he has put in at the range with us.

I thank Carol Bradley for all of her hard work and for keeping everything running smoothly around the office. I greatly appreciate her willingness to help with the projects or whatever else may arise.

I would like to thank my parents and other family members for their encouragement and support throughout my life and during my studies here at OSU. A special thanks goes to my wife, Erin, for her patience and willingness to help. Many long weekends and late nights that I should have spent with her I spent in my office writing this thesis and I greatly appreciate her understanding, love, and support.

Last, but not least, I would like to thank all of the other graduate students here in the animal science department. I appreciate the opportunities you have given me to assist with your projects and I am tremendously grateful for your help with mine. I will always cherish the friendships and the experiences we have shared together.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

NOMENCLATURE

ADG	Average Daily Gain
cm	centimeters
d	day(s)
EPD	Expected Progeny Difference
h	hour(s)
kcal	kilocalorie
kg	kilogram(s)
mm	millimeter(s)
WSW	Weigh-suckle-weigh method
yr	year(s)

CHAPTER I

INTRODUCTION

Milk production is a major factor contributing to the weaning weight of calves, and weaning weight is one of the most important factors determining the profitability of any cow-calf operation. For these reasons, improvement of calf weaning weight is often of high priority and can be accomplished through selection. This selection can be achieved within a herd, however, a more rapid change can be obtained by introduction of animals from outside the herd. Calves require not only the genetic potential for growth, but also a desirable environment in which to express those genes. The cow's maternal ability or milk production supplies a great portion of this environment. A large body of evidence indicates that while weaning weight is influenced by many factors, supply of milk is the single most important component. This maternal ability can be evaluated using Milk Expected Progeny Differences (EPD). Milk EPD provide a method of comparing sires based on the maternal performance of their daughters. The milk EPD is expressed in pounds of calf produced by these daughters, not pounds of milk as one may suspect. Therefore, by using milk EPD to compare bulls, effective selection pressure can be placed on weaning weight.

Experimental evaluation of EPD is in order to evaluate their effectiveness when used in a selection program and to predict subsequent improvement in performance.

Milk yield of beef cows has been estimated using various methods. These methods include hand-milking, machine milking with or without prior injection of oxytocin to stimulate milk ejection, weighing the calf before and after nursing, and indirectly by weighing the calf at weaning. These estimates of milk yield of grazing cattle have been made at intervals varying from weekly to five times during the entire lactation. Although each of these methods has been studied in relatively great detail, much controversy still remains as to which method best estimates milk production in beef cows in terms of accuracy, precision, and repeatability. Still, when determining which method to use in a particular situation, practicality and availability of resources should be the deciding factors.

In an attempt to more accurately predict milk production in beef cattle, numerous researchers have studied body, udder, and teat measurements and conformation scores to investigate correlations between various physical characteristics and milk production. Such measurements include length of teats, distance between teats, diameter of teats, circumference of udder, length of udder, and depth or height of udder. Conformation scores have been assigned to each teat individually and to the udder itself as well as to the suspension of the udder. Such studies were conducted in hopes of discovering alternative avenues to accurately estimate the genetic potential for milk production to increase net income of cow-calf operations by producing heavier calves at weaning.

The purpose of this study was to evaluate the differences in milk producing ability of cows bred for divergent milk production based on milk EPD of their sires and to evaluate the differences in selected udder characteristics of these same cows. In addition, relationships among the selected udder characteristics and milk production will be analyzed to determine how these associations can be used to develop criteria for selection of bulls on the basis of measurements during one lactation of their daughters.

CHAPTER II

REVIEW OF LITERATURE

In today's beef industry, calves marketed at weaning are predominantly sold on a weight basis, therefore, it is essential for producers to understand methods by which weaning weight can be managed to maximize profitability. Preweaning gain is greatly influenced by the milk production of the cow and the genetic merit for growth expressed in the calf. It is evident that milk production plays a key role in the production efficiency of any beef cattle operation. Selection for milk production can be aided by the use of expected progeny differences (EPD). The use of EPD to evaluate genetic merit for milk production has allowed producers to optimize the maternal ability of their cows for their particular environment.

Milk EPD

The Expected Progeny Difference (EPD) is an estimate of the genetic merit of an individual animal as a parent when compared to another individual animal of the same breed. For a given trait, the difference in EPD values between two parents of the same breed represents the actual difference a producer can expect from future offspring, when each of the parents are bred to mates of equal value. EPD are used to describe the genetic merit of an individual for a specific trait of economic importance. The Milk EPD is unique because it predicts the genetic merit of a bull for maternal traits that will be expressed in his daughters. The Milk EPD predicts differences in weaning weights of calves out of a bull's daughters. This EPD is measured in units of calf weaning weight, not units of milk produced. EPD are used by producers to compare animals and rank them as potential parents. The reliability of EPD can be determined by regressing the performance of an individual on its own EPD, or the EPD of parents, and comparing the expected value to that of the calculated regression coefficient (Mallinckrodt et al., 1993). In most cases, the actual difference in weaning weight is larger than that of the expected value based on the EPD.

Marston et al. (1992) investigated the relationship of milk EPD of a dam to actual milk production and offspring weaning weights in Angus and Simmental cattle. They determined simple correlations between 205-d total milk yield and adjusted 205-d calf weaning weights of 0.30 and 0.47 for Angus and Simmental, respectively. In addition, milk EPD was positively correlated to adjusted WW ($r = .38$, $r = .39$) and total milk yield ($r = .32$, $r = .44$) for Angus and Simmental, respectively. The authors determined that a 1 kg change in milk EPD resulted in a 4.85 ± 1.14 kg change in WW in Angus and a 3.74 ± 1.73 kg change in WW in Simmental. They concluded that milk EPD should be useful for changing milk production potential in the beef cattle industry, and that milk EPD seem to be conservative in estimating genetic differences.

Marshall and Long (1993) studied the effect of sire EPD on crossbred cows. They found that a 1 kg change in sire's milk EPD was associated with a 13.4 kg change in daughter 214-d milk yield. The differences in daughter's milk yield were positively related to differences in sire's milk EPD although the magnitude of the relationship was somewhat less than the expected 20.4 kg/kg change in cumulative milk based on genetic evaluation theory. A 1 kg change in sire total maternal weaning weight EPD was associated with a 1.18 kg change in daughter's calf weaning weight. This value is greater than it's theoretical expectation of one. Although rather low, positive correlations were determined between daughter milk yield and sire milk EPD ($r = .14$) and sire total maternal weaning weight EPD ($r = .14$). Correlations of weaning weight with both sire milk EPD ($r = .18$) and sire total maternal weaning weight EPD ($r = .17$) were also relatively low and positive. The authors concluded that differences among sires in milk and total maternal EPD, on average, were positively related to actual crossbred daughter milk production and daughter's offspring weaning weight. The magnitudes of such relationships were relatively modest in terms of selection response, but they were reasonably consistent with theoretical expectations.

In a study using the Hereford and Simmental breeds, Mallinckrodt et al. (1993) evaluated the relationship of calf weaning weights and estimates of 205-d milk yield with total maternal EPD and maternal milk EPD. They reported that changes in calves' 205-d adjusted weights were greater than predicted by maternal milk EPD of dams of both breeds and Hereford maternal grandsires, but were similar to changes predicted by Simmental maternal grandsires. These changes in calf 205-d adjusted weights were also greater than those predicted by total maternal EPD of Hereford dams and maternal grandsires, but were similar to those predicted in Simmental dams and maternal grandsires. Results of this study indicated that maternal milk and total maternal EPD are reasonably good predictors of genetic differences in milk yield and weaning weight.

Diaz and Notter (1991) found a $0.69 \pm .19$ kg change in adjusted weaning weight for every 1 kg change in grandsire milk EPD ($P < .0004$) in calves from Hereford x Angus cows. Even though this was less than the expected value of one, they reported that selection of purebred sires using EPD accurately predicted performance of their crossbred progeny.

In a study utilizing Herefords, Diaz et al. (1992) reported that the relationship between the milk EPD of sires and the actual milk production of daughters was positive and linear. The study found correlations of .26 ($P < .01$) and .20 ($P < .05$) between sire's milk EPD and daughter's milk production, and grandsire's milk EPD and calf's weaning weight, respectively. They also concluded that EPD of purebred sires accurately predict performance of crossbred daughters.

Milk Production

Milk production has a great influence on calf weaning weight and has been studied extensively in beef cows (Lamond et al., 1969; Totusek et al., 1973; Belcher and Frahm, 1979; Chenette and Frahm, 1981; Butson and Berg, 1984; Jenkins and Ferrell, 1984; Bourdon and Brinks, 1987; Mallinckrodt et al., 1993; Marshall and Long, 1993). In order for maximum performance to be achieved, peak lactation, and shape and duration of lactation curves must be understood to ensure that nutritional requirements are met. This will allow for the most efficient production of calves and thus maximizing net returns.

The lactation curve for beef cows varies among breeds and levels of milk produced. The curve tends to be more convex for higher milking cows and more linear for lower milking cows (Gaskins and Anderson, 1980). Kress and Anderson (1974) reported a quadratic lactation curve, while Gleddie and Berg (1968) found a significant linear decrease in milk yield over the lactation.

Mallinckrodt et al. (1993) and Jenkins and Ferrell (1984) both reported that milk production increased rapidly until it reached a peak at approximately d 60 of lactation. Much variation has been found among breeds in the time of peak milk yield (Jenkins and Ferrell, 1992), and different crosses have also been found to peak at different times (Jenkins and Ferrell, 1984; Butson and Berg, 1984b). Some studies have indicated that Herefords tend to peak relatively early compared to other breeds (Jenkins and Ferrell, 1992; Kress and Anderson, 1974). Clutter and Nielson (1987) found that low producing cows peaked earlier in lactation than high producing cows. After peak lactation, milk production steadily declines (Kress and Anderson, 1974; Robison et al., 1978; Chenette and Frahm, 1981). By weaning, cows were producing very little to no milk (Kress and Anderson, 1974). In addition, much of the difference in milk production between breeds had diminished by weaning (Hardt et al., 1988).

Mallinckrodt et al. (1993) reported that peak milk yield occurred at about d 60 of lactation in both Polled Hereford and Simmental and that higher producing cows had a more rapid decline in production after the peak. They also determined a positive correlation ($r = .24$) between calf birth weight and milk yield in Polled Hereford cows, however this result was not significant.

Clutter and Nielson (1987) found that in a group of cows bred for high, medium, or low milk production based on genetic potential of their breed of sire, high milk cows reached their peak of lactation on average at d 58. Medium and low milk producing cows reached their peak on average about one week earlier. The high group tended to maintain that level for a longer period of time when compared to the low and medium groups. They also noted that differences in milk production among the groups increased as the cows aged. The pooled, within milk-group correlation between calf gain to 205 d and milk intake was 0.60.

Jenkins and Ferrell (1992) reported that Herefords reached peak milk production earlier than Angus, Braunvieh, and Red Poll. However, Charolais, Gelbvieh, Limousin, Pinzgauer, and Simmental cows did not differ in time at which peak milk production was achieved. They also reported that cows fed 210 vs 170 kcal of metabolizable energy per unit of metabolic body weight achieved peak lactation later at which time peak yield was found to be higher. These results are consistent with findings of Broster and Broster (1984) who determined that, in dairy cows, peak was delayed and yield at that time was increased as energy allowance increased.

Neville (1962) evaluated milk yield using the weigh-suckle-weigh method and determined that nutrition coupled with genetic merit for milk production of the cow can have an effect on growth of the calf. Also, nutrition available to the calf other than that supplied by milk, such as pasture or creep feed, may make it difficult to determine how much of the calf performance can be explained by cow milk production. Ultimately, he discovered a range of 400 to 4200 lbs of milk produced by the Hereford cows during the eight-month lactation. It was concluded that the first 60 d of lactation contributed more to differences in calf weight gains compared to the latter stages of lactation.

Jeffrey et al. (1971a) concluded that milk yield had the greatest influence on preweaning performance, explaining about 60% of the variation in average daily gain (ADG) to weaning and 40 to 50% of the variation in weaning weight. A 1-kg increase in daily milk yield resulted in an 11- to 14-kg increase in weaning weight. Breed of dam explained about 23% of total variance in ADG to weaning, most of which was accounted for by breed differences in milk yield.

Gifford et al. (1949) found that calf weight gain and milk yield of Hereford cows were significantly correlated only during the first four months of lactation. He also found indications that milk production during the first six months was a direct result of consumption capacity of the calves. Higher producing cows that supplied an amount above that which was consumed by the calves would adjust to the amount of consumption of the calf and produce less milk than they were capable of, thus the advantage of high producing cows was lost.

Gleddie and Berg (1968) found no sex of calf or calf birth weight effect on milk production of the dam. However, breed of dam did explain 82.5% of the variation in average milk yield, and 71.3% of the variation in calf ADG was attributed to milk yield. In comparing crossbred and purebred Hereford cows, Anderson et al. (1986) reported that heterosis accounts for an increase in milk production of 21%.

The effect of sex of calf on milk production is highly variable from females receiving more milk (Jeffrey et al., 1971b; Rutledge et al., 1971), to no effect of sex of calf (Robison et al., 1978; Lawson, 1981; Butson and Berg, 1984a), to males receiving more milk (Pope et al., 1963; Jeffery et al., 1971a; Daley et al., 1987). Most studies reported that male calves were significantly heavier at weaning than female calves (Linton et al., 1968; Brown et al., 1970; Lawson, 1976; Butson et al., 1980). Sex of calf accounted for 8.41% (Linton et al., 1968) and 17% (Cundiff et al., 1966) of the variance in weaning weight. However, there are studies that indicate that sex of calf did not affect weaning weight (Gregory et al., 1950; Marston et al., 1992).

No significant differences existed between younger (3 and 4 yr) and older (≥ 9 yr) Polled Hereford cows when comparing them based on total milk production (Boggs et al., 1980). Butson and Berg (1984a) found that dams ranging in age from 3 yr to maturity produced 25 to 39% more milk than 2 yr-old cows, respectively. Rutledge et al. (1971) reported a quadratic response of age of cow on milk production with peak occurring at 8.4 yr in Hereford cows.

Sheldon (1983) determined that heavier fetuses could stimulate an increase in milk production due to an increase in placental lactogen secretion. It was also demonstrated that the effect of the environment on production is quite large and that a sufficient environment must exist in order to support the genetic potential for milk production. This was justified by the fact that, in mature cows during years with an abundance of available forage, the calf birth weight effect had a more positive relationship with milk production.

Furr and Nelson (1964) determined that milk production was lowest during the winter months for fall calving range beef cows in north central Oklahoma. Availability of spring grass supported a recovery in milk production and cows that were on a lower level of feed through the winter showed the most dramatic increase in milk production.

Means of Measurement

There are several different methods for measuring milk yield in beef cows. These methods include weigh-suckle-weigh (WSW), machine milking with oxytocin injection, hand milking, and udder cannulation. The two most widely used methods are WSW and machine milking. Some studies have reported no differences in milk production estimates between these two methods (Schwulst et al., 1966; Wistrand and Riggs, 1966). Others have found the estimates were greater with WSW (Mondragon et al., 1983) or greater with machine milking (Belcher et al., 1980). Correlations that have been reported between average WSW milk yield and average machine milk yield: 0.469 (Belcher et al., 1980), 0.58 (Gleddie and Berg, 1968), and 0.77 (Beal et al., 1990). Totusek et al. (1973) studied the differences between WSW and hand milking. The WSW estimates of milk production were higher than the hand milking estimates, and the methods had different lactation curves. The WSW method was more precise, and the correlation between the two methods at three evenly spaced intervals was 0.92, 0.95, and 0.95. Wistrand and Riggs (1966) also evaluated the machine milking and calf nursing methods. They determined that the two methods predicted similar yields.

Beal et al. (1990) determined that the mechanical milk collection procedure had higher repeatability than the WSW method. They also determined that the time of separation had no effect on milk production estimates. It was reported that the mechanical milk method was a more accurate indicator of milk production when only one estimate was made. However, the ability of the WSW method to estimate milk production was similar to that of the mechanical milking method when four WSW were performed.

Three methods of estimating milk yield in beef cows were evaluated by Lam et al. (1970). They determined that allowing the calf to nurse first then administering oxytocin to stimulate residual milk removal resulted in the highest estimates of 24-h milk production. Results of this method are calculated by adding calf weight change to the amount of residual milk collected. Lower estimates of milk production were obtained when cows were given oxytocin to evacuate udders and six hours later another injection of oxytocin was administered followed by milk collection using catheters. The lowest estimates of milk production were obtained by the WSW method. Calves were allowed to nurse the prior afternoon and then separated from the cows. WSW was performed the following morning and afternoon, and the two estimates were combined to estimate 24-h milk production. Results from these three methods were not significantly different.

Totusek et al. (1973) reported estimates of milk yield utilizing the WSW method were higher and less variable than hand milking estimates at every stage of lactation. Average daily milk yield for 210 d estimated by the WSW method was 29% higher than the yield estimated by hand milking. They determined that a limited number (2 to 4) of daily estimates of milk yield throughout the lactation could provide an accurate estimate of total milk production. Correlations between daily milk yield and total milk yield based on estimates of two or more selected days generally increased with each additional estimate.

Williams et al. (1979) studied the WSW method using Hereford cows. Separation intervals of 4, 8, and 16 h were compared to determine their effect on estimates of milk production. They reported correlations of 0.25, 0.46, and 0.45 between calf ADG and 4-, 8-, and 16-h production estimates, respectively, and indicated that when production was estimated to a 24-h basis measurement errors were ± 1.4, ± 0.7, and ± 0.3, respectively. They recommended an 8-h separation time due to the fact that 16 h was not natural and resulted in a distended condition of the udder, and 4 h had greater measurement error and lower correlation with ADG. Lamond et al. (1969) stated that the calf suckles many times each day and storage capacity of the udder is unlikely to limit milk production in the field. Therefore, any long separation period such as 8 or 16 h could underestimate the true secretion rate in cows with small mammary glands.

Christian et al. (1965) indicated that frequent nursing may prevent pressure build-up in the udder and allow a greater amount of milk intake over a 24-h period. Drewry et al. (1959) reported that the average number of times calves suckled per day were 4.6, 4.8, and 3.0 times for the first, third, and sixth month of lactation, respectively. Day et al. (1987) performed two experiments to determine whether suckling behavior of calves with similar growth potential varies depending on the dam's estimated milk production level and stage of lactation. They reported that frequency of suckling was associated with milk production level of the cow, and the pattern of nursing changes as the lactation period progresses. This was in agreement with Williams et al. (1977) who reported that as calves got older they tended to nurse less often and they tended to supplement their diets from other sources as their capacity for milk increased.

By taking repeated measurements of milk production, a more accurate estimate of total milk production could be calculated. The correlation between measured milk yield and total milk production was 0.80 (Totusek and Arnett, 1965) and 0.87 for two estimates; 0.91 for four estimates; and 0.93 for five estimates (Totusek et al., 1973). There was greater variation in milk estimates later in lactation. Using the WSW method, early estimates indicated calf capacity while later estimates were indicative of cow production and persistency (Totusek et al., 1973). Repeated measures of calf gain were highly correlated as well. Correlations between calf ADG over three different periods ranged from 0.74 to 0.99 (Reynolds et al., 1978). Correlations of ADG with individual estimates of milk yield by WSW ranged from 0.24 to 0.44 (Beal et al., 1990), and from 0.82 to 0.88 (Totusek et al., 1973). Correlations of ADG with individual estimates of milk yield by mechanical milking ranged from 0.70 to 0.74 (Beal et al., 1990), and correlations of ADG with individual milk yield estimates by hand milking ranged from 0.73 to 0.83 (Totusek et al., 1973).

Although each of these methods has been studied in relatively great detail, much controversy still remains as to which method best estimates milk production in beef cows in terms of accuracy, precision, and repeatability. Still, when determining which method to use in a particular situation, practicality and availability of resources should be the determining factors as to which method should be used.

Relationships of Udder Characteristics with Milk Yield

Milk yield of the cow is one of the most important factors influencing calf growth and production. The actual amount of milk that a calf receives may be dependent on the size and shape of the teats. Some breed associations have developed a scoring system to evaluate the total mammary system, but little information is available to evaluate the usefulness of these systems in a beef production system. The dairy industry has evaluated udder conformation for many years using descriptive type scores and has found a positive relationship between udder size and milk production (Kersey DeNise et al., 1987). The udder dimensions that are generally of interest are teat length, distance, diameter, and udder length, width, depth, and height. Teat length is recorded as the distance from the point of attachment to the udder to the distal end of the teat. This measurement may be subjective in that the point of attachment to the udder is not always clear, but this problem can be alleviated when the same person consistently makes the measurements. Measurement of the distance between the alignment at the front and rear teats determines teat distance, and udder height as measured by Moore et al. (1981) is considered to be the distance from the tip of the front teat to the floor.

Tomar (1973) studied udder and teat measurements and their relation with milk production in Hariana cattle. He found that the length and width of the udder for all calvings averaged 39.4 cm and 34.3 cm, respectively, and that both measurements increased gradually through the fourth lactation, and then declined in the fifth lactation. The average depth of udder in this herd was found to be 17.8 cm. Lactation had a significant effect on udder depth, which averaged 15 cm for cows in their first lactation to 23 cm for cows in their fifth lactation. A significant increase in length of both the fore and rear teats was noted as cows increased in lactation number, and the udder became more pendulous as cows increased in age. Udder length ($r = .455$) and udder width ($r = .481$) were highly associated with milk production for all calvings. This study also revealed that the correlation between milk yield and fore and rear teat length were positive at all lactations. The correlation for all calvings between milk yield and fore and rear teat length were 0.352 and 0.362, respectively (Tomar, 1973).

Qureshi et al. (1984) studied the correlation of teat measurements and teat and udder shape with milk yield in Gir cows. Teat length, teat diameter, and teat placement were measured, and the frequency of different types of udders and teats were determined. Milk yield was comprised of the average of three days (day prior to measurements, day of measurements, and day following measurements). They found that the front teats were significantly longer than the rear teats and that the distance between the front teats was significantly greater than the distance between the rear teats. Teat length was correlated to teat diameter (r = .492), teat placement (r = .406), and test milk yield (r = .315). Teat diameter was also significantly correlated with teat placement (r = .282) and test milk yield (r = .289). Udders were classified into three types: bowel type, rounded type, and goat type. The bowel type udder had the highest frequency (56.0%) followed by the rounded type udder (42.5%). Brantov (1966) found similar results in Red Steppe cows. The rounded type udder had the highest frequency (52.6%) followed by the cup-shape type udder (42.6%) and the goat type udder (4.8%). Milk yield was 12% higher for cows with a cup-shaped udder compared to cows with a goat-type udder with cows having a rounded udder being intermediate (Brantov, 1966). The different teat types in Gir cows were also studied and their frequencies were reported. Cylindrical type teats were found to have the highest frequency (62.0%) followed by funnel shaped teats (31.0%) and bottle shaped teats (7.0%; Qureshi et al., 1984).

Teat length and circumference, distance between teats, and udder length, depth, size, and index were studied by Borodin (1963) in Simmental cattle during the second month of lactation. Milk yield was determined to be correlated with udder length (r = .177), udder depth (r = .357), and udder size (r = .392). Cows that had the highest milk yields had cup-shaped udders with a length not exceeding 50 cm and a depth 90 to 100% of this. Fuhrer (1961) also studied Simmental cattle and reported correlations between milk yield and horizontal udder circumference (r = .599) and udder volume (r = .661). Borodin (1963) suggested that, in selection, udder measurements should be used in addition to visual appraisal.

Tavildarova et al. (1963) studied udder shape and size of various breeds of cows in Kazakhstan and indicated that, within breeds, the milk yield of cows with cup-shaped udders exceeded that of cows with rounded udders by 6.0 to 18.1%. In general, rounded udders had a smaller circumference, relatively greater depth, and the teats were closer together when compared to cup-shaped udders. Although there was no appreciable difference in teat length, the fore teats tended to be longer than the rear teats, and rounded udders tended to have longer teats than cup-shaped udders. While teat length and thickness did not vary appreciably during lactation, udder circumference and depth, and the distance between the teats decreased as lactation progressed (Tavildarova et al., 1963).

Kebe (1994) reported that cows sired by high milk EPD bulls had udders that were significantly more pendulous and had greater distance between teats than cows sired by low milk EPD bulls. The author also found positive phenotypic correlations between milk yield and total distance between teats, average teat length, and udder support score. He concluded that total distance between teats, a measurement that was highly repeatable, may be a useful indicator of udder circumference, size, or volume which are highly correlated to milk yield but are more difficult to measure.

Moore et al. (1981) tested the relationships of teat conformation and udder height to milk production in Holstein cows. They obtained similar results for front and rear teats but teat shape means differed significantly for total milk yield. Cows with funnel-shaped teats had significantly higher milk yields than cows with cylindrical-shaped teats, and yields from cows with bottle-shaped teats were intermediate to these two groups. They also found that teat length increases with age and estimated correlations between age at calving and teat length of 0.33 and 0.30 for front and rear teats, respectively. Simple correlations between udder height and total milk yield (r = -.32) and 305-d milk (r = -.34) were strongly negative. There was also a strong negative association between udder height and age at calving indicating a weaker attachment of the udder in older cows. Each centimeter increase in udder height was associated with a decrease of 46 kg in 305-d milk. They found it apparent that cows with deep udders yield more milk (Moore et al., 1981).

Frisch (1982) reported an optimum range for teat length in beef cattle. The weaning weights of calves from cows with all four teats ≤ 50 mm long were 5.0 kg lighter than calves from cows with at least one teat > 50 mm long, presumably due to lower milk production associated with shorter teats. The mortality rate of calves born to cows with at least one teat ≥ 90 mm long was significantly higher than calves born to cows with all four teats < 90 mm long. The high mortality rate was due to the association of teat length with teat width. Teats ≥ 90 mm in length had true milk cistern hernia and in consequence also had teat widths ≥ 45 mm in diameter (teats ≥ 35 mm in diameter were classed as bottle teats). Further results indicated that incidence of supernumerary teats showed no consistent pattern and no relationships with any production trait were found.

Kersey DeNise et al. (1987) analyzed the relationship of cow longevity and calf weights with udder shape and udder capacity of Hereford cows ranging in age from 3 to 10 yr old. Scores for udder capacity and udder shape along with calf weights were recorded on approximately d 75 and 205 of lactation. Age of cow was a significant source of variation for both udder shape and capacity. Day of lactation was a significant source of variation for udder capacity; as lactation progressed udder capacity score declined indicating a decrease in udder size. Correlations between udder shape and udder capacity were low, ranging from -0.10 in 3 yr old cows to 0.10 in 6 yr old cows. Neither of these characteristics affected the number of years cows remained in the herd, but cows with unbalanced udders had more udder defects. The regressions of early weight of the calf and weaning weight of the calf on udder capacity score were significant within each age of cow. However, little of the variation in weights at either age was explained by udder capacity.

Batra and McAllister (1984) examined the heritabilities and phenotypic and genetic correlations among udder measurements and milk yield in Holstein and Ayrshire heifers during first lactation. Phenotypic correlations of teat length, teat diameter, and teat distance with udder height were all negative suggesting that longer and wider teats tended to be associated with deeper udders that were closer to the ground. Phenotypically, udder height was significantly negatively correlated with milk yield, while genetically teat diameter and teat distance were positively correlated with milk yield in the Ayrshire heifers. This indicates that selection of heifers with greater distance between teats would result in higher milk production during the first lactation. They concluded that heritability estimates of udder measurements and milk yield were moderate and that selection for these traits would likely succeed, and that little importance should be given to the udder measurements in heifer selection since only front teat diameter and teat distance were genetically related to milk yield.

Lin et al. (1987) investigated correlations between milk production traits and udder measurements during the first lactation of Holstein heifers. They reported that teat lengths and teat diameters were positively correlated genetically and phenotypically. Udder height had slight negative genotypic and phenotypic correlations with teat length, diameter, and distance. High producing heifers had longer teats, greater teat diameter, greater distance between teats, and lower udders than low producing heifers. Petersen et al. (1985) also reported that high producing cows had greater distance between teats, greater udder perimeters, and larger areas of the udder floor. Udder height was more closely related, genetically and phenotypically, to first lactation yield traits than teat length, diameter, or distance (Lin et al., 1987). This signifies the difficulty to be encountered in selecting for high milk yield with good udder suspension.

In conclusion, the importance of beef cow milk yield on calf weaning weight is widely accepted and selection for this trait is effective to make genetic improvement in calf performance. Differences in milk EPD of sires are positively related to differences in milk production of their daughters. Much variation exists among breeds as well as within breeds for total milk production, peak milk yield, day of peak lactation, and rate at which milk production declines following the peak. Both genetic and environmental factors contribute to this variation. With respect to milk yield, the greatest difficulty that arises seems to be that of accuracy of measurements. Though controversy exists as to which method best estimates milk yield, the WSW method is the most widely used method of milk yield estimation. Other methods that can be used are hand milking, machine milking, or machine milking with oxytocin injections. The basis for using udder measurements and scores is to correlate those measurements with milk yield of the cow. The conformation and size of the udder as well as the shape and size of the teats all play a critical role in the amount of milk a cow produces as well as the ability of the calf to nurse.

LITERATURE CITED

Batra, T. R. and A. J. McAllister. 1984. Relationships among udder measurements, milking speed, milk yield, and CMT scores in young dairy cows. Can. J. Anim. Sci. 64:807.

Beal, W. E., D. R. Notter, 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., 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. Agr. Exp. Sta. Anim. Sci. Res. Rep. MP-107:6.

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

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

Borodin, G. M. 1964. Evaluation of the cow's udder by measurements. Anim. Breed. Abstr. 32:304.

Bourdon, R. M., and J. S. Brinks. 1987. Simulated efficiency of range beef production. I. Growth and milk production. J. Anim. Sci. 65:943.

Brantov, J. 1966. The udder of Red Steppe cows. Anim. Breed. Abstr. 34:32.

Broster, W. H., and V. J. Broster. 1984. Long term effects of plane of nutrition on the performance of dairy cows. J. Dairy Res. 51:149.

Brown, C. J., M. L. Ray, F. Smith, and R. M. Smith, Jr. 1970. Factors affecting weaning traits of beef calves in eastern Arkansas. Ark. Agr. Exp. Sta. Bull. 750:3.

Butson, S., and R. T. Berg. 1984. Lactation performance of range beef and dairy-beef cows. Can. J. Anim. Sci. 64:253.

Butson, S., R. T. Berg, and R. T. Hardin. 1980. Factors influencing weaning weights of range beef and dairy-beef calves. Can. J. Anim. Sci. 60:727.

Chenette, C. G., and R. R. Frahm. 1981. Yield and composition of milk from various two-breed cross cows. J. Anim. Sci. 53:483.

Christian, L. L., E. R. Hausser, 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.

Cundiff, L. V., R. L. Willham, and C. A. Pratt. 1966. Effects of certain factors and their two-way interactions on weaning weight in beef cattle. J. Anim. Sci. 25:972.

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

Day, M. L., K. Imakawa, C. A. 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.

Diaz, C., and D. R. Notter. 1991. Are expected progeny differences of Polled Hereford sires for milk expressed in commercial crossbreeding. J. Anim. Sci. 69(Suppl. 1):218 (Abstr.).

Diaz, C., D. R. Notter, and W. E. Beal. 1992. Relationship between milk expected progeny differences of Polled Hereford sires and actual milk production of their crossbred daughters. J. Anim. Sci. 70:396.

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.

Frisch, J. E. 1982. The use of teat measurements or calf weaning weight as an aid to selection against teat defects in cattle. Anim. Prod. Sci. 32:127.

Fuhrer, H. 1961. Results of udder examinations in German Simmental cows. Anim. Breed. Abstr. 29:417.

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 found overestimated. J. Anim. Sci. 8:605.

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.

Gregory, K. E., C. T. Clunn, and M. L. Baker. 1950. A study of some of the factors influencing the birth and weaning weights of beef calves. J. Anim. Sci. 9:338.

Jeffery, H. B., R. T. Berg, and R. T. Hardin. 1971a. Factors affecting preweaning performance in beef cattle. Can. J. Anim. Sci. 51:561.

Jeffery, H. B., R. T. Berg, and R. T. Hardin. 1971b. 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. Sci. 39:479.

Jenkins, T. G., and C. L. Ferrell. 1992. Lactation characteristics of nine breeds of cattle fed various quantities of dietary energy. J. Anim. Sci. 70:1652.

Kebe, S. 1994. Interrelationships among udder characteristics and milk yield of beef cows sired by high or low milk expected progeny difference bulls. M. S. Thesis, Oklahoma State Univ., Stillwater.

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

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

Lam, C. F., D. R. Lamond, J. R. Hill, Jr., and C. B. Loadhold. 1970. Three methods of estimating milk production of beef cows. South Carolina Agr. Exp. Sta. 6.

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

Lawson, J. E. 1976. Birth and weaning weights of Herefords and crosses among the Hereford, Highland, and Angus breeds. Can. J. Anim. Sci. 56:147.

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.

Lin, C. Y., A. J. Lee, A. J. McAllister, T. R. Batra, G. L. Roy, J. A. Veseley, J. M. Wauthy, and K. A. Winter. 1987. Intercorrelations among milk production traits and body and udder measurements in Holstein heifers. J. Dairy Sci. 70:2385.

Linton, A. C., J. S. Brinks, H. H. Stonaker, T. M. Sutherland, and L. C. Faulkner. 1968. Factors affecting weaning weights of cattle. Proc. West. Sect., Amer. Soc. of Anim. Sci. 19:319.

Mallinckrodt, C. H., R. M. Bourdon, B. L. Golden, R. R. Schalles, and K. G. Odde. 1993. Relationship of maternal milk expected progeny differences to actual milk yield and calf weaning weight. J. Anim. Sci. 71:355.

Marshall, D. M., and M. B. Long. 1993. Relationship of beef sire expected progeny difference to maternal performance of crossbred daughters. J. Anim. Sci. 71:2371.

Marston, T. T., D. D. Simms, R. R. Schalles, K. O. Zoellner, L. C. Martin, and G. M. Fink. 1992. Relationship of milk production, milk expected progeny difference, and calf weaning weight in Angus and Simmental cow-calf pairs. J. Anim. Sci. 70:3304.

Mondragon, I., J. W. Wilton, O. B. Allen, and H. Song. 1983. Stage of lactation effects, repeatabilities and influences on weaning weights of yield and composition of milk in beef cattle. Can. J. Anim. Sci. 63:751.

Moore, R. K., S. Higgins, B. W. Kennedy, and E. B. Burnside. 1981. Relationships of teat conformation and udder height to milk flow rate and milk production in Holsteins. Can. J. Anim. Sci. 61:493.

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

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

Qureshi, M. I., C. M. Taylor, and B. B. Singh. 1984. A note on teat measurements and shape of udder and teat and its correlation with milk yield in Gir cows. Indian Vet. J. 61:225.

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

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.

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

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.

Sheldon, C. 1983. Placental traits in beef cattle. M. S. Thesis, Colorado State Univ., Fort Collins.

Tavildarova, T. F., A. G. Panasenko, N. Kozahmetov, and N. Kulgarina. 1963. Udder shape and size of cows of various breeds in Kazakhstan. Anim. Breed. Abstr. 31:336.

Tomar, S. S. 1973. Udder and teat measurements and their relation with milk production in Hariana cattle. Indian J. Dairy Sci. 26:25.

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.

Williams, J. H. D. C. Anderson, and D. D. Kress. 1977. Nursing behavior of young Hereford calves. Proc. West. Sec., Amer. Soc. Anim. Sci. 28:35.

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

Wilson, L. L., J. E. Gillooly, M. C. Rugh, C. E. Thompson, and H. R. Purdy. 1968. Relation of milk and progeny growth traits of Angus x Holstein cows. J. Anim. Sci. 27:1512(Abstr.).

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

CHAPTER III

EVALUATION OF MILK YIELD AND UDDER CHARACTERISTICS IN BEEF COWS SIRED BY HIGH AND LOW MILK EPD BULLS

ABSTRACT

Maternal milk is an important factor influencing calf weaning weight and overall production efficiency in beef herds. The objective of this study was to determine the differences in milk production of crossbred daughters sired by high or low milk EPD Angus and Hereford bulls and to determine relationships between selected udder characteristics and milk production. Bulls (n = 35) were chosen from each breed to represent high or low milk EPD. Mean EPD in kg for high Angus (HA), low Angus (LA), high Hereford (HH) and low Hereford (LH) were + 8.7, - 6.1, + 7.4, and – 3.9, respectively. Cows used in this study were produced through the mating of these bulls to Hereford-Angus and Hereford-Angus-Brahman cows. They ranged in age from 7 to 10 yr old. All cows were bred by artificial insemination to South Devon bulls and calves were born in the spring from early February to early April and in the fall from early September through early November. Milk production data were collected 7 times prior to weaning at 28-d intervals using the weigh-suckle-weigh method. The final milk production data corresponded to a 205-d weaning age for all calves. Udder measurements and scores

were taken during periods three and six (d 93 and 177) after complete removal of milk from the udder by suckling. Cows were restrained in a squeeze chute and visual conformation scores were given to each teat and the udder. Linear measurements were taken on the length of each teat, distance between the front teats, distance between the rear teats, and the diagonal distance from the left front teat to the right rear teat. Data were analyzed using least squares. Factors included in the model were breed, milk EPD level, season, year, sex of calf (for milk production and calf performance data), age of dam, and all two-way interactions. Age of calf was included as a covariate. High milk EPD cows produced more ($P < .05$) milk than low milk EPD cows. Angus cows produced more ($P < .01$) milk than Hereford cows. Calves from high milk EPD cows were on average 19.8 kg heavier ($P < .03$) than calves from low milk EPD cows, and average daily gain was greater ($P < .04$) for calves from high milk EPD cows than calves from low milk EPD cows with all calves having similar ($P = .16$) birth weights. Average teat scores indicated that teats of high milk EPD cows were more ($P < .02$) funnel-shaped at d 93 of lactation and teats of low milk EPD cows were more cylindrical in shape. Hereford cows had longer ($P < .001$) teats than Angus cows at d 93 and 177 of lactation. Hereford cows had more ($P < .03$) pendulous udders at d 93 than Angus cows. These results further confirm the utility of milk EPD to predict differences in milk production and calf performance. These results also provide evidence that udder conformation of older high and low milk EPD cows is similar.

INTRODUCTION

Milk production of a dam is a major factor contributing to the weaning weight of her offspring, and weaning weight is one of the most important factors determining the profitability of any cow-calf operation. For these reasons, improvement of calf weaning weight is often of high priority and can be accomplished through selection. Improvement can be achieved through selection within a herd, however, a more rapid change can be obtained by introduction of animals from outside the herd. Calves require not only the genetic potential for growth, but also a desirable environment in which to express those genes. The cow supplies a great portion of this environment. A large body of evidence indicates that while weaning weight is influenced by many factors, supply of milk is the single most important component. This maternal ability can be evaluated using Milk Expected Progeny Differences (EPD). Milk EPD provide a method of comparing sires based on the maternal performance of their daughters. The milk EPD is expressed in kilograms of calf produced by these daughters, not kilograms of milk produced as one may suspect. Therefore, by using milk EPD to compare bulls, effective selection pressure can be placed on weaning weight.

In a study evaluating the effect of sire EPD on crossbred cows, it was determined that a 1 kg change in sire's milk EPD was associated with a 13.4 kg change in daughter 214-d milk yield (Marshall and Long, 1993). In this study, the differences in daughter's milk yield were positively related to differences in sire's milk EPD. A similar study verified that differences in milk production were similar to or greater than those predicted by maternal milk EPD or total maternal EPD. Maternal milk EPD was positively related heifers (Lin et al., 1987). In a study utilizing Holstein cows it was determined that teat shape means differed significantly for total milk yield. Cows with funnel-shaped teats had significantly higher milk yields than cows with cylindrical teats, and yields from cows with bottle-shaped teats were intermediate to these two groups. This study also revealed that cows with deeper udders yielded more milk (Moore et al., 1981).

The purpose of the present study was to evaluate the differences in milk producing ability of cows bred for divergent milk production based on milk EPD of their sires and to evaluate the differences in selected udder characteristics of these same cows. In addition, relationships among the selected udder characteristics and milk production were analyzed to determine how these associations could be used to develop criteria for selection of bulls on the basis of measurements during one lactation of their daughters.

MATERIALS AND METHODS

Data were collected on 208 cows during the spring and fall of 2000. Cows were sired by Angus and Hereford bulls that differed in milk expected progeny difference (milk EPD). Bulls (n = 35) were chosen to form four groups (High Milk EPD Angus n = 12, Low Milk EPD Angus n = 10, High Milk EPD Hereford n = 6, Low Milk EPD Hereford n = 7). Milk EPD averages differed by 14.8 and 11.3 kg for the Angus and Hereford sire groups, respectively (Table 1). These bulls were mated to Hereford x Angus or Hereford x Angus x Brahman crossbred cows that were ½ Hereford, ¼ Angus, ¼ Brahman or ½ Angus, ¼ Hereford, ¼ Brahman to produce crossbred females. Cows ranged in age from 7 to 10 yr old.

Table 1. Average milk expected progeny differences (EPD) (kg) of Angus and Hereford sires

Breed	n	Milk EPD level	Milk EPD
Angus	12	High	+8.7
Angus	10	Low	-6.1
Hereford	6	High	+7.4
Hereford	7	Low	-3.9

All cows were artificially inseminated to South Devon bulls during a 30-d breeding period. Following the artificial insemination period, cows were placed in pasture with crossbred bulls. Calves were born in the spring (n = 105) from early February to early April with an average birth date of March 2, 2000 (SD = 15 d). Calves were born in the fall (n = 103) from early September to early November with an average birth date of October 2, 2000 (SD = 18 d). Calves were weighed and all males were castrated within 24 h of birth. Calves received no creep feed. Cows were managed under spring or fall calving systems that are typical of commercial beef management systems. Pastures were either Bermudagrass or native range consisting of Big Bluestem, Little Bluestem, Indiangrass, Switchgrass, and Cheatgrass. Cows were maintained in moderate body condition. Protein supplement and hay were provided during the winter months.

Milk Production Evaluation. Milk production data were collected seven times prior to weaning at 28-d intervals using the weigh-suckle-weigh (WSW) method. Collection dates corresponded to d 37, 65, 93, 121, 149, 177, and 205 of lactation for both the spring and fall calving groups. Cows and calves were gathered from pastures and placed in holding pens the afternoon prior to WSW. Calves were separated from cows at approximately 1800. The following morning, at 0545, calves were placed with cows and allowed to nurse. While nursing, pairs were separated into smaller groups (approximately 18 cows/calves per pen). All calves were allowed to nurse until the udder was completely empty. This was done to ensure that all milk was removed from the udder at the beginning of the separation period. Upon completion of nursing, calves were separated from the cows. Later that morning, at 1145, calves were weighed and returned to their dams to nurse. After nursing, calves were weighed again and the difference between the two weights was the 6-h milk production of the cow. This procedure was repeated again later that day at 1745 to obtain another 6-h milk production estimate. These two 6-h estimates were used to calculate a 24-h milk production estimate for each cow. Residual milk and defecation or urination between weighings was considered random with respect to the groups. Milk production was analyzed on a monthly basis and as average milk production from the monthly estimates. Average milk production was spring or fall calving systems that are typical of commercial beef management systems. Pastures were either Bermudagrass or native range consisting of Big Bluestem, Little Bluestem, Indiangrass, Switchgrass, and Cheatgrass. Cows were maintained in moderate body condition. Protein supplement and hay were provided during the winter months.

Milk Production Evaluation. Milk production data were collected seven times prior to weaning at 28-d intervals using the weigh-suckle-weigh (WSW) method. Collection dates corresponded to d 37, 65, 93, 121, 149, 177, and 205 of lactation for both the spring and fall calving groups. Cows and calves were gathered from pastures and placed in holding pens the afternoon prior to WSW. Calves were separated from cows at approximately 1800. The following morning, at 0545, calves were placed with cows and allowed to nurse. While nursing, pairs were separated into smaller groups (approximately 18 cows/calves per pen). All calves were allowed to nurse until the udder was completely empty. This was done to ensure that all milk was removed from the udder at the beginning of the separation period. Upon completion of nursing, calves were separated from the cows. Later that morning, at 1145, calves were weighed and returned to their dams to nurse. After nursing, calves were weighed again and the difference between the two weights was the 6-h milk production of the cow. This procedure was repeated again later that day at 1745 to obtain another 6-h milk production estimate. These two 6-h estimates were used to calculate a 24-h milk production estimate for each cow. Residual milk and defecation or urination between weighings was considered random with respect to the groups. Milk production was analyzed on a monthly basis and as average milk production from the monthly estimates. Average milk production was analyzed instead of total milk production because data at d 65 of lactation for the fall calving group was not collected due to inclement weather. Average milk production is based on seven estimates for the spring calving group and six estimates for the fall calving group.

Udder Characteristics Evaluation. Udder characteristics were evaluated during periods three and six corresponding to d 93 and 177 of lactation after complete removal of milk from the udder by suckling. Cows were restrained in a squeeze chute and visual conformation scores were given to the udder and each teat. Teat shape and udder support were scored on a scale from one to nine as suggested by Ziehe (1989) and shown in Figure 1.

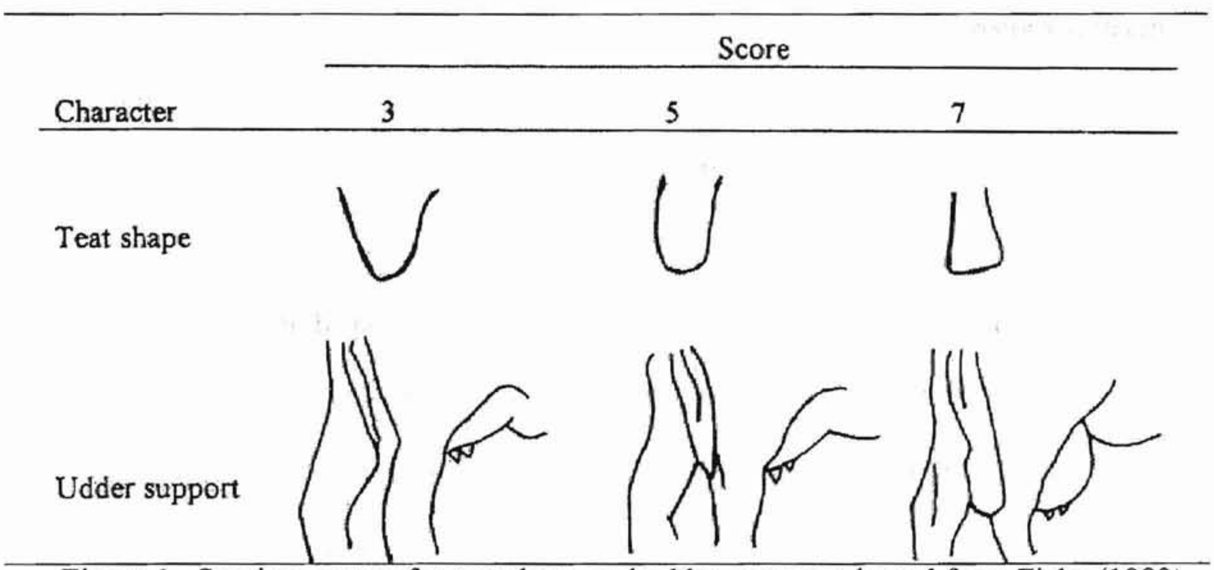

Figure 1. Scoring system for teat shape and udder support adapted from Ziehe (1989).

Teat shape scoring was rooted in the consideration that a cylindrical shape from top to bottom would be ideal with a score of five. Any deviation from that shape would either move toward a funnel shape, that when extreme was assigned a score of one, or toward a bulbous shape that when extreme was assigned a score of nine. For analysis of this trait, the four scores for each cow were averaged and the cow was assigned an average teat shape score. Udder support was scored on how appropriately the udder was attached to the abdominal cavity. A strong attachment reflected by the way the udder was held up into the body cavity was considered ideal and resulted in a score of one. When the attachment was loose in both front and rear, the udder was considered to have a very weak attachment and in the worst case a score of nine was assigned. A score of five was assigned for an average strength of attachment between the two extremes. All scores were assigned by the same person at all evaluations.

Linear measurements of udder dimensions included teat length, distance between the front teats, distance between the rear teats, and the diagonal distance from the left front teat to the right rear teat. Distance between the front teats, distance between the rear teats, and diagonal distance from the left front to the right rear teat were recorded in cm. These three values were summed and analyzed as total distance between teats. Measurements were made by the same operator at all evaluations using a metric ruler. For teat length, a score of one or two was assigned. A score of two was assigned when the distance between the point of attachment to the udder and the distal end of the teat was > 5 cm. If this distance was ≤ 5 cm, a score of one was assigned. For analysis of this trait, the four teat length scores for each cow were averaged and the cow was assigned an average teat length score.

Statistical Analysis. Milk production and calf performance data were analyzed using least squares analysis of variance using the MIXED procedure of SAS (1990) to determine the effects of breed, milk EPD level, season, age of dam, sex of calf, and all two-way interactions on 24-h milk production estimates and average milk production of cows, and birth weight, 205-d weaning weight, and average daily gain of calves. Age of calf was included in the model as a covariate.

Data on udder characteristics were analyzed using least squares analysis of variance using the MIXED procedure of SAS (1990) to determine the effects of breed, milk EPD level, season, age of dam, and all two-way interactions on average teat shape, average teat length, total distance between teats, and udder support scores. Age of calf was included in the model as a covariate. Interactions in both models were removed if they were confounded or if they failed to represent an important ($P < .30$) source of variation on the dependent variable. For these reasons, most interactions were removed from the model.

Residual correlations were calculated between average milk production and calf performance traits and all udder characteristics using the GLM procedure of SAS (1990). Correlations were calculated using the full statistical model from the analysis of each trait.

RESULTS AND DISCUSSION

Monthly Milk Production. Least squares means and standard errors for monthly milk production estimates by cow group with tests of significance are given in Table 2. Least squares means and standard errors for monthly milk production estimates main effects are shown in Table 3. Breed exhibited a significant effect at d 149 ($P < .005$) and d 205 ($P < .03$) at which time Angus cows had higher estimates of daily milk production than Hereford cows. Milk production estimates of Angus cows were higher at every measurement throughout lactation except for d 121. Breed differences varied throughout lactation indicating different lactation curves for Angus and Hereford cows (Figure 2). Differences among breed x milk EPD level groups were also observed (Figure 3). Gaskins and Anderson (1980) also reported that lactation curves for beef cows vary among breeds and levels of milk produced.

Although no differences were significant, cows sired by high milk EPD bulls had higher estimates of milk production at all stages of lactation. Marston et al. (1992) observed a positive correlation between milk EPD and total milk yield of 0.32 and 0.44 for Angus and Simmental, respectively. The breed x milk EPD level interaction was significant ($P < .05$) at d 65 of lactation. This interaction is due to the fact that Angus cows sired by low milk EPD bulls had higher estimates of milk production than Angus cows sired by high milk EPD bulls at that time.

Season had a significant impact on milk production at d 37, 93, 177, and 205. Spring-calving cows had higher estimated milk yields on d 37 ($P < .0001$) and d 93 ($P < .001$). Fall-calving cows produced more milk on d 177 ($P < .003$) and 205 ($P < .005$).

These days fell in the months of April through June for both spring- and fall-calving cows, and the differences can be attributed to the quality of forage available at this time. Lalman et al. (2000) reported that increasing dietary intake was associated with a curvilinear increase in milk yield in primiparous beef cows. Jenkins and Ferrell (1992) found that cattle of most breeds responded to increased energy intake with a linear increase in milk yield. Broster and Broster (1984) determined in dairy cows that milk yield increased as energy allowance increased.

Age of dam significantly influenced milk production throughout lactation. As a general trend, 10 yr old cows produced less milk ($P < .05$) than 8 and 9 yr old cows on d 37, 93, 121, 177, and 205. This indicates that older cows were past their peak production in terms of age and produced less milk compared to their younger contemporaries. Rutledge et al. (1971) reported a quadratic response of age of cow on milk production with peak occurring at 8.4 yr of age in Hereford cows.

Cows nursing male calves produced more milk ($P < .03$) at d 93 of lactation compared to cows nursing heifer calves. Male calves are generally larger than female calves enabling them to consume more milk. This higher demand for milk by male calves may cause a dam to produce milk at a higher level than if she was nursing a female calf. This is supported by the fact that cows nursing steers produced more milk throughout lactation although differences were smaller later in lactation. Previous reports have concurred with these findings indicating cows nursing male calves produce more milk (Pope et al., 1963, Daley et al., 1987; Jeffrey et al., 1971a). In contrast, others have found that cows nursing female calves give more milk (Jeffrey et al., 1971b; Rutledge et al., 1971). Still, others have reported no effect of sex of calf on milk production of a dam (Robison et al., 1978, Lawson, 1981; Butson and Berg, 1984).

Several significant interactions of breed or EPD level with other fixed effects existed although no obvious patterns emerged. There was a breed x sex of calf interaction at d 37 ($P < .002$) and at d 149 ($P < .05$). In addition, at d 37, there was a breed x season interaction ($P < .02$). Milk EPD level x sex of calf was significant ($P < .001$) at d 205.

Average Milk Production. Least squares means and standard errors for average milk production estimates for main effects are presented in Table 4. Average 205-d milk production of cows was significantly affected by breed, EPD level, and age of dam at calving. Angus cows had a higher ($P < .01$) average milk production estimate throughout lactation than Hereford cows. As expected, cows sired by high milk EPD bulls had a higher ($P < .05$) average milk production estimate (11.5 %) than cows sired by low milk EPD bulls. This effect of milk EPD level has been previously reported by Marston et al. (1992) and Marshall and Long (1993). Eight ($P < .001$) and 9 ($P < .004$) yr old cows had higher average milk production estimates than 10 yr old cows.

Two significant interactions between main effects existed for average milk yield. There was a significant ($P < .03$) EPD level x sex of calf interaction. This was due to the small difference in average milk supplied to steer calves on high vs low milk EPD females as compared to the significantly ($P < .01$) higher amount of average milk supplied to heifers on high milk EPD cows vs those on low milk EPD cows. There was also a season x sex of calf interaction ($P < .04$). This interaction was due to spring-born steers being supplied a greater ($P < .05$) amount of milk than spring-born heifers while the difference between the amounts of milk received by the fall-born steers and heifers was small.

Calf Performance. Calf birth weights, weaning weights, and average daily gains least squares means and standard errors by cow group with tests of significance are presented in Table 5. Sires were selected not only for divergent merit for milk production, but also for similar birth weights. Birth weights of calves were not different for breed ($P = .33$) or milk EPD level ($P = .16$). However, milk EPD level was significant for weaning weight. Calves of high milk EPD cows were on average 9.9 kg heavier ($P < .03$) at weaning than calves of low milk EPD cows. When comparing sire EPD to observed differences in calf weaning weights one would expect, based on sires used in this study, Angus calves to have an average of 14.8 kg difference in weaning weight between the high and low EPD groups. Likewise, one would expect the high and low EPD Hereford groups to differ in weaning weight by 11.3 kg. Actual differences in weaning weight for Angus and Hereford calves were 12.9 kg and 6.8 kg, respectively. These values were lower than expected, possibly due to the decrease in milk production of older cows. Diaz and Notter (1991) found a $0.69 \pm .19$ kg change in adjusted weaning weight for every 1 kg change in grandsire milk EPD ($P < .0004$) in calves from Hereford x Angus cows. This was also less than the expected value of one. In addition, they reported that selection of purebred sires using EPD accurately predicted performance of their crossbred progeny. In contrast, Marston et al. (1992) and Mallinckrodt et al. (1993) both determined that changes in calf weaning weights were greater than those predicted by maternal milk EPD indicating that milk EPD seem to be conservative in estimating genetic differences.

In the present study, average daily gain was greater ($P < .04$) for calves out of high milk EPD cows compared to calves out of low milk EPD cows and for calves out of Angus-sired dams vs those out of Hereford-sired dams. These results provide verification that milk EPD of purebred sires are a useful predictor of calf performance.

Correlations between average milk production and calf performance traits are listed in Table 6. The correlation between average milk production and calf weaning weight was 0.56 ($P < .001$), and the correlation between average milk production and calf average daily gain was 0.58 ($P < .001$).

Teat Shape. Least squares means and standard errors for average teat shape by cow group with tests of significance are presented in Table 7. Least squares means for average teat shape main effects are shown in Table 8. Average teat shape was determined from the four teat conformation scores assigned to each cow. There were no significant breed differences for average teat score early or late in lactation. At d 93, high milk EPD cows had lower ($P < .01$) scores than low milk EPD cows. These results indicate that teats of high milk cows were more funnel-shaped, and the teats of low milk cows were more cylindrical in shape. This may be due to the greater amount of milk production early in lactation; therefore the udder is fuller causing the teat to increase in diameter at the point of attachment. However, this conclusion is negated by the fact that there was also a significant effect of season at d 93. Average teat scores for spring-calving cows were higher ($P < .05$) than scores for fall-calving cows indicating teats were more funnel-shaped for fall-calving cows, but at the same time spring-calving cows produced more average milk. Kebe (1994) also reported that average teat scores were higher ($P < .05$) for spring-calving cows than for fall-calving cows during a study utilizing these same cows at 2 to 4 yr of age. Moore et al. (1981) reported that Holstein cows with funnel-shaped teats had significantly higher milk yields than cows with cylindrical type teats.

At d 93 of lactation, 7 yr old cows had higher ($P < .05$) scores than 10 yr old cows signifying that teats of older cows were more funnel-shaped than teats of younger cows. Average teat scores were similar for all cow groups late in lactation. There were no significant main effects at d 177 of lactation, but there was a significant ($P < .03$) milk EPD level x season interaction.

Average Teat Length. Least squares means and standard errors for average teat length by cow group with tests of significance are given in Table 9. Least squares means and standard errors for average teat length main effects are shown in Table 10. Teats of Hereford cows were longer than those of Angus both early ($P < .001$) and late ($P < .01$) in lactation. Kebe (1994) reported the teats of Hereford cows were longer ($P < .05$) than those of Angus cows during their first and second lactations. There was no milk EPD level effect or breed x milk EPD level interaction for teat length.

A significant ($P < .05$) season effect was present at d 177 displaying the fact that teats of spring-calving cows were longer than those of fall-calving cows. Teat lengths were similar for all cows regardless of age at d 93; however, at d 177 teat lengths of 10 yr old cows were longer ($P < .03$) than those of 7 yr old cows. An increase in teat length has been indicative of increased milk production in several studies (Frisch, 1982; Batra and McAllister, 1984; Qureshi et al., 1984; Lin et al., 1987). In contrast, teat lengths between high and low milk EPD cows were similar in the present study with low milk EPD Herefords actually having longer teats than high milk EPD Herefords even though the high milk EPD Herefords produced more milk.

Distance Between Teats. Least squares means and standard errors for total distance between teats by cow group with tests of significance are presented in Table 11. Least squares means and standard errors for total distance between teats main effects are shown in Table 12. Total distance between teats is the sum of the distance between the front teats, distance between the rear teats, and the diagonal distance between the left front teat and right rear teat. Total distance between teats was used to indicate udder size. There were no significant ($P > .05$) main effects or interactions for total distance between teats early or late in lactation. At d 93 and 177, Hereford cows had greater distance between teats than Angus, and high milk EPD cows had greater distances between teats than low milk EPD cows. In general, distance between teats increased as cows aged, however, none of these differences were significant ($P > .13$).

In the previous study by Kebe (1994), high milk Angus had greater ($P < .05$) distance between teats than low milk Angus cows. In addition, the author found distances to be greater ($P < .05$) for spring-calving cows than for fall-calving cows, and that 3 yr old cows had greater ($P < .01$) distances between teats than 2 yr old cows. In each of these instances, greater distance between teats was related to higher milk yields. Earlier studies have compared various characteristics indicating udder size with milk production. Tomar (1973) reported that udder length (r = .455) and udder width (r = .481) were highly associated with milk production in Hariana cattle. Borodin (1963) determined milk yield to be correlated with udder length (r = .177) and udder size (r = .392) in Simmental cattle. Fuhrer (1961) also studied Simmental cattle and reported positive correlations between milk yield and horizontal udder circumference (r = .599) and udder volume (r = .661).

Udder Support. Least squares means and standard errors for udder support scores by cow group with tests of significance are given in Table 13. Least squares means and standard errors for udder support scores main effects are presented in Table 14. Hereford cows had higher (P < .03) scores at d 93 than Angus cows indicating udders of Hereford cows had a weaker attachment and were more pendulous. There was no difference (P = .16) between Angus and Hereford cows later in lactation. High milk EPD cows had higher scores than low milk EPD cows, but differences were not significant (P = .13). Moore et al. (1981) found it apparent that Holstein cows with deeper udders yield more milk. They reported a decrease of 46 kg in 305-d milk yield for every centimeter increase in udder height measured as distance from the tip of the front teat to the floor. Lin et al. (1987) reported that high producing Holstein heifers had lower udders than low producing heifers. Borodin (1963) determined a correlation between milk yield and udder depth of 0.357 in Simmental cattle.

Differences between seasons (P > .30) and age of dam (P > .64) were also negligible both early and late in lactation. A significant (P < .004) milk EPD level x age of dam interaction did exist at d 177 of lactation. This was due to high milk cows having higher ($P < .05$) udder scores, more pendulous udders, at age 7 than low milk cows, and low milk cows having higher ($P < .02$) udder scores at age 9 than high milk cows.

In comparison to results of the previous study by Kebe (1994), udder support scores have increased considerably as the cows have aged for all cow groups, but the differences between all groups are still small ($P = .66$). These results show that cows sired by high milk EPD bulls are not at a disadvantage in terms of udder longevity when compared to cows sired by low milk EPD bulls.

IMPLICATIONS

This study verifies that differences in milk expected progeny difference among sires were positively related to actual crossbred daughter milk production and daughter's offspring weaning weight. Producers who use sire milk expected progeny difference values as a selection tool should expect such selection to be effective and be able to rank bulls with confidence. This study also indicated small differences in udder characteristics between cows sired by high or low milk expected progeny difference bulls except for average teat shape early (d 93) in lactation. This difference indicated high milk EPD cows had teats that were more funnel-shaped than low milk EPD cows; a trait that has been indicative of higher milk production in several studies. No other traits were significantly different between high and low milk expected progeny difference cows indicating that higher producing cows are not at a disadvantage in terms of udder longevity.

Table 2. Least squares means and standard errors for monthly measurements of 24-h milk production by cow group with tests of significance

	Milk production (kg)						
Cow Group	d 37[a]	d 65	d 93	d 121	d 149	d 177	d 205
High Angus	6.51 ± .30	5.78 ± .60	5.09 ± .31	3.63 ± .28	3.95 ± .33	2.86 ± .30	4.15 ± .28
Low Angus	6.17 ± .27	7.07 ± .51	4.39 ± .27	3.42 ± .25	3.27 ± .29	2.40 ± .27	3.39 ± .26
High Hereford	6.37 ± .46	6.39 ± 1.09	4.46 ± .46	4.02 ± .43	2.47 ± .48	2.34 ± .45	3.02 ± .43
Low Hereford	5.75 ± .36	4.76 ± .72	3.85 ± .37	3.72 ± .34	2.65 ± .39	2.23 ± .36	3.05 ± .35
P-values							
Breed	.41	.26	.10	.31	.01	.31	.02
Level[b]	.15	.82	.05	.45	.48	.39	.25
Breed x Level	.67	.05	.88	.87	.23	.59	.21
Level(Angus)	.39	.09	.07	.56	.11	.23	.04
Level(Hereford)	.26	.20	.27	.56	.76	.84	.96

[a] Monthly milk productions were performed every 28 d starting on d 37.

[b] Milk EPD level.

Table 3. Least squares means and standard errors for monthly measurements of 24-h milk production

		Milk production (kg)						
Effect		d 37[a]	d 65	d 93	d 121	d 149	d 177	d 205
Breed	Angus	6.98 ± .23	7.07 ± .45	5.23 ± .24	3.88 ± .21	3.97 ± .25^{c}	2.89 ± .23	4.14 ± .22^{c}
	Hereford	6.66 ± .35	6.14 ± .75	4.58 ± .35	4.25 ± .32	2.82 ± .37^{d}	2.51 ± .34	3.33 ± .32^{d}
Milk EPD Level	High	7.08 ± .32	6.70 ± .71	5.26 ± .32	4.20 ± .30	3.53 ± .34	2.86 ± .32	3.94 ± .30
	Low	6.55 ± .26	6.51 ± .51	4.54 ± .35	3.93 ± .23	3.27 ± .28	2.54 ± .26	3.54 ± .25
Season	Fall	4.84 ± .31^{c}	n/a	3.52 ± .28^{c}	3.99 ± .24	3.42 ± .30	3.48 ± .30^{c}	5.00 ± .28^{c}
	Spring	8.80 ± .33^{d}	6.60 ± .47	6.28 ± .30^{d}	4.14 ± .27	3.36 ± .32	1.92 ± .31^{d}	2.47 ± .29^{d}
Age of Dam[b]	7	6.39 ± .57^{c}	7.06 ± 1.12	4.83 ± .59^{cd}	-	3.27 ± .62	2.83 ± .58^{cd}	3.42 ± .55^{cd}
	8	7.79 ± .41^{d}	6.35 ± .87	5.53 ± .42^{d}	4.51 ± .33^{c}	3.55 ± .44	2.97 ± .41^{d}	4.05 ± .39^{cd}
	9	6.74 ± .37^{cd}	6.60 ± .77	5.31 ± .37^{d}	3.62 ± .19^{d}	3.48 ± .39	3.08 ± .36^{d}	4.25 ± .34^{d}
	10	6.35 ± .26^{c}	6.40 ± .52	3.93 ± .26^{c}	-	3.28 ± .28	1.92 ± .26^{c}	3.23 ± .24^{c}
Sex of Calf	Female	6.50 ± .29	6.07 ± .57	4.42 ± .31^{c}	4.06 ± .24	3.63 ± .31	2.71 ± .27	3.42 ± .26
	Male	7.14 ± .30	7.14 ± .66	5.38 ± .32^{d}	4.07 ± .25	3.15 ± .31	2.69 ± .29	4.06 ± .28

[a] Monthly milk productions were performed every 28 d starting on d 37.

[b] Records of 7 yr old cows were combined with 8 yr old cows and records of 10 yr old cows were combined with 9 yr old cows for milk production 4 due to confounding.

[c, d] Within a column and model term, means without a common superscript differ ($P < .05$).

n/a – not available

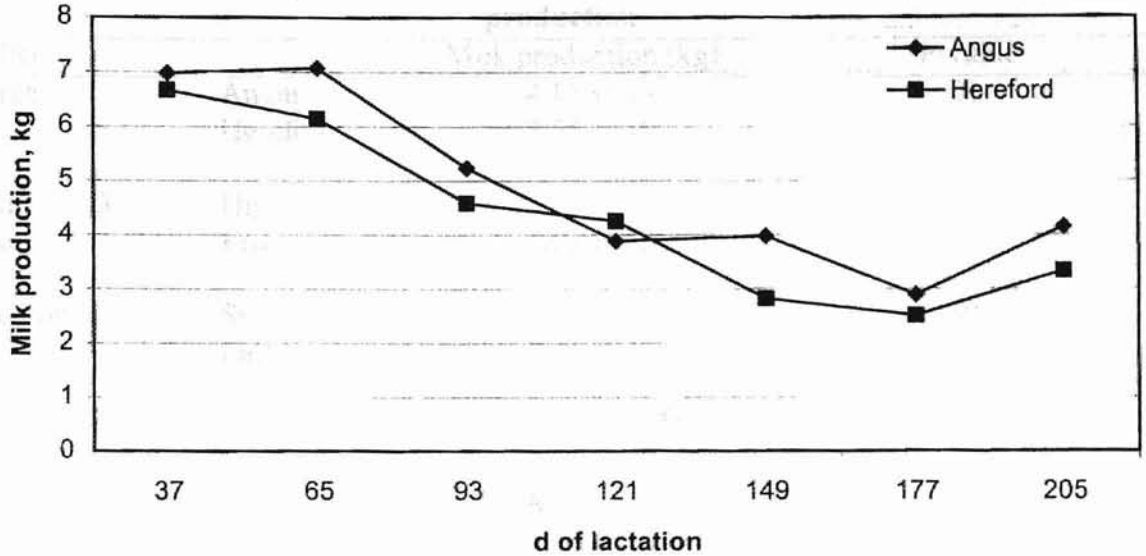

Figure 2. Monthly 24-h milk production least squares means for cows sired by high and low milk EPD Angus and Hereford bulls by breed.

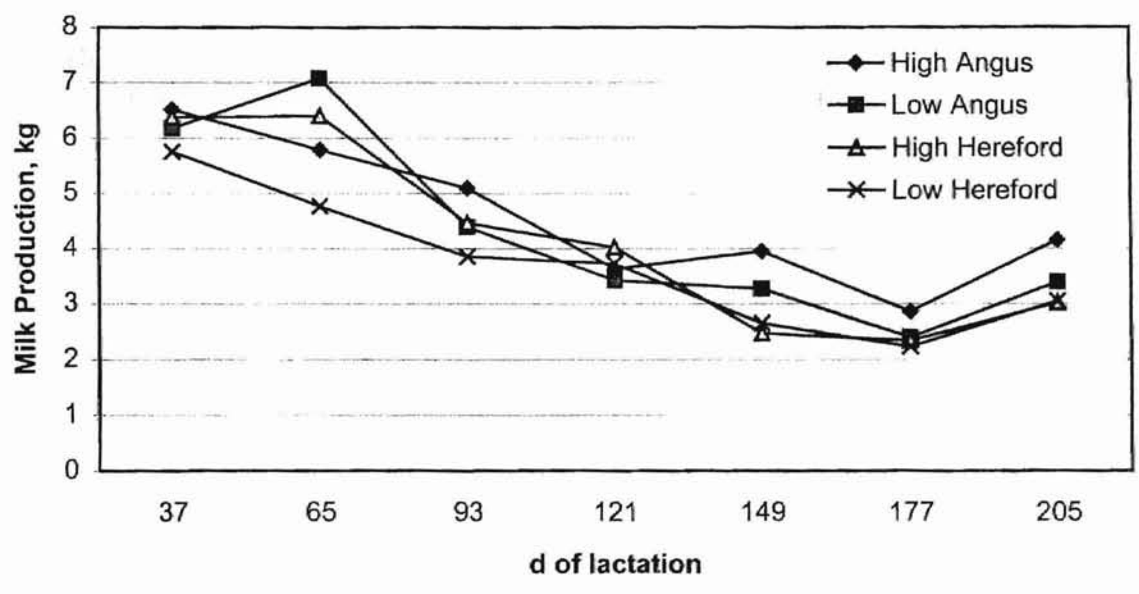

Figure 3. Monthly 24-h milk production least squares means for cows sired by high and low milk EPD Angus and Hereford bulls by cow group.

Table 5. Least squares means and standard errors for calf birth weight, weaning weight, and average daily gain by cow group with tests of significance

Cow group	Weights (kg)		
	Birth weight	**Weaning weight**	**Average daily gain (birth to weaning)**
High Angus	38.1 ± .7	222.8 ± 4.0	.90 ± .02
Low Angus	38.1 ± .6	209.9 ± 3.6	.84 ± .02
High Hereford	40.0 ± 1.1	211.2 ± 6.1	.84 ± .03
Low Hereford	37.9 ± 1.2	204.3 ± 4.9	.81 ± .02
P-values			
Breed	.34	.07	.03
Level[a]	.16	.03	.03
Breed x Level	.17	.50	.32
Level(Angus)	.96	.01	.01
Level(Hereford)	.08	.34	.48

[a] Milk EPD level

Table 5. Least squares means and standard errors for calf birth weight, weaning weight, and average daily gain by cow group with tests of significance

Cow group	Weights (kg)		
	Birth weight	**Weaning weight**	**Average daily gain (birth to weaning)**
High Angus	38.1 ± .7	222.8 ± 4.0	.90 ± .02
Low Angus	38.1 ± .6	209.9 ± 3.6	.84 ± .02
High Hereford	40.0 ± 1.1	211.2 ± 6.1	.84 ± .03
Low Hereford	37.9 ± 1.2	204.3 ± 4.9	.81 ± .02
P-values			
Breed	.34	.07	.03
Level[a]	.16	.03	.03
Breed x Level	.17	.50	.32
Level(Angus)	.96	.01	.01
Level(Hereford)	.08	.34	.48

[a] Milk EPD level

Table 6. Correlations between average milk production and calf performance traits

	Correlation	
	Adjusted weaning weight	Average daily gain
Average milk production	.56*	.58*
Adjusted weaning weight	-	.99*
Average daily gain		-

* P < .0001

Table 7. Least squares means and standard errors for average teat shape by cow group with tests of significance

	Average score (1 to 9)	
Cow group	**d 93**	**d 177**
High Angus	4.71 ± .08	4.79 ± .09
Low Angus	4.84 ± .07	4.78 ± .08
High Hereford	4.70 ± .13	4.80 ± .14
Low Hereford	5.09 ± .10	4.78 ± .10
P-values		
Breed	.17	.97
Milk EPD Level	.01	.91
Breed x Milk EPD Level	.15	.97
Milk EPD Level(Angus)	.22	.94
Milk EPD Level(Hereford)	.02	.92

Table 8. Least squares means and standard errors for average teat shape

Effect		Average score (1 to 9)	
		d 93	**d 177**
Breed	Angus	4.78 ± .06	4.79 ± .06
	Hereford	4.80 ± .08	4.79 ± .09
Milk EPD	High	4.71 ± .08[a]	4.80 ± .09
Level	Low	4.97 ± .06[b]	4.78 ± .07
Season	Spring	4.89 ± .07[a]	4.79 ± .08
	Fall	4.79 ± .07[b]	4.79 ± .08
Age of Dam	7	5.03 ± .14[a]	4.93 ± .15
	8	4.81 ± .10[ab]	4.77 ± .10
	9	4.71 ± .08[b]	4.69 ± .09
	10	4.80 ± .06[ab]	4.77 ± .06

[a, b] Within a column and model term, means without a common superscript letter differ (P < .05).

Table 9. Least squares means and standard errors for average teat length by cow group with tests of significance

	Average teat length[a]	
Cow group	**d 93**	**d 177**
High Angus	1.74 ± .04	1.74 ± .04
Low Angus	1.74 ± .03	1.75 ± .04
High Hereford	1.85 ± .06	1.87 ± .06
Low Hereford	1.94 ± .05	1.88 ± .05
P-values		
Breed	.001	.003
Milk EPD Level	.25	.81
Breed x Milk EPD Level	.32	.97
Milk EPD Level(Angus)	.90	.81
Milk EPD Level(Hereford)	.19	.90

[a] Teats < 5 cm in length were assigned a score of 1. Teats > 5 cm in length were assigned a score of 2.

Table 10. Least squares means and standard errors for average teat length

Effect		Average teat length[a]	
		d 93	**d 177**
Breed	Angus	1.74 ± .03[b]	1.74 ± .03[b]
	Hereford	1.89 ± .04[c]	1.88 ± .04[c]
Milk EPD	High	1.79 ± .04	1.80 ± .04
Level	Low	1.84 ± .03	1.82 ± .03
Season	Spring	1.79 ± .03	1.84 ± .03[b]
	Fall	1.84 ± .03	1.78 ± .03[c]
Age of Dam	7	1.87 ± .07	1.72 ± .07[b]
	8	1.82 ± .05	1.85 ± .05[bc]
	9	1.76 ± .04	1.79 ± .04[bc]
	10	1.83 ± .03	1.88 ± .03[c]

[a] Teats < 5 cm in length were assigned a score of 1. Teats > 5cm in length were assigned a score of 2.

[b, c] Within a column and model term, means without a common superscript letter differ (P < .05).

Table 11. Least squares means and standard errors for total distance between teats by cow group with tests of significance

	Total distance[a] (cm)	
Cow group	**d 93**	**d 177**
High Angus	37.78 ± 1.12	34.75 ± 1.03
Low Angus	35.29 ± .94	32.34 ± .87
High Hereford	37.01 ± 1.71	34.87 ± 1.56
Low Hereford	37.81 ± 1.28	35.49 ± 1.18
P-values		
Breed	.45	.13
Milk EPD Level	.54	.48
Breed x Milk EPD Level	.16	.16
Milk EPD Level(Angus)	.09	.07
Milk EPD Level(Hereford)	.71	.75

[a] Total distance between teats is the sum of distance between front teats, distance between rear teats, and diagonal distance between left front teat and right rear teat.

Table 13. Least squares means and standard errors for udder support score by cow group with tests of significance

Cow group	Score (1 to 9)	
	d 93	**d 177**
High Angus	5.42 ± .15	5.54 ± .15
Low Angus	5.17 ± .14	5.22 ± .13
High Hereford	5.74 ± .23	5.72 ± .23
Low Hereford	5.64 ± .19	5.47 ± .17
P-values		
Breed	.03	.16
Milk EPD Level	.28	.13
Breed x Milk EPD Level	.66	.80
Milk EPD Level(Angus)	.20	.10
Milk EPD Level(Hereford)	.70	.40

Table 14. Least squares means and standard errors for udder support score

Effect		Score (1 to 9)	
		d 93	**d 177**
Breed	Angus	5.30 ± .11[a]	5.38 ± .10
	Hereford	5.69 ± .16[b]	5.60 ± .14
Milk EPD Level	High	5.58 ± .15	5.63 ± .15
	Low	5.40 ± .12	5.35 ± .11
Season	Spring	5.56 ± .15	5.72 ± .12
	Fall	5.42 ± .14	5.26 ± .12
Age of Dam	7	5.45 ± .27	5.58 ± .25
	8	5.34 ± .19	5.48 ± .17
	9	5.57 ± .17	5.48 ± .15
	10	5.61 ± .12	5.41 ± .11

[a, b] Within a column and model term, means without a common superscript letter differ ($P < .05$).

LITERATURE CITED

Batra, T. R. and A. J. McAllister. 1984. Relationships among udder measurements, milking speed, milk yield, and CMT scores in young dairy cows. Can. J. Anim. Sci. 64:807.

Borodin, G. M. 1964. Evaluation of the cow's udder by measurements. Anim. Breed. Abstr. 32:304.

Broster, W. H., and V. J. Broster. 1984. Long term effects of plane of nutrition on the performance of dairy cows. J. Dairy Res. 51:149.

Butson, S., and R. T. Berg. 1984. Lactation performance of range beef and dairy-beef cows. Can. J. Anim. Sci. 64:253.

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

Diaz, C., and D. R. Notter. 1991. Are expected progeny differences of Polled Hereford sires for milk expressed in commercial crossbreeding. J. Anim. Sci. 69(Suppl. 1):218 (Abstr.).

Frisch, J. E. 1982. The use of teat measurements or calf weaning weight as an aid to selection against teat defects in cattle. Anim. Prod. Sci. 32:127.

Fuhrer, H. 1961. Results of udder examinations in German Simmental cows. Anim. Breed. Abstr. 29:417.

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.

Jeffery, H. B., R. T. Berg, and R. T. Hardin. 1971a. Factors affecting preweaning performance in beef cattle. Can. J. Anim. Sci. 51:561.

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

Jenkins, T. G., and C. L. Ferrell. 1992. Lactation characteristics of nine breeds of cattle fed various quantities of dietary energy. J. Anim. Sci. 70:1652.

Kebe, S. 1994. Interrelationships among udder characteristics and milk yield of beef cows sired by high or low milk expected progeny difference bulls. M. S. Thesis, Oklahoma State Univ., Stillwater.

Lalman, D. L., J. E. Williams, B. W. Hess, M. G. Thomas, and D. H. Keisler. 2000. Effect of dietary energy on milk production and metabolic hormones in thin, primiparous beef heifers. J. Anim. Sci. 78:530.

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.

Lin, C. Y., A. J. Lee, A. J. McAllister, T. R. Batra, G. L. Roy, J. A. Veseley, J. M. Wauthy, and K. A. Winter. 1987. Intercorrelations among milk production traits and body and udder measurements in Holstein heifers. J. Dairy Sci. 70:2385.

Mallinckrodt, C. H., R. M. Bourdon, B. L. Golden, R. R. Schalles, and K. G. Odde. 1993. Relationship of maternal milk expected progeny differences to actual milk yield and calf weaning weight. J. Anim. Sci. 71:355.

Marshall, D. M., and M. B. Long. 1993. Relationship of beef sire expected progeny difference to maternal performance of crossbred daughters. J. Anim. Sci. 71:2371.

Marston, T. T., D. D. Simms, R. R. Schalles, K. O. Zoellner, L. C. Martin, and G. M. Fink. 1992. Relationship of milk production, milk expected progeny difference, and calf weaning weight in Angus and Simmental cow-calf pairs. J. Anim. Sci. 70:3304.

Moore, R. K., S. Higgins, B. W. Kennedy, and E. B. Burnside. 1981. Relationships of teat conformation and udder height to milk flow rate and milk production in Holsteins. Can. J. Anim. Sci. 61:493.

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

Qureshi, M. I., C. M. Taylor, and B. B. Singh. 1984. A note on teat measurements and shape of udder and teat and its correlation with milk yield in Gir cows. Indian Vet. J. 61:225.

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.

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

Tomar, S. S. 1973. Udder and teat measurements and their relation with milk production in Hariana cattle. Indian J. Dairy Sci. 26:25.

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.

SAS. 1990. SAS User's Guide: Statistics. SAS Inst., Inc., Cary, NC.

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

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

Ziehe, G. K. 1989. Evaluation of udder and teat characteristics of F_1 females by Angus, Gray Brahman, Gir, Indu-Brazil, Nellore, and Red Brahman sires. M. S. Thesis, Texas A & M Univ., College Station.

APPENDIX

Table 15. Levels of significance for main effects model terms on 24-h milk production estimates and average milk production

	P-values							
	d of lactation							
Model term	37	65	93	121	149	177	205	Avg
Breed	.4060	.2555	.0961	.3123	.0048	.3052	.0238	.0076
EPD Level	.1531	.8191	.0523	.4499	.4848	.3900	.2489	.0427
Season	.0001	-	.0003	.3523	.3656	.0022	.0044	.9124
Age of dam	.0294	.9505	.0020	.0188	.9437	.0225	.0555	.0010
Sex of calf	.0828	.1860	.0299	.9537	.2160	.9423	.0550	.3126

Table 16. Levels of significance for interaction terms on 24-h milk production estimates and average milk production

Interaction term	P-values							
	d of lactation							
	37	65	93	121	149	177	205	Avg
Breed x EPD level	.6694	.0460	.8770	.8699	.2345	.5910	.2131	.4891
Breed x season	.0133	ND	ND	.1479	ND	ND	ND	ND
Breed x age of dam	ND	ND	ND	.0781	ND	ND	ND	ND
Breed x sex of calf	.0019	ND	.1306	ND	.0492	ND	ND	.0633
EPD level x season	.1972	ND	ND	ND	ND	ND	ND	ND
EPD level x age of dam	ND	ND	ND	.0974	ND	ND	ND	ND
EPD level x sex of calf	.1728	ND	.1269	ND	ND	ND	.0005	.0293
Season x age of dam	.0452	ND	ND	ND	ND	.1775	.0771	ND
Season x sex of calf	.2684	ND	ND	ND	.0654	.0015	.0214	.0348
Age of dam x sex of calf	ND	.2902	.2320	ND	ND	ND	ND	.2004

ND – Non discernible.

Table 17. Levels of significance for main effects model terms on average teat shape (ATS), average teat length (ATL), total distance between teats (TDBT), and udder support scores (USS)

	P-values							
	d 93 of lactation				d 177 of lactation			
Model term	ATS	ATL	TDBT	USS	ATS	ATL	TDBT	USS
Breed	.1651	.0004	.4532	.0255	.9652	.0025	.1280	.1635
EPD Level	.0121	.2522	.5413	.2836	.9099	.8071	.4843	.1346
Season	.0177	.9964	.5902	.7404	.1952	.0298	.3042	.3009
Age of dam	.2385	.3926	.2498	.6484	.5437	.0631	.6894	.9186

Table 18. Levels of significance for interaction terms on average teat shape (ATS), average teat length (ATL), total distance between teats (TDBT), and udder support scores (USS)

	P-values							
	d 93 of lactation				d 177 of lactation			
Interaction term	ATS	ATL	TDBT	USS	ATS	ATL	TDBT	USS
Breed x EPD level	.1515	.3173	.1605	.6624	.9701	.9690	.1645	.8036
Breed x season	ND	ND	ND	.2906	ND	ND	ND	ND
Breed x age of dam	ND	ND	ND	ND	ND	ND	ND	ND
EPD level x season	.2411	ND	.0902	ND	.0229	ND	.0812	ND
EPD level x age of dam	.1074	ND	.2501	ND	.2889	ND	.0569	.0039
Season x age of dam	ND	ND	.0834	.1206	.0142	ND	.2261	ND

ND – Non discernible.

Table 19. Correlations between average milk production and udder characteristics

	Correlation							
	ATS1	ATS2	ATL1	ATL2	TDBT1	TDBT2	US1	US2
MILK	-.04	-.02	-.09	.01	-.21**	-.26***	-.02	.04
ATS1		.11	.01	-.03	-.12	-.04	-.11	-.04
ATS2			-.01	.01	-.22**	-.23**	-.15*	-.11
ATL1				.76***	.07	.03	.25***	.17*
ATL2					.08	.02	.19**	.12
TDBT1						.89***	.38***	.37***
TDBT2							.28***	.31***
US1								.52***
US1								

List of acronyms: MILK = average 205-d milk production, ATS1 = average teat shape at d 93, ATS2 = average teat shape at d 177, ATL1 = average teat length at d 93, ATL2 = average teat length at d 177, TDBT1 = total distance between teats at d 93, TDBT2 = total distance between teats at d 177, US1 = udder support score at d 93, US2 = udder support score at d 177

* P < .05

** P < .01

*** P < .001

VITA 2

Kyle Jeffrey Stutts

Candidate for the Degree of

Master of Science

Thesis: EVALUATION OF MILK YIELD AND UDDER CHARACTERISTICS IN BEEF COWS SIRED BY HIGH AND LOW MILK EPD BULLS

Major Field: Animal Science

Biographical:

Education: Graduated magna cum laude from Brenham High School, Brenham, Texas in May, 1995; received Bachelor of Science degree in Animal Science from Texas A&M University, College Station, Texas, in May, 1999. Completed the requirements for the Master of Science degree with a major in Animal Science at Oklahoma State University, Stillwater, Oklahoma in August, 2001.

Experience: Raised and exhibited purebred beef cattle. Worked for a commercial cow-calf operation and in the equipment rental industry during undergraduate work. Employed by Oklahoma State University, Department of Animal Science as a graduate research and teaching assistant, August 1999 to present.

Professional Memberships: American Society of Animal Science, American Registry of Professional Animal Scientists.