Lactation curves and milk production in beef cattle with varying degrees of crossbred influence
by David George Casebolt

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Animal Science
Montana State University

Abstract:
The majority of today's research appears to be toward the ascertainment of which breeds of cattle or breed crosses function in a more efficient manner under range conditions. It was the purpose of this study to provide a segment of the information required to adequately evaluate the genotypic groups involved. A beef breed and several beef breed crosses were evaluated on the basis of their ability to produce milk under range conditions, and a more quantified lactation curve for each genotypic group was developed. Data were collected from Hereford (HH), Angus x Hereford (AH), 25% Simmental x 75% Hereford (1S3H), Simmental x Hereford (1SlH), and 75% Simmental x 25% Hereford (3S1H) cows at the Northern Agricultural Research Center at Havre, Montana. In order to minimize the variability in milk production attributed to age of dam, only 4- and 5-year-old cows were used. A total of 545 observations were collected on 76 cows during 1982. Least squares analysis of variance using the fixed effects model was used to determine the effect of independent variables and two-way interactions on milk production. Breed of dam, age of dam, sex of calf, pregnancy status, and the sex of calf x age of dam and pregnancy status x age of dam interactions were significant sources of variation for milk production. Mean 24 h milk production estimates for HH, AH, 1S3H, 1S1H, and 3S1H were 8.8, 11.6, 10.2, 12.6, and 11.3 kg, respectively. Peak milk production for the HH, AH, 1S3H, 1S1H, and 3S1H cows was achieved at day 40, 46, 34, 48, and 37 of the lactation period, respectively. Hereford cows gave 2.7 kg less milk per day than the crossbred cows grouped together ($P < .05$). There was no significant difference in the milk production of the AH and 1SlH cows (Fl) and no significant difference was detected between the 1S3H and 3S1H cows (backcross). The Fl cows gave 1.2 kg more milk ($P < .05$) than the backcross cows. It appeared that crossbred cows maintained a more persistent lactation as compared with their straightbred contemporaries. Heterosis appeared to have a positive effect on the level of milk produced by the dam. Considering this, crossbreeding conceivably would be a means of improving milk production in a relatively short period of time.

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Date 24 September 1984

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The majority of today's research appears to be toward the ascertainment of which breeds of cattle or breed crosses function in a more efficient manner under range conditions. It was the purpose of this study to provide a segment of the information required to adequately evaluate the genotypic groups involved. A beef breed and several beef breed crosses were evaluated on the basis of their ability to produce milk under range conditions, and a more quantified lactation curve for each genotypic group was developed. Data were collected from Hereford (HH), Angus x Hereford (AH), 25% Simmental x 75% Hereford (1S3H), Simmental x Hereford (1S1H), and 75% Simmental x 25% Hereford (3S1H) cows at the Northern Agricultural Research Center at Havre, Montana. In order to minimize the variability in milk production attributed to age of dam, only 4- and 5-year-old cows were used. A total of 545 observations were collected on 76 cows during 1982. Least squares analysis of variance using the fixed effects model was used to determine the effect of independent variables and two-way interactions on milk production. Breed of dam, age of dam, sex of calf, pregnancy status, and the sex of calf x age of dam and pregnancy status x age of dam interactions were significant sources of variation for milk production. Mean 24 h milk production estimates for HH, AH, 1S3H, 1S1H, and 3S1H were 8.8, 11.6, 10.2, 12.6, and 11.3 kg, respectively. Peak milk production for the HH, AH, 1S3H, 1S1H, and 3S1H cows was achieved at day 40, 46, 34, 48, and 37 of the lactation period, respectively. Hereford cows gave 2.7 kg less milk per day than the crossbred cows grouped together ($P < .05$). There was no significant difference in the milk production of the AH and 1S1H cows (F1) and no significant difference was detected between the 1S3H and 3S1H cows (backcross). The F1 cows gave 1.2 kg more milk ($P < .05$) than the backcross cows. It appeared that crossbred cows maintained a more persistent lactation as compared with their straightbred contemporaries. Heterosis appeared to have a positive effect on the level of milk produced by the dam. Considering this, crossbreeding conceivably would be a means of improving milk production in a relatively short period of time.

INTRODUCTION

Unlike the days of the open range when grass was abundant and a cattleman's main concern was maintaining as much weight as possible on his steers, today's producer is continually being pressured to operate in a more efficient manner. Whether a producer in today's economy will be a success or not is determined by the ability of that producer to develop a quality product, in this case lean red meat, in a manner that maximizes the use of his available resources and by his ability to market that product.

Today's producer has at his disposal a large variety of breeds and breed crosses. Researchers at the present appear to be centering their attention on finding out which breeds function in a more efficient manner under a variety of environmental conditions. Efficiency in this case is the ability of the cow to convert low quality forage into amount of calf weaned. To maximize production efficiency, the evaluation of different crossbred types under different environmental conditions becomes very important. It has been well documented that milk production is one of the most important environmental factors influencing the rate of growth of the calf during the preweaning stage of development, thus rendering milk production a major component of efficiency. This study provides some insight as to the milk production aspect of efficiency.

Five genotypic groups of beef cattle (Hereford, Angus-Hereford, Simmental-Hereford, 25% Hereford-75% Simmental, and 75% Hereford-25% Simmental) were studied under range conditions. The objectives of this study were to (1) determine if differences in milk production existed among the genotypic groups involved in the study, (2) develop a more quantified lactation curve for each of the genotypic groups, and (3) investigate the relationships between milk production and various preweaning growth traits of the calf.

LITERATURE REVIEW

Mammary Gland Development (Fetal)

Several texts have been written dealing with the development of the mammary gland. The following is a summary of the reviews of a few of these texts (Cowie and Tindal, 1971; Schmidt, 1971; Anderson, 1974; Cowie and Buttle, 1974; Frandson, 1974) on the development and hormonal control of the mammary gland. The first sign of development of the mammary gland in the bovine occurs at a very early stage of fetal growth. A layer of cuboidal cells originating from the ectoderm differentiate from the underlying mesenchyme forming the mammary band in the inquinal region. During the 4th and 5th week of fetal development, several layers of cells develop from the lower layer of the ectoderm (Malpighian layer) collectively referred to as the mammary lines. With further differentiation the mammary lines progressively develop into the mammary crest. This stage of development is immediately followed by a second intermediate stage, the formation of the mammary hillock. The mammary hillocks give rise to the mammary buds. Two mammary buds form on each mammary line, and these are the precursors to the rear and fore quarters of each half of the udder. The mammary bud then inundates the mesenchyme until the entire bud has receded into the mesenchyme with the exception of a small opening at the outermost edge causing a depression referred to as the mammary pit. At this stage of development the stromal tissue is well developed.

Prolific development of the mesenchume tissue surrounding the mammary bud during the second month of embryonic life marks the beginning of the formation of the teat. The mammary bud is forced above the surface of the surrounding epithelium in conjunction with the forming of a slight opening in the distal end of the bud.

A progressive invagination of Malpighian layer of cells during the end of the first trimester of pregnancy forms the primary mammary cord. The primary mammary cord proceeds along a path of least resistance as it invaginates the mammary bud. The primary mammary cord ultimately develops into the teat cistern, the gland cistern, and major ducts in the udder. Canalization of the primary mammary cord occurs at a fetal age of approximately 100 d (Schmidt, 1971) with the separation of cells at the center of the primary mammary cord. This separation of cells begins at the proximal end and progresses toward the distal end forming the teat lumen.

At 4 mo of fetal age the tip of the mammary bud is opened, the cells of the mammary bud have developed characteristics similar to that of the epidermal layer of the skin, and the gland cistern has become well defined. Continual separation of cells towards the distal end results in the formation of the teat cistern. The streak canal is the final part of the primary mammary cord to become canalized.

At approximately 13 wk of fetal age several secondary sprouts branch off of the terminal end of the primary mammary cord. These ultimately give rise to the duct system in the mature mammary gland. Further development of the duct system becomes quiescent at this time in the fetus.

It is believed that the development of the mammary gland during the fetal stage of development is completed by 6 mo (Schmidt, 1974). At birth the teats are well developed, the teat and gland cisterns are well defined, secondary mammary cords are present, the nonsecretory tissue of the udder is well developed, and vascular systems of the udder are comparable to that in the adult.

Mammary Gland Development (Birth to Puberty)

There is very little new development is the mammary gland from birth to puberty. Most of the growth during this stage of development is attributed to an increase in connective tissue and deposition of adipose tissue in the mammary gland. The growth of the mammary gland during the early postnatal period is thought to be isometric with that of the growth of the body. The udder continues to develop to some extent in that the ducts continue to grow and attain the shape of those characteristic of the mature udder. The capacity of the udder increases during this time frame. The quarters continue to grow until the front and rear quarters become attached at the base.

Mammary Gland Development (Puberty)

Approximately 2 mo prior to the first estrus marks the bebinning of a time of rapid parenchymal proliferation (Cowie and Buttle, 1974). Sinha and Tucker (1969) observed that during the immediate 2 mo period following birth the deoxyribonucleic acid content of the mammary gland in 65 Holstein heifers increased 1.6 times faster ($P < .01$) than body weight. At 5 to 9 mo of age Sinha and Tucker (1969) noted the comparable value increased to 3.5 and then declined to 1.5 at 9 to 12 mo of age. Between d 20 and the day of estrus during the estrous cycle an increase of 118% was observed in the deoxyribonucleic acid content of the mammary gland but declined thereafter (Sinha and Tucker, 1969). This development of the mammary gland after puberty with each estrous cycle is attributable to the hormones of the ovary (estrogen and progesterone) in conjunction with prolactin and somatatrophin (STH) from the anterior pituitary (Turner and Gardner, 1931). Sinha and Tucker (1969) observed that the highest sustained levels of prolactin in the pituitary gland occurred within 3 d prior to ovulation with minimal levels occurring during the time of ovulation. It is during the first estrous cycle of puberty and subsequent estrous cycles that accelerated growth of buds and branches from the sides and ends of the secondary and tertiary sprouts is observed. This final bud resulting from the branching and rebranching is thought to be the precursors to the alveoli (Schmidt, 1971). Swanson and Poffenborger (1979) suggest that this continuous development of the mammary gland associated with puberty and recurring estrous could result in mammary glands of heifers of advanced sexual maturity at conception starting development more advanced than mammary glands of heifers which conceive at a more immature stage of sexual development.

Histologically, at estrus the alveolar lumina are filled with a secretion. The epithelium of these small ducts are cuboidal in shape. During the progestation phase (diestrus) the lumina are void of any secretion and the epithelium is columnar in shape.

The majority of tissue making up the udder during this time frame of development is adipose tissue. This suggests that there is some regression proliferation of mammary cells associated with estrus during the later portions of the cycle (progestational phase).

Mammary Gland Development (during Pregnancy)

It is during pregnancy that the major portion of mammary growth is achieved and further development of the duct system occurs. The amount of growth is dependent upon the amount present at the initiation of the pregnancy. Cowie and Buttle (1974) state that the intensity of the growth of the duct system during pregnancy is dependent on the age of the individual animal since in older animals a considerable amount of duct growth will have occurred prior to conception. Hammond (1927) observed that contradictory to the above there was very little development in the length of the ducts in the mammary gland during the gestation period. The further development of the duct system augmented by the extension and branching of the duct system present prior to conception leads to the emergence of small interlobular ducts and eventually the alveoli. The lobulo-alveolar system progressively displaces the adipose tissue of the stroma in the mammary gland. Development of the secretory tissue becomes evident during the fourth month of pregnancy (Schmidt, 1971; Cowie and Buttle, 1974). During the last trimester of pregnancy secretory tissue continues to develop with the emergence of new alveoli (hyperplasia) and through hypertrophy as the alveoli begin to display secretory activity. The noted enlargement of the mammary gland during the last 2 mo of pregnancy is a result of the alveoli becoming enlarged from the accumulation of secretory material.

With each successive pregnancy there is further development of the mammary gland up to the point that mature size is attained. This probably is the reason that maximum milk production is not achieved until the third or fourth lactation (Wada and Turner, 1959; Klett et al., 1962; Christian et al., 1965; Melton et al., 1967b; Todd et al., 1969; Rutledge et al., 1971). Figure 1 graphically shows the dynamics of mammary growth during pregnancy, lactation, and the drying period.

Mammary Gland Development (during Lactation)

Though most of the development of the secretory tissue is completed prior to parturition, additional growth does take place during the early portion of the lactation. This additional growth continues up until the peak of lactation, when the DNA content of the mammary gland is at its maximum level (Schmidt, 1971). Very little growth takes place after the peak lactation period.

Hormonal Control of Mammary Growth

Lasfargues and Murray (1959) concluded that growth hormone was involved with the development of the mammary epithelium during the embryonic stage of development in mice. Of the several other hormones evaluated by Lasfargues and Murray (1959), prolactin appeared to be responsible for stimulating the adipose tissue and the epithelium to prepare for lactation. Estradiol stimulated the adipose tissue and progesterone was responsible for promoting the degeneration of

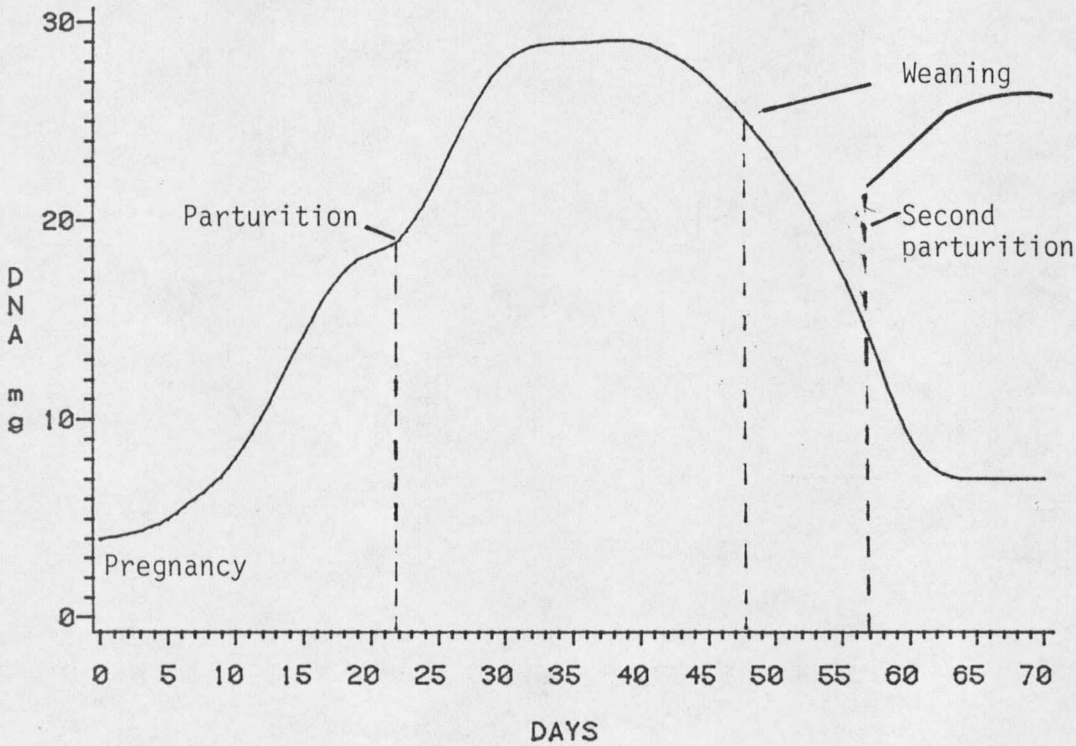

FIGURE 1. CHANGES IN THE DNA CONTENT OF THE SIX ABDOMINAL-INGUINAL MAMMARY GLANDS OF RATS DURING PREGNANCY, LACTATION, AFTER WEANING, AND A SECOND LACTATION. (FROM SCHMIDT 1971, BIOLOGY OF LACTATION. 74.)

connective tissue. This breakdown of connective tissue is thought to be a function of the mammary gland spreading factor arrived at by Elliot and Turner (1954) and their work with various rodents. Cortisal conditioned the gland for secretion by inducing ductal distension, initiating the formation of the alveoli and a hyperactivity of the adipose tissue (Lyons et al., 1958).

Hormonal control of the mammary gland during the fetal stage generally was defined as beginning at approximately 90 d of age in the cow (Turner, 1952) but is not well documented in the literature. Anderson (1974) comments on the importance of insulin in combination with prolactin and its accelerative effect on growth of the primary mammary cord. Aldasterone apparently synergizes with insulin and prolactin in promoting branching and differentiation of the duct system (Anderson, 1974). Erb (1977), in a review of the hormonal control of mammo-genesis, comments on the sequential basis to the development of the mammary gland and its secretory function. The first step requires insulin for at least one division of the parent cells. Step two, the formation of organelles in the daughter cell, requires cortisal and step three, the secretory capability of the cells, apparently requires prolactin.

Allometric growth of the udder in cattle commences up until a short time prior to puberty. Sud et al. (1968) observed in heifers that rapid growth of the udder starts prior to puberty and plateaued at 9 to 12 mo of age. This rapid growth may be a result of the duct proliferation stimulated by estrogen but normal lobule-alveolar growth requires a combination of estrogen and progesterone.

After puberty the development of the mammary gland during each recurring estrous cycle is due to the hormones of the ovary, estrogen, and progesterone, in combination with prolactin and somatatrophin (STH) which are hormones of the anterior pituitary (Schmidt, 1971). This growth apparently continues with each estrous cycle up to 30 mo of age in dairy heifers (Turner, 1963) even though the growth may be equal to or less than general body growth after 12 mo of age up to 3 yr. Both estrogen and progesterone have been shown to play an important role in mammogenesis and the synchronization of lactogenesis (Chew et al., 1977; Erb, 1977). It is generally agreed upon by researchers that estrogen is responsible for ductal growth and progesterone in the development of the lobulo-alveola system.

The placenta appears to take over the growth stimulating effects of the anterior pituitary gland during pregnancy. Schmidt (1971) refers to several studies that observed no regression of mammary gland development in mice, rats, and monkeys hypophysectomized during pregnancy. If this indeed is the case it is reasonable that a larger placenta may correspondingly produce a larger amount of estrogen and placental lactogen. Digiacomo et al. (1978) and Hayden et al. (1979) in their work with nonruminant species have observed a positive correlation of birth weight with placental weight. Erb et al. (1980) have shown that milk yield was positively correlated with the amount of circulating prolactin and birth weight of the calf. Birth weight was observed to be positively correlated with the amount of circulating estrone and estradial 17B.

In summary, the hormonal requirements for normal mammary gland development are estrogen, progesterone, prolactin, and somatatrophin (STH) (Lyons et al., 1958; Nickerson et al., 1978). The placenta appears to possess lactogenic and mammogenic properties and has the ability to take over the growth regulating function the anterior pituitary has over the mammary gland.

It appears that insulin and the adrenal corticoids are more involved in the maintaining of a normal metabolic state but have been shown to have a direct effect on the cell proliferation of the mammary gland and its secretive process.

Nutritional Effects on Milk Production

The domesticated ruminant, in this case the bovine, has evolved in a manner that enables it to utilize low quality forage associated with range conditions and convert it into high quality protein (beef and milk). The ability of the lactating ruminant to provide an optimum nutritional environment to the calf during the early stages of development is dependent on the genotype of the dam (relative to milk production) and the nutritional environment of the dam.

The influence of the maternal performance of the cow on the preweaning growth of the calf has been thoroughly documented. Neville (1962), Gleddie and Berg (1968), and Jeffery and Berg (1971a) have shown that approximately 60% of the variation observed in calf daily gain to weaning and weaning weight is accounted for by the milk production of the dam. This suggests that milk production is one of the most important factors influencing the weaning weight of the calf.

The phenotypic variability of an individual is made up of two components, the variability due to the genotype of the individual and the variability due to the environment. It therefore becomes evident that the plane of nutrition not only during the lactation period but also during the gestation period prior to parturition may have an important influence on the milk yield of the dam.

Several studies have shown that low levels of protein and energy fed prior to calving significantly reduced milk production during the following lactation period. Dunn et al. (1965) observed that dams fed a high energy pre-calving ration weaned calves which gained 7 kg more from birth to 109 d than calves raised on dams fed a low level pre-calving energy level. It was also observed that dams on a high level pre-calving energy ration produced an average of 1.5 kg more milk daily than cows fed a moderate energy level after calving. Bond and Wiltbank (1970) and Bond et al. (1964) observed lighter body weights and lower milk production in heifers fed low energy and low protein levels during the first lactation. This suggests that cows entering the lactation in a below optimal state of body condition will sacrifice milk production to maintain liveweight later in the lactation. This is in agreement with Grainger and Wilhelms (1979) where underfed groups of dairy cows aged 3 to 8 yr gained significantly more liveweight (roughly .58 kg/cow/d) than those fed a high level (.36 kg/cow/d) while producing significantly less milk, milk fat, and milk protein. The literature further substantiates the negative relationship that exists between milk yield and the increase in liveweight during the lactation (Vaccaro and Dillars, 1966; Todd et al., 1968; Jeffery et al., 1971a).

The energy requirements for lactating cows have been shown to be dependent on the relative size of the cow and the level of milk production at which the cow is producing (Kronberg et al., 1983). Ewing et al. (1967) reported a moderate to high relationship between the mature weight of the cow and the weaning weight of the calf (approximately 9.78 kg of added weaning weight/100 kg increase in cow weight) under conditions in which energy intake was not equalized for cows of different sizes. In a study conducted by Wilson et al. (1969), it was observed that cows receiving 85% of the N.R.C. requirements for digestible energy lost an average of 54.4 kg of body weight during lactation compared to the groups of cows receiving 115% of the N.R.C. requirements which maintained their initial weights. The observed difference in daily milk yield (2.96 kg) was highly significant.

From the TDN requirements calculated by Ewing et al. (1968) for beef cows, for each 3 units increase in milk production a 1 unit increase in TDN was required.

Furr and Nelson (1964) observed that there was a positive relationship between the amount of milk produced and the level of nutrients consumed. It has been observed that cows decrease their voluntary intake as forage becomes more mature and when forages are low in nutrients such as protein (McClymont, 1957; Arnold, 1964). Streeter et al. (1974) found that Brown Swiss cows when compared to Herefords and Charolais x Angus cows had a higher daily intake and produced more milk. This seems to imply that breed differences exist in terms of forage utilization. Holloway et al. (1979) observed that cows grazing high quality pastures consumed 1.7 kg/d more DM than cows grazing low quality pastures but produced similar amounts of milk. Milk from those cows grazing high quality pastures was .42 percentage units higher in butterfat ($P < .04$).

Several researchers (Chambers et al., 1960; Pope et al., 1963; Christian et al., 1965; Mangus and Brinks, 1971) have shown that overconditioned heifers produced lighter calves at weaning, experienced a depression in milk production, and that a negative environmental correlation existed between the weaning weight of the cow and the weaning weight of her calves. Kress and Burfening (1972) in a study involving seven different lines of Hereford cattle found that heifers subjected to the poorer preweaning and postweaning environments were the best producers in terms of 180 d weights of their progeny. This observation led Kress and Burfening (1972) to conclude that at least a part of the environmental portion of the phenotypic relationship between early growth rate and the most probable producing ability for 180 d weight was negative.

Totusek (1968) found that a high level of nutrition had no lasting effects in terms of body size and productivity, but in relation to a low level of nutrition there was moderate depression in body size to 4 yr of age and improvement in terms of milk production and weaning weight of calves produced. This was expressed in terms of a 9.1 kg advantage per calf raised on cows that were weaned at 140 d as compared to those weaned at 240 d and creep fed.

Age of Dam Effects

The effect age of dam has on the amount of milk produced by the cow has been indirectly dealt with in a previous section in terms of the progressive development of the duct system in the mammary gland. Several studies have studied the effect of age on total milk production of the cow and others have investigated the effect of advancing age on milk yield indirectly by searching into the effect age has on pre-weaning performance of the calf. Erb et al. (1980) using Holstein cows and first-calf heifers and Jeffery et al. (1971) working with Hereford, Angus, and Galloway cows reported correlations between age of dam and milk yield ranging from .22 to .43. A correlation of .32 was observed between age of dam and average daily gain of the calf which in itself is highly associated with milk production by Jeffery et al. (1971).

Though considerable variation exists between individuals, in general it appears that maximum milk yield is realized during the fifth lactation at 6 yr of age in most beef cattle (Koch and Clark, 1955; Swiger et al., 1962; Minyard and Dinkel, 1965; Jeffery et al., 1971). Klett et al. (1965) found that age of dam had a highly significant effect on milk production. Klett et al. (1965) observed daily milk production estimates of 3.54, 3.85, and 4.38 kg for age groups 3 to 5 yr, 6 to 8 yr, and 9 to 12 yr, respectively, for Angus cows. Estimates for the same age groups in Hereford cows were 2.65, 2.91, and 4.61 kg, respectively. Gifford (1953), in his research with Hereford, Angus, and Shorthorn cows, concluded that beef cows between the ages of 2 and 3 yr produced the least amount of milk of any of the other ages studied. It was observed that milk yields increased up to about 6 yr of age. Gifford (1953) reported total milk yields of 542, 526, 660, 631, 715, and 569 kg for Hereford cows of 2 to 3, 3 to 4, 4 to 5, 5 to 6, 6 to 7, and 7+ yr of age, respectively. Similarly for Aberdeen-Angus cows of the aforementioned age groups milk yields of 667, 903, 1029, 818, 1085, and 1116 kg, respectively, were reported. Shorthorns included in the study produced 770, 1054, 700, and 966 kg of milk during ages of 2 to 3, 4 to 5, 5 to 6, and 6 to 7 yr of age. Melton et al. (1967b), using Aberdeen-Angus, Hereford, and Charolais cows 2, 3 to 5, and over 5 yr of age reported milk yields of 553, 667, and 809 kg for the respective age groups. These results indicate that there is some variation between breeds for the age at which peak milk production is reached.

It has been well established that weaning weight of the calf is highly correlated with the milk production of the dam (Melton et al., 1967a,b; Totusek et al., 1973; Kress and Anderson, 1974; Belcher and Frahm, 1979). Minyard and Dinkel (1965) reported that weaning weights among calves raised on purebred Angus and Hereford cows were lowest for cows 2 yr of age. Peak production was observed to be at 8 yr of age which is in agreement with several earlier reports (Sawyer et al., 1948; McCormick et al., 1956; Nelms and Bogart, 1956). Kress and Burfening (1972) observed that mean 180 d weights for Hereford cows were lighter for both immature and old (11 yr and older) dams. Swiger et al. (1962) found the age of peak production expressed by weaning weight of the calves to be 6 yr, which is in agreement with findings of Koch and Clark (1955). Brown (1960) observed an increase in the age of the dam resulted in a subsequent decline in calf weaning weight during the periods past peak production. Franke et al. (1975) noted that cow age significantly affected the average daily gains from birth to 3 mo of age in Angus and Hereford cows.

Several studies have derived correction factors used for adjusting weaning records of calves to an equivalent age of dam basis. The most recent additive adjustment factors listed for the adjustment of 205 d weights in male calves by the Beef Improvement Federation (1981) were 27.2, 18.2, 9.1, 0, and 9.1 kg for the cow ages of 2, 3, 4, 5 to 10, and 11 yr and older, respectively. Also cited were the adjustment factors of 24.5, 16.3, 8.2, 0, and 8.2 to be added to the 205 d weights in female calves nursed by cows of the same age groups. Minyard and Dinkel (1965) using Angus and Hereford cows from 20 separate herds arrived at the following additive correction factors: 31.3, 15.0, 9.5, 5.9, 1.8, 1.4, 0, 4.1, 10.4, 10.9, 17.2, and 18.6 kg for the cow ages 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, and 13+, respectively. These are in general agreement to those provided by the B.I.F. (1981). Woldehawariat et al. (1977) in a summary of several studies involving a variety of breeds list the values -25.78, -16.20, -8.28, -2.77, 0.00, 0.37, 0.68, 0.61, and -1.32 as constants for the effects of age of dam on weaning weight for the dam ages 2, 3, 4, 5, 6, 7, 8, 9, and 10 yr, respectively.

Nelsen and Kress (1981) conducted a study using Angus and Hereford calves to evaluate additive versus multiplicative correction factors. They determined that for the Angus the multiplicative adjustments of 1.12, 1.07, 1.04, 1.02, 1.01, 1.00, 1.01, 1.02, and 1.02 for the respective ages 2, 3, 4, 5, 6, 8, 9, 10, and 11+ were preferred. The additive factors 26.3, 16.8, 8.6, 2.3, 1.4, 0.0, 0.0, 3.2, and 9.1 were preferred for the respective age-of-dam Hereford adjustments. Nelsen and Kress (1981) conjectured that an age-of-dam correction to a set of mature ages (5 to 10 yr) rather than to a single age was preferred as a smaller number of adjustments were required.

Espe (1946) suggests that this increase in productivity associated with age is largely a function of greater digestive capacity associated with an increase in body size in conjunction with an increase in udder capacity. Espe (1946) makes the inference that a system of correcting milk yield for liveweight may have more merit than an age-correction system in dairy cattle.

Effect of Calf Birth Weight

The effect the birth weight of the calf has on the subsequent milk yield of the dam has been the subject of several studies. Adkinson et al. (1977) observed that the sire of the fetal calf has a significant effect upon the dam's subsequent milk yield. This association between the sire of the fetus and dam milk production may be a result of the size of the fetus. Digiacomo et al. (1978) and Hayden et al. (1979) observed a high positive correlation between the weight of the placental mass and the birth weight in the rhesus monkey and goat. The effect of estrogen and placental lactogen on the development of the mammary gland has already been referenced. Hence, large placental masses may result in an increase in the amount of the above-mentioned ovarian and placental hormones. A positive correlation of

.22 has been observed between birth weight and the amount of circulating estrogen (Erb et al., 1980). Bolander et al. (1976) reported higher levels of placental lactogen in high producing dairy cows as compared to low producing cows. Erb et al. (1980) reported a positive correlation of .32 between the birth weight of the calf and the milk yield of the dam. This was lower than the .75 correlation observed by Heyns (1960) but similar to those observed by Neidhart et al. (1979) of .25 and .34 for two separate years and the .43, .29, and .12 reported by Drewry et al. (1959) for the first, third, and sixth months, respectively. Chew et al. (1981) noted that a positive linear relationship existed between calf birth weights ranging between 23 and 50 kg and milk production. Several studies have shown that cows giving birth to heavier calves yield more milk (Drewry et al., 1959; Melton et al., 1967b). Milk yields of cows nursing twin calves have been shown by several studies to be higher than those cows raising a single calf (Bowman and Hendy, 1970; Wood, 1975). Christian et al. (1965), working with Hereford cows, and Gleddie and Berg (1968), using Hereford, Angus, Galloway, and several F1 crossbred cows, after observing a minimal association between calf birth weight and milk yield came to the conclusion that birth weight was not an important factor influencing milk production. In support of this conclusion Jeffery et al. (1971a) observed a correlation of .18 and .11 between birth weight and milk production for the two respective years of the study. Burfening et al. (1978) have shown that birth weight in cattle is an heritable trait implying that selection for heavier birth weights may be a means to increase milk production.

Sex of Calf

Bull calves usually have heavier birth weights than their female counterparts (Foote, 1974). Maurer et al. (1983) observed that males were significantly heavier at birth than the female calves. In the study by Chew et al. (1981), a difference of 1.3 kg was noted between the mean birth weights of the male and heifer calves. Woldehawariat et al. (1977) summarized the work of several authors to arrive at the additive factor of 1.72 kg to correct heifer calves to a bull basis for birth weight. This may possibly be the result of the longer gestation period associated with dams bearing a male fetus. Jainudeen and Hafez (1980) stated that male calves are carried 1 to 2 d longer than female calves. The possible effect of sex of calf on milk yield may be partially due to the difference in placental mass of male births versus a female birth.

Several researchers have found that sex of calf has a significant effect on milk production. Melton et al. (1967b) found that the daily milk production of cows rearing male calves was .58 kg above that of the cows rearing heifer calves during the 77 d postpartum period of the lactation. As the lactation progressed this difference diminished to .10 kg per day. Total milk production during a 175 d lactation for cows rearing bull calves was 703.1 kg as compared to 649.9 kg for cows nursing heifer calves.

Contradictory to this report, Christian et al. (1965) reported that dams of bull calves did not give more milk than those nursing heifer calves. Rutledge et al. (1971) also noted that dams nursing female calves produced significantly more milk than those nursing males. Rutledge et al. (1971) reported that Hereford cows nursing heifer calves gave approximately 56 kg more milk over a 205 d lactation.

Cow Body Weight

Several studies have looked into the question of the relative efficiency of the small cow versus the large cow for beef production. Kress et al. (1969) concluded that overconditioned cows were less efficient producers in terms of pounds of calf weaned. They also observed that there was no significant difference in efficiency of light weight and heavy cows when the salvage values of the cows were ignored. Clark and Touchberry (1963) reported a negative correlation of -.12 between the body size and milk yield in dairy cattle. In a more recent study by Davis et al. (1983), results suggest that smaller sized cows were more efficient in the production of calves but when salvage value was included the importance of cow size was reduced.

Jeffery et al. (1971a) reported a small positive correlation between the postcalving weight of the cow and milk yield. They also observed a correlation of .73 and .76 over a 2 yr study between cow age and postcalving weight.

A gain in body weight on the part of the cow has been shown to have a negative effect on milk production (England et al., 1961; Hohenboken et al., 1973). Jeffery et al. (1971a) reported correlations of -.12 and -.21 between summer gain and milk yield for two different years.

Studies have also shown that selection of heifers superior in weaning weight may result in increased genetic potential, but may also result in decreased milk production. Christian et al. (1965), using fraternal twin Hereford heifers, reported a small negative correlation (-.10) between the weaning weight of the dam and her milk production during the first 60 d of the lactation. A negative nonsignificant association (r = -.07) was reported by Christian et al. (1965) between the height of the withers of the dam at 240 d of age and her eventual milk production. They suggested that the relationship between milk production and weight therefore may be a result of the structural size of the cow rather than of the variation in body condition.

Breed Effect

There is an extensive assemblage of research concerned with evaluating the milk production capabilities of various dairy breeds of cattle and a variety of breed crosses. Of the 40 to 50 breeds of beef cattle found in North America only a handful have been thoroughly appraised regarding milk production of the dam. Williams (1977) provides an overview of the milk production for six of the more common beef breeds at the time. Breed of cow accounted for 82.5% of the variance in milk production data collected by Gleddie and Berg (1968).

Heterosis appears to have a positive effect on the milk production of the dam. Several researchers have observed that crossbred cows produce higher levels of milk than straightbred cows. Lawson (1981) noted that the Hereford x Highland cows significantly exceeded the Highland and Hereford cows in 24 h milk yield for June, August, and October milking dates. Heterosis effects for 24 h milk yield of 14.0%, 18.4%, and 22.1% were observed by Lawson (1981) for June, August, and October, respectively. He concluded that under range conditions the Hereford x Highland crosses maintained a more persistent lactation than the Hereford and Highland cows. This is somewhat contradictory to the conclusion of Notter (1976) that persistency of the lactation increased with a decrease in average milk production in all but one of the breed groups studied. McGinty and Frerichs (1971) conducted a study which compared the production of Brown Swiss x Hereford cows to that of Hereford cows. Based on milk production estimates collected at day 85, 135, and 180 of the lactation, they concluded that the Brown Swiss x Hereford cross yielded more milk than the Hereford cows. Although calves nursed by both genotypic groups had creep feed available to them, calves raised by Brown Swiss x Hereford cows weaned calves 25 kg heavier than calves raised by Hereford cows. Jeffery et al. (1971a) in their work with Hereford, Angus x Galloway, and a synthetic group of Angus, Galloway, and Charolais breeding concluded that the Angus x Galloway and hybrid groups were equal in milk production but excelled the Hereford group by 1.2 and 1.5 kg for 1966 and 1967, respectively.

As a result of the findings presented by Lawson (1981) and McGinty and Frerichs (1971), it appears that crossbreeding can improve milk production. It is with this in mind that several researchers designed specific studies to evaluate a variety of crossbred cows. Chennette and Frahm (1981) ascertained the differences in milk yield and composition of milk produced by eight crossbred groups. These groups were made up of 4-yr-old Hereford x Angus, Angus x Hereford, Simmental x Angus, Simmental x Hereford, Brown Swiss x Angus, Brown

Swiss x Hereford, Jersey x Angus, and Jersey x Hereford cows, respectively. They established in this particular study that milk yields were highest (average 8.09 ± .41 kg/d) for Brown Swiss x Angus and Jersey x Angus cows. The Hereford x Angus cows and the reciprocal cross cows were found to be moderate in milk yield (6.52 ± .40 kg/d) with the Jersey x Hereford, Brown Swiss x Hereford, Simmental x Angus, and Simmental x Hereford dams producing milk yields at an intermediate level (average 7.38 ± .41 kg/d).

In a similar type study, Gaskins and Anderson (1980) found that a significant difference existed between the milk yields of Angus x Hereford, Simmental x Angus, and Jersey x Angus dams. The observed least-squares means for 24 h milk were5.8, 7.7, and 7.7 kg/d for the Angus x Hereford, Simmental x Angus, and Jersey x Angus cows, respectively.

Factors Affecting the Shape of the Lactation Curve

The preceding review on factors affecting milk yield lists the environmental factors assumed to dominate the shape of the lactation curve. Schmidt and Van Vleck (1974) list body condition of the cow at calving, the genetic potential of the cow, freedom from metabolic and infectious diseases, and the feed regimen during the post calving period as influencing the peak yield of the cow. Wood (1968) found that lactations starting in March tended to show an extended peak. He postulated that this extended peak was due to the nutritional stimulus of the May grazing.

Persistency, defined as the rate of decline in yield during the postcalving period, is important in maintaining a steady growth of the calf (Klett et al., 1962). The rate of decline is emphasized by pregnancy and is most notable during the twenty-second week of pregnancy placing it at approximately the 7th to 8th month of a normal lactation curve (Schmidt and Van Vleck, 1974). Age of dam has also been implicated to be an influencing factor by Smith and Legates (1962). They noted that first-calf heifers maintained a more persistent lactation than the older cows. Christian et al. (1965) reported a similar observation with 2-yr-old dams yielding 4.7% more of their total milk during the period of 60 to 240 d postpartum than the older cows. Holloway and Worley (1983) reported milk intake curves of Angus calves grazing fescue-legume pastures which were more persistent than those of calves grazing fescue. This suggests that forage quality may play an important role in determining the shape of the curve.

Effect of Milk Production on Various Calf Traits

Though the nutritional environment provided by the cow to her calf is not the only contribution the cow makes to her calf, it has been shown to be a very influential one. Klett et al. (1962) stated that milk production of the dam is probably the greatest single factor influencing the weight of a calf. Neville (1962) reported that 66% of the variability in the weight of the calf at 8 mo of age was due to the amount of milk produced by the cow. Drewry et al. (1959) reported similar results in that 60% of the variation at 6 mo of age was due to milk consumption. A more recent study by Jeffery et al. (1971b) reported that of all the variables considered, milk production accounted for 40% to 50% of the variability in weaning weight and 60% of the variation in the postweaning daily gain of the calf.

As the calf matures and forage becomes more readily available, the dependency of the calf on the maternal ability of the cow decreases. Franke et al. (1975) noted that milk production of the dam did not significantly influence the average daily gain of the calf from 5 to 7 mo of age in Hereford and Angus calves. Pope et al. (1963) indicated that as the lactation progressed the correlation between ADG decreased from .8 to .25. Dawson et al. (1960) similarly found that when creep feed was available to the calf the effect of the amount of milk given by the cow would not be as marked as those not fed a supplement. Neville et al. (1962) reported that the relationship between ADG and milk production could be effectively reduced with an improvement in the quality of the forage available to the calf. Correlations between milk yield and ADG ranged from .46 to .84 and the unweighted average was approximately .71 (Neville, 1962; Furr and Nelson, 1964; Melton et al., 1967b; Gleddie and Berg, 1968; Wilson et al., 1968; Jeffery et al., 1971b).

Estimated correlations between weaning weight of beef calves with the milk production of their dams ranged from .12 to .88 (Neville, 1962; Furr and Nelson, 1964; Melton et al., 1967b; Totusek et al., 1973; Belcher and Frahm, 1979; Chenette and Frahm, 1981). Jeffery et al. (1971b) expressed this positive relationship in terms of a 1 kg per d increase in milk production resulted in an increase of 11.3 to 14.6 kg in the weaning weight of the calf.

MATERIALS AND METHODS

Experimental Design

This study was conducted at the Northern Agricultural Research Center located 11 miles southwest of Havre, Montana. The data were collected in 1982 from five genotypic groups comprised of straightbred and crossbred cattle. The genotypic groups consisted of Hereford, Angus-Hereford, 25% Simmental-75% Hereford, Simmental-Hereford, and 75% Simmental-25% Hereford dams. The study extended from the beginning of the calving season (March 18, 1982) to weaning with the last data collection period occurring on October 4, 1982.

The objective was to attain 15 cows per breed group with 10 being an absolute minimum. The number of animals available to the study was 112 and 81 were utilized in the study. In order to minimize the variability in milk production attributed to age of dam, only 4- and 5-yr-old cows were used.

All dams within each breed group were raised on the station with the exception of the 75% Simmental-25% Hereford cows. The pre-weaning environment of the 75% Simmental-25% Hereford dams used in this study was diversified in that they were developed on nine separate ranches located throughout Montana. The selection criteria for the purchase of the 75% Simmental-25% Hereford dams as heifers were that (1) they be sired by the same Simmental sires as the Simmental-Hereford and 25% Simmental-75% Hereford dams developed on the station, and

(2) the average of the weaning weight ratios of the 75% Simmental-25% Hereford heifers purchased from each respective rancher was equal to the herd average.

The total number of cows used in the study as well as the ultimate number of dams per breed group are outlined in Table 1. Dams were mated to either Charolais or Tarentaise sires. The matings were conducted on a random basis within each dam breed group. The distribution of Charolais and Tarentaise sired calves within each dam breed group is summarized in Table 1.

Table 1. Number of cows by breed of sire and breed of dam

Breed of sire	Breed of dam[a]					Total
	HH	AH	1S3H	1S1H	3S1H	
CH	9	6	7	8	5	35
T	7	10	8	7	9	41
TOTAL	16	16	15	15	14	76

[a]HH = Hereford, AH = Angus-Hereford, 1S3H = 25% Simmental-75% Hereford, 1S1H = Simmental-Hereford, 3S1H = 75% Simmental-25% Hereford, CH = Charolais, and T = Tarentaise.

The weigh-suckle-weigh method was used to measure milk production. Calves were separated from their dams at 7 a.m. on the day of the designated data collection period. Prior to separation the cow-calf pairs were aroused and allowed to nurse for 20 to 30 minutes. Cows were weighed at this time, given a body condition score and a visual inspection to ensure that each cow had been completely suckled out prior to separation. The condition score consisted of a score on a scale of 1 to 10 with one representing an individual of very poor body condition and ten being one that is overconditioned. A hip height measurement was taken during the initial data collection period for each cow. It was assumed this measurement would not vary significantly during the lactation period and no further height measurements were taken. All physiological disorders such as mastitis, calf scours, etc., were treated at this time.

A separation time of 6 h was applied in the prebreeding period of this study as a result of conclusions reached in an earlier study conducted by Williams et al. (1979), which revealed that a separation time of 8 h was an optimum length of time when compared with 4 and 16 h separation periods. Chenette and Frahm (1981) observed that daily milk yields were 1.04 kg higher ($P < .05$) for cows in a 6 h separation group than those of the cows in a 12 h separation group. During the post-breeding period, separation periods ranged from 5.5 h to as much as 10.25 h as a result of the large number of animals involved. Subsequent to completion of the separation period, calves were weighed, allowed to nurse for approximately 20 minutes, and were immediately reweighed. The difference between the two weights was an estimate of the milk production of that cow for the preceding separation period. Conversion to a 24 h milk production estimate was accomplished by the use of the appropriate multiplicative factor.

Early calf weights during the prebreeding period were taken on a dial scales. As the calves became older calf weights were taken using a digital scale. It became necessary to develop a calf restriction box which could be inserted onto the digital scale restricting the forward and backward movement of the calf. Calf weights could then be taken with a higher degree of accuracy (to the nearest .454 kg) as the variability in weights associated with excessive motion from one end of the scales to the other (average of a 4.5 kg difference between ends) was reduced.

Herd Management (Nutrition)

Prior to the calving season, all dams eligible to be placed on the study were fed the various rations listed in Table 2, with the respective dates for each change in the feed regimen listed accordingly. Percent protein for the separate feed components is listed in Table 3.

Table 2. Prepartum feed regimen

Dates[a]	Feed (kg/head/day)			
	Hay	Untreated straw	Treated straw[b]	Corn silage
Dec 28-Jan 03	1.8	1.1	---	---
Jan 04-Jan 08	2.3	1.0	1.4	8.4
Jan 09-Jan 15	---	---	5.4	9.0
Jan 16-Feb 12	4.5	2.9	---	9.0
Feb 12-calving	4.5	---	---	9.0

[a]Dates for 1981 and 1982.

[b]Barley straw treated with ammonia.

Table 3. Chemical analysis of feed components

Feed	% Protein	% Phosphorus	% Calcium
Hay (first cutting)	13.3	.25	.92
Hay (second cutting)	19.0	.27	1.32
Barley straw	4.8	.09	.30
Ammonia-treated barley straw	7.6	---	---
Corn silage [a]	2.8	---	---

[a]Total moisture content of 62.6%.

After parturition the cow-calf pairs were relocated to a pasture allocated for the study immediately following the recording of birth weight, calving difficulty score, sex, and proper identification of the calf. During the postpartum period the feed ration consisted of approximately 13.6 kg/head/day of first cutting hay and any forage available in the pasture up to April 22, 1982. An observed reduction in cow condition as measured by body weight warranted a ration change to increase the protein and energy levels available to the cow. On April 23 a ration of approximately 50% first cutting and 50% second cutting alfalfa hay was fed with the amount of feed fed/head/day remaining the same. Total feed fed at any given date was dependent on the number of animals.

The feeding period ended on May 7, after which the cows were placed on a spring pasture predominantly composed of crested wheatgrass (Agropyron cristatum). June 7 was the start of the breeding season.

The test herd was incorporated with the breeding herd and moved to the breeding pasture with no further milk tests being conducted until completion of the breeding season (July 27). The breeding pasture was a segment of the Webb Thackery lease located in the Bearpaw Mountains approximately 18 miles south of Havre, Montana. Vegetative composition of the breeding pasture as well as the postbreeding, preweaning summer pasture was of the rough fescue/bluebunch wheatgrass (Festuca scabrella/Agropyron spicatum) habitat type as summarized by Mueggler and Stewart (1980) with a ponderosa pine (Pinus ponderosa) overstory. Following the completion of the breeding season the milk production study herd was separated from the breeding herd and placed on late summer pasture up through weaning on October 4.

Herd Management (Health)

Daily observations were conducted to isolate and treat individuals with definite physiological disorders. Individuals suffering from a disorder during a milk production data collection period were removed, treated appropriately, and milk production was measured later. If the individual, be it the cow or the calf, had not satisfactorily recovered from its affliction or if the disorder resulted in death, the pair was removed from the study.

Some dams in the early stages of lactation (up through day 28) were observed to produce milk in excess of the calf's capacity. This ultimately resulted in the nursing of a distinct quarter(s) causing the unsuckled quarter(s) to become distended and painful. Untreated, the disorder would possibly have had an adverse effect on the dam's potential milk production for the remainder of the lactation period. The condition also restricted the availability of the dam's maximal daily milk-producing capabilities to the calf as its metabolic requirements became more demanding. Individuals displaying the affliction were isolated and placed on restricted feed. The condition warranted hand milking of the irritated quarter(s) and application of a petroleum based ointment to the ventral portion of the mammary gland. This treatment was continued until normal nursing of all quarters was achieved (on the average this required 4 d). Approximately 16% of the cows used in the study warranted treatment for this condition. Of the cows afflicted with the condition, 46% were 50% Simmental-50% Hereford cows.

A trauma to the mammary gland involving the epidermis of the teat required a similar treatment. As a result of the nursing of the calf and the aridity of the environment, severe lesions to the teat due to dehydration of the epidermis was observed with some individuals. With extreme cases the condition progressed to a point where the calf would not be allowed to nurse. The treatment for severely cracked teats required restraining the animal for hand milking followed by a generous application of ointment to the traumatized teat(s) daily until the condition was remedied. A total of five individuals developed the extreme form of epidermal dehydration requiring treatment. The length of the treatment was dependent on the severity of the condition. In the most severe cases treatment was continued for 5 d.

Sunburned udders, a condition commonly associated with breeds having lightly pigmented udders, were encountered during the early spring months immediately following a spring snow storm. There were some cases of rather severe and painful third degree burns to the epidermis of the udder. A total of nine cases were observed requiring treatment. The treatment applied was identical to the management practice used with the previous conditions involving the epidermis of the udder.

Mastitis is commonly defined as an inflammation of the mammary gland which is a reaction of the udder to neutralize the irritant. Mastitis can be the result of an injury to the gland or it can be caused by the infection of bacterial or myotic pathogens. In acute cases, inflammation of the mammary gland without treatment will result in reduced productivity (Erb et al., 1980) or in some cases total atrophy of the affected quarter(s).

Infectious mastitis can be divided into two major categories. Subclinical mastitis refers to that form of the disease in which the infectious organisms are present but there is no change in the appearance of the udder. Clinical mastitis refers to the other extreme and is usually described as subacute, acute, and septic. Subacute mastitis is a condition in which the milk is of abnormal color or viscosity. Acute mastitis is associated with the symptoms of inflammation, such as heat, pain, redness, and swelling of the affected quarter(s). Septic mastitis refers to the most extreme form of mastitis which is characterized by generalized symptoms such as elevated body temperature, depressed appetite, and evidence of pain. Untreated, death may result within a few days.

Two cows were diagnosed as suffering from subacute mastitis. Treatment of the infected cows consisted of an antibiotic therapy involving the injection of hetacillin-potassium (Hetacin-K) into the infected quarter(s) via the streak canal. The treatment was unsuccessful in restoring a normal lactation in both cases, and the infected cows were removed from the study.

Pneumonia, a disease thought to be caused by a virus, was diagnosed in an individual cow during the latter portion of the study. The weakened body condition of the cow warranted her immediate removal from the study. As the condition was incurred during the latter portion of the lactation this particular cow's early milk production records were included in the final analyses.

Common calf scours is a disease which is associated with reduced vitality in the calf. It can occur at any age but is generally associated with the early growth period. The calf infected with scours is generally listless, its eyes appear dull and its ears droop, the feces can be discolored and have a thin consistency, and in severe cases dehydration and death may occur. Calves suffering from scours during a milk test period were treated with the sulfa drug, Sulkamycin-S (sulfamethazine and meomycin sulfate), in conjunction with penicillin. In cases of severe dehydration a balanced electrolyte solution was administered orally. These calves were removed from that particular milk production estimation period and were retested the following day or when the calf was considered fully recovered.

Naval ill is an infectious process which is initiated prenatally or immediately after birth and is caused by a variety of micro-organisms. A single case was observed in which the knees and hock joints became arthritic and inflamed. Treatment consisted of the administration of an injectible penicillin-streptomycin mixture. In this case the treatment was unsuccessful resulting in the death of the calf.

Two cases of deaths involving calves were observed in which the immediate cause of death could not be determined.

Eighty-one cow-calf pairs were used initially in the study with five pairs having to be removed from the study group for a variety of physiological reasons (Table 4).

Table 4. Number of cow-calf pairs removed from the study

Disorder	Breed group					Total
	HH	AH	1S3H	1S1H	3S1H	
Cow						
Pneumonia	0	1[a]	0	0	0	0
Mastitis	0	0	0	1	1	2
Calf						
Naval ill	0	0	1	0	0	1
Death (unknown causes)	0	1	0	0	1	2
TOTAL	0	1	1	1	2	5

[a]Data from the early portion of this cow's lactation was included in the final analyses.

All calves were branded and vaccinated for blackleg and malignant edema, and the bull calves castrated on May 6, 1982. During a 4 d period succeeding the branding date no milk production estimates were collected to allow the calves to recover from the trauma associated with branding.

Statistical Analysis

Data were examined using a residual analysis procedure outlined in Neter and Wasserman (1974). The presence of outliers for each breed group was determined by the use of a standardized residual plot of milk production on day of lactation. Observations having an unusually large studentized residual (r_i), which should not be confused with a standardized residual, were appropriately tested using the following test statistic:

$$t_1 = r_i \frac{n - p - 1}{(n - p - r_i^2)^{1/2}},$$

where

r_i = the studentized residual for observation i,

p = the number of coefficients, and

n = the number of observations.

Observations lying within the rejection region were carefully evaluated to determine if the extreme observation could justifiably be edited from the data set. A total of 560 observations were initially available for analysis. Upon completion of all editings for outliers 545 observations remained in the data set for the final analyses.

The least squares analysis of variance procedure outlined by Harvey (1975) using the fixed effects model was used to evaluate the effect of all independent variables and two-way interactions on milk production. All nonsignificant two-way interactions, as revealed in preliminary analyses, were removed to arrive at the final linear model. The resulting linear mathematical model used as a basis for the final analysis was as follows:

$$Y_{ijklm} = u + a_i + b_j + c_k + d_l + (bc)_{jk} + (cd)_{kl} + e_{ijklm},$$

where

Y = milk production of the nth cow of the ith breed diagnosed as in the lth pregnancy status at weaning and the kth age raising a calf of the jth sex

u = the overall population mean,

a_i = the effect of the ith breed of dam,

b_j = the effect of the jth sex of calf,

c_k = the effect of the kth age of dam,

d_l = the effect of the lth pregnancy status at weaning,

$(bc)_{jk}$ = interaction effect for sex of the calf and age of dam,

$(cd)_{kl}$ = interaction effect for age of dam and pregnancy status, and

e_{ijklm} = the random errors.

The assumptions were made that all independent variables were fixed, random errors were normally and independently distributed with a mean equal to zero and a variance of v_E^2, and that all three-way interactions were nonsignificant.

Sire breed of calf approached significance ($P < .08$) during the initial analysis but became nonsignificant when the covariable birth weight was included in the analysis.

The covariables, date of birth, calf birth weight, day of lactation, and day of year, were included in all preliminary analyses of milk production. Date of birth and day of year were found to be nonsignificant ($P > .05$) and consequently were excluded from the final analyses.

Linear contrasts were performed to ascertain where the dissimilarities existed among breed group means. Differences were determined to be significant by use of the "t" test (Snedecor and Cochran, 1980). The orthogonal comparisons made were that of the Hereford cows (HH) versus the crossbred cows, Angus-Hereford (AH) versus Simmental-Hereford (1S1H), 25% Simmental-75% Hereford (1S3H) versus 75% Simmental-25% Hereford (3S1H), and that of the F1 (AH and 1S1H) contrasted with the backcross dams (1S3H and 3S1H).

Milk production curves were determined by the curvilinear regression model:

$$\overline{Y}_X = \overline{Y} + b_1(X-\overline{X}) + b_2(X-\overline{X})^2 + b_3(X-\overline{X})^3$$

where

$\overline{Y}_X$ = the estimated milk production for day X of the lactation period

$\overline{Y}$ = estimated mean milk production

b_1, b_2, b_3 = the estimated slope constants,

X = known day of lactation, and

$\overline{X}$ = estimated mean day of lactation.

The above estimators substituted in the above prediction equation were obtained using the method of least squares. Milk production estimates were limited to those days ranging from day 14 to day 168 of the lactation.

The preceding analysis failed to consider individual cow to arrive at the lactation curves; consequently a second analysis was performed with cow nested within breed included in the model as a main effect. Dependencies were encountered as the data set consisted of a small number of records. The data were therefore adjusted for age of dam, sex of calf, sire breed of calf, pregnancy status, and all significant two-way interactions to allow cow to be included in the model. The model was consequently altered such that cow breed and cow within cow breed were the only main effects in the model.

A second method was used to develop lactation curves for each cow and each breed group. The algebraic model was a gamma-type function and was

$$y_n = an^b \exp(-cn)$$

where y_n is the average daily milk production in the nth day and a, b, and c are the method constants developed by Wood (1967). Solution required the taking of the natural log of the above equation which converted it to a simple linear regression model:

$$\ln(y_n) = \ln(a) + b \ln(n) - cn.$$

The constants were calculated using least squares regression methods. Peak yield was defined as $y_{max} = a(b/c)^{b}e^{-b}$ and occurring when n = b/c and was calculated for each individual. A persistency factor was calculated as $c^{-(b+1)}$ and total yield was calculated by the summation of calculated daily yield up to 180 d for each individual cow (Wood, 1967).

Lactation curves were also developed following a reclassification of the cows into groups dependent on average daily milk production and pounds of calf weaned. Cows were ranked within their respective breed groups in accordance with their average daily milk production and secondly with respect to the 180 d adjusted weaning weights of their calf. The top three cows within each breed group were then grouped together and classified as high producers in terms of milk production or pounds of calf weaned. A total of four classes were developed ranging from high producers to low producers with two intermediate classes. The lactation curves were then arrived at through the use of least squares procedures previously outlined. A similar reclassification and analysis involved the grouping of the cows into one of two groups, straightbred or crossbred.

The corresponding body weight changes of the calf and the cow during the lactation period were analyzed using the same model. All independent variables and two-way interactions were evaluated with the nonsignificant interactions being removed from the model. The regression model was similar to that used in the development of the lactation curves.

Evaluation of the relationship between the early growth traits of the calf and the milk production of the dam required the calculation of lactation curves for each cow to obtain an estimate of each cow's average daily milk production. Residual correlations of average daily milk production with calf weaning weight, condition score, daily rate of gain, birth weight, hip height, and withers height were calculated from least squares analyses of variance following the adjustments for breed of dam, sex of calf, age of dam, pregnancy status, and the significant two-way interactions.

RESULTS AND DISCUSSION

Effects of Breed and Other Main Effects

The length of the lactation period for the cows in this study ranged from 148 to 202 d with the average length of the lactation period being 185 d. This was comparable to the 196, 195, and 175 d lactations studied by Gaskins and Anderson (1980), Kress and Anderson (1974), and Melton et al. (1967b), respectively, but was considerably shorter than the lactation periods studied by other researchers (Dawson et al., 1960; Christian et al., 1965; Gleddie and Berg, 1968; Rutledge et al., 1971; Totusek et al., 1973; Neville et al., 1974), whose weighted mean length of lactation was 254 d and ranged from 210 to 365 d.

The analysis of variance for 24 h milk production (Table 5) indicated that the main effects of breed of dam, sex of calf, and age of dam were significant sources of variation. The pregnancy status of the dam at the time of weaning of her calf approached significance ($P < .08$).

Least-squares means for these main effects are listed in Table 6. Sex of calf by age of dam and pregnancy by age of dam subclasses are tabulated in Table 7. Hereford cows gave significantly less milk per day (8.8 kg/d) than the crossbred cows grouped together (11.4 kg/d). There was no significant difference in the milk production of the Angus x Hereford (AH) and Simmental x Hereford (SH) cows

Table 5. Least-squares analysis of variance for daily milk production (N = 545)

Source	df	Mean squares milk production (kg^2)
Breed (B)	4	67.9**
Sex of calf (S)	1	41.6*
Age of dam (AD)	1	218.0**
Pregnancy status (P)	1	29.7†
S x AD	1	60.0*
P x AD	1	87.4**
Regressions		
Day lact-linear	1	1164.0**
B x day lact-linear	4	14.2
Day lact-quadratic	1	308.6**
B x day lact-quadratic	4	9.5
Day lact-cubic	1	319.6**
B x day lact-cubic	4	10.2
Birth weight-linear	1	98.1**
Residual	519	9.5

†P < .08.

*P < .05.

**P < .01.

Table 6. Least-squares means and standard errors for milk production

Effect	N	Milk production (kg)	Range
Overall mean	545	10.9 ± .26	
Breed			
HH	113	8.8 ± .53	5.7 to 13.3
AH	104	11.6 ± .57	7.2 to 17.0
1S3H	115	10.2 ± .52	7.1 to 15.4
1S1H	109	12.6 ± .56	8.2 to 16.5
3S1H	104	11.3 ± .54	5.6 to 15.0
Age of cow, years			
4	256	11.7 ± .29	5.6 to 17.0
5	289	10.1 ± .33	5.7 to 16.5
Sex of calf			
Male	223	10.6 ± .30	5.7 to 17.0
Female	322	11.2 ± .30	5.6 to 16.5
Pregnancy status			
Pregnant	419	11.2 ± .26	5.7 to 17.0
Open	126	10.6 ± .36	5.6 to 16.2

Table 7. Least-squares means and standard errors for milk production of significant two-way interactions with age of dam

Effect	Milk production (kg)	
	Age = 4	Age = 5
Sex of calf		
Male	11.7 ± .35 (127)[a]	9.4 ± .41 (96)
Female	10.8 ± .36 (129)	11.7 ± .36 (193)
Pregnancy status		
Pregnant	11.5 ± .31 (173)	10.9 ± .30 (246)
Open	11.9 ± .40 (83)	9.2 ± .53 (43)

[a]Number of observations are in parentheses.

which gave 11.6 and 12.6 kg/d, respectively. No significant difference in milk production was detected between the backcross cows, 25% Simmental x 75% Hereford (1S3H) and 75% Simmental x 25% Hereford (3S1H) cows, which gave 10.2 and 11.3 kg/d, respectively. The F1 cows (AH and SH) gave significantly more milk per day (12.1 kg/d) than the backcross cows which collectively averaged 10.8 kg/d.

Average daily milk production for the HH cows in this study was 3.9 kg higher than the average of those observed with HH cows studied by Klett et al. (1962), Christian et al. (1965), Melton et al. (1967b), Gleddie and Berg (1968), Jeffery et al. (1971b), Rutledge et al. (1971), Totusek et al., (1974), Kress and Anderson (1974), Neville et al. (1974), Streeter et al. (1974), and Williams et al. (1979a), which ranged from 2.9 to 7.6 kg. This can possibly be attributed to the variability between studies in age of cow, separation times, environments, and the number of observations within the lactation period as well as a result of a year effect due to exceptional forage production during the year the study was conducted. A comparison of the average milk production for the F1 cows involved in this study with those cited in the literature reveal a trend similar to that for Herefords. The AH dams studied by Chenette and Frahm (1981) and Gaskins et al. (1980) produced an average of 4.8 kg/d less milk (6.8 kg) than the AH cows of comparable age in this study (11.6 kg). Mean daily milk production of the SH cows in this particular study were 5.7 kg higher than those observed by Chenette and Frahm (1981). Notter et al. (1978) conducted a similar study in which the average milk production of the AH and Simmental cross cows were below that of the average milk yields reported in this study; however, all of the observations were taken during the latter portion of the lactation period. There were no results reported for the 1S3H and 3S1H cows in the literature.

Four-year-old cows produced significantly more milk (11.7 kg) than the 5-yr-old cows (10.1 kg). Gifford (1953) observed similar results for 4- and 5-yr-old Herefords. This age of peak milk production, however, is younger than those found by Klett et al. (1962), Todd et al. (1969), Rutledge et al. (1971), and Melton et al. (1976b).

Cows nursing heifer calves produced significantly more milk (11.2 kg) than those cows nursing male calves (10.6 kg). Christian et al. (1965) and Rutledge et al. (1971) reported similar results with cows nursing heifer calves producing at higher levels than cows nursing male calves. Several researchers (Pope et al., 1963; Melton et al., 1967b; Jeffery et al., 1971b) have observed contradictory results with cows nursing male calves producing significantly more milk than cows nursing female calves. This observation appears to be specifically true with the older cows (Table 7). Five-year-old cows nursing heifer calves produced more milk (11.7 kg) than their contemporaries nursing male calves (9.4 kg). The reverse was true with the 4-yr-old cows in that those cows raising female calves gave slightly less milk (10.8 kg) than those 4-yr-old cows with male calves at their sides (11.7 kg).

It should be noted that this interactive relationship may be the result of a combination low number of observations for the 5-yr-old cows rearing bull calves and from an individual cow within this class having an unusually low least squares mean for milk production. The low mean is the result of a milk production estimate of 0.0 kg midway through the lactation period. Stress to the calf during the collection period is attributed to this low estimation. Following the exclusion of the milk production estimates associated with the aforementioned cow the least squares mean for 5-yr-old cows rearing bull calves becomes comparable with the other classes (11.0 kg).

Pregnancy status of the cow during the lactation period was approaching a significant level with pregnant cows producing slightly more milk (11.2 kg) than those cows failing to become pregnant (11.6 kg). It appears that the failure to become pregnant in some cows may have been the direct result of not having attained a body condition optimal to reproduction during the breeding season. Consequently, in order to try and achieve this optimal body condition, milk production was apparently sacrificed to gain in body weight. This appears to have been especially true in terms of the older cows. Table 7 lists the means and standard errors for the pregnancy status by age of dam interaction ($P < .01$).

The regression of milk production on calf birth weight was found to be significant ($P < .01$). The results indicated that daily milk production will increase .037 ± .012 kg for every kg increase above the mean birth weight. The mean birth weight in this study was 44.6 kg (±5.9 kg). This supports the positive relationship observed between the birth weight of the calf and the milk production of the dam observed by Chew et al. (1981), Erb et al. (1980), and Heidhart et al. (1979). Chew et al. (1981) found that peak yields were when calf birth weight was between 45 and 50 kg. The results in this study suggest that a more linear relationship exists as the quadratic effect was nonsignificant. This seems illogical as the incidence of dystocia increases with the heavier birth weights and milk production would obviously be adversely affected.

Lactation Curves (Breeds)

The shape of the lactation curves was determined with linear, quadratic, and cubic nonorthogonal polynomial regressions (Table 8). Separate polynomial regressions were fitted for each of the genotypic groups. Similar to a study by Abadia and Brinks (1972), linear, quadratic, and cubic regression coefficients (Table 8) were significantly different from zero ($P < .01$). The linear, quadratic, and cubic coefficients were not significantly different among breeds.

Table 8. Regression coefficients for breed lactation curves[a]

Breed	Linear	Quadratic	Cubic
HH	-.0935	-4.098×10^{-4}	1.174×10^{-5}
AH	-.0630	-5.409×10^{-4}	6.656×10^{-6}
1S3H	-.0542	-2.605×10^{-4}	4.540×10^{-6}
1S1H	-.0732	-6.551×10^{-4}	9.207×10^{-6}
3S1H	-.0535	-2.842×10^{-4}	5.162×10^{-6}

[a]Expressed in kilograms.

Figure 2 shows the fitted lactation curves for each of the five genotypes. The dissimilarity in the curves for the five genotypic

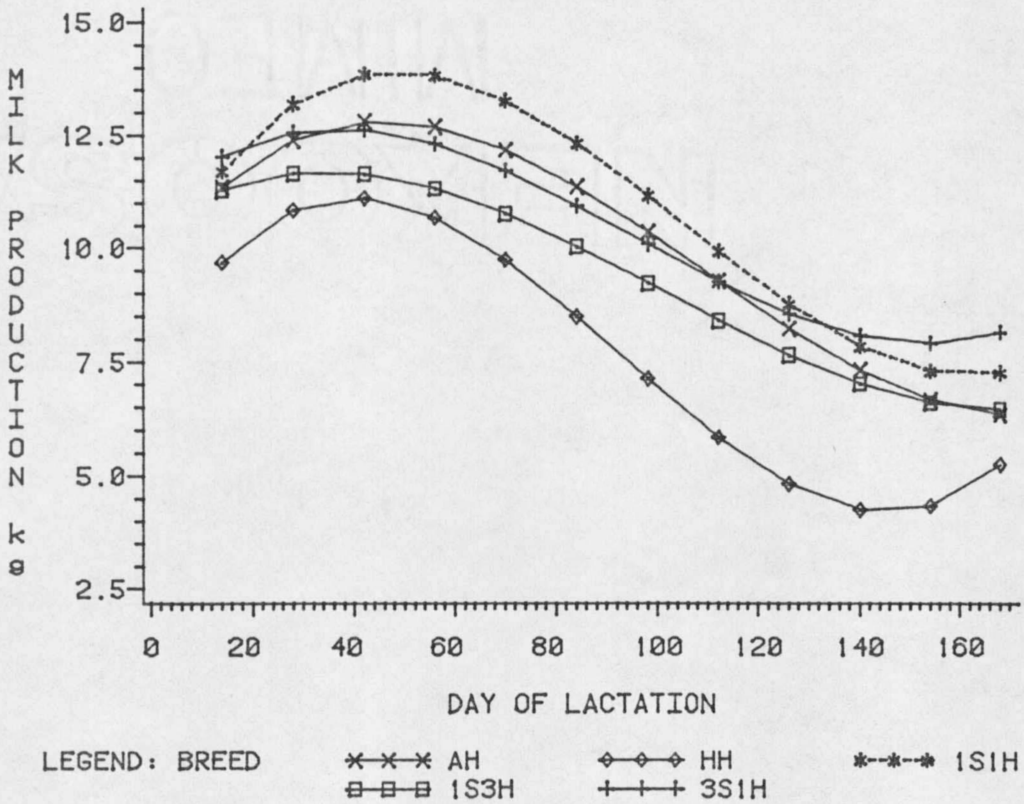

FIGURE 2. DAILY MILK PRODUCTION FOR DIFFERENT BREED AND BREED CROSSES (LEAST SQUARES)

groups is not in the curvilinearity of the curves but in the magnitude of milk production. All breed groups showed similar curvilinear trends. The HH cows produced at a lower level throughout the lactation period as compared with the crossbred cows. F1 cows produced slightly less milk in the early and later portion of the lactation period as compared to the backcross cows but achieved a higher level of peak milk production.

Peak milk production, estimated as that day on the derived lactation curves where maximum milk yield was achieved, for the HH, AH, 1S3H, 1S1H, and 3S1H cows was on day 40, 46, 34, 48, and 37 of the lactation period, respectively. These results are consistent with that of Abadia and Brinks (1972) which showed a peak in milk yield at between 30 and 45 d postpartum for registered Hereford heifers. Neidhardt (1979) observed that peak milk production in Brahman cattle occurred around 30 d, while Totusek et al. (1973) found that peak milk production was at approximately 49 d into the lactation; however, these results are not in agreement with the observations of Gaskins and Anderson (1980), Kress and Anderson (1974), and Gleddie and Berg (1968) which showed that milk production for AH and mature HH cows declined at a linear rate throughout the lactation. This disagreement can be attributed to the small number of milk production measurements taken during the lactation and the post peak period of the lactation when a majority of the measurements were taken.

Figure 3 depicts the lactation curves for the genotypic groups following the incorporation of cow within breed into the model. Though the variability in milk production between individual cows was found to

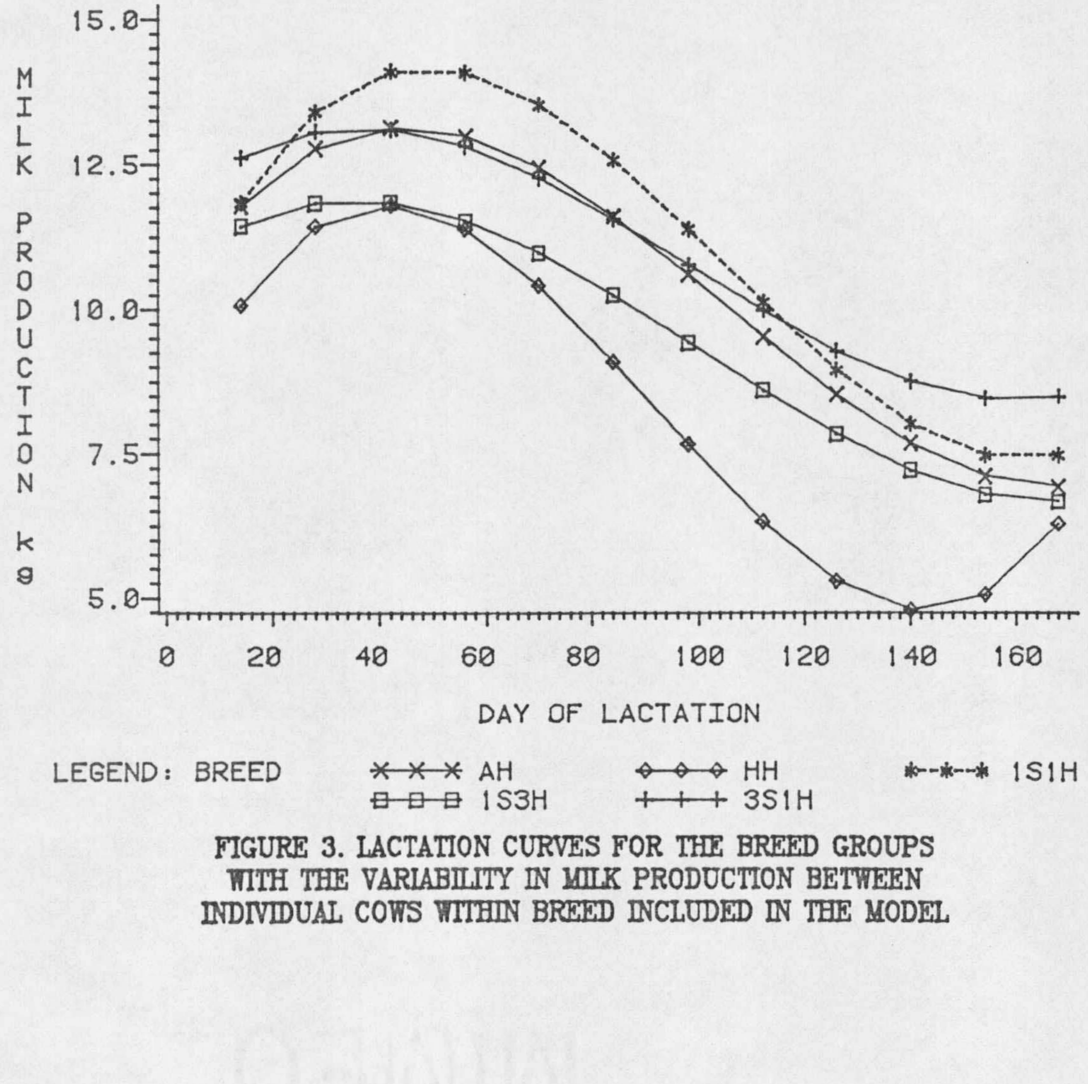

FIGURE 3. LACTATION CURVES FOR THE BREED GROUPS WITH THE VARIABILITY IN MILK PRODUCTION BETWEEN INDIVIDUAL COWS WITHIN BREED INCLUDED IN THE MODEL

be significant (Table 9), the differences between the lactation curves arrived at with the model excluding cow nested within breed (Figure 2) as compared with the lactation curves shown in Figure 3 appear unimportant.

Table 9. Least-squares analysis of variance for daily milk production adjusted for main effects (N = 545)

Source	df	Mean squares milk production (kg^2)
Breed (B)	4	59.9*
Cow/Breed	71	19.3**
Regressions		
Day lact-linear	1	1173.9**
B x day lact-linear	4	17.2
Day lact-quadratic	1	302.8**
B x day lact-quadratic	4	10.4
Day lact-cubic	1	338.6**
B x day lact-cubic	4	13.8
Residual	454	8.8

*P < .05.

**P < .01.

The corresponding changes in body weight of the cows during the lactation period are shown in Figure 4. Body weight of the cow appears to decrease during the early portion of the lactation to a point just after that period of peak milk yield. The estimated day

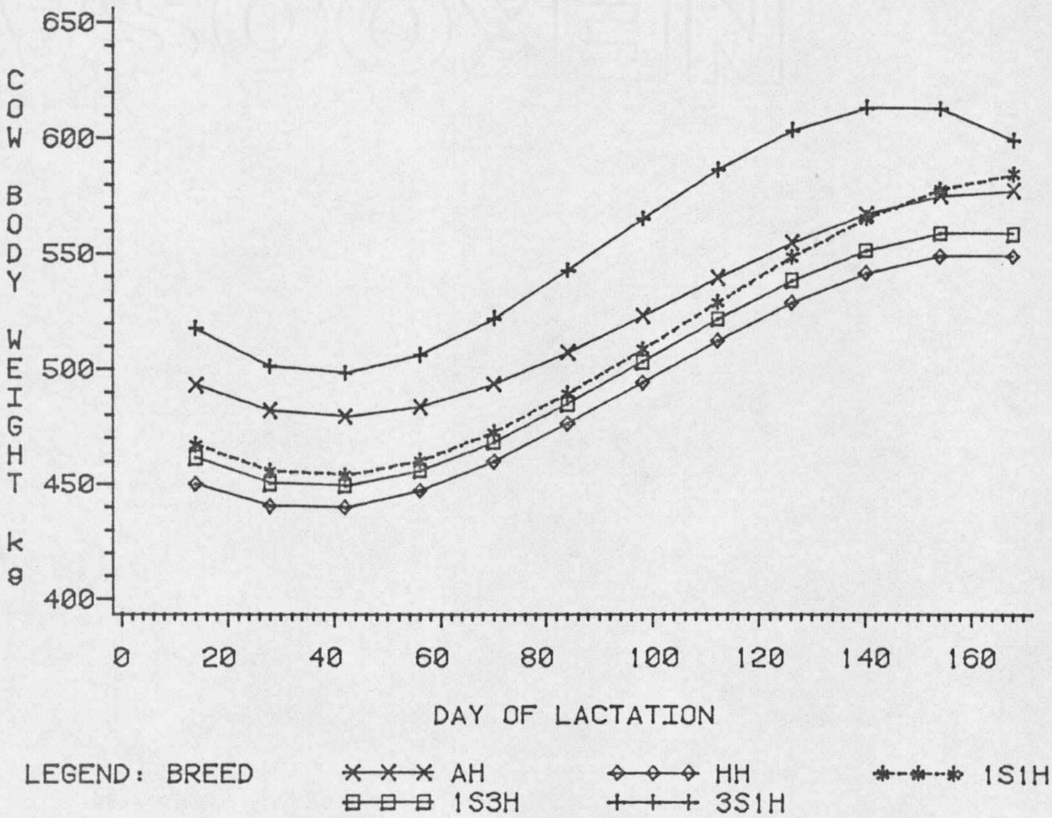

FIGURE 4. COW BODY CONDITION TRENDS DURING THE LACTATION PERIOD

of the lactation where cow body weight was at its lowest was day 37, 42, 36, 38, and 38 for the HH, AH, 1S3H, 1S1H, and 3S1H cows, respectively. Body weight progressively increases during the post peak milk production portion of the lactation. This is logical from a biological viewpoint as the demand on the cow is at its highest during the early portion of the lactation. As the calf's dependency decreases and forage quality increases, the body condition of the cow begins to regenerate.

Apparently no differences exist in the cyclic changes of body condition between breed groups. Similar to the lactation curves the difference appears to be in magnitude which in this case is the initial difference in body size between the genotypic groups.

Figure 5 depicts the lactation curves for the HH cows and the crossbred cows treated as a single group. The linear, quadratic, and cubic regressions (Table 10) were different from zero ($P < .01$). The linear regression coefficient (Table 11) for the crossbred cattle was significantly lower than that of the straightbred cattle implying that the crossbred cattle maintained a more persistent lactation than that of the HH cows with persistency in this case being defined as the rate of decline in milk production during the lactation. This observation is similar to that of Nielsen et al. (1983) and Holloway and Worley (1983) in that cows averaging larger amounts of milk during the lactation had more persistent lactations as compared to lower milking cows. However, Notter (1976) noted the persistency of lactation increased when the average daily milk production decreased. The difference in

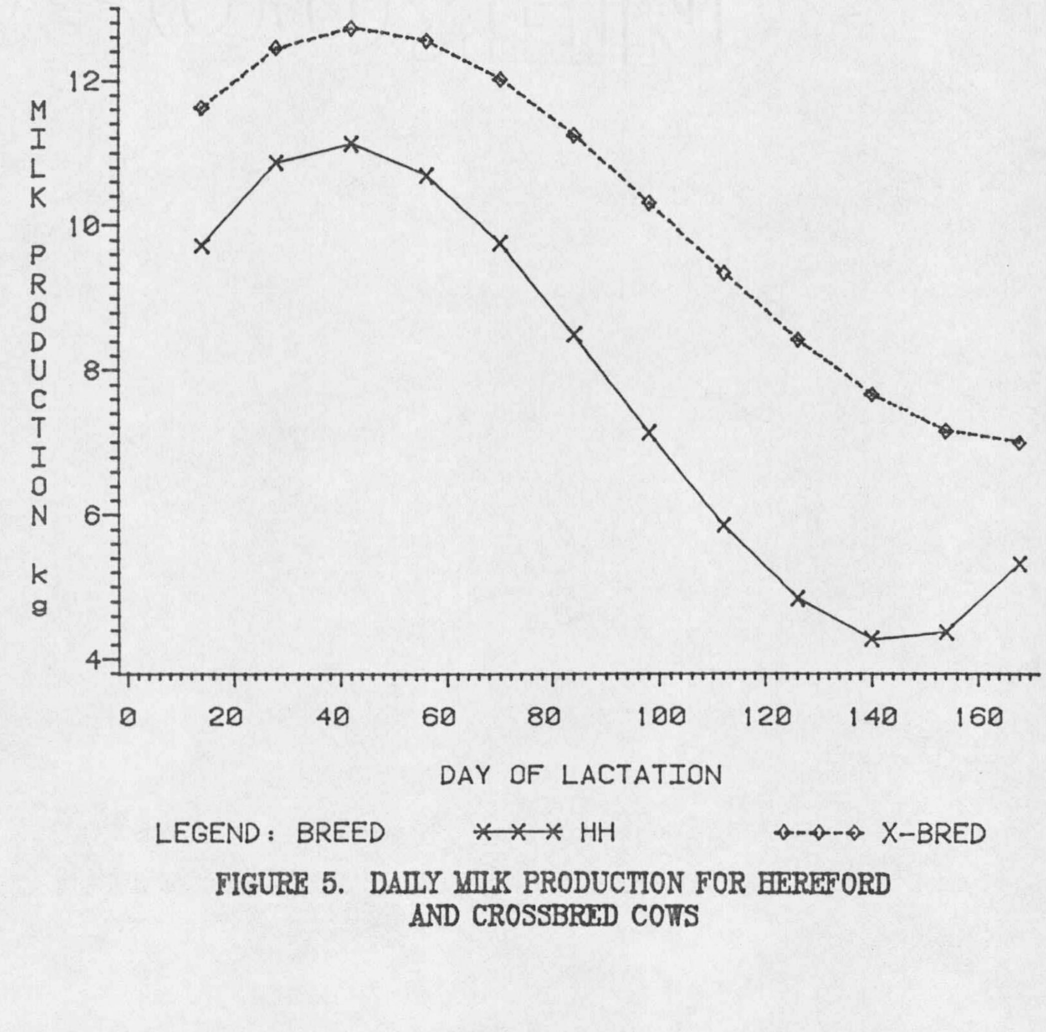

FIGURE 5. DAILY MILK PRODUCTION FOR HEREFORD AND CROSSBRED COWS

Table 10. Analyses of variance for milk production of crossbred and straightbred cows (N = 545)

Source	df	Mean squares Milk production (kg^2)
Breed (B)	1	179.1**
Sex of calf (S)	1	71.7**
Age of dam (AD)	1	231.8**
Pregnancy status (P)	1	34.0†
S x AD	1	52.2*
P x AD	1	90.2**
Regressions		
Day lact-linear	1	976.2**
B x day lact-linear	1	45.8*
Day lact-quadratic	1	191.8**
B x day lact-quadratic	1	0.1
Day lact-cubic	1	283.5**
B x day lact-cubic	1	27.5
Birth weight-linear	1	110.4**
Residual	531	9.6

†P < .07.

*P < .05

**P < .01.

Table 11. Least-squares means, standard errors, and regression coefficients for milk production in crossbred and straightbred cows[a]

Effect	N	Milk production	Regression coefficients		
			Linear	Quadratic	Cubic
Overall mean	545	10.1±.31	---	---	---
Breed					
Crossbred	432	11.4±.29	-.06001948	-4.2666×10^{-4}	6.1381×10^{-6}
HH	113	8.8±.54	-.09330595	-4.0871×10^{-4}	1.1690×10^{-5}

[a]Expressed in kilograms.

the cubic regression coefficient between the crossbred and HH cows was approaching significance (P = .07).

Figure 6 depicts the lactation curves of the genotypic groups derived through the use of an algebraic model proposed by Wood (1967) and used by Torres-Hernandez and Hohenboken (1980) and Cobby and Le Du (1978). The model $y_n = an^b \exp(-cn)$ requires that the exponent b must be less than unity. If this is not the case there is an ever increasing milk yield. The subsequent least squares analysis revealed that several individual cows failed to meet this restriction. Also several of the b exponents that were equal to or greater than unity were observed to be negative numbers. In association with the discrepancies concerning the b exponent, several of the a constants were observed to be exceptionally large and in one case to be a negative number. Consequently, an analysis as to whether or not differences existed between

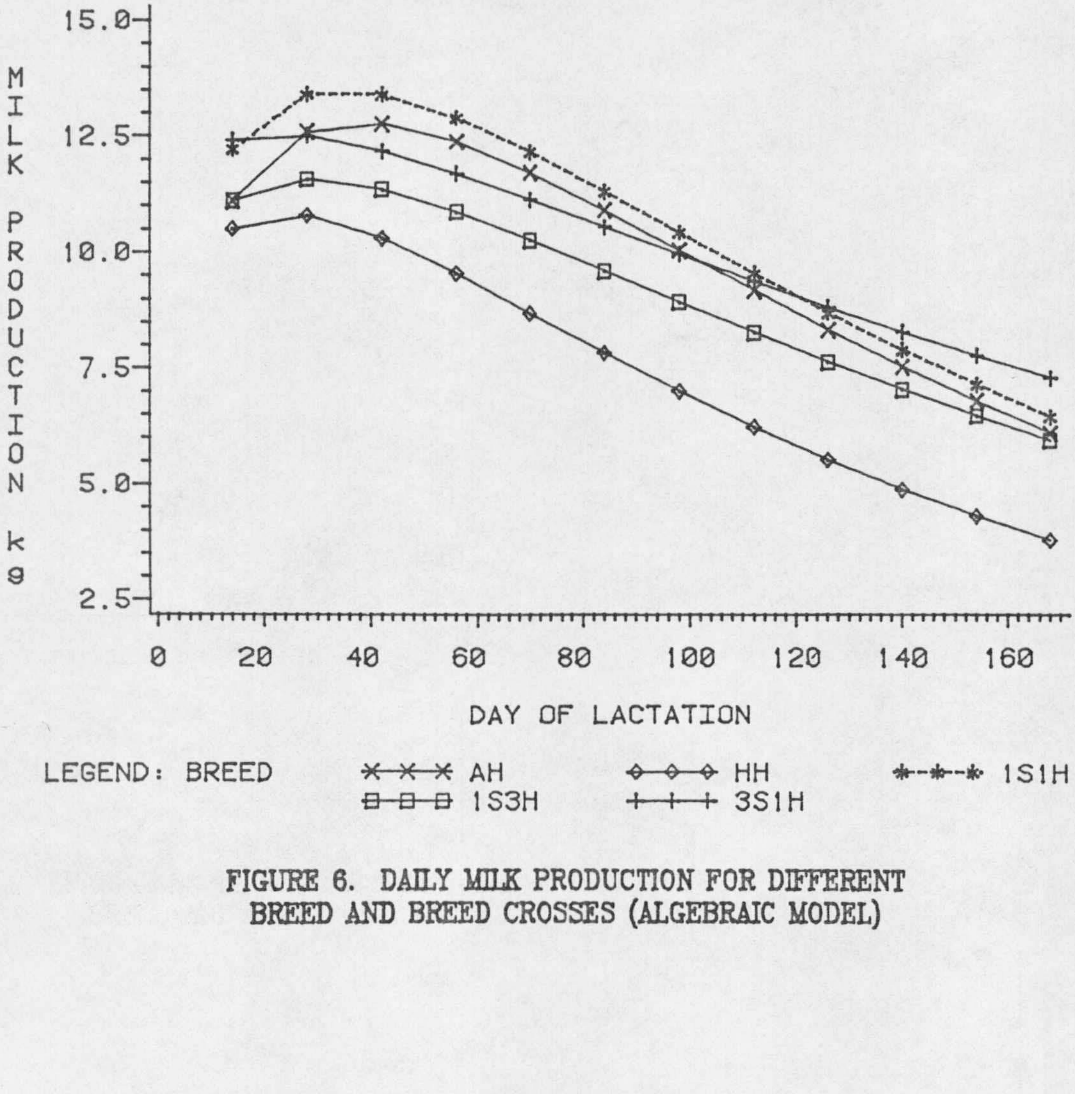

FIGURE 6. DAILY MILK PRODUCTION FOR DIFFERENT BREED AND BREED CROSSES (ALGEBRAIC MODEL)

breeds and individuals in maximum milk yield, persistency, day of maximum milk production, and total milk production was not possible using this procedure. Hypotheses as to why this particular model was inappropriate for individual cows in the analysis of daily milk production for beef cattle but sufficient in terms of dairy cattle (Wood, 1967; Cobby and Le Du, 1978) and sheep (Torres-Hernandez and Hohenboken, 1980) are (1) the difference in the number of 24 h milk production estimates collected in this study as compared to the analogous dairy and sheep studies, and (2) a difference in the feed regimens employed in the various milk yield studies. The example presented by Wood (1967) evaluated a Holstein-Fresian lactation with the values for the algebraic values being calculated from observations taken weekly from the first 44 wk of the lactation as compared with the 7.5 observations taken during a lactation period in this study.

Holloway and Worley (1983) appeared to have a similar problem with the equation of Wood (1967) in that during their preliminary analysis they experienced difficulty in obtaining convergence. They attributed this to not having enough data early in the lactation for convergence to occur. Calculated data points using the net energy requirements of the calves were added to the data set to obtain convergence.

In reference to the differences in feed regimens, dairy cattle are generally fed in accordance with their level of production and are therefore on a controlled diet. Torres-Hernandez and Hohenboken (1979) maintained their crossbred ewes on improved pasture throughout the study. A result of this type of management was that there was no surge in daily milk production associated with improvement in the quality of range forages during the fall months. Figure 7 represents an example of an individual cow's lactation curve developed using the algebraic model as well as the actual data points collected during the lactation. The following values were calculated by least squares regression methods: a = 70.3, b = .209366, -c = .00032937, from which y_{max} = 10.2 kg/d and n_{max} = 636 d. It becomes evident that the surge in milk production during the latter portion of the lactation of a range cow results in constants that lead to unrealistic values, in this case day of peak production.

Hence, the curves in Figure 6 were calculated from cow breed group means rather than individual observations. Similar conclusions were arrived at as to the differences in the level of milk production between breed groups using the algebraic model as compared to the least squares method. Day of peak milk production was observed to occur several days earlier (Appendix Table 25) in Figure 6 as compared with the similar curves arrived at through the least squares analysis.

Lactation Curves (High Producer Versus Low Producer)

Figure 8 characterizes the lactation curves for cows differing in the level of milk production. The high producing cows produced at a level above that of the lower producing cows throughout the lactation. The lower producing cows initiated the lactation at a level comparable to that of the intermediate cows but declined at an almost linear rate. Table 12 revealed that a significant difference existed in the shape of lactation (due to the quadratic term) curves between

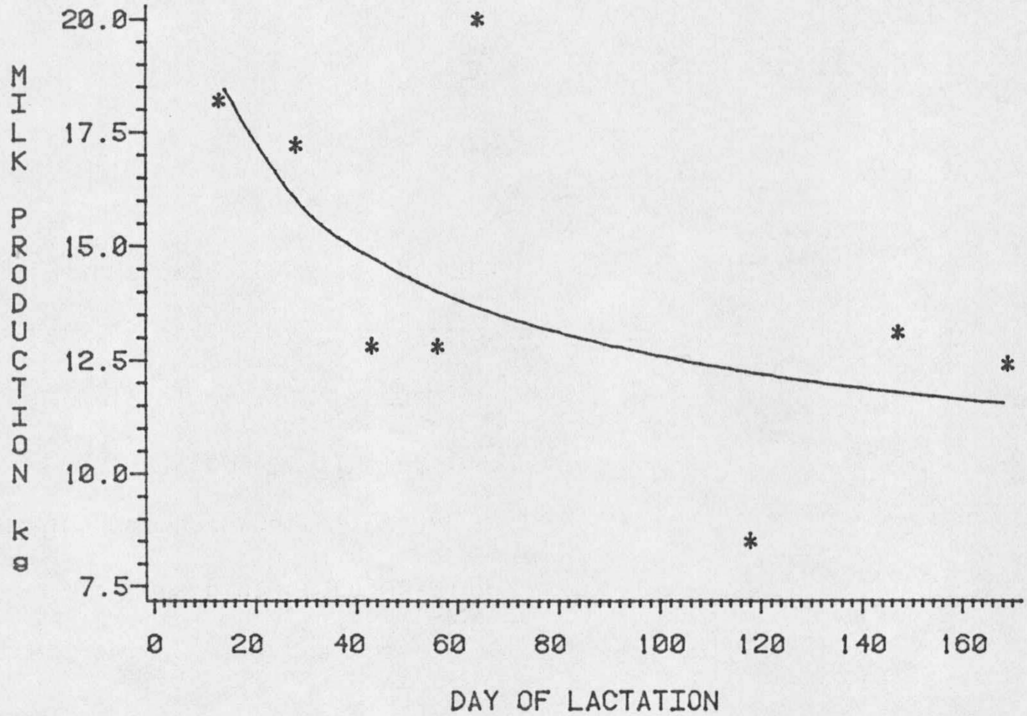

FIGURE 7. ACTUAL 24 HR. MILK PRODUCTION OBSERVATIONS AND ESTIMATED LACTATION CURVE FOR INDIVIDUAL COW (8557) USING THE WOODS EQUATION

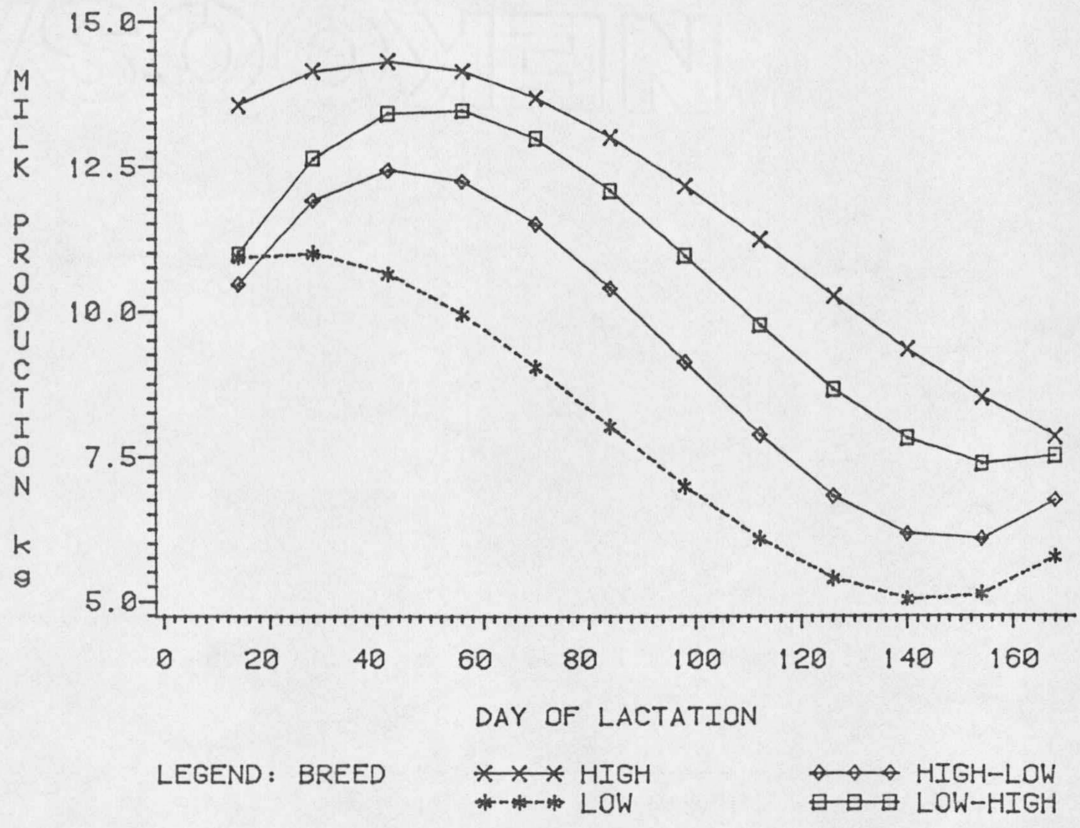

FIGURE 8. LACTATION CURVES FOR COWS DIFFERING IN LEVEL OF MILK PRODUCTION

Table 12. Mean squares from analysis of variance of milk production for cows differing in levels of milk production

Source	df	Mean squares (kg^2)
Milk production ranking (MR)	3	196.0**
Sex of calf	1	64.8**
Regressions		
Day lact-linear	1	1240.7**
MR x day lact-linear	3	11.3
Day lact-quadratic	1	296.1**
MR x day lact-quadratic	3	30.6*
Day lact-cubic	1	353.4**
MR x day lact-cubic	3	15.0
Birth weight-linear	1	37.6*
Residual		8.9

*P < .05.

**P < .01.

the different milk production groups. The regression line depicting the lactation curve for the low milk production and high milk production groups includes a quadratic term that is somewhat smaller than that for the intermediate regression lines (Table 13). Therefore, it appears that the only difference between a high milking cow and a low producing cow is the magnitude of milk production and the ability of the high producing individual to maintain a high level of milk production. Both the low and high producing groups give the impression of a linear rate of decline in milk production when compared to the two intermediate groups. The two intermediary groups display the classic form of the lactation curve in terms of the increasing daily milk production up to a point of peak production followed by a rapid decline.

Table 13. Means and regression coefficients for daily milk production of high versus low producing cows[a]

Effect	N	Mean (SE)	Regression coefficients		
			Linear	Quadratic	Cubic
Overall Mean	538	11.1 (.23)	---	---	---
Production level					
High	132	13.2 (±.48)	-.0518	-4.44×10^{-4}	3.84×10^{-6}
Low-high	138	12.3 (±.46)	-.0700	-6.83×10^{-4}	9.82×10^{-6}
High-low	131	10.6 (±.46)	-.0844	-5.18×10^{-4}	1.13×10^{-5}
Low	137	8.2 (±.46)	-.0740	-5.12×10^{-5}	6.67×10^{-6}

[a]Expressed in kilograms.

These observations are similar to the lactation curves presented by Gifford (1953) in that the higher producing cows began the lactation at a higher level but are somewhat contradictory in that the high producing cows observed by Gifford (1953) did not maintain that high level of production as was the observation in this study.

Lactation Curves (High Weaning Versus Low Weaning)

Figure 9 represents the lactation curve of cows grouped on the basis of the weaning weight of their calves. The heavier weaning calves were raised on dams that maintained a higher level of milk production throughout the lactation period. The average calf weaning weights for the high production, medium-high, medium-low, and low production cows was 257.5, 234.8, 221.2, and 199.3 kg, respectively. This observation emphasizes the important role dam's milk production has on the preweaning growth of the calf. Though there is no significant difference in the shape of the lactation curves (Table 14) of Figure 9, it does appear that those cows having a higher degree of persistency wean heavier calves.

Relationship of Preweaning Calf Traits with Milk Production

The relationships between the preweaning growth traits of the calf and the milk production of its dam were found to be positive and significant. The correlations between the milk production of the dam and various preweaning traits of the calf are listed in Table 15. The correlation between milk production and preweaning gain of the

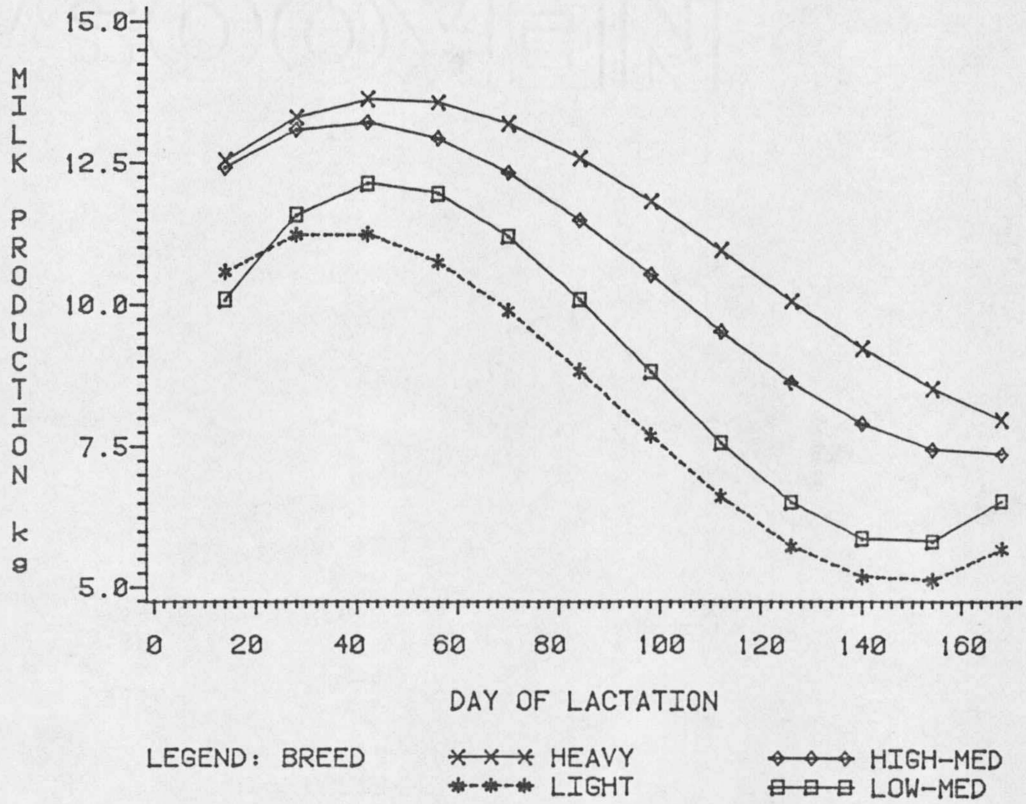

FIGURE 9. LACTATION CURVES FOR COWS DIFFERING IN LEVEL OF CALF PRODUCTION

Table 14. Mean squares from analysis of variance of milk production for cows ranked according to calf weaning weight

Source	df	Mean squares (kg^2)
Weaning weight rankings (WR)	3	94.5**
Sex of calf (S)	1	74.1**
Age of dam (AD)	1	62.0*
Pregnancy status (PS)	1	6.6
AD x PS	1	43.0*
Regressions		
Day lact-linear	1	1184.0**
WR x day lact-linear	3	16.1
Day lact-quadratic	1	288.4**
WR x day lact-quadratic	3	5.7
Day lact-cubic	1	326.8**
WR x day lact-cubic	3	13.0
Residual	518	9.6

*$P < .05$.

**$P < .01$.

Table 15. Residual correlations among preweaning calf traits and milk production

Trait	Calf cond. score	Calf hip ht.	Calf withers ht.	Calf ADG	Calf birth wt.	Weaning wt.
Avg. daily milk production	.40**	.40**	.83**	.49**	.20	.49**
Calf cond. score[a]		.24	.18	.58**	.10	.55**
Calf hip height[a]			.88**	.62**	.54**	.70**
Calf withers height[a]				.56**	.46**	.63**
Calf ADG[b]					.25**	.96**
Calf birth weight						.52**

[a]At the time of weaning.

[b]From birth to weaning.

*P < .05.

**P < .01.

calf of .49 was lower than the correlations observed by Furr and Nelson (1959), Pope et al. (1963), Gleddie and Berg (1968), Holmes et al. (1968), Jeffery et al. (1971a), and Totusek et al. (1973), ranging from .59 to .88, but higher than the .14 correlation observed by Todd et al. (1968). Knapp and Black (1941), Franke et al. (1975), and Belcher and Frahm (1979), during the early portion of the lactation, observed a similar correlation to that observed in this study ranging from .41 to .52 between milk production and calf average daily gain.

Figure 10 graphically represents the relationship between calf ADG and day of lactation. It is interesting to note that calf ADG decreases during the early portion of the lactation period. Biologically speaking this is generally not the case; therefore this trend can be attributed to the cubic effect on the regression. As the lactation period progresses calf ADG increases at a linear rate for a period of time after which a gradual tapering off occurs. If we consider the lactation curves and the calf growth curves in Figure 10 we note a declining relationship between milk production of the cow and calf gain as the lactation progressed. This observation is supported by the correlations reported by Gifford (1953), Neville (1962), and Melton et al. (1967) that tended to be higher early in the lactation than in the latter portion.

The weight of the calf had a similar correlation (.49) with the milk production of the dam. This is comparable to the correlation value of .42 observed by Belcher and Frahm (1979) and the .51 value

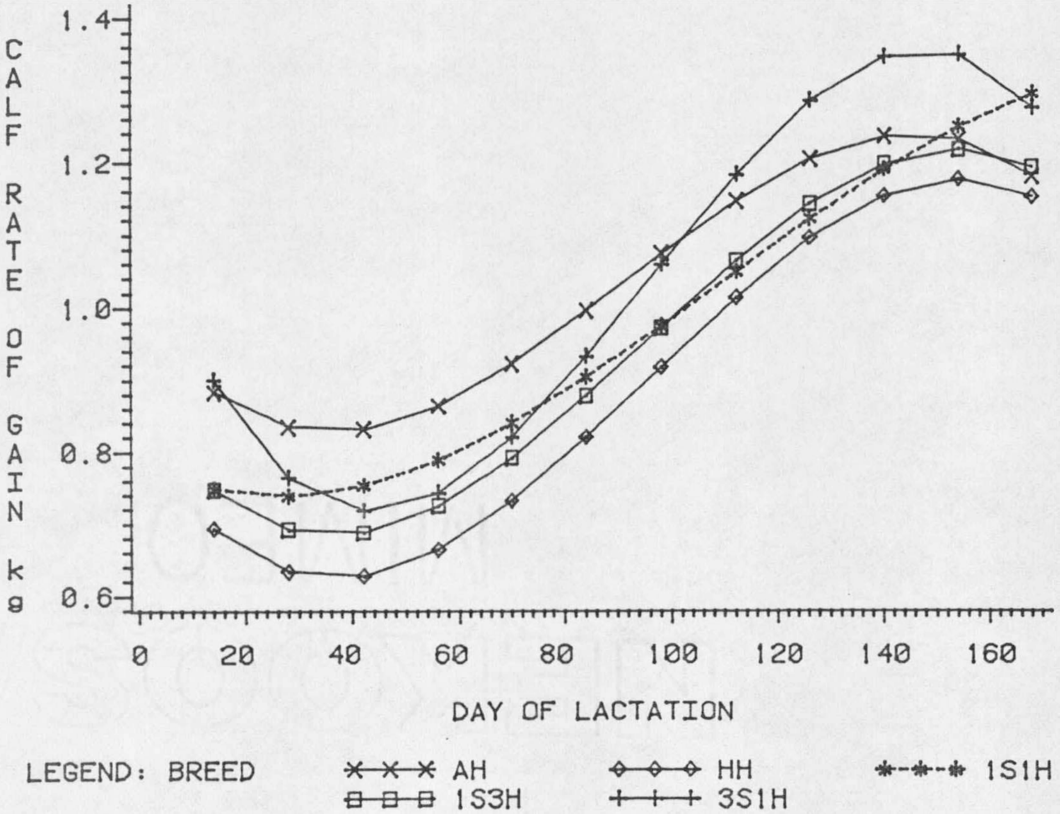

FIGURE 10. DAILY GAIN IN BODY WEIGHT OF CALVES DURING THE LACTATION PERIOD

found by Kress and Anderson (1974) but is considerably lower than the correlation of .88 between weaning weight and milk yield observed by Totusek et al. (1973).

The correlation between the birth weight of the calf and the milk yield of the dam was small and nonsignificant (Table 15). This is contradictory to the findings by Erb et al. (1980) of a correlation of .28 between birth weight and milk production. Although the correlation between birth weight and milk production was nonsignificant, the significant correlation between birth weight and calf average daily gain (.25) and birth weight and weaning weight (.52) may indirectly be revealing the positive relationship birth weight has with the milk production of the dam.

SUMMARY

Milk production estimates were made on 76 4- and 5-year-old cows developed at the Northern Agricultural Research Center, using the weigh-suckle-weigh technique. The breed groups that made up the study consisted of Hereford (HH), Angus-Hereford (AH), 25% Simmental-75% Hereford (1S3H), Simmental-Hereford (1S1H), and 75% Simmental-25% Hereford (3S1H) cows. A separation time of 6 h was incorporated in the study with milk production estimates being taken every 14 d (±1 d) during the lactation period prior to the breeding season and at monthly intervals during the period following the breeding season up to weaning time. The statistical analysis consisted of a residual analysis to determine if possible outliers were present followed by least squares analysis of variance procedures using the fixed effects model to determine the effect of all independent variables and two-way interactions on milk production. The final linear mathematical model included breed of dam, sex of calf, age of dam, pregnancy status of the dam at weaning, sex of calf x age of dam interaction, and age of dam x pregnancy status interaction. Mean milk production for the HH, AH, 1S3H, 1S1H, and 3S1H cows, respectively, was 8.8, 11.6, 10.2, 12.6, and 11.3 kg.

To incorporate the variability in milk production between individual cows within each breed group, it was necessary to adjust the data to all the significant independent variables and two-way

interactions as dependencies were observed when cow within breed was placed in the original model. The variability in milk production between individual cows was found to be significant. The resulting milk production means were 9.4, 11.8, 10.4, 12.8, and 11.7 kg for the HH, AH, 1S3H, 1S1H, and 3S1H cows, respectively.

Separate polynomial regressions were fitted for each of the genotypic groups. The linear, quadratic, and cubic regressions were significantly different from zero ($P < .01$). There was no significant differences observed between the linear, quadratic, and cubic coefficients among breeds. This implies that the differences among the breed groups lies not in the shape of the lactation curve (day of peak milk production and persistency) but in the magnitude of milk production.

Peak milk production estimated as that day on the lactation curve where maximum milk production is achieved was on day 40, 46, 34, 48, and 37 of the lactation period for the HH, AH, 1S3H, 1S1H, and 3S1H, respectively. This suggests that the time period during which the nutritional demands of the lactating beef cow are highest is between day 30 and day 60 of the lactation.

Lactation curves for each of the breed groups were also derived using an algebraic model. There were some dissimilarities between the two procedures, but the conclusions arrived at concerning the observed differences between breed groups were the same.

Although in general there were no significant differences in the shape of the lactation curves among breed groups, it appears from a casual visual appraisal that the crossbred cows had a tendency to maintain a more persistent lactation than that of the straightbred cows. This became more apparent when the crossbred cows were collectively grouped together and compared with the straightbred Hereford cows. A positive relationship was observed between the milk production of the cow and various preweaning growth traits of the calf. Residual correlations of .4, .4, .8, .49, and .49 were noted between milk production and calf condition score, calf hip height, calf withers height, calf ADH, and weaning weight, respectively ($P < .01$).

It can therefore be concluded from this study that higher levels of milk production can be achieved in a relatively short period of time through crossbreeding. High producing individuals can be determined at any point between day 40 and day 140 in the lactation period. It is also evident that the nutrient requirements of the lactating cow are between day 30 and day 50 of the lactation period. Finally, we can conclude from this study that the heavier calves at weaning are a result of high producing cows that maintain a high level of milk production throughout the lactation period.

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APPENDIX

Table 16. Parameters for the algebraic model describing the shape of the lactation curve for each individual cow[a]

Cow number	Breed	$\log_e a$	$\log_e b$	$\log_e c$
7030	AH	2.956152	.1646706	-.00548375
7042	AH	3.101116	.0467815	-.00451361
7044	HH	2.719161	.09493251	-.00419965
7049	HH	3.234901	.1964787	-.01549623
7050	HH	2.718656	.1573838	-.00744998
7067	AH	1.565500	.6999579	-.01537191
7071	1S1H	.384153	.9722832	-.01647683
7076	1S3H	2.848823	.2169273	-.00718966
7095	1S1H	3.161921	.1449767	-.00635692
7096	1S1H	1.627887	.6929232	-.01540347
7100	1S1H	2.489784	.3342601	-.00858554
7105	HH	2.742083	.2486622	-.00691654
7121	AH	3.829883	-.1515111	-.00442487
7126	1S3H	3.489261	-.1319991	.00185442
7134	1S3H	1.934528	.4539047	-.01229862
7141	HH	8.734613	-1.636120	.00684576
7144	AH	2.705750	.3140616	-.00939969
7148	1S3H	2.310554	.3801305	-.01277979
7172	AH	.247538	.9609899	-.01623798
7175	AH	2.884778	.1680749	-.01015930
7201	1S1H	2.708931	.2533196	-.00894327
7204	HH	.634508	.9649412	-.01955630
7223	HH	5.395104	-.6509177	-.00331636
7229	1S3H	2.781680	.3474396	-.01182289
7237	AH	2.870017	.1338305	-.00559506
7238	1S3H	4.002267	-.1974002	-.00126660
7264	1S3H	2.819314	.1189917	-.00616317
7270	1S1H	4.270045	-.1947446	-.01043035
7271	1S3H	2.491298	.1652333	-.00785457
7272	1S1H	1.877341	.5837277	-.01281806
7273	1S1H	2.586335	.3152087	-.00519447
7282	AH	1.758344	.5831398	-.01186837
7446	3S1H	3.441117	-.0201426	-.00144755
7609	1S1H	.951267	.8148735	-.01647275
7613	1S1H	1.973520	.6418806	-.01667539

Table 16. Continued

Cow number	Breed	$\log_e a$	$\log_e b$	$\log_e c$
7616	1S1H	.600239	1.059956	-.02460430
7720	3S1H	2.524029	.3063456	-.01088956
7723	3S1H	1.871895	.6413751	-.01608448
7743	3S1H	2.036491	.4374976	-.00841560
7776	3S1H	2.266820	.3043984	-.00517200
8021	AH	1.152674	.8134854	-.01483650
8042	AH	.780957	.9793125	-.02242484
8065	1S3H	-.375538	1.196287	-.01826952
8079	1S3H	2.975516	.1877629	-.01028859
8089	1S3H	1.721647	.6078876	-.01214539
8101	HH	1.433566	.7069609	-.01825738
8118	HH	2.852859	.3319264	-.01964362
8124	HH	.360995	.8831254	-.01245234
8126	AH	6.268917	-.8593516	.00591599
8131	HH	3.927003	-.4262955	.00598181
8144	1S1H	3.364650	-.0182223	-.00491310
8152	1S3H	2.965068	.1364507	-.00557307
8182	1S3H	3.701786	-.0918990	-.00307844
8186	HH	2.279009	.3914562	-.01033394
8192	1S1H	2.255811	.3789725	-.00890148
8202	AH	3.565278	-.0063424	-.00307988
8218	1S3H	3.600577	-.0239497	-.00413492
8230	HH	6.462165	-1.165335	.00794939
8232	AH	2.420958	.3752259	-.01086485
8237	1S1H	1.925389	.5948927	-.01310097
8242	HH	3.287712	.0147823	-.00371340
8244	1S1H	1.596914	.6665313	-.01563053
8246	HH	.9034286	1.0225920	-.02755846
8256	1S1H	3.828170	-.0444220	-.00723344
8259	1S1H	2.682434	.3705322	-.00969622
8262	HH	.623661	.9222415	-.01840543
8265	1S1H	2.032446	.4286030	-.00631753
8297	AH	1.903132	.5609061	-.01247031
8301	1S3H	3.979902	-.2339291	.00049395
8557	3S1H	4.252546	-.2093660	.00032937

Table 16. Continued

Cow number	Breed	$\log_e a$	$\log_e b$	$\log_e c$
8806	3S1H	3.296428	.03543705	-.00328770
8820	3S1H	2.798704	.2050553	-.00685714
8828	3S1H	3.829207	-.2033425	-.00020542
8883	3S1H	4.831442	-.6807743	.01073331
8884	3S1H	12.472280	-2.962540	.04010126
8890	3S1H	4.629138	-.5178223	.00610955

[a]Milk yield estimates derived using these constants are expressed in pounds.

Table 17. Least-squares means and regression coefficients for each individual cow[a]

Cow number	Mean milk production	Mean day of lactation	Coefficients		
			Linear	Quadratic	Cubic
7030	11.42	80.75	-.0074954	-2.134×10^{-4}	9.534×10^{-6}
7042	8.53	80.75	-.051431	-2.679×10^{-5}	4.086×10^{-6}
7044	7.48	80.78	-.040406	-1.430×10^{-4}	5.448×10^{-6}
7049	9.36	80.67	-.159896	-2.910×10^{-4}	1.861×10^{-5}
7050	7.83	80.42	-.093174	-2.742×10^{-4}	1.453×10^{-5}
7067	14.86	80.68	.022391	-7.160×10^{-4}	-8.626×10^{-6}
7071	13.70	80.82	-.056104	-1.446×10^{-3}	1.362×10^{-5}
7076	12.07	81.94	.010787	-5.539×10^{-5}	-9.080×10^{-6}
7095	12.83	81.39	-.083021	-4.536×10^{-4}	9.080×10^{-6}
7100	12.79	80.99	-.036740	-5.952×10^{-4}	2.724×10^{-6}
7121	7.60	80.76	-.101058	9.670×10^{-5}	1.044×10^{-5}
7126	9.60	81.78	-.020755	1.358×10^{-4}	3.632×10^{-6}
7134	8.90	81.71	-.039310	-3.609×10^{-4}	1.816×10^{-6}
7141	5.71	81.20	-.140660	1.907×10^{-5}	1.680×10^{-5}
7144	8.33	79.33	-.246940	2.319×10^{-3}	7.446×10^{-5}
7148	9.47	81.80	-.115009	-5.766×10^{-4}	1.498×10^{-5}
7172	11.67	80.86	-.032547	-1.192×10^{-3}	8.626×10^{-6}
7175	7.15	79.32	-.077771	1.857×10^{-4}	7.264×10^{-6}
7201	10.93	81.15	-.116505	-4.245×10^{-4}	1.634×10^{-5}
7204	13.34	80.54	-.145827	-1.663×10^{-3}	2.679×10^{-5}
7223	7.00	80.42	-.197914	-1.398×10^{-4}	2.951×10^{-5}
7229	13.47	81.76	-.098192	-3.419×10^{-4}	7.264×10^{-6}
7237	9.22	81.10	-.042264	-1.362×10^{-4}	2.724×10^{-6}
7238	9.31	81.80	-.017070	4.812×10^{-4}	-6.356×10^{-6}
7264	8.10	81.87	-.018759	4.540×10^{-6}	-1.816×10^{-6}

Table 17. Continued

Cow number	Mean milk production	Mean day of lactation	Coefficients		
			Linear	Quadratic	Cubic
7270	8.61	81.13	-.164308	-3.464×10^{-4}	1.907×10^{-5}
7271	7.09	81.73	-.090061	-5.121×10^{-4}	1.453×10^{-5}
7272	14.03	80.99	-.098679	-9.325×10^{-4}	1.498×10^{-5}
7273	16.54	81.31	-.072627	-9.611×10^{-4}	1.634×10^{-5}
7282	13.79	80.79	-.057829	-8.422×10^{-4}	7.264×10^{-6}
7446	12.50	81.35	-.015666	-8.308×10^{-5}	-4.540×10^{-7}
7609	11.00	81.99	.014011	1.979×10^{-4}	-1.362×10^{-5}
7613	15.47	80.78	-.106752	-1.010×10^{-3}	7.264×10^{-6}
7616	13.61	80.95	-.163817	-1.478×10^{-3}	2.815×10^{-5}
7720	9.78	81.22	-.105244	-4.953×10^{-4}	1.453×10^{-5}
7723	14.76	81.17	-.077175	-1.044×10^{-3}	6.810×10^{-6}
7743	12.01	81.28	-.083487	-6.751×10^{-4}	1.453×10^{-5}
7776	11.86	80.90	-.048440	-5.198×10^{-4}	1.453×10^{-5}
8021	16.96	81.38	-.085567	-1.826×10^{-3}	1.952×10^{-5}
8042	12.78	80.86	-.043499	-8.367×10^{-4}	1.816×10^{-6}
8065	13.01	81.88	=.106555	-1.367×10^{-3}	2.315×10^{-5}
8079	9.41	81.86	-.114650	-3.591×10^{-4}	1.180×10^{-5}
8089	15.37	81.71	.038482	-8.862×10^{-4}	-9.534×10^{-6}
8101	10.63	80.00	-.177696	-5.575×10^{-4}	3.677×10^{-5}
8118	7.65	81.29	-.083222	2.097×10^{-4}	-4.540×10^{-7}
8124	11.30	80.56	-.026206	-7.804×10^{-4}	7.264×10^{-6}
8126	10.01	81.32	-.126956	-8.263×10^{-5}	1.952×10^{-5}
8131	6.45	80.46	.022585	2.806×10^{-4}	-7.264×10^{-6}
8144	8.22	81.05	-.077703	3.723×10^{-5}	8.172×10^{-6}
8152	10.00	81.73	-.099804	-2.424×10^{-4}	1.407×10^{-5}

Table 17. Continued

Cow number	Mean milk production	Mean day of lactation	Coefficient		
			Linear	Quadratic	Cubic
8182	9.56	81.73	-.141705	-1.648×10^{-4}	2.225×10^{-5}
8186	11.22	80.41	-.120882	-7.268×10^{-4}	1.907×10^{-5}
8192	11.96	81.05	-.080190	-7.795×10^{-4}	1.317×10^{-5}
8202	12.26	80.78	-.018807	1.407×10^{-4}	-4.540×10^{-6}
8218	10.70	81.86	-.039574	1.966×10^{-4}	-1.816×10^{-6}
8230	6.13	80.43	-.152225	1.966×10^{-4}	2.452×10^{-5}
8232	12.04	81.00	-.141352	-1.049×10^{-3}	2.043×10^{-5}
8237	16.22	81.22	-.040922	-9.466×10^{-4}	4.086×10^{-6}
8242	9.68	80.49	-.062531	1.090×10^{-5}	1.816×10^{-6}
8244	13.45	81.18	-.154969	-1.307×10^{-3}	2.679×10^{-5}
8246	12.32	80.01	-.209510	-9.806×10^{-4}	3.587×10^{-5}
8256	9.77	81.49	-.130555	-6.810×10^{-6}	9.534×10^{-6}
8259	16.33	81.07	-.065125	-7.532×10^{-4}	4.994×10^{-6}
8262	12.62	77.88	-.093895	-1.478×10^{-3}	1.907×10^{-5}
8265	14.90	82.08	-.017350	-1.002×10^{-3}	7.264×10^{-6}
8297	13.83	84.75	-.096701	-1.052×10^{-3}	1.453×10^{-5}
8301	8.76	81.56	.007748	4.880×10^{-4}	-9.988×10^{-6}
8557	13.00	81.11	-.071052	3.196×10^{-4}	5.448×10^{-6}
8806	10.80	81.26	-.111362	-2.756×10^{-4}	1.680×10^{-5}
8820	14.96	80.90	.134142	-1.470×10^{-3}	-4.722×10^{-5}
8828	9.51	81.51	-.009515	1.280×10^{-4}	-3.632×10^{-6}
8883	5.61	81.40	.131486	1.089×10^{-3}	-3.450×10^{-5}
8884	11.03	81.27	-.304660	1.045×10^{-3}	1.021×10^{-4}
8890	7.35	83.25	-.027206	7.872×10^{-4}	-1.816×10^{-6}

[a]Mean milk production and regression coefficients expressed in kilograms.

Table 18. Length of lactation and estimated average daily and total milk production for each individual cow

Cow number	Avg. daily milk production (kg)	Total milk yield (kg)	Length of lactation (d)
7030	10.9	1819.9	167
7042	8.4	1401.6	167
7044	7.1	1243.8	176
7049	8.5	1471.6	173
7050	7.2	1171.6	162
7067	12.9	2202.1	171
7071	10.7	1663.0	155
7076	11.5	2029.1	176
7095	11.6	2006.7	173
7096	13.4	2323.9	173
7100	11.5	1858.9	162
7121	7.7	1291.1	167
7126	9.9	1655.8	167
7134	7.9	1351.5	171
7141	5.7	974.2	172
7144	10.9	1405.6	129
7148	8.0	1390.9	174
7172	8.9	1514.0	170
7175	7.9	1077.2	136
7201	9.9	1667.7	168
7204	9.5	1626.0	171
7223	6.7	1077.3	161
7229	12.5	2105.9	168
7237	8.6	1548.6	179
7238	10.2	1768.8	174
7264	7.9	1377.5	175
7270	7.7	1302.3	170
7271	5.9	1004.6	170
7272	12.0	1943.2	162
7273	14.4	2477.9	172
7282	11.7	1984.7	169
7446	12.1	2148.6	177
7609	11.0	1917.8	175
7613	14.3	2041.5	143
7616	10.9	1617.9	149
7720	8.7	1420.6	164
7723	12.1	2062.8	171
7743	10.4	1818.8	174
7776	10.7	1583.4	148
8021	12.8	2143.0	167

Table 18. Continued

Cow number	Avg. daily milk production (kg)	Total milk yield (kg)	Length of lactation (d)
8042	10.4	1818.9	175
8065	9.9	1685.8	170
8079	8.3	1468.1	177
8089	13.1	2232.6	171
8101	9.6	1345.6	140
8118	7.4	1334.3	179
8124	9.5	1621.8	170
8126	9.8	1611.8	164
8131	7.0	1145.6	163
8144	8.3	1349.4	163
8152	9.4	1609.9	171
8182	9.2	1569.1	170
8186	9.6	1605.8	168
8192	10.1	1714.4	169
8202	12.4	2094.3	169
8218	10.9	1888.7	173
8230	6.5	1000.8	153
8232	9.4	1703.2	182
8237	14.1	2291.4	162
8242	9.7	1579.7	163
8244	10.5	1752.2	167
8246	10.9	1528.9	140
8256	9.2	1688.0	183
8259	14.6	2402.3	165
8262	9.6	1518.6	159
8265	12.6	2184.5	174
8297	11.2	1942.2	173
8301	9.9	1555.7	157
8557	13.6	2305.1	169
8806	10.2	1772.9	174
8820	13.0	1926.0	148
8828	9.5	1706.9	179
8883	8.1	1209.6	150
8884	10.6	1488.1	140
8890	9.2	1625.8	177

Table 19. Least-squares means and regression coefficients for milk yield adjusted for main effects

Effect	N	Milk[a] production (kg)	Regression coefficients		
			Linear	Quadratic	Cubic
Overall mean	545	11.2 (.34)	----	----	----
Breed					
HH	113	9.4 (.74)	-.0987	-4.36×10^{-4}	1.33×10^{-5}
AH	104	11.8 (±.79)	-.0642	-5.04×10^{-4}	6.85×10^{-6}
1S3H	115	10.4 (±.75)	-.0545	-2.71×10^{-4}	4.63×10^{-6}
1S1H	109	12.8 (±.79)	-.0745	-6.82×10^{-4}	9.57×10^{-6}
3S1H	104	11.7 (±.76)	-.0531	-2.50×10^{-4}	5.01×10^{-6}

[a]Standard errors in parentheses.

Table 20. Means and regression coefficients for daily milk production of cows weaning heavy versus light weight calves[a]

Effect	N	Mean (SE)	Regression coefficients		
			Linear	Quadratic	Cubic
Overall mean	538	11.0(.27)	----	----	----
Production level					
Heavy weaning wt	127	12.7(±.53)	-.0481	-4.51×10^{-4}	4.30×10^{-6}
Medium-high	138	11.7(±.49)	-.0633	-3.80×10^{-4}	6.12×10^{-6}
Medium-low	135	10.4(±.52)	-.0840	-5.60×10^{-4}	1.16×10^{-5}
Low	138	9.1(±.48)	-.0790	-2.86×10^{-4}	8.49×10^{-6}

[a]Expressed in kilograms

Table 21. Least-squares analysis of variance for calf average daily gain (N = 545)

Source	df	Mean squares Calf average daily gain (kg^2)
Breed (B)	4	0.13†
Age of dam (AD)	1	0.79**
Sex of calf (S)	1	0.28*
Sire breed of calf (SC)	1	0.03
Pregnancy status (P)	1	0.70**
B x AD	4	0.07
B x S	4	0.11
AD x SC	1	0.22*
AD x P	1	0.69**
Regressions		
Day lact-linear	1	10.31**
B x day lact-linear	4	0.10
Day lact-quadratic	1	1.40**
B x day lact-quadratic	4	0.04
Day lact-cubic	1	2.56**
B x day lact-cubic	4	0.11
Birth weight-linear	1	0.01
Residual	510	0.06

†P < .06.

*P < .05.

**P < .01.

Table 22. Means and regression coefficients for calf average daily gain[a]

Effect	N	Mean (SE)	Regression coefficients		
			Linear	Quadratic	Cubic
Overall mean	545	0.89(.02)	----	----	----
Breed					
HH	113	0.80(±.04)	6.63×10^{-3}	2.97×10^{-3}	-6.81×10^{-7}
AH	104	0.98(±.04)	5.47×10^{-3}	1.81×10^{-5}	-6.26×10^{-7}
1S3H	115	0.86(±.04)	6.46×10^{-3}	2.69×10^{-5}	-6.58×10^{-7}
1S1H	109	0.89(±.04)	4.74×10^{-3}	2.18×10^{-5}	-2.59×10^{-7}
3S1H	104	0.91(±.04)	8.53×10^{-3}	4.83×10^{-5}	-1.13×10^{-7}

[a]Expressed in kilograms.

Table 23. Least-squares analysis of variance for cow body condition during lactation (N = 545)

Source	df	Mean squares Cow body condition (kg^2)
Breed (B)	4	21204.6**
Age of dam (AD)	1	8181.9†
Sex of calf (S)	1	157057.8**
Sire breed of calf (SC)	1	30277.6**
Pregnancy status (P)	1	3400.4
B x AD	4	5443.6†
B x S	4	19532.8**
AD x SC	1	14864.9*
AD x P		38887.6**
Regressions		
Day lact-linear	1	410621.7**
B x day lact-linear	4	1713.9
Day lact-quadratic	1	68845.8**
B x day lact-quadratic	4	184.8
Day lact-cubic	1	88491.0**
B x day lact-cubic	4	1296.9
Birth weight-linear	1	74783.8**
Residual	510	2427.8

†$P < .07$.

*$P < .05$.

**$P < .01$.

Table 24. Means and regression coefficients for cow body condition[a]

Effect	N	Mean (SE)	Regression coefficients		
			Linear	Quadratic	Cubic
Overall mean	545	496.47(±4.24)	----	----	----
Breed					
HH	113	472.34(±8.62)	1.228	5.82×10^{-3}	-1.13×10^{-4}
AH	104	504.34(±9.22)	1.044	6.38×10^{-3}	-1.00×10^{-4}
1S3H	115	481.34(±8.37)	1.243	6.16×10^{-3}	-1.18×10^{-4}
1S1H	109	485.53(±9.04)	1.279	7.72×10^{-3}	-1.07×10^{-4}
3S1H	104	538.78(±9.23)	1.557	6.06×10^{-3}	-1.84×10^{-4}

[a]Expressed in kilograms.

Table 25. Parameter means for algebraic model of lactation curves

Breed	Log a	b	-c	Peak (day)	Yield (kg)	Log (s)
HH	2.62	.2558	-.0178	24	10.8	5.6905
AH	2.33	.3832	-.0101	38	12.8	6.3575
1S3H	2.75	.2091	-.0074	28	11.6	5.9240
1S1H	2.57	.3214	-.0093	34	13.5	6.1755
3S1H	3.07	.1189	-.0054	22	12.5	5.8461

Table 26. Least-squares analysis for milk production with sire breed of calf included in the model (N = 545)

Source	df	Mean squares milk production (kg^2)
Breed (B)	4	65.7**
Age of dam (AD)	1	160.0**
Sire breed of calf (SC)	1	0.8
Sex of calf (S)	1	41.4*
Pregnancy status (P)	1	23.4
S x AD	1	49.5*
AD x Preg	1	64.2**
Regressions		
Day lact-linear	1	1174.1*
B x day lact-linear	4	12.8
Day lact-quadratic	1	303.8**
B x day lact-quadratic	4	9.8
Day lact-cubic	1	331.2**
B x day lact-cubic	4	9.2
Birth weight-linear	1	82.1**
Birth weight-quadratic	1	14.3
Residual	517	9.5

* $P < .05$.

** $P < .01$.

Table 27. Residual correlation among cow traits and milk production

Trait	Condition score	Weight	Hip height	Rate of gain by period[a]
Average daily milk production	.00	.04	.11	.10
Condition score		.19	.07	.01
Weight			.63*	.05
Hip height				.06

[a]Weight changes between 24 h milk yield estimation periods.

*$P < .01$.

Table 28. Linear contrast among breed groups for various cow traits

Linear contrast	Difference	p-value
Milk production (kg)		
HH vs crossbreds	-2.59	.006
AH vs 1S1H	- .99	.138
1S3H vs 3S1H	-1.12	.103
AS and 1S1H vs 1S3H and 3S1H	1.17	.009
Condition score		
HH vs crossbred	- .57	.377
AH vs 1S1H	.44	.241
1S3H vs 3S1H	.09	.439
AH and 1S1H vs 1S3H and 3S1H	.47	.308
Cow weight (kg)		
HH vs crossbred	-32.92	.014
AH vs 1S1H	17.64	.125
1S3H vs 3S1H	-56.78	.005
AH and 1S1H vs 1S3H and 3S1H	0.48	.464
Cow hip height (cm)		
HH vs crossbreds	-3.14	.003
AH vs 1S1H	-3.04	.010
1S3H vs 3S1H	-5.47	.001
AH and 1S1H vs 1S3H and 3S1H	-0.20	.274

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