RELATIONSHIPS AMONG ESTIMATED BREEDING VALUES FOR PREWEANING CALF GROWTH, DAM MILK PRODUCTION, COW-CALF BEHAVIOR, AND CALF PERFORMANCE.

by

Jane Tosh

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ABSTRACT

Forty-six cow-calf pairs were used to evaluate calf preweaning growth and dam milk production. Calf weights, milk yields, and cow weights were obtained weekly for 7 weeks from Group 1 (n=24), beginning when these calves were 23 days of age (SD=4), and on three additional occasions during the pasture season using Group 1 and Group 2 (n=22). Milk yield estimated with a calf-nursing method averaged 2.2 kg (SD=1.4) after a separation of 5.64 h (SD=0.65). During confinement prior to the pasture season, spatial arrangement and animal activity were recorded at 15-min intervals from 1200-1500 h, one day each week. Calf activity on pasture was recorded on two occasions but from sunup to sundown. Average cow-calf distance for each pair (CCDO), and suckling (PSO) and grazing (PG) activity of each Group 1 calf as a percent of the total number of observations, were calculated. Calf weights and milk yields were analyzed using multiple regression models. Calf weight (adjusted for age, sex, and breed of sire of calf; and age of dam) was studied for influences of direct estimated breeding value (EBV_D) of calf, weight of dam, maternal estimated breeding value (EBV_M) of dam, milk yield, CCDO, PSO, and PG. EBV_D had a positive linear relationship with weaning weight that varied with age of dam ($P<.05$). EBV_D of calf, EBV_M of dam, milk yield, and PSO had positive influences, and PG a negative influence, on calf growth rate ($P<.001$). Influences of cow weight, EBV_M of cow, EBV_D of calf, calf weight, CCDO, PSO, and PG, on yield (adjusted

for days in lactation, separation interval, and cow age) were investigated; none of these variables affected persistency of lactation ($P>.10$). Expression of EBV_M in yield diminished as EBV_M approached superior levels, particularly in young dams. Yields peaked with mid-range values of EBV_D, CCDO, PSO, and PG.

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INTRODUCTION

Weaning weight of beef calves is an economically important trait upon which the major source of income to cow-calf producers is based. Preweaning average daily gain and weaning weight are essentially the same measure of growth. Numerous factors influencing preweaning performance have been extensively investigated.

Dams influence growth of their calves by transmitting half of the genes that determines the genetic potential of the calf, and by providing the maternal environment during gestation and preweaning periods. The primary aspect of maternal environment is milk production (Willham, 1982). Studies by Jeffery and Berg (1971), Mondragon *et al*. (1983), Montano *et al*. (1986), Reynolds *et al*. (1978), and Rutledge *et al*. (1971), among others, have generally shown a significant association between milk production and growth of calves.

Maternal effects are environmental in their influence on offspring although they are determined by genetic and environmental factors (Koch, 1972). A number of studies have investigated factors affecting milk production yet effects of variables of the calf are not well established.

The objectives of the present study were:

1) to estimate the genetic potential, or breeding value, of the calf for the direct contribution to growth and of the dam for the maternal contribution to growth, and determine their relationships to actual

growth exhibited;

2) to investigate the influence of yield of milk on calf performance;
3) to examine associations between the breeding values and milk production of the dam;
4) to evaluate early cow-calf distances, and calf feeding behavior, that is, suckling and grazing activity;
5) to determine relationships between the behavioral traits and the breeding values;
6) to investigate associations between behavior and both dam's milk production and calf preweaning performance.

LITERATURE REVIEW

Calf Growth

Average daily gain, total gain, or weaning weight describes preweaning growth. Weaning weight equals birthweight plus cumulated gain; calves heavier at birth thus tend to maintain a slight advantage at weaning (Jeffery _et al_., 1971b; Neville, 1962; Singh _et al_., 1970). Age at weaning has a positive effect on weaning weight (Ahunu and Makarechian, 1986; Butson _et al_., 1980; Marshall _et al_., 1976; Nelson and Kress, 1981; Thrift _et al_., 1978) as expected. Routine adjustment of weights to a standard age (Anderson and Willham, 1978; Fredeen _et al_., 1982; Kemp _et al_., 1984; Neville _et al_., 1974; Sharma _et al_., 1982) assumes a constant rate of gain, that is, linear growth during the preweaning phase.

Some Factors Influencing Calf Growth

Year. Many studies including Ahunu and Makarechian (1986), Franke et al. (1975), Nelson et al. (1982), Thrift et al. (1978), and Tong and Newman (1980) have shown an effect of year on preweaning calf growth. Years may differ in environmental conditions: weather, herd management, quantity and quality of available feed and pastures, and health of dams and calves. Effects of geographical location (Anderson and Willham, 1978; Fredeen et al., 1982; Leighton et al., 1982) suggests an influence of weather and subsequent nutrition. Herd effects (Nelson and Kress, 1981) indicate environmental differences. Availability of creep feed is associated with improved growth (Anderson and Willham, 1978; Marshall et al., 1976; Hohenboken et al., 1973). Numerous factors may differ among years.

Sex of calf. It is generally known that male calves gain faster and achieve heavier weaning weights than female calves. Numerous studies including those by Ahunu and Makarechian (1986), Fredeen et al. (1982), Kemp et al. (1984), Leighton et al. (1982), and Nelson and Kress (1981), with greater than 1000 weaning weight records, recorded sex differences of 5.1-25.6 kg corresponding to a 3-13% advantage for males. Where male calves are castrated, differences in weaning weight between sexes are reduced yet remain significant (Anderson and Willham, 1978; Marlowe et al., 1965; Neville et al., 1974). Similar trends are seen when preweaning ADG is the variable of interest (Ahunu and Makarechian, 1986; Fredeen et al., 1982; Marlowe et al., 1965).

Size of difference in weaning weight between sexes is influenced by other variables. Although Lawlor et al. (1984), Nelson et al. (1982), Notter et al. (1978), and Reynolds et al. (1978) did not find a year X sex interaction, it was significant for crossbred calves but not Hereford or beef synthetics in work by Ahunu and Makarechian (1986). Nelson and Kress (1981) observed herd X sex interactions resulted from greater sex differences in herds with higher average performance. Herds differ in physical environment, management, or genotypic value. Anderson and Willham (1978) found a creep management X sex interaction supporting Marlowe et al. (1965) who noted that sex differences varied with feeding regime. Male calves could have greater nutritional requirements than heifers (Anderson and Willham, 1978; Sharma et al., 1982). One may thus suspect that sex differences in weaning weight are greater for calves with superior milk producing dams as well. Kemp et al. (1984), Lawlor et al. (1984), Minyard and Dinkel (1965), and Nelson et al. (1982) did not find a cow age X sex interaction although Anderson and Willham (1978) did for bulls but not steers versus heifers. Ahunu and Makarechian (1986) found a cow age X sex interaction only in crossbreds. Sex differences were affected by cow age in work of Leighton et al. (1982) and Nelson and Kress (1981); age of dam may influence the maternal environment or milk provided to the calf. Sex effects do not depend on breed of sire (Belcher and Frahm, 1979; Cundiff et al., 1974; Nelson et al., 1982; Notter et al., 1978). To conclude, nutritional environment may have an important influence on sex differences. The effect of sex of calf on preweaning growth is complex.

Breed of sire of calf. Breeds of cattle differ in growth potential. Belcher and Frahm (1979) found Red Poll and Shorthorn sire breeds did not affect calf weaning weight. However, Cundiff et al. (1974) showed this to be an important effect with Hereford, Angus, and Shorthorn sires. Studying both British and slower maturing European breeds, Lawlor et al. (1984), Nelson et al. (1982), Notter et al. (1978), Thrift et al. (1978), and Tong and Newman (1980), among others, demonstrated a breed of sire of calf effect. Results of Fredeen et al. (1982) with four European breeds is in agreement.

Breed of sire effects appear to be independent of year (Belcher and Frahm, 1979; Gregory et al., 1965; Lawlor et al., 1984; Nelson et al., 1982) and sex of calf (Belcher and Frahm, 1979; Lawlor et al., 1984; Nelson et al., 1982; Notter et al., 1978). Although an age of dam X breed of sire interaction was not found by Lawlor et al. (1984) or Nelson et al. (1982), it was revealed in an extensive study by Tong and Newman (1980): Charolais and Limousin sired calves were observed to be at a greater disadvantage with young dams than calves sired by Hereford, Angus, Maine-Anjou, Shorthorn, or Simmental bulls.

Age of dam. Anderson and Willham (1978), Kemp et al. (1984), Marlowe et al. (1965), Neville et al. (1974), and Sharma et al. (1982) are only a few of those who have shown an effect of age of dam on preweaning growth. Weaning weight increases as age of dam increases from two to four or five years of age and remains constant thereafter only slightly declining in cows over nine years of age (Ahunu and Makarechian, 1986; Leighton et al., 1982; Minyard and Dinkel, 1965; Nelson and Kress, 1981; Thrift et al., 1978). Tong and Newman (1980) observed a similar pattern of calf weaning weights with dams five years of age and older considered as one group. Linear and quadratic effects of age of dam on weaning weight found by Jeffery et al. (1971b) and

Reynolds et al. (1978) provides further evidence that this effect is curvilinear. This effect is associated with milk production of the dam; Neville (1962) and Rutledge et al. (1971) found age of dam to be unimportant when milk yield and cow weight was held constant.

Cow age effects are influenced by other variables. Age of dam interactions with year (Lawlor et al., 1984; Nelson et al., 1982), herd (Nelson and Kress, 1981), and region (Leighton et al., 1982) have been found. When environmental conditions limit milk production, calves of young cows may have restricted growth. Sellers et al. (1970) did not find a creep feeding X age of dam interaction; however Anderson and Willham (1978) did in one of two data sets and they concluded that creep feed made available to calves would compensate for low milk yields of young dams. Age of dam effects also depend on sex and breed of calf. Calves with greater growth potential may be more severely handicapped if milk is limited.

Weight of dam. Neither mature weight of dam (Neville, 1962) nor weight at calving (Singh et al., 1970) was found to affect preweaning growth of calves in two studies. Godley and Tennant (1969) observed a positive effect of weight of Angus dams but no effect for Herefords. Hohenboken et al. (1973) calculated a correlation coefficient of 0.16 for weight at calving and calf weaning weight in Herefords. Correlations ranged from 0.29-0.38 depending on sex and year in work by Jeffery and Berg (1972a). Here and in a second study (Jeffery and Berg, 1972b), an association of cow weight with age and milk production was claimed rather than a direct influence of dam's weight on calf growth. Marshall et al. (1976) and Tanner et al. (1965) found similar correlations. Although regression coefficients were small and in many cases nonsignificant (Jeffery and Berg, 1972a; Jeffery and Berg 1972b), Marshall et al. (1976) found an increase of .367 kg in weaning weight for each kg increase in cow weight. Tanner et al. (1965) observed a linear effect of cow weight on calf weaning weight in Angus and a cubic effect in Herefords. A cubic effect found by Rutledge et al. (1971) appeared very nearly linear. In their review, Morris and Wilton (1976) noted the majority of authors found a positive relatioship between cow weight and calf growth yet considerable ranges of results were seen.

Changes in weight of dam during the nursing period may also influence calf growth. Singh et al. (1970) observed this to be a negative effect; correlation coefficients calculated by Butson et al. (1980) were low and negative. Results suggest that weight gain in dams during lactation is at the expense of milk production.

Dam's Milk Production

Measurement of Milk Production

To investigate relationships between dam's milk production and offspring growth, various methods of measuring milk yields are used. These techniques do not measure the same trait. Removal of milk by machine milking (Belcher and Frahm, 1979; Klett et al., 1965), handmilking (Hohenboken et al., 1973; Randel, 1981), or by teat catheters (Bowden, 1981; Jeffery and Berg, 1971), frequently with the aid of injected oxytocin, provides estimates of milk production of the cow. Calf milk consumption is measured with nursing methods: calves are weighed, allowed to suckle, and reweighed with the difference in weight providing the estimate (Drewry et al., 1959; Lampkin and Lampkin, 1960; Melton et al., 1967; Montano et al., 1986; Notter et al., 1978; Smith et al., 1982). Only milk which is consumed provides food energy for calf growth.

Somerville and Lowman (1980) noted that calves appeared unable to consume all available milk during the first month of lactation. When nursing sessions were followed by milking, Economides et al. (1976) found 9-47% of total milk yield was not removed by the calf in the first month, and Neidhardt et al. (1979) found 25%. At older ages some milk was still unconsumed. In a study by Schwulst et al. (1966) retained milk was 15, 11, and 6% of total production when calves were two, three, and five weeks of age, respectively. Amounts unconsumed are important only in the earliest stages of lactation and may vary with production of the dam, and calf sex, breed, and weight.

Comparison of methods of measurement. Wistrand and Riggs (1966) tested machine milking and calf nursing techniques on each half of cows' udders finding no differences in milk estimates. Heifer 150-day yields were also unaffected by method in work by Somerville and Lowman (1980); however calf-weight-change yields were greater than machine yields in second lactation cows. Totusek et al. (1973) observed daily yields determined by calf suckling were higher at all stages of lactation and resulted in a curvilinear lactation curve with a peak at seven weeks whereas that by handmilking was essentially linear. Mondragon et al. (1983) also found higher yields with calf nursing methods; and smaller differences in yield could be detected between animals with nursing methods but this was less so in first parity where yields were lower and calves could consume a greater proportion of available milk. Coefficients of variation determined by Somerville and Lowman (1980) and

Totusek et al. (1973) were lower for yields determined by nursing thus requiring fewer replications. The positive calf nursing stimulus minimizes stress to the cow, evokes more complete milk letdown (Christian et al., 1965; Totusek et al., 1973), and reduces variation in milk estimates. Either method is useful to compare individuals when absolute yields are unimportant (Chow et al., 1967; Mondragon et al., 1983; Totusek et al., 1973). Correlations between total yield determined by milking and calf nursing were 0.83-0.95 (Chow et al., 1967; Totusek et al., 1973). During the first month of lactation correlations are lower (Gleddie and Berg, 1968) since dam's production and calf consumption are unequal.

Separation interval. Dams and calves must be separated for an interval prior to measurement of milk yield. Results then represent yield for that time period. Chenette and Frahm (1981) tested cow-calf separation intervals of six, nine, and twelve hours and multiplied estimates by a factor to calculate 24-hr yields since time of day does not influence production (Lamond et al., 1969; Neidhardt et al., 1979). Yields were affected, decreasing with longer intervals in agreement with results of Williams et al. (1979a). Williams et al. (1979b) observed cows in discomfort after 16-hr separation intervals and suggested lower yields could be due to increased udder pressure and limited udder capacity. Although Chenette and Frahm (1981) found similar variances for different separation periods, Williams et al. (1979b) discovered smaller coefficients of variation and higher repeatabilities with longer intervals. Measurement error could be inflated with short intervals when yields are multiplied by large factors particularly if the separation interval is not exactly maintained. To reduce this problem, Belcher and Frahm (1979), Cundiff et al. (1974), Neidhardt et al. (1979), and Schwulst et al. (1966) adjusted yields for actual time interval; however Williams et al. (1979a) found no adjustment was necessary when small groups of 12 cows were measured. Some researchers compensate for limited ingestion of young calves by setting short separation intervals at early ages and lengthening them as the calf grows (Deutscher and Whiteman, 1971; Economides et al., 1976; Furr and Nelson, 1964; Somerville and Lowman, 1980). Estimates of milk yield reflect separation interval.

Sources of error in calf-nursing method. Measurement errors may occur upon weighing of calves. Calf defecation and/or urination between the two weighings will result in underestimation of milk consumption. This effect reduced yield by .244kg in a study by Neidhardt et al. (1979) in agreement with weight of feces and urine from a sample of calves. Somerville and Lowman (1980) observed defecation and/or urination at 8% of nursings during the first week of lactation but rarely afterwards; an opposite trend was found by Schake et al. (1966). Rainfall beginning between the two weighings also affected yields estimated by Neidhardt et al. (1979) due to water holding capacity of calves' hair coat. Poor weather may influence suckling behavior of calves and estimates for the test day. These factors must be considered when studying milk yields measured by calf-nursing methods.

Factors Influencing Milk Production

Lactation curve. Estimated milk yields reflect calf age, or stage of lactation of the dam, at the time of measurement. Late lactation yields tend to be lower than those at earlier stages (Boggs et al., 1980; Butson and Berg, 1984a; Lawson, 1981; McGinty and Frerichs, 1971; Robison et al., 1978), as expected. An important effect of month was demonstrated by Belcher and Frahm (1979) and Butson and Berg (1984b). When milk production was regressed on days postpartum, Gleddie and Berg (1968) found a correlation of -0.46 and a linear regression coefficient of -0.02 kg/day. However, Abadia and Brinks (1972), Dawson et al. (1960), Lampkin and Lampkin (1960), Montano et al. (1986), and Neidhardt et al. (1979) observed that lactation curves peaked within the second month. Kress and Anderson (1974) calculated a quadratic regression equation for milk production on day of lactation; it was unknown whether peak yield occurred at 20 days or earlier where estimates were not made. Detection of a peak depends on method and frequency of estimation of yield as well as other factors.

Shape of the lactation curve is not well established for beef cows. Correlations between milk yield and calf age found by Drewry et al. (1959) were -0.37 and -0.33 in the first and third month of lactation, respectively but there was no association in the sixth month suggesting a flattening of the lactation curve. In contrast, regression coefficients by month in work by Melton et al. (1967) were -0.021 to -0.031 kg/day and indicated a more profound effect of day as lactation progressed -- a non-additive or curvilinear effect. Of 62 Hereford cows, Lamond et al. (1969) found 46 had a linear decline in production, two showed no change, and 14 had curvilinear components to their lactation curves; rate of linear decrease was greatest for high producers. Notter et al. (1978) concluded that breed groups with high yields were, in general, less persistent with rapid rates of decline in the second half of lactation. In that late period, Chenette and Frahm (1981) found no differences between breed groups; high producers experienced major decreases in yields at earlier stages. Gaskins and Anderson (1980) showed Angus X Hereford lactation curves were more linear while those of higher yielding Angus X Simmental and Angus X Jersey cows were more convex. Also, cows on higher levels of nutrition tend to be more persistent in their yields (Bartle et al., 1984; Bowden, 1981). Late lactation yields may be influenced by pasture conditions (Chenette and Frahm, 1981; Kropp et al., 1973b). Klett et al. (1965) concluded beef cattle are more flexible in their response to changing feed conditions than dairy cows. Linear, quadratic, and cubic terms for day explained 95% of the variation in yield of heifers studied by Abadia and Brinks (1972). Thus calf age or day of lactation has an important effect on milk yields.

Year. Butson and Berg (1984b), Drewry et al. (1959), Keller (1980), Kress et al. (1984), and Reynolds et al. (1978) found year differences to be an unimportant source of variation in milk yield. This is expected if there was no genetic progress, and estimation methods, herd management, and physical environment were constant from year to year. Caution is required to avoid confounding of year effects and age of cows. Lawson (1981), Marshall et al. (1976), Neville et al. (1974), Richardson et al. (1977), and Rutledge et al. (1971) showed year effects to be significant but did not offer any explanation. Abadia and Brinks (1972) attributed large differences between years to different milking and management procedures. Usually physical environment is important since it is difficult to control for grazing animals. Jeffery et al. (1971a) found yield differences between two years reflected differences in range conditions. As pastures were improved Lampkin and

Lampkin (1960) observed corresponding increases in milk production. Normal fluctuations in weather and pastures, and the nutritional environment of the cow, appears to account for the influence of year.

Cow age. Although some research has found no relationship between the age of a cow and her milk production (Kress et al., 1984; Marshall et al., 1976; Neidhardt et al., 1979; Rutledge et al., 1972), others have shown yields increase with age (Drewry et al., 1959; Keller, 1980; Lawson, 1981; Melton et al., 1967; Williams et al., 1979b). Gaskins and Anderson (1980) calculated a linear rate of improvement of 1.0 kg/day/year as age increased from two to four years. Cow age effects in a study by Butson and Berg (1984a) resulted in three-, four-year-old, and mature (≥5 years) dams producing approximately 25%, 36%, and 39% more milk per day than two-year-olds; differences between four-year-old and mature dams were not significant. Robison et al. (1978) observed increases in yield until five years of age with little change to eight years and then a slight decline in older cows. Peak age of production seen by Dawson et al. (1960) and Rutledge et al. (1971) agree with this pattern. In a herd of Hereford cows, Neville et al. (1974) found yields plateaued at five to eight years of age but in a second herd this was shifted to six to nine years due to age at first calving, a management difference between herds. Linear and quadratic effects of cow age detected by Jeffery et al. (1971a) accounted for 12.6% and 15.3% of variation in milk yield in the two years studied.

Cow age also affects shape of the lactation curve. Work by Drewry et al. (1959) and Notter et al. (1978) showed age effects in early lactation but not at six months. Mondragon et al. (1983) found cows in first parity had similar yields over three periods whereas second and third parity cows decreased production. Christian et al. (1965) observed that although older dams produced more milk, two-year-olds were more persistant in their production. The curve for lower producing two-year-olds was more linear than the lactation curves of older cows in a study by Gaskins and Anderson (1980). Thus by late lactation all age groups could have similar levels of yield. To conclude, cow age has a positive influence on total production primarily by improving early lactation yields.

Cow weight. Change in weight during lactation has been related to milk production. Correlations between gain and yield were -0.28 (Lampkin and Lampkin, 1960), -0.35 (Hohenboken et al., 1973), and -0.48 (Richardson et al., 1977). When yields were regressed on gain, regression coefficients of -0.0023 kg/kg (Neidhardt et al., 1979), -0.0043 to -0.0124 kg/kg depending on year and adjustment for cow breed (Jeffery et al., 1971a), and -1.036 kg/kg for heifers (Richardson et al., 1977) were obtained. These values are small, yet a loss of 10 kg during lactation was associated with a .01-10 kg increase in daily milk yield. Losses of up to 100 kg of body weight make this an important variable.

The relationship between lactation gain of the cow and yield is affected by numerous factors. Comparisons among breeds show those with high milk potential lose more weight and yield more milk (Belcher and Frahm, 1979; Deutscher and Whiteman, 1971; Holloway et al., 1975). There may be differences in efficiency of conversion of body weight. Gain would also depend on condition. Growth requirements during first lactation may control weight change in heifers. Mondragon et al. (1983) observed less variation in condition of heifers than cows which have undergone previous lactations. Nutritional environment is also expected to influence lactational weight change and yields, and has been studied by Baker et al. (1981b), Bartle et al. (1984), Bowden (1981), and Richardson et al. (1977). Environmental conditions are important: Jeffery et al. (1971a) found that Hereford cows tended to gain weight at the expense of milk under limited grazing conditions of one year whereas other breed groups did not. Prolonged nutritional deficiencies could adversely affect body weight, milk yields, and reproductive rate. With adequate nutrition, weight gain during lactation is negatively associated with yield.

Body weight, or size of cow may influence milk production. Hohenboken et al. (1973), Keller (1980), Lampkin and Lampkin (1960), Williams et al. (1979b), and Wilson et al. (1969), among others, did not find an association between various measures of body size and milk yield. This agrees with the overall results of Mondragon et al. (1983) although Rutledge et al. (1971) found a positive relationship between postparturient weight and total yield. Morris and Wilton (1976), in their review of size and biological efficiency of dairy cows, obtained a positive but low average correlation of 0.33 for body size and milk yield. This value was affected by age, lactation number, size trait studied, and time of measurement. However, body size does not have a very important effect on yields of beef cows.

Sex of calf. Butson and Berg (1984b), Chenette and Frahm (1981), Marshall et al. (1976), Notter et al. (1978), Wilson et al. (1969), and many others have not found variation in milk production due to sex of calf. Richardson et al. (1977) found males consumed more milk but when yields were adjusted for birthweight there was no effect. Similarly, an advantage of 0.4212 kg in daily yield of cows nursing male calves was calculated by Jeffery et al. (1971a), yet when cow summer weight gain was dropped from the model and calf birthweight was included, the effect of sex became nonsignificant. In the following year dams of heifer calves yielded from 0.3557 to 0.3656 kg more daily milk depending on variables of the cow and calf included in the model. When birthweight was accounted for, Rutledge et al. (1971) found heifer calves consumed more milk than males. Nevertheless, sex of calf usually has no influence on dam's milk production.

Breed of sire of calf. The theory that calf growth potential stimulates milk production of the dam has been tested. Reynolds et al. (1978) observed up to a 26% improvement in yield when dams were suckled by crossbred calves compared to straightbred calves. However, studies using Limousin and Charolais bulls (Chenette and Frahm, 1981), Simmental and Selkirk Red (synthetic beef breed) bulls (Sliworsky and Crow, 1984), and bulls of numerous breeds varying in growth potential (Kress et al., 1984; Notter et al., 1978), did not find variation in milk yield due to breed of sire of calf. Wyatt et al. (1977b) found no differences in yields among dams with fostered Angus X Hereford or Charolais X Friesan calves. Based on these few studies, it seems genotype of the calf does not have an important effect on dam's milk production. Further investigation is necessary.

Calf suckling behavior. The suckling behavior of calves has been proposed to account for differences in milk yields due to management and method of estimation of yield (Christian et al., 1965; Dawson et al., 1960), and for calf sex (Jeffery et al., 1971a; Melton et al., 1967; Richardson et al., 1977) and breed of sire (Reynolds et al., 1978) effects. The hypothesis is that calves which are aggressive and suckle vigorously stimulate their dams to produce more milk. This is difficult to test. Few studies have investigated associations between valid behavioral data of calves and milk yield of dams. A once-daily suckling treatment applied by Randel (1981) from 30 days of lactation to first estrus did not result in yields differing from normal suckling frequency. Milk production was shown to be negatively associated with total calf suckling time (Koots and Crow, 1983) and with number of suckling events (Odde et al., 1985). This agrees with results found by Drewry et al. (1959) for the first month of lactation but no relationship was found for the third and sixth month. These results indicate that the calf suckling hypothesis may be unfounded. It appears that calves which suckle for shorter periods and less frequently have dams which yield more milk. More work is needed before behavioral influences on yield can be understood.

Effect of Milk on Calf Growth

Milk production is considered the primary maternal influence on calf preweaning growth. Correlation coefficients for dam's milk yield and calf rate of gain found by Franke et al. (1975), Hohenboken et al. (1973), Jeffery and Berg (1971), Lampkin and Lampkin (1960), and Reynolds et al. (1978), among others, are moderate in size, ranging from 0.34-0.78. Similar values are seen when yield is correlated with weaning weight (Butson et al., 1980; Hohenboken et al., 1973; Marshall et al., 1976; Neville, 1962; Robison et al., 1978).

Regression of calf growth traits on dam's milk yield reveals the effect of each additional unit of milk. This is an important effect (Butson et al., 1980; Jeffery et al., 1971b; Neville, 1962; Rutledge et al., 1971) but it is difficult to compare regression coefficients. Size of the coefficient varies widely with growth trait studied as expected. Values of 0.032-0.053 kg calf weight/ kg milk (Montano et al., 1986) and 0.018-0.023 kg/kg (Mondragon et al., 1983) for total milk yield were 100X smaller than regression coefficients for yield as a sum of four milk estimates (Marshall et al., 1976; Neville, 1962). The effect of a unit of milk also varies with other variables included in the regression model.

Jeffery et al. (1971b) found milk yield explained 58-61% of variation in calf ADG and 25-47% of variation in weaning weight. In a second study of weaning weight (Butson et al., 1980) this value was 36-38%. Neville (1962) and Rutledge et al. (1971) reported that milk accounted for 60% and 66% of variance in weaning weight, respectively.

The effect of milk on calf growth is certainly important but its influence depends on age of calf. Drewry et al. (1959), Franke et al. (1975), Lampkin and Lampkin (1960), and Neville (1962) demonstrated that milk yield was more closely associated with calf growth rate in early periods. Milk is the only food young calves can utilize. As calves mature creep feed and/or pasture is consumed in increasing amounts while milk production of the dam is declining. Relationships among milk consumption, creep or forage intake, and calf growth have been investigated by Bartle et al. (1984), Boggs et al. (1980), Hohenboken et al. (1973), Holloway et al. (1975), and LeDu et al. (1976b).

Behavioral Influences on Calf Growth

Mother-Infant Relationships

Although the contribution of dam's milk production to calf growth is most important, perhaps behavior is also a function of mothering ability. Maternal behavior involves care and nutrition of young, and as Lent (1971) states, facilitates learning processes.

Following parturition, only a few minutes of contact bonds the cow to her calf (Houpt and Wolski, 1982; Kilgour, 1985). Buddenberg et al. (1986) studying attentativeness of the dam to her calf upon the first approach of humans concluded that the influences on this behavior are primarily nongenetic. Drewry et al. (1959) found it was correlated with milk yield but not calf growth.

Animals are classed as 'hiders' or 'followers' depending on the pattern of mother-infant relationships exhibited following the post-partum period. Domestic cattle are hiders (Arnold and Dudzinski, 1978; Craig, 1981; Kilgour, 1985, Wood-Gush et al., 1984). Lent (1971) reviewed behavioral characteristics of wild ungulate hiders. Intense mother-infant contact of the post-partum period ceases upon the infant selecting a hiding place away from the birth site. This is followed by long periods of separation. Mothers vocalize to call out young to suckle. Mothers thus establish activity patterns whereas the infant is responsible for spatial decisions; these characteristics are seen in cattle (Arnold and Dudzinski, 1978; Edwards and Brown, 1982). Calves tend to lie-out in groups or creches (Arnold, 1985b; Arnold and Dudzinski, 1978; Wood-Gush et al., 1984). As the hiding phase progresses infants act increasingly independent. Lickliter (1984) found domestic goat kids were primarily responsible for mother-infant contact in all but the first week of life. Mother-infant distance eventually declines and contact increases converging to that found for followers. For example, kids lacked close proximity to their dams for the first six weeks, thereafter decreasing distance until 10 weeks of age where they spent the greatest percent of time less than one mother length from their dam (Lickliter, 1984) thus terminating the hiding phase. Wood-Gush et al. (1984) observed a peak in cow-calf interaction at six weeks corresponding to a change in the ratio of calf lying to standing. However, knowledge of the hider behavior of cattle is limited.

All ungulate species demonstrate waning mother-infant contact as weaning approaches (Lent, 1971). Arnold et al. (1985) found some indication of a threshold level of milk yield below which ewes prevented suckling; ewes with high yields maintained a strong bond longer. When young are capable of rapid removal of milk, yields are dwindling thus they increase efforts but cause discomfort to the dam (Lent, 1971). Natural weaning is precipitated. Unfortunatly, little is known of behavior associated with weaning processes in domestic livestock.

Calf Suckling Behavior

Suckling is a mother-infant interaction. However, understanding this behavior is simplified by focusing on the calf. Hiders suckle infrequently and for long duration (Arnold, 1985b; Lent, 1971). Calves suckle three to six times per day (Lewandrowski and Hurnik, 1983; Odde et al., 1985; Rugh and Wilson, 1971; Wyatt et al., 1977a) varying with individual (Gary et al., 1970). These frequencies apply to daylight observations as well (Cartwright and Carpenter, 1961; Drewry et al.,

1959) since most suckling events occur during the diurnal period (Cartwright and Carpenter, 1961; Lewandrowski and Hurnik, 1983, Odde et al., 1985; Schake and Riggs, 1969). Odde et al. (1985) found the greatest bouts of suckling at the onset of daylight. Duration of each bout is 10-15 minutes (Gary et al., 1970; Lewandrowski and Hurnik, 1983; Rugh and Wilson, 1971; Wyatt et al., 1977a) and does not depend on interval (Schake and Riggs, 1969). Gary et al. (1970), Lewandrowski and Hurnik (1983), Rugh and Wilson (1971), Odde et al. (1985), and Wyatt et al. (1977a) observed total time devoted to suckling was 32-71 minutes/ day.

Does suckling behavior change over the preweaning period? Craig (1981) claims frequency decreases somewhat with calf age. Declines in frequency and total suckling time seen by Drewry et al. (1959) may not be statistically significant. Although Odde et al. (1985) found no effect of age, calf weight was negatively associated with suckling incidence due to greater milk consuming capacity as weight increased. Lewandrowski and Hurnik (1983) found age did not affect suckling of calves' own dams but cross-suckling increased with age. This resulted from a weakening parental bond and greater milk-seeking efforts of the calf upon declining yields as lactation progressed (Lewandrowski and Hurnik, 1983).

Calf sex has not been shown to be a source of variation in suckling activity (Odde et al., 1985; Rugh and Wilson, 1971).

The influence of suckling behavior on calf growth has not been well established. Drewry et al. (1959) found frequency and total suckling time was positively correlated with calf weight and gain during the first month. However, Koots and Crow (1983) observed calves heavier at weaning tended to spend less time suckling in agreement with results of a large study by Odde et al. (1985). A negative association is perhaps expected since suckling behavior also appears to be negatively related to milk yield. Further work is necessary. Knowledge of sources of variation in suckling activity and the effect of this trait on calf preweaning growth is particularly lacking.

Calf Grazing Behavior

Mature cattle occupy more time grazing than ruminating, idling, walking, or sleeping (Kropp et al., 1973a). Grazing is largely diurnal (Arnold, 1985a; Baker et al., 1981a; Compton and Brundage, 1971; Gary et al., 1970; Sneva, 1970) with two intense periods of activity, one beginning near sunrise and the second in the evening prior to sunset (Arnold, 1985a), and some midday (Gary et al., 1970; Kropp et al., 1973a) or intermittant (Adams, 1984; Sneva, 1970) grazing. A majority of animals in the same activity indicates social facilitation of feeding behavior (Compton and Brundage, 1971; Gary et al., 1970). Total grazing time is 7-11 hr/day (Arnold and Dudzinski, 1978; Baker et al., 1981a; Compton and Brundage, 1971; Hinch et al., 1982; Kropp et al., 1973a). However, environmental factors such as climate, availability of supplemental feed, topography, and quality and quantity of grass may influence this behavior. Compton and Brundage (1971) and LeDu et al. (1976b) observed longer grazing times as the season progressed and pasture quality declined. Grazing time increases when feed is short (Arnold, 1985a), and with animal pressure (Baker et al., 1981b) as long as pasture size and total available feed is not limited (Baker et al., 1981a). Kropp et al. (1973a) suggested seasonal change in grazing activity was due to growing nutritional requirements of fall-calving cows. Other variables such as age, sex, breed, and size of animal may influence grazing.

Grazing activity of suckling calves is less well understood. Initial investigation of grass by the calf leads to grazing behavior by about three weeks of age (Wood-Gush et al., 1984). Calves gradually increase total grazing time (Arnold, 1985a; Koots and Crow, 1983; LeDu et al., 1976b; Wood-Gush et al., 1984) by improving both frequency and duration (Baker et al., 1981a). With milk available, poor pasture quality or quantity may have less influence on grazing activity of calves than dams. But as yields decline and calves become heavier they must rely more on other food sources. Baker et al. (1976) found an effect of level of milk on calf grazing in the month prior to weaning. At lower levels of milk, grazing time must be increased in order to meet nutritional requirements. Koots and Crow (1983) observed heavier calves at weaning tended to spend more time grazing. Few have investigated the influence of this behavior on growth. There are many confounding effects associated with growing calves. Nutrient intake is not only a function of grazing time but also rate of consumption and quality of diet (Adams, 1984). Therefore, many studies have investigated the effect of intake (Boggs et al., 1980; LeDu et al., 1976a; Marshall et al., 1976; Wyatt et al., 1977c) rather than feeding behavior.

MATERIALS AND METHODS

Source of Data

Animals studied were part of the University of Manitoba beef cow herd of approximately 100 Selkirk Red Line cows. This line was developed during 1971-1982 from a base stock of Charolais X Angus heifers and North Devon bulls. Selkirk Red Line cows were mated to two Angus and two Simmental bulls to produce calves of two different genotypes for growth in the spring of 1985. At calving they were housed in pens along an open-sided barn and fed corn silage. The calving season was in March-May.

Group 1 consisted of 24 cow-calf pairs balanced for sex and breed of sire of calf. The calves were, on average, born 8 April (SD=4 days) to three-year-old (n=5), four-year-old (n=2), and mature (5+ years) (n=17) dams. Group 2 originally comprised 24 cow-calf pairs but two were excluded due to health problems. Twenty-two pairs (12 male calves and 10 female calves) balanced for breed of sire of calf thus formed Group 2. These calves were, on average, born 13 April (SD=18 days) to two-year-old (n=3), three-year-old (n=1), four-year-old (n=4), and mature (n=14) dams.

Calculation of EBVs

Estimated breeding values for the direct and maternal contribution to preweaning growth were calculated for all calves and dams in the herd using weaning weight records from 1972-1985. Weaning weights were adjusted for year, sex of calf, age of dam (2, 3, 4, or 5+ years), and age at weaning by a General Linear Models procedure (SAS, 1982). Adjusted weaning weight records for each individual and its relatives were used to determine direct EBV (EBV_D); adjusted weaning weight records for offspring of each individual and offspring of its female relatives were used to determine maternal EBV (EBV_M). The method of calculation followed Chesnais (1980) and was described by Willham (1982). For computation, heritability and repeatability of preweaning growth were set at .25 (Preston and Willis, 1970) and .45 (Lasley, 1972), respectively. Appendix I provides sample computer programs using SAS (1982).

EBVs were expressed as indexes relative to the herd average: EBV = 100 + deviation (kg). Average EBV_D of Group 1 and Group 2 calves was 101.95 (SD=6.34) with 63% (SD=3%) accuracy, and average EBV_M of their dams was 100.14 (SD=6.29) with 69% (SD=5%) accuracy.

The EBVs were inspected to confirm their validity. Slope of the relationship between EBV_D of calf and EBV_D of dam approached the expected value of 0.5, as did that for EBV_M of calf and EBV_M of dam. Slope of the relationship between weaning weight (phenotype) and EBV_D of calf (genotype) was within the range of expected values of 1-4 kg/unit EBV_D. The slope equals one if EBV_D is an accurate estimate of the true breeding value and environmental deviations average to zero; if EBV_D is a poor estimate, based only on the animal's own record, the expected value is $1/h^2=4$. The relationship between calf weaning weight and EBV_M of dam was also found to be within the range of these expected values.

Animal Management and Data Collection

Table 1 demonstrates the schedule of data collection for the two animal groups.

Following spring calving, Group 1 animals were housed six cow-calf pairs per pen. The four 18.1 X 4.5 m pens were one-third covered. Pens were balanced for sex and breed of sire of calf, and had similar means for cow age (years), calf birth date, and calf birthweight. During this confinement period, calf weights, milk consumption, cow weights, and behavioral data were collected weekly. Calves averaged 23 days of age at the first record. Data collection required two days of each week and continued for seven weeks.

One unthrifty calf and its dam were excluded from the study; the pair was replaced at the end of Week 3. A second calf died suddenly following Week 4.

Milk consumption was measured by a calf-suckling method. Cows and calves were separated in the morning for a period of approximately five hours. Calves were then weighed and placed in pens with their dams in small groups of two to four pairs per pen. Actual time interval of separation was calculated for each cow-calf pair. Cross-nursing within the small groups was prevented, and incidences of calf defecation and urination were recorded. Upon completion of suckling, calves were reweighed. Suckling was considered complete if the calf did not pursue its dam for a period of a few minutes; all calves were given a minimum of 15 minutes to suckle. Differences in calf weight between the two weighings measured milk consumption and also provided an estimate of dam's milk production.

During the confinement period, behavioral data included spatial

Table 1. Schedule of data collection.

	GROUP 1 (n=24)	GROUP 2 (n=22)
CONFINEMENT (EARLY) PERIOD	Data: calf weight, milk consumption, cow weight, CCD[a], PSC[b] Week of: 30 April 7 May 14 May 21 May 28 May 4 June 11 June	
PASTURE PERIOD	Data: calf weight, milk consumption, cow weight, PSP[c] Week of: 2 July 30 July 3 Sept[d]	Data: calf weight, milk consumption, cow weight, PSP[c] Week of: 9 July 16 Aug 4 Sept[d]
WEANING	Data: calf weight Week of: 16 Oct	Data: calf weight Week of: 16 Oct

[a] CCD=cow-calf distance (m)
[b] PSC=calf suckling activity during confinement (% of observations)
[c] PSP=calf suckling activity on pasture (% of observations)
[d] behavioral data (PSP) was not obtained this week.

arrangement and activity of Group 1 animals within pens. One person observed each pen from a position at an end of the pen under roof cover and at a height of about 1.5 m above the floor. Position of animals and their activity were recorded on scaled pen diagrams at 15-minute intervals from 12 noon to 3 p.m. Colour-coded neck tags aided animal identification. Presence of an observer did not appear to distract the animals. An attempt was made to balance pens for the person observing and data was collected under fairly uniform weather conditions. Distances between the cow and calf of each pair (CCD) were calculated from co-ordinates of animal midpoints on the diagrams. Percent of observations in which each calf exhibited suckling activity (including cross-suckling) (PSC) was determined by day of observation.

In mid-June, Group 1 was pastured together with some heifers and a bull. Group 2, also with some heifers and a bull, were located on another pasture. Throughout the summer they were rotated amongst two or three 30-acre paddocks of brome-alfalfa grass. Calf weights, milk consumption, cow weights, and behavioral data were collected for Group 1 and Group 2 animals monthly for three months during the pasture season.

Milk consumption was measured as in the confinement period. Behavioral data consisted of calf activity recorded at 15-minute intervals from sunup to sundown. Two people, in shifts, observed one group in a day. The observer followed animals about the pasture but kept at a distance to permit normal behavior. Animals were identified by numbered ear tags and use of binoculars. In the pasture period, activities were classified as sleeping, lying awake, lying ruminating, standing ruminating, standing or walking, grazing, suckling and cross-suckling. Days chosen for observations had favourable weather. Behavioral data were not obtained in the last month due to poor weather and pasture conditions which necessitated combining groups and supplemental feeding. Percent of observations in which each calf was classed as grazing (PG), and suckling (including cross-suckling) (PSP), were calculated by day of observation.

Weaning of the herd on 16 October 1985 provided an additional calf weight record. Group 1 and Group 2 calves were, on average, 188 days of age (SD=13 days) at weaning.

Statistical Analyses

Calf weight data were analyzed by multiple regression models. Groups were pooled because preliminary analysis indicated homogeneity of calf growth lines. An assumption of linear growth rate during the preweaning period was made. Model Ia included the independent variables age of calf, sex of calf (coded male=1, female=0), age of dam (2, 3, 4, or 5+ years), and breed of sire of calf (coded Simmental=1, Angus=0). Model Ib consisted of all Model Ia independent variables except breed of sire of calf, plus the covariate EBV_D of calf; a strong correlation between breed of sire and EBV_D of calf was suspected. Models Ic, Id, and Ie were similar to Model Ia but also included the covariates weight of dam, EBV_M of dam, and milk consumption adjusted for separation interval, respectively. The purpose of these analyses was to determine the influence of the covariates on calf growth adjusted for sex of calf, age of dam, and breed of sire of calf.

Similarly, multiple regression models were used to analyze milk production. Groups were pooled due to homogeneity of lactation curves. Model IIa included the independent variables days in lactation, separation interval, incidence of defecation or urination between the two calf weighings (coded as 1), and as in Model Ia, sex of calf, cow age, and breed of sire of calf. Following preliminary analyses, some of these were dropped due to nonsignificance (P>.10): cubic and quadratic terms for days in lactation, incidence of defecation or urination, sex of calf, and breed of sire of calf. The remaining independent variables plus the covariates cow weight, EBV_M of cow, EBV_D of calf, and calf weight constituted Models IIb, IIc, IId, and IIe, respectively. The effect of the covariates on milk yields adjusted for day of lactation, separation interval, and cow age were investigated with these models.

Calf weight and dam milk production data, available for a sample of animals from 1984 and 1983 calf crops, were analyzed for the effects of EBV_D of calf and EBV_M of dam in a similar manner. Materials and methods utilized in those years and comparative plots are contained in Appendix II.

Cow-calf distance data were available only for Group 1 animals during the confinement period. Pens were closed off to a smaller size for some observations (n=96) and one-factor analysis of variance found that this had a significant (P<.001) affect on CCD. Although additive adjustment for this effect, or proportional adjustment of pen size, could have been done, deleting observations with small pens maximized repeatablity of CCD. Means for CCD by day of observation and pair (CCDD) were then calculated. This trait was regressed on calf age to determine if the pattern of mother-infant distance agreed with that illustrated by Lent (1971) for 'hiders'.

Overall means for CCD by cow-calf pair (CCDO) were calculated. These data were analyzed by one-factor analyses of variance for the effects of sex of calf and breed of sire of calf, and by regression on each of the independent variables cow age, EBV_D of calf, and EBV_M of cow.

Preliminary analysis of PSC data, available only for Group 1 calves during the confinement period, found no effect (P>.10) of calf age; observation days were thus pooled. Chi-square tests were then used to determine if the frequency of suckling activity differed among calves, sexes, and breeds of sire of calf. PSC was also analyzed by regression on each of the independent variables age of dam, EBV_D of calf, and EBV_M of dam.

Chi-square tests found frequency of calf suckling activity, observed while animals were on pasture, differed (P<.10) between groups as did frequency of calf grazing activity (P<.05). Chi-square tests by group were used to determine if frequency of these activities differed among days of observation, calves, sexes, and breeds of sire of calf. Regression analyses of PSP and PG by group for the effects of age of dam, EBV_D of calf, and EBV_M of dam were also conducted.

Percent of all observations in confinement and pasture periods in which each Group 1 calf exhibited suckling activity (PSO) was calculated.

Group 1 calf weight data were analyzed by multiple regression models. Model IIIa was similar to Model Ia for both groups. Model IIIa independent variables plus the behavioral covariates CCDO, PSO, and PG constituted Models IIIb, IIIc, and IIId, respectively. The purpose of these analyses was to determine the influence of mother-infant distance, suckling activity, and grazing activity on calf growth adjusted for sex of calf, age of dam, and breed of sire of calf.

Multiple regression models were also used to analyze Group 1 milk production data. Model IVa was similar to Model IIa for both groups. Models IVb, IVc, and IVd contained the behavioral covariates CCDO, PSO, and PG, respectively, in addition to Model IVa independent variables. These models investigated the effect of the covariates on milk yields adjusted for day of lactation, separation interval, and age of dam.

Full regression models contained all possible interactions and linear, quadratic, and cubic terms for continuous independent variables but only those that approached significance ($P<.10$) were retained. Separate analyses for each covariate were necessary to avoid intercorrelation among independent variables, and to simplify interpretation of multiple regression equations.

Table 2 provides numbers of observations, means, and standard deviations for variables included in the multiple regression analyses.

Table 2. Number of observations, means, and standard deviations (SD) for variables included in multiple regression models.

Variable	Number	Mean and SD
Calf weight (kg)	341	128.85 ± 48.91
Milk yield (kg)	295	2.23 ± 1.36
Separation interval (hr)	297	5.64 ± 0.65
Cow weight (kg)	294	576.76 ± 74.02
EBV_D of calf	46	101.95 ± 6.34
EBV_M of cow	46	100.14 ± 6.29
CCDO (m)	24	6.02 ± 1.00
PSO (%)	24	5.74 ± 2.01
PG (%)	24	37.67 ± 9.86

RESULTS AND DISCUSSION

All final models, regression coefficients, and results of hypothesis tests in the multiple regression analyses of 1985 data are presented in Appendix III.

Calf Growth

With Model Ia, calf age, sex of calf, age of dam, and breed of sire of calf were found to influence calf weight. The relationship between calf age and weight represents growth rate and any variable that interacts with calf age influences ADG. Growth curves derived from Model Ia are seen in Figure 1; sex of calf, breed of sire of calf, and age of dam interact with calf age. Male calves gained 0.092±0.022 kg/day (P<.001) more than females. Similar differences in growth rate between the sexes were observed by Ahunu and Makarechian (1986), Fredeen *et al*. (1982), Marlowe *et al*. (1965), Nelson *et al*. (1982), and Reynolds *et al*. (1978). The superior growth potential of Simmental-sired calves resulted in an additional 0.076±0.023 kg/day over the ADG of the Angus calves in this study. Work by Fredeen *et al*. (1982), Jeffery *et al*. (1971b), Nelson *et al*. (1982), and Notter *et al*. (1978), comparing growth rate of slower maturing European breeds and British breeds is in agreement. As age of dam increased, ADG of calves increased by 0.032±0.014 kg/day/year of age. Ahunu and Makarechian (1986), Kemp *et al*. (1984), and Marlowe *et*

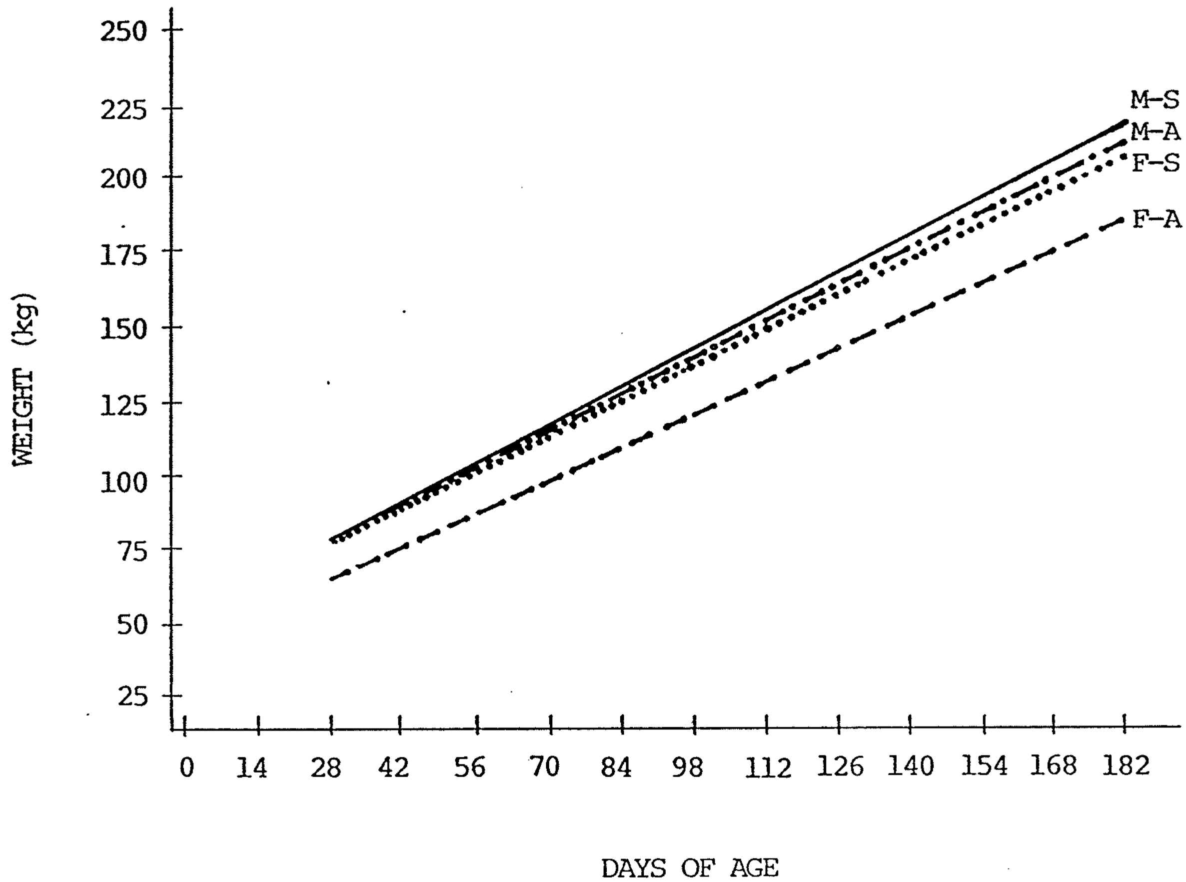

Figure 1. Plots of predicted calf weight against age by sex - breed of sire of calf combination (M=male, F=female; S=Simmental, A=Angus) for calves with mature dams.

al. (1965) also found similar improvements as age of dam increased from two to five years but this effect diminished with older ages. Jeffery et al. (1971b) and Reynolds et al. (1978) noted a curvilinear influence of cow age on calf growth. Sex of calf, breed of sire of calf, and age of dam have been shown to have important effects on preweaning gain of calves.

Age of dam effects on calf weight, illustrated in Figure 2, are curvilinear, probably reflecting milk production levels of the age groups. Improved weaning weights as age of dam increases from three to four years, leveling off with mature dams, is typical of other studies (Ahunu and Makarechian, 1986; Leighton et al., 1982; Minyard and Dinkel, 1965; Nelson and Kress, 1981; Thrift et al., 1978; Tong and Newman, 1980). Studies have shown lowest weaning weights for calves of two-year-olds. The small sample of two-year-olds in this investigation had an unusually high performance.

Since age of calf interacted with age of dam, shape of the relationship between calf weight and age of dam (Figure 2) varies with calf age. This resulted from the differences among age of dam groups for rate of gain of calves.

EBV_D of calf. With Model Ib there was a linear relationship between genetic potential for growth and calf weight. Analyses of 1984 and 1983 calf weight data found similar relationships. In 1984, EBV_D effects were linear; in 1983 the cubic term for EBV_D was significant ($P<.05$) but the regression lines appear nearly linear.

The relationship between genetic potential and growth of calves depended on age of both the calf and the dam in 1985. Positive regression coefficients for calf age X EBV_D and age of dam X EBV_D indicate

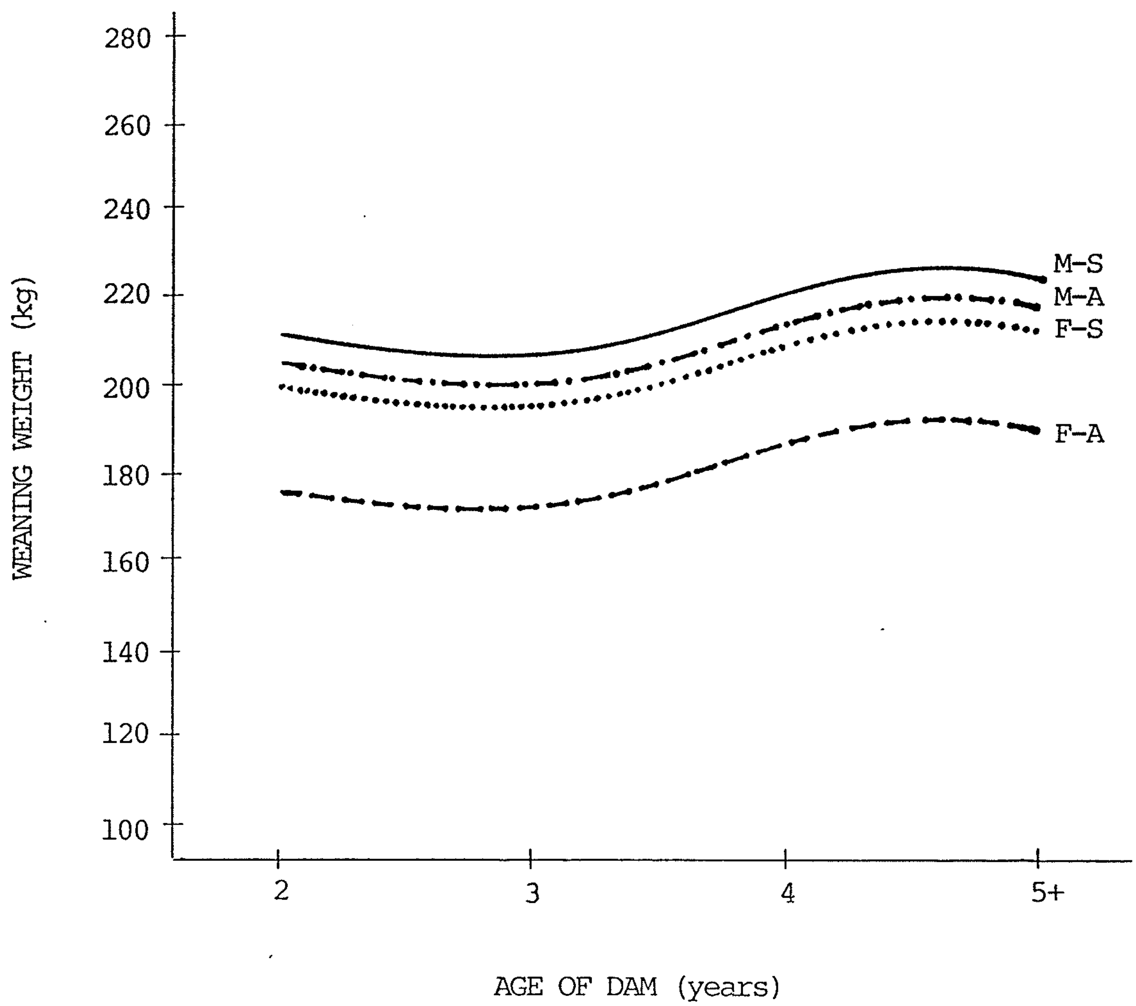

Figure 2. Plots of predicted calf weight at weaning against age of dam by sex - breed of sire of calf combination (M=male, F=female; S= Simmental, A=Angus).

that a unit increase in EBV_D resulted in larger improvements in weight of calves that were older or had older dams. The weight of older calves represents realized differences in genetic potential; EBV_D was determined from weights at weaning. Older dams provide a favourable maternal environment allowing full expression of the calf's genetic potential. This differential effect of EBV_D is demonstrated in Figure 3 for two ages of dam. In 1984 and 1983, slope of the lines varied with age of calf but not age of dam (Figures A-1 and A-2). In general, genotype had a positive linear association with phenotype.

The calf age X EBV_D interaction for the 1985 data reveals a 0.012± 0.001 kg/day increase in ADG for each unit increase in EBV_D. Although appearing to be a small effect, a 10% change in EBV_D resulted in a 0.12 kg/day change in ADG. The 1984 and 1983 regression coefficients for calf age X EBV_D were identical, 0.010±0.002 kg/day, and very similar to that found in 1985. As expected, genetic potential for growth had a consistent and important influence on ADG.

Weight of dam. A linear influence of weight of dam on calf weight was detected by Model Ic. This influence was independent of other variables in the model. The regression coefficient of -0.023±0.013 kg calf/kg dam suggests that lighter dams nursed heavier calves. A 100-kg difference in weight altered calf weight by only 2.3 kg. Jeffery and Berg (1972b) claimed cow weight was associated with age and milk production rather than having a direct influence on calf weight. Cows that increase fatness and thus weight, do so at the expense of milk production (Willham, 1972) and subsequent calf weights. In a review of the literature, Morris and Wilton (1976) found cows that lost more weight during nursing weaned heavier calves. In this study the effect of cow

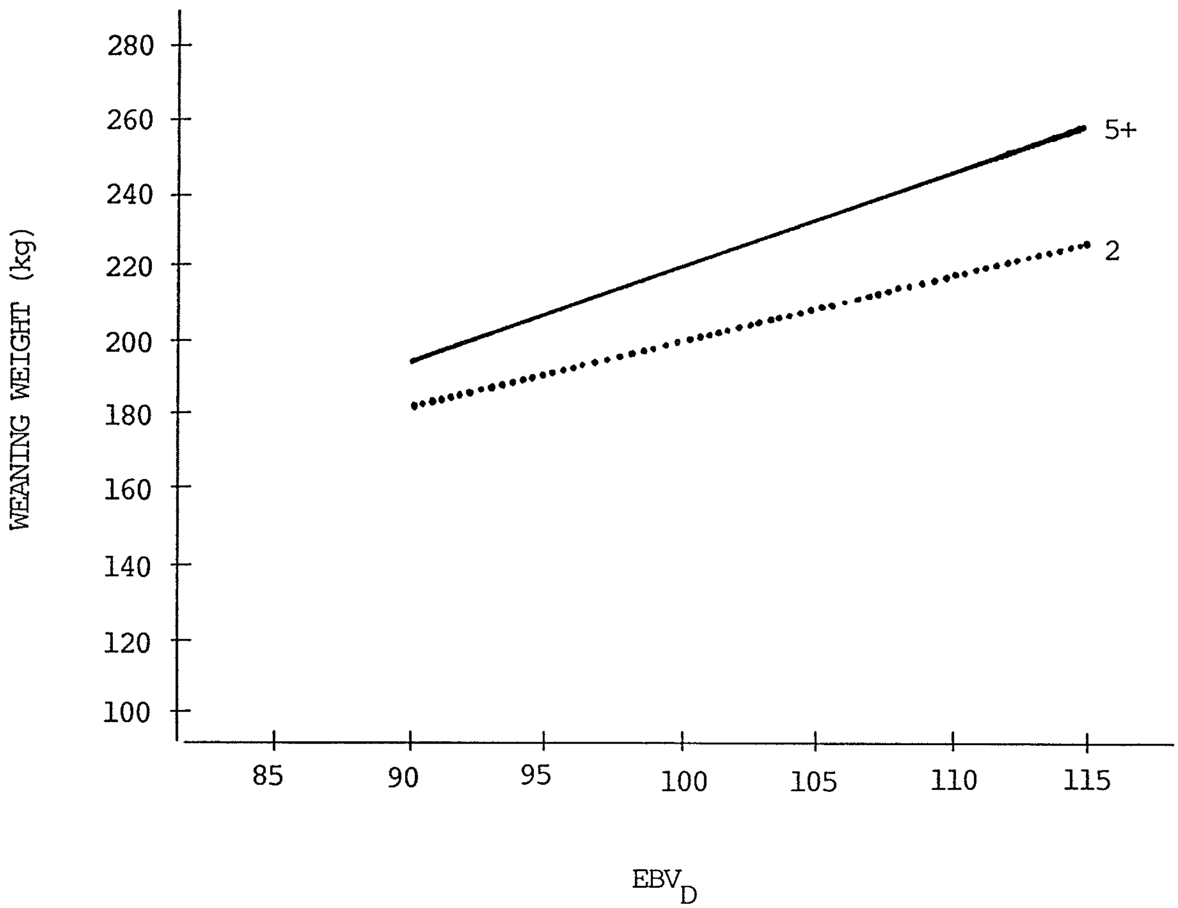

Figure 3. Plots of predicted weight of male calves at weaning against EBV_D of calf by age of dam (years).

weight was marginally significant ($P<.10$) and therefore may not be of consequence.

EBV_M of dam. The curvilinear relationship between calf weight and EBV_M of dam, found using Model Id, is shown in Figure 4. Shape of the curves vary with breed of sire of calf. Throughout the middle range of EBV_M where genetic potential for maternal environment is the herd average, the curves become flatter. Here a unit change in EBV_M has a smaller effect on calf weight than in either of the peripheral ranges of EBV_M. This shape is difficult to explain. Nevertheless, an overall trend of increasing calf weight as maternal ability improves was expected, and in both 1984 and 1983 analyses, the relationship was linear (Figures A-3 and A-4).

Calf age interacted with EBV_M of dam in all three years. Weight at weaning is the response to dam's maternal ability over a long period and EBV_M was determined from weaning weights. Regression coefficients for calf age X EBV_M of dam were identical in 1984 and 1983; a unit change in calf age resulted in a 0.011 ± 0.003 kg/EBV_M change in slope of calf weight on EBV_M of dam. Thus dam's potential maternal ability had a greater influence on the weight of older calves.

The breed of sire of calf X EBV_M of dam interaction resulted in flatter curves for Simmental calves as compared to Angus calves (Figure 4). Simmental calves achieved smaller benefits in weight as EBV_M improved. This does not support the hypothesis that calves of higher growth potential are limited by maternal environment (Tong and Newman, 1980). In 1984 however (Figure A-3), the results were different: as EBV_M improved Simmental calves showed larger increases in weight than Angus calves. This amounted to a 0.640 ± 0.267 kg/EBV_M difference in

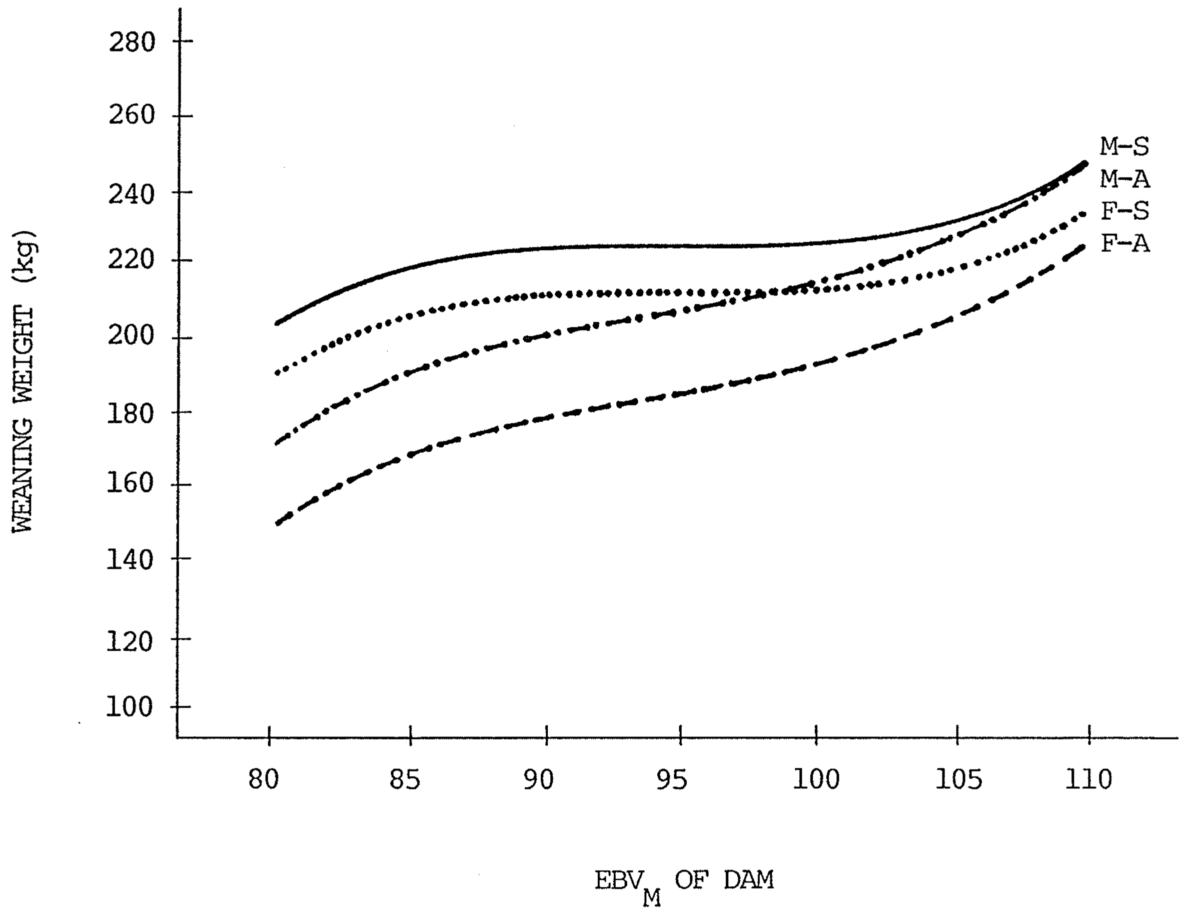

Figure 4. Plots of predicted calf weight at weaning against EBV_M of dam by sex - breed of sire of calf combination (M=male, F=female; S= Simmental, A=Angus) for calves with mature dams.

slope of the regression of calf weight on EBV_M of dam. Breed of sire of calf did not influence the relationship between EBV_M and calf weight in 1983 (Figure A-4).

Sex of calf did not interact with EBV_M of dam in 1985 or 1983 but did so in 1984. In 1984 a unit change in EBV_M had a more profound effect on weight of female calves than male calves. Slope of the regression line was 0.900 ± 0.274 kg/EBV_M greater for females although it was expected that males with a higher growth potential would be more sensitive to changes in maternal ability.

The relationship between EBV_M of dam and calf weight may depend on variables associated with growth potential of the calf, for example, breed of sire and sex of calf. But there were differences among years.

The calf age X EBV_M of dam interaction, highly significant ($P<.001$) in all three years, indicates the influence of EBV_M of dam on growth rate of the calf. A unit improvement in EBV_M increased ADG by 0.009 ± 0.002 kg/day in 1985 and very similar amounts in the previous two years. This consistent influence of the genetic potential for maternal ablity on calf ADG approximates the magnitude seen for effects of EBV_D of calf.

Dam's Milk Production

Factors Influencing Milk Production

Model IIa evaluates effects of days in lactation, cow-calf separation interval, and age of cow on yield of milk. Lactation curves, the relationship between days and yield, are shown in Figure 5. The slope, or persistency of lactation is influenced by any variable that interacts with days. Here separation interval and age of cow are sources of

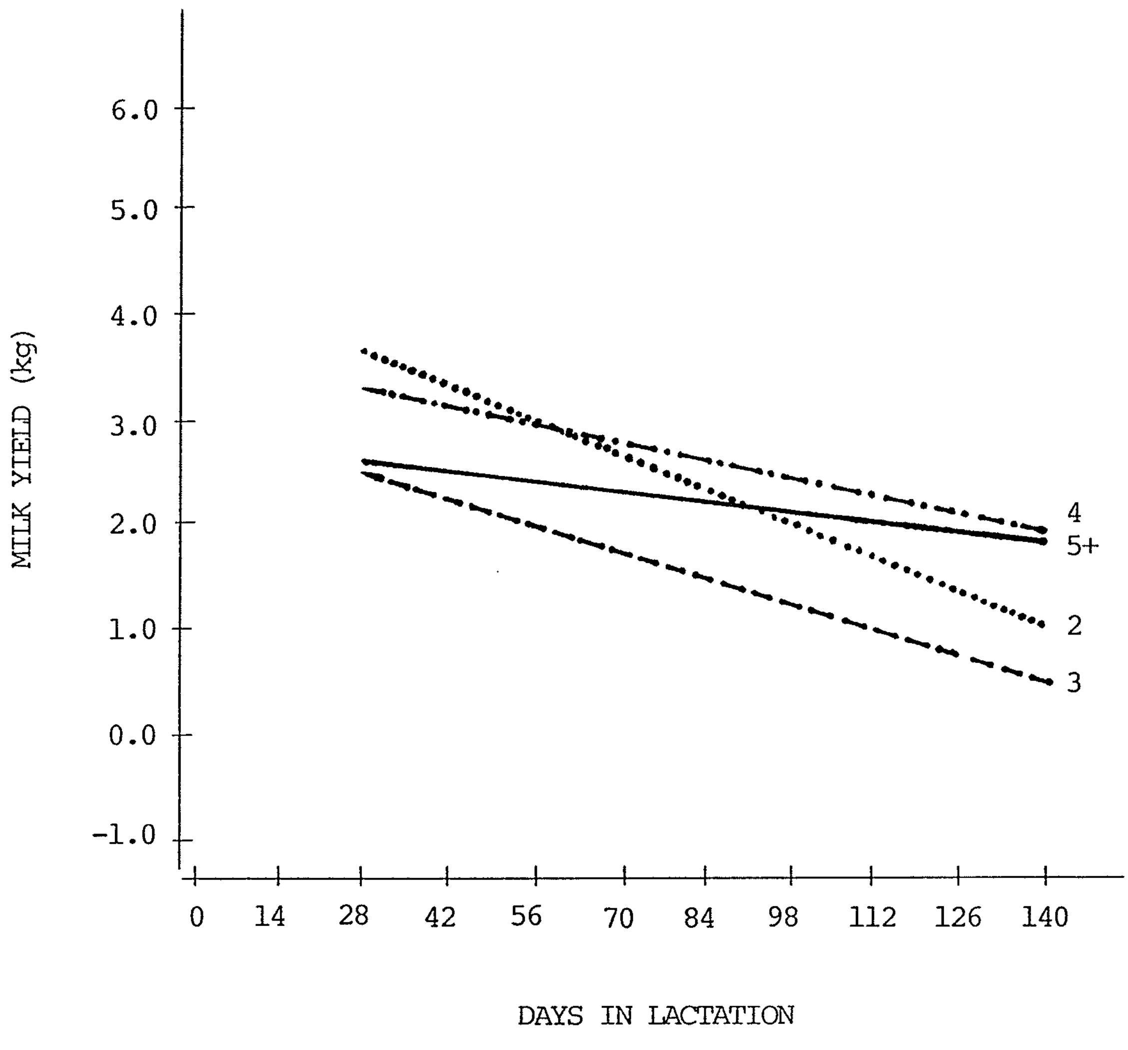

Figure 5. Plots of predicted milk yield against days in lactation by age of cow (years).

variation in persistency. The regression coefficient for days X separation interval indicates more rapid rates of decline with extended intervals. Each additional hour altered the slope by -0.0065±0.0030 kg milk/day. Williams et al. (1979a) did not find an interaction between separation interval and period, but only the first eight weeks of lactation was studied. Age of cow effects improved persistency by 0.0057±0.0023 kg/day/year of age in this study. Mature dams were most persistent in their production. In contrast, Christian et al. (1965) and Mondragon et al. (1983) observed that two-year-olds were most persistent. In work by Lamond et al. (1969), rate of linear decrease was greatest in cows with high total yield. Gaskins and Anderson (1980) found higher-producing three- and four-year-olds had more rapid rates of decline during the second half of lactation than did two-year-olds; shape of the lactation curve differed with cow age. Butson and Berg (1984a) concluded that the shape of lactation curves of beef cows is not yet established. Yield at any one point in lactation depends on the amount of available milk, separation interval, days in lactation or age of the calf, its effectiveness to consume milk, and relationships among these factors.

Age of cow effects on milk yield were curvilinear as illustrated in Figure 6. The small sample of two-year-olds had an unusually high level of performance. Butson and Berg (1984a) and Williams et al. (1979b) found this age group had lower yields than three-year-olds, and Gaskins and Anderson (1980) calculated a linear rate of improvement in daily yield of 1.0 kg/year as age increased from two to four years. Disregarding the two-year-olds, the curvilinear response of milk yield to age of cow (Figure 6) follows a typical pattern. Dawson et al. (1960),

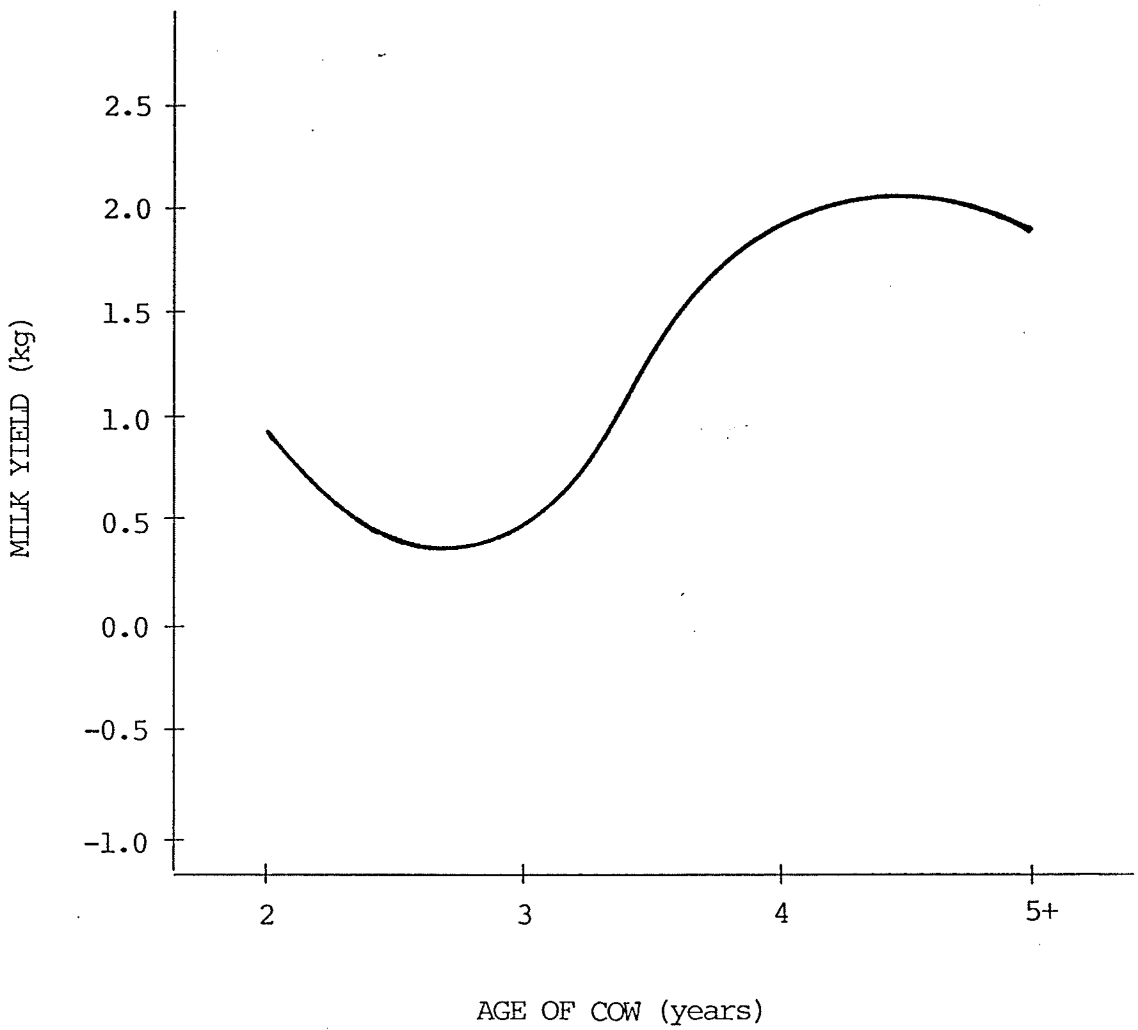

Figure 6. Plot of predicted milk yield on the last day of estimation (146 days) against age of cow.

Jeffery et al. (1971a), Neville et al. (1974), and Robison et al. (1978) showed increasing yields that leveled off at five to six years of age. Rutledge et al. (1971) found a quadratic effect of age and maximum yields at 8.4 years. Neville et al. (1974) and Robison et al. (1978) noted that cows nine years and older had declining yields. Perhaps poor performance of older cows reduced the overall yield of the mature (5+ years) cow group in this study.

Age of cow effects on yield (Figure 6) depend on stage of lactation due to the days X age of cow interaction. Rank of the age groups differs as lactation progresses because there are differences in rate of decline and the lactation curves cross each other.

The trend for cow age effects on yield (Figure 6) reflects that for weaning weight (Figure 2). It is apparent that cow age influences late lactation milk yield and calf weaning weight in a similar manner.

Cow weight. With Model IIb a quadratic effect of cow weight on milk yield that varied with separation interval was found. With the average interval, 5.64 hours (SD=0.65), maximum yields were obtained from 540-kg cows. (Average cow weight was 577kg (SD=74).) Longer intervals shifted the maximum yield to heavier cows. Yields obtained with longer intervals reflect udder capacity (Chenette and Frahm, 1981; Christian et al., 1965; Williams et al., 1979b) which varies with content of fatty tissue. Morris and Wilton (1976) noted that the variable, weight, ignores condition. Thus the ideal weight may be associated with fatness, and capacity of the udder for production and storage of milk within the time period of the cow-calf separation. Nevertheless, the separation interval X cow weight interaction was marginally significant (P<.10); if P<.05 was the criterion for determination of regression models, cow weight would not have been considered to affect milk yield. Butson and Berg (1984b), Hohenboken et al. (1973), Keller (1980), Marshall et al. (1976), and Williams et al. (1979b) did not find cow weight to be associated with yield of milk.

EBV_M of cow. A quadratic relationship between genetic potential for maternal ability and yield of milk was detected using Model IIc. The quadratic term was marginally significant ($P<.10$). Figure 7 presents the relationship for two cow ages. Yields of mature cows improve as EBV_M increases but at a diminishing rate, whereas production of two-year-olds show a gradual and slight increase then decline. In 1983, a diminishing positive effect of EBV_M was seen for all cow ages (Figure A-6). The significant cubic term ($P<.01$) resulted in a slight rise in production at the low range of EBV_M in that year, but only one dam was represented by EBV_M less than 90. In 1984, the relationship was positive and linear (Figure A-5). In general, as EBV_M increases, yield of milk shows an improvement but this influence may diminish with dams of superior potential.

The marginally significant ($P<.10$) age of cow X EBV_M interaction was demonstrated (Figure 7). Realization of potential maternal ability in yield of milk was particularly restricted in young dams. The regression coefficient for this interaction in the 1984 data, similar in magnitude to that of 1985, reveals a 0.043 ± 0.016 kg/EBV_M/year of age increase in slope of the relationship between yield and EBV_M. Older dams were able to realize a larger improvement in yield with an increase in potential. This may depend on environmental conditions of the year. In 1983, EBV_M did not interact with age of dam.

Trends in effects of EBV_M on milk yield differed from those on calf

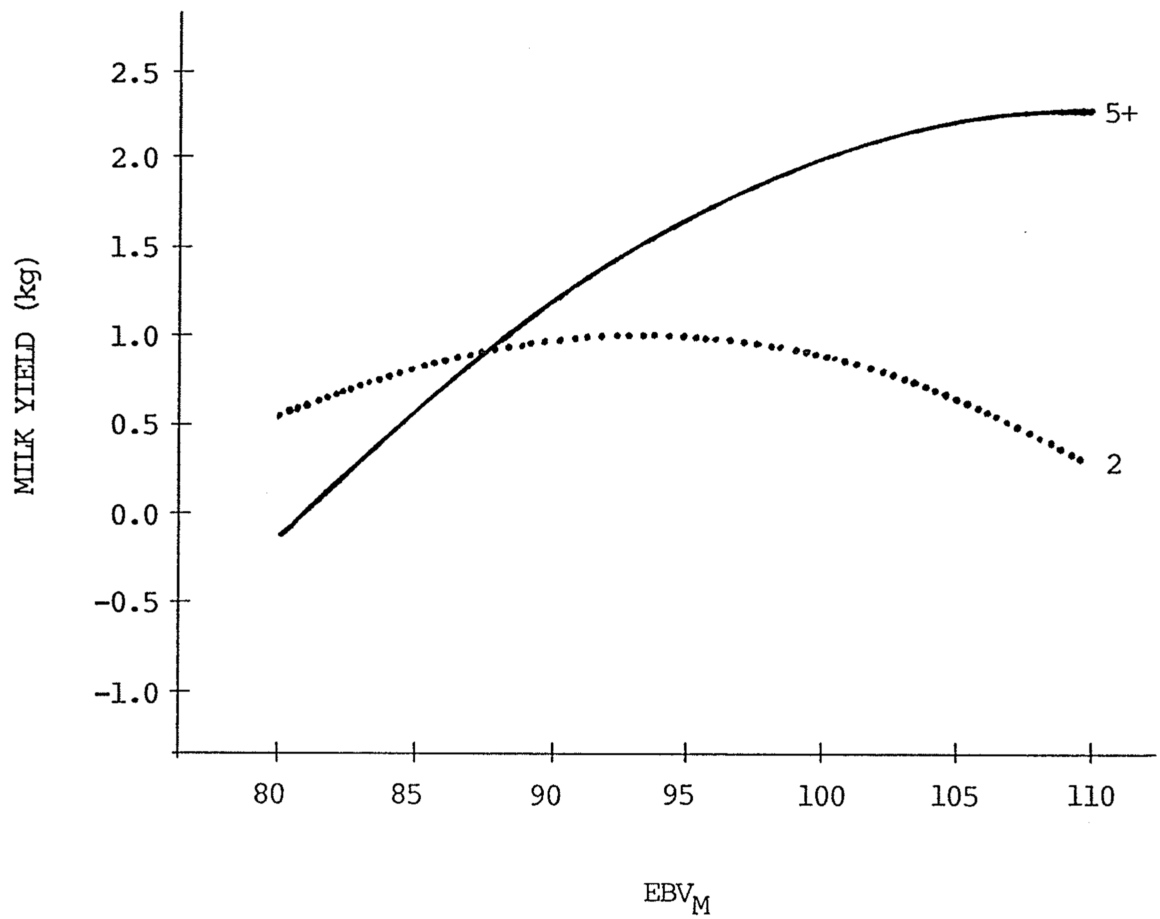

Figure 7. Plots of predicted milk yield on the last day of estimation (146 days) against EBV_M of cow by age of cow (years).

weaning weight. It appears that realization of potential maternal ability was limited in yield of milk but not in weight of calves. In addition, expression of EBV_M in calf weight was not dependent on age of cow. Perhaps EBV_M affects actual milk production but the yields obtained did not indicate this. Behavioral variables associated with maternal ability may also contribute to calf weaning weight (Drewry et al., 1959).

No other interactions with EBV_M were detected using Model IIc. The influence of potential maternal ability on yield of milk did not depend on stage of lactation, and persistency or shape of lactation curves did not vary with EBV_M.

EBV_D of calf. Model IId reveals a curvilinear relationship between calf genetic potential for growth and dam's milk production. As illustrated in Figure 8, when EBV_D increases the calf consumes greater quantities of milk, but with above average potential, consumption declines. Thus yields of milk did not reflect growth potential. In 1984, consumption increased with EBV_D although the effect of a unit change in growth potential was smaller about the herd average where the curve flattened (Figure A-7). In 1983, yields increased linearly with EBV_D of calves suckling mature dams; with two-year-old dams, however, yield declined (Figure A-8). Environmental conditions and average EBV_D for breed of sire groups may have differed among years. To summarize, consumption of milk tended to increase with growth potential of the calf but year and other factors were sources of variation in the response.

EBV_D of calf was associated with dam's milk yield, but calf growth potential with regard to sex and breed of sire was not. Earlier work by Butson and Berg (1984b), Chenette and Frahm (1981), Marshall et al.

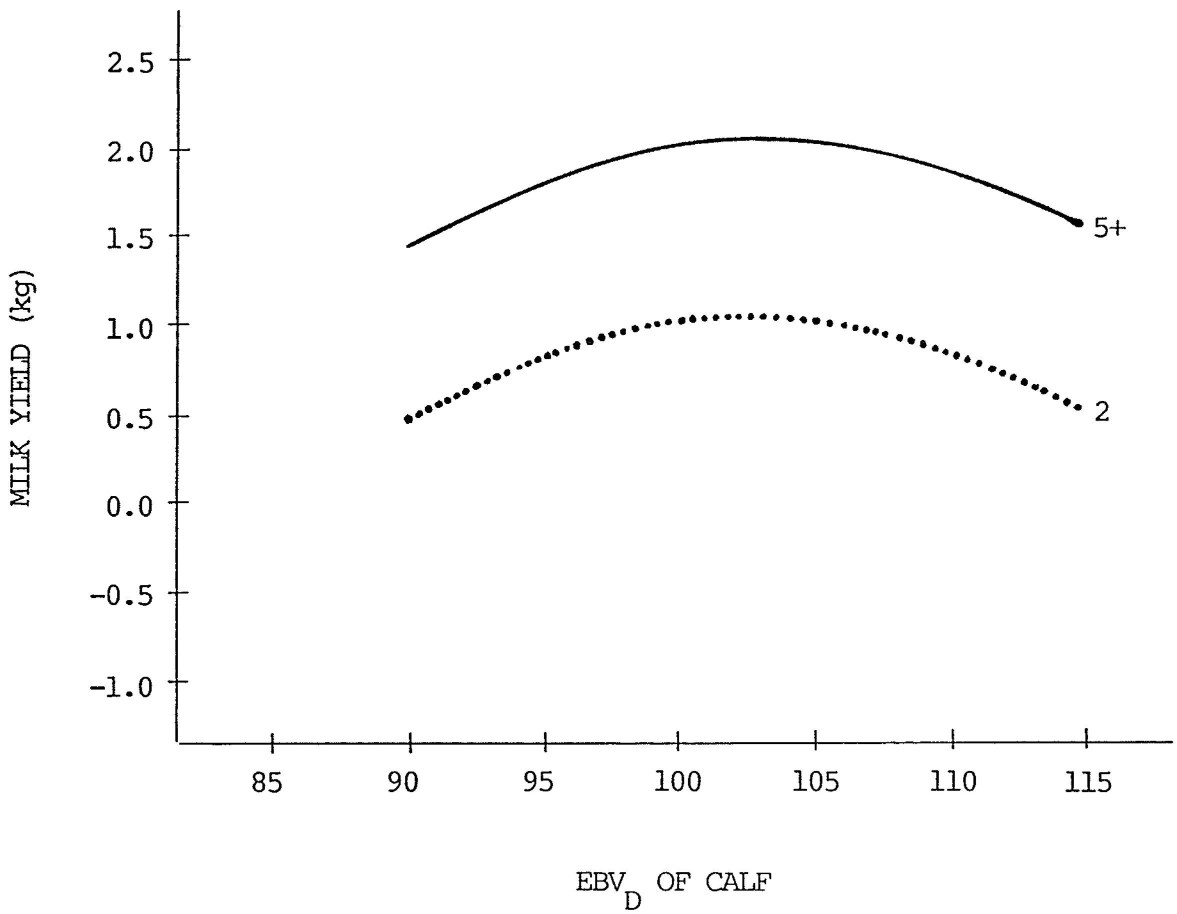

Figure 8. Plots of predicted milk yield on the last day of estimation (146 days) against EBV$_D$ of calf by age of cow (years).

(1976), Notter et al. (1978), and Wilson et al. (1969), among others, failed to find an influence of sex of calf on yield. Although Jeffery et al. (1971a) and Richardson et al. (1977) observed an advantage to dams nursing male calves, adjustment for calf birthweight removed any significant effect. No influence of breed of sire of calf on yield was detected by Kress et al. (1984), Notter et al. (1978), or Sliworsky and Crow (1984), but it approached significance in a study by Chenette and Frahm (1981). Reynolds et al. (1978) reported up to a 26% improvement in amount of milk produced by cows nursing crossbred calves compared to straightbred calves. The effect of breed of sire of calf on yield of milk is not resolved.

Considering all three years, both consumption of milk and weaning weight generally increased with EBV_D. Evidently larger quantities of milk were required to realize a superior growth potential in these calves.

Only one interaction with EBV_D was observed to influence yield: cow age X EBV_D of calf in 1983 ($P<.001$). The influence of growth potential on milk consumed depended on cow age that year; slope of the relationship changed by 0.053 ± 0.014 kg/EBV_D/year of age. Calves of older dams were able to increase consumption to a greater degree meeting the nutritional requirements of an increase in growth potential. This may vary with environmental factors.

Days in lactation did not interact with EBV_D of calf. Thus the relationship between EBV_D and dam's milk yield did not depend on stage of lactation and EBV_D did not influence persistency of production.

Weight of calf. A linear effect of calf weight on milk consumption was found with Model IIe. There was, however, a marginally significant

(P<.10) separation interval X calf weight interaction. The average interval (5.64 hr) resulted in a 2-kg increase in consumption for each 100-kg improvement in weight. With each unit change in separation interval, slope of the relationship between milk yield and calf weight was altered by 0.015±0.008 kg milk/kg calf. Thus an increase in calf weight had a greater impact on consumption where the separation interval was longer. Dams of heavier calves may not be able to produce, in a short interval, the large amounts of milk required. Odde et al. (1985) found heavier calves had a greater capacity to consume milk thus frequency of suckling declined. After a short separation interval heavy calves may not be hungry enough to ingest large amounts of milk. Butson and Berg (1984b) reported positive associations between daily yield and calf ADG that are comparable to those found by this study for calf weight and yield. Most often calf performance is considered a dependent variable which is affected by milk yield of the dam.

It is unknown why phenotype and genotype for growth differed in their association with yield of milk. The curvilinear response to genotype, EBV_D of calf, was unexpected. Why did milk consumption decline when Model Ib indicates above average EBV_D were realized in calf weight? Calf weight, the phenotype, was measured throughout the preweaning period, whereas only one estimate of genotype was obtained for each calf. Perhaps this accounts for the differing effects.

Effect of Milk on Calf Growth

Milk yield adjusted for separation interval was included as an independent variable in Model Ie. This variable had a positive linear effect on calf weight. Calves that consumed more milk were heavier. It has been established that calves that consume more milk gain faster (Franke *et al*., 1975; Hohenboken *et al*., 1973; Jeffery and Berg, 1971; Reynolds *et al*., 1978; Williams *et al*., 1979b) and achieve heavier weaning weights (Butson *et al*., 1980; Hohenboken *et al*., 1973; Marshall *et al*., 1976; Neville, 1962; Robison *et al*., 1978).

The influence of adjusted yield on calf weight depended on calf age, or stage of lactation. Each day, slope of the relationship between calf weight and dam's milk changed by 0.036±0.011 kg calf/kg milk. On the last day of estimation (146 days), a 1-kg increase in yield was associated with 4.27-kg improvement in weight. The ratio of kg calf weight per kg milk consumed became larger in late lactation because calves were heavier and dams' yields were beginning to decline.

Calf weight tended to increase with both milk yield and EBV_M of dam, the genotype for maternal ability. Effects of these factors are greater in older calves since they are exposed to maternal influences over a longer period.

The calf age X milk yield interaction reveals that to achieve the heavier weights, ADG was improved by 0.036±0.011 kg/day/kg milk. Jeffery *et al*. (1971b), Montano *et al*. (1986), and Neville (1962) found very similar changes in growth rate per kg change in daily yield. In this study a 3-kg improvement in milk consumption (average consumption was 2.2kg (SD=1.4)) affected ADG by 0.108 kg/day; the influence of sex or breed of sire of calf was smaller. When milk was included in the model, cow age was not found to act on ADG. Indeed, the effect of 1-kg of milk on calf ADG approximates the effect of one year in cow age as seen in Model Ia. Therefore variation in ADG due to age of cow was explained by milk yield. Yet addition of genotype for maternal ability, EBV_M, did not remove the influence of cow age on ADG. To conclude, milk yield, an expression of maternal ability, has an important positive effect on calf preweaning growth.

Behavioral Traits

Mother-Infant Relationships

Hider pattern of mother-infant distance. Cow-calf distances were obtained during the first ten weeks of life of the calf. Average cow-calf distances by day of observation and cow-calf pair (CCDD) plotted against age of calf did not display any distinct trend. There was, however, a significant cubic relationship ($P<.05$) between these two variables. The estimated regression equation showed gentle undulation of CCDD with time. Large mother-infant distances during the first few weeks of life and gradual declines, were expected. This characteristic pattern of 'hider' behavior illustrated by Lent (1971) is said to be exhibited by domestic cattle (Arnold and Dudzinski, 1978; Craig, 1981; Kilgour, 1985; Wood-Gush et al., 1984). Temporary environment, such as weather or distractions from other pens, may explain the slight fluctuations in CCDD. Small pens would probably prevent calves from lying-out at a distance from their dams. Hence there is insufficient evidence that hider behavior was exhibited.

Factors influencing mother-infant distance. Overall means for cow-calf distance were calculated for each Group 1 cow-calf pair (CCDO). Average CCDO was 6.02 m (SD=1.00). Sex and breed of sire of calf were not found to affect this trait. Further, no relationship between CCDO and age of cow, EBV_D of calf, or EBV_M of cow was detected.

Mother-infant distance and calf growth. With Model IIIb a quadratic relationship between CCDO and calf weight was found. Figure 9 demonstrates weight reaching a maximum at CCDO=5.96 m, about the middle of the range in values for this trait. Deviation in either direction from the ideal cow-calf distance was detrimental to calf weight, but only slightly so. The curve of the relationship was nearly flat. Cow-calf distance had a highly significant (P<.001) albeit small influence on calf weight.

Other factors in the model did not interact with CCDO. Therefore CCDO effects were independent of those variables of the calf and the cow.

CCDO did not interact with age of calf, and thus did not influence ADG. Rather, the small effect on weight resulted from an increase in the y-intercept of growth curves, or birthweight. Small differences in birthweight were maintained throughout the preweaning period. Since birthweight is expressed prior to mother-infant behavior, birthweight may actually affect cow-calf distance. Alternatively, some unknown trait correlated with CCDO could have influenced birthweight.

Mother-infant distance and milk yield. A cubic relationship between CCDO and yield of milk was revealed by Model IVb. The relationship is illustrated in Figure 10. Peak yields were achieved with above-average cow-calf distance and declined with either larger or smaller CCDO. There was also a small improvement as CCDO approached the smallest value.

No interactions with CCDO were found using Model IVb. The influence of cow-calf distance on yield did not depend on separation inter-

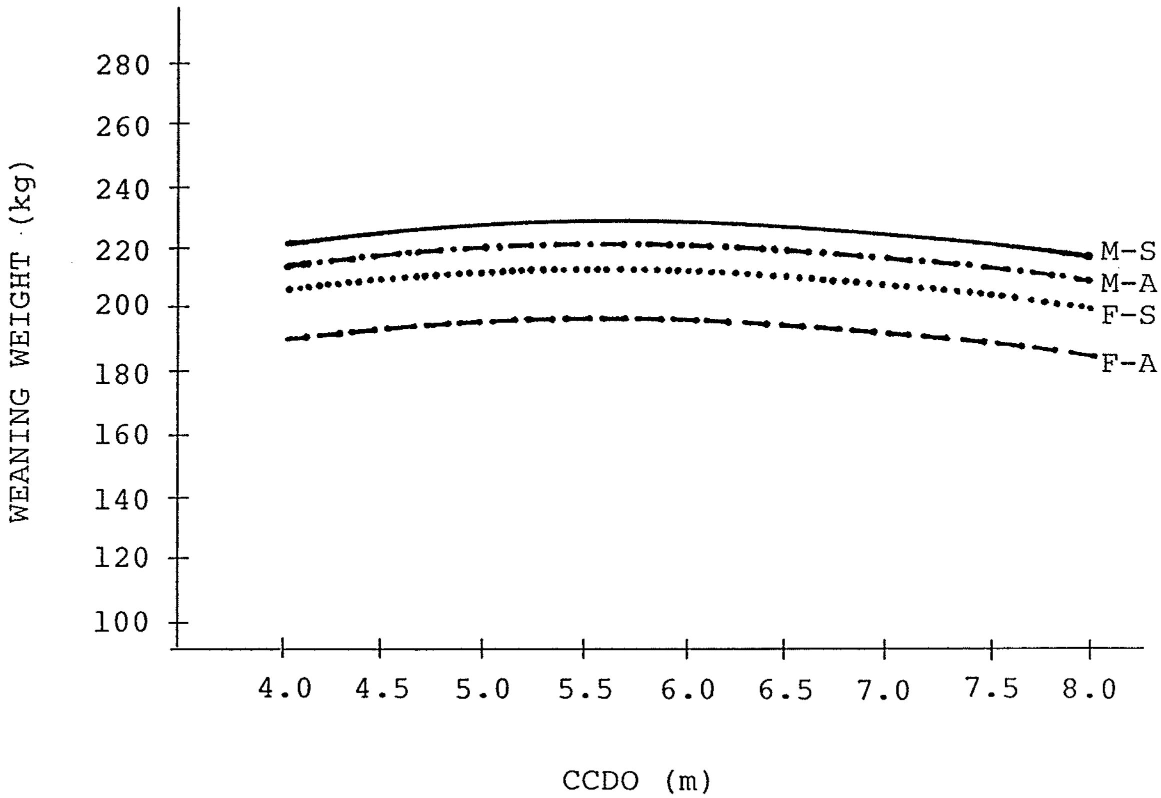

Figure 9. Plots of predicted calf weight at weaning against average cow-calf distance by sex - breed of sire of calf combination (M=male, F=female; S=Simmental, A=Angus) for Group 1 calves with mature dams.

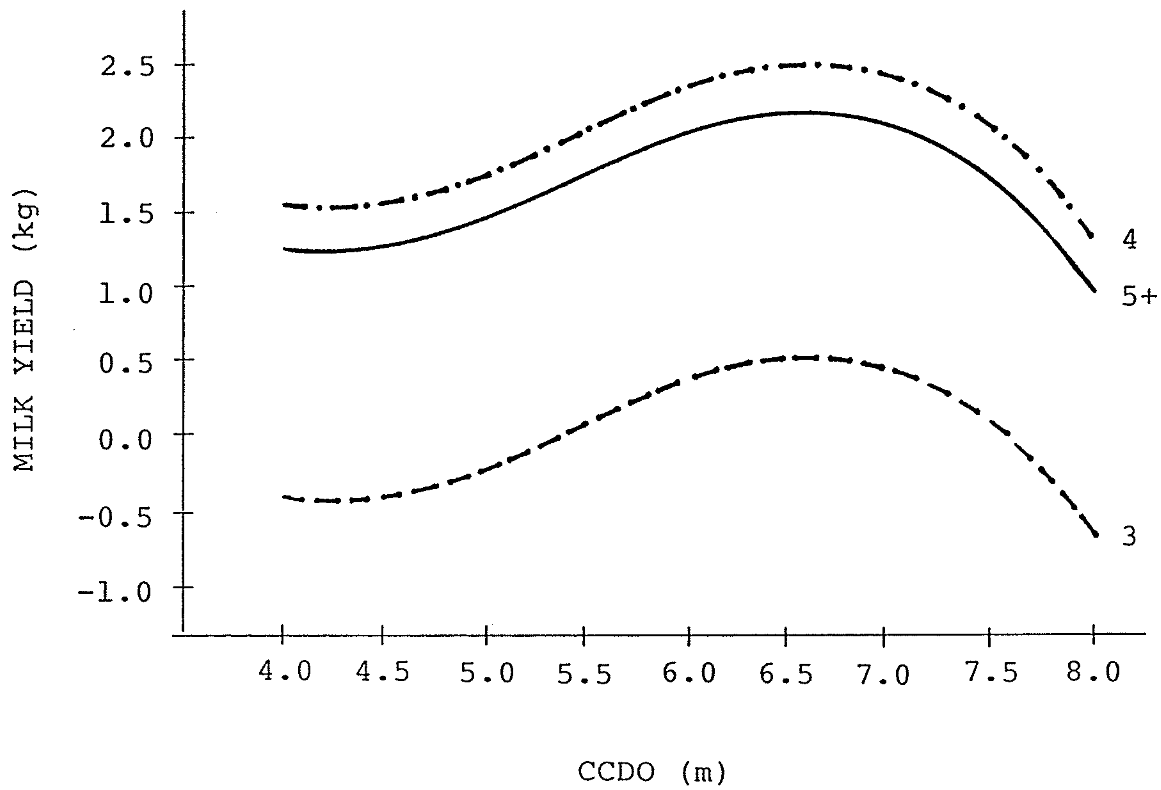

Figure 10. Plots of predicted milk yield on the last day of estimation (146 days) against average cow-calf distance by age of dam (years) for Group 1.

val, age of cow, or stage of lactation, and slope of lactation curves did not vary with CCDO.

Although yield of milk was related to cow-calf distance, growth rate was not. An association of mother-infant distance with maternal ability, and the role of this behavioral trait in preweaning calf growth is not established.

Calf Suckling Behavior

Factors influencing suckling behavior. Frequency of suckling behavior exhibited by Group 1 calves during the confinement period, did not differ with calf, sex or breed of sire of calf. Odde et al. (1985) and Rugh and Wilson (1971) also found no variation in suckling between the sexes. No relationship was detected between PSC and EBV_D of calf or EBV_M of dam in this study. Age of dam, however, had a significant linear effect ($P<.05$) of 1.11±0.53 %PSC/year of age. Calves of older and thus higher-yielding dams spent more time suckling. Age of dam accounted for 16.57% of variation in PSC.

Suckling activity observed in Group 1 calves during the later pasture period was unaffected by all variables tested.

Frequency of suckling behavior observed in Group 2 calves during the pasture period, did not differ among days of observation, calves, sexes or breeds of sire. PSP was unaffected by age of dam in this group. Although marginally significant ($P<.10$), EBV_D of calf had a positive linear association with PSP explaining 17.78% of the variation. EBV_M of dam had a similar influence ($P<.05$) and accounted for 28.49% of variation in PSP. Thus growth potential and dam's potential maternal ability were linked to suckling activity of Group 2 calves during the pasture period.

Suckling activity and calf growth. Average PSO was 5.74% (SD= 2.01). With Model IIIc a quadratic effect of suckling activity on calf weight was found; both terms were marginally significant ($P<.10$). The relatively linear relationship between weight and PSO is revealed in Figure 11. Weights improved with greater suckling activity. Evidently more active calves are able to procure more milk. Drewry et al. (1959) found frequency and total suckling time were positively correlated with calf weight and milk consumption during the first but not third or sixth month of age. In contrast, a larger study by Odde et al. (1985) showed a negative association between suckling incidence and weight. Although nonsignificant, Koots and Crow (1983) observed a similar trend. More work is needed to establish relationships between suckling and growth of calves.

PSO interacted with age of calf. An improvement in suckling activity had a greater influence on weight of calves that were older. Older calves are affected by differences in suckling activity over a longer period; their weights show a larger response.

The sex of calf X PSO interaction, although marginally significant ($P<.10$), resulted in flatter curves for males in comparison to females (Figure 11). Females experienced greater improvements in weight with an increase in suckling activity. They were apparently able to extract more milk from their dams whereas the effort of males was less effectual. Female calves have lower nutritional requirements for growth and may not consume all available milk without an increase in activity, whereas males are limited by dam's production.

Improved calf weights were achieved by an increase in ADG. For

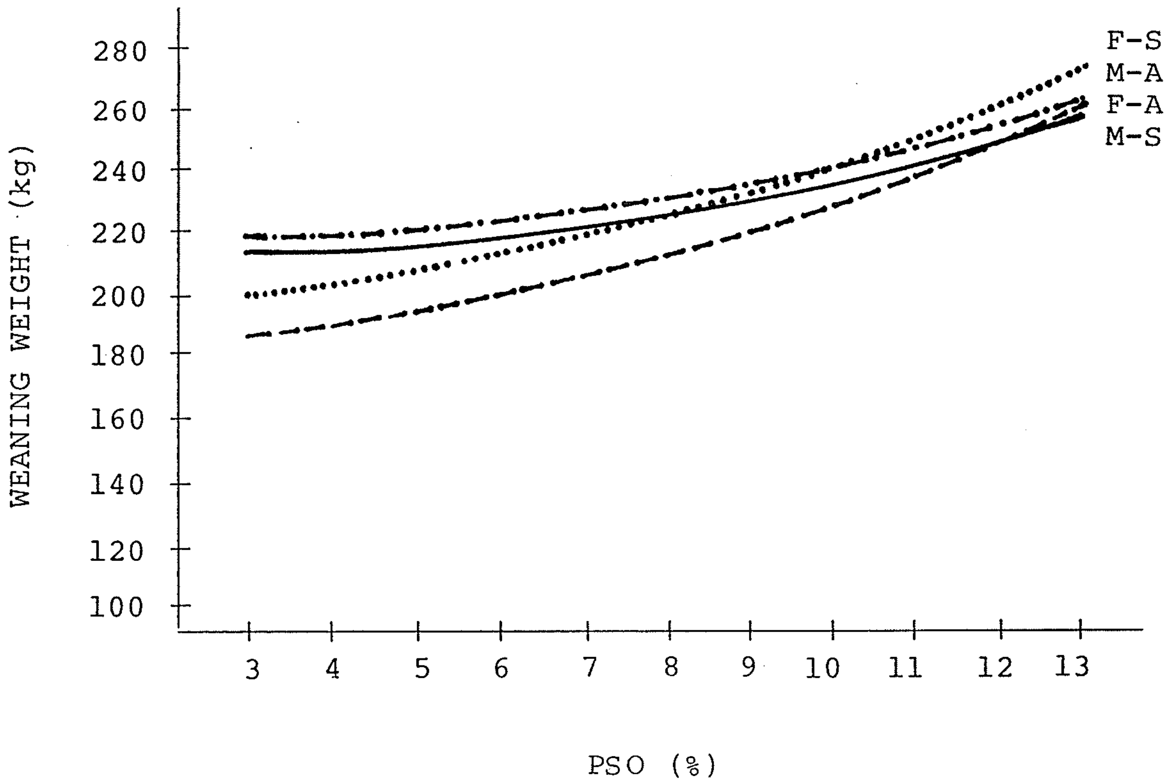

Figure 11. Plots of predicted calf weight at weaning against calf suckling activity by sex - breed of sire of calf combination (M=male, F=female; S=Simmental, A=Angus) for Group 1 calves with mature dams.

each percentage point increase in suckling activity, growth rate increased by 0.030±0.006 kg/day. Therefore this behavior had a substantial positive influence on calf preweaning growth.

Suckling activity and milk consumption. A quadratic relationship between PSO and yield of milk was determined using Model IVc. Shown in Figure 12, yields were maximized at PSO=7.00%. Any deviation from this frequency had a negative effect on yield. Perhaps at low levels of activity, increased efforts of the calf extracts milk that is available but not usually consumed. Following the peak, however, increased activity may not improve yield because dam's production during the separation interval is completely consumed. Indeed, calves of low producers possibly increase suckling activity in an attempt to get sufficient nutrients; low yields would then be associated with the highest levels of activity. Drewry _et al_. (1959), Koots and Crow (1983), and Odde _et al_. (1985) found a negative asssociation between suckling and dam's milk yield.

No interactions with PSO were detected. The influence of suckling activity on yield of milk was independent of other variables in the model, and persistency of lactation did not vary with PSO.

The relationship between PSO and milk yield (Figure 12) differed from that for calf weight (Figure 11). At high levels of activity, weight continued to improve while yields declined. Amounts of milk consumed diminished but these calves suckled more vigorously and were apparently able to acquire larger amounts of daily milk to achieve heavier weights.

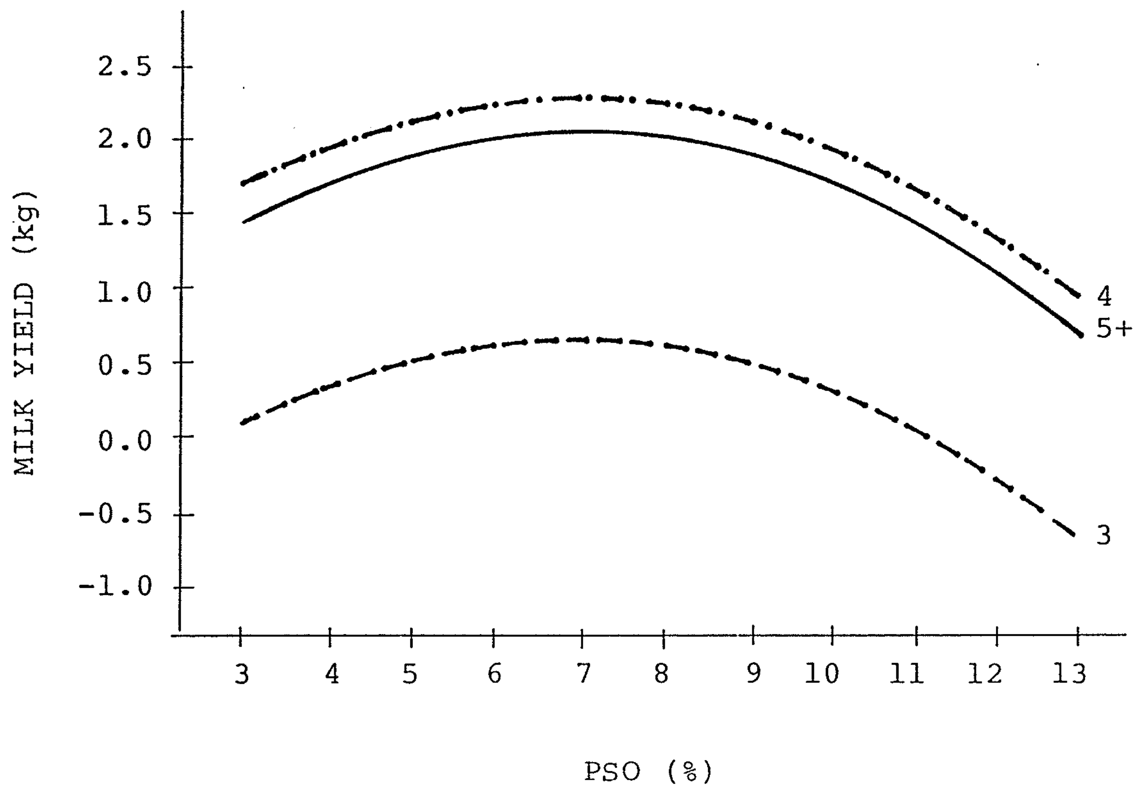

Figure 12. Plots of predicted milk yield on the last day of estimation (146 days) against calf suckling activity by age of dam (years) for Group 1.

Calf Grazing Behavior

Factors influencing grazing behavior. Frequency of grazing behavior exhibited by Group 1 calves increased by 10.77% ($P<.001$) from 2 July to 30 July. Arnold (1985a), Baker <u>et</u> <u>al</u>. (1981b), Koots and Crow (1983), LeDu <u>et</u> <u>al</u>. (1976b), and Wood-Gush <u>et</u> <u>al</u>. (1984) noted increased grazing as calves became older. Grazing activity differed among calves ($P<.05$) but not between sexes. Although marginally significant ($P<.10$), Simmental-sired calves grazed 3.22% less often than the lower growth potential Angus calves. Further, EBV_D of calf had a negative linear effect ($P<.05$) of -0.46 ± 0.17 %PG/unit EBV_D; 25.97% of the variation in PG was explained. Calves with higher growth potential spent less time grazing. No relationship was found to exist between PG and age or EBV_M of dam. In conclusion, grazing behavior was related to traits of the calf and not the maternal ability of the dam.

Frequency of grazing behavior observed in Group 2 calves also differed among the two observation days ($P<.001$) and calves ($P<.01$) but not sexes or breeds of sire. PG had a significant quadratic relationship ($P<.05$) with EBV_D of calf, generally declining as genetic potential increased, and accounted for 34.03% of the variation. Again there was no relationship between PG and age of dam. Nevertheless, EBV_M of dam had a negative linear effect ($P<.05$) on grazing activity; 23.26% of variation was explained. Calves of dams with superior maternal ability require a smaller proportion of nutrients from sources other than milk, and thus are not as active in consuming grass. In Group 2 calves, growth potential and dam's potential maternal ability were associated with grazing activity.

Grazing activity and calf growth. Average PG of Group 1 calves was

37.67% (SD=9.86). A quadratic influence of grazing activity on calf weight that varies with age, sex, and breed of sire of calf, and age of dam was revealed with Model IIId.

Age of calf interacted with PG thus the relationship between grazing activity and weight depended on age. Older calves have the advantage of a longer period of exposure to any differences in PG. At young ages, calves are in confinement and prohibited from display of grazing behavior. Once they begin to demonstrate this activity the effect is negligable but increases with age.

The sex X PG and breed of sire X PG interactions caused variation in shape of the relationship between calf weight and grazing activity. These effects at weaning are shown in Figure 13 for calves of mature dams. As grazing activity increases, weight of Angus-sired calves continually declines, while weight of Simmental-sired calves slightly declines then shows improvement. Increased activity was particularly deleterious to female calves compared to males. More active grazing adversely affects the weight of calves with low growth potential. Perhaps their grazing activity is at the expense of suckling activity and consumption of milk.

PG also interacted with age of dam. Increased grazing activity had a more adverse influence on weaning weight of calves with older dams. These dams are high milk producers and grazing activity of their calves is evidently not the best investment of time.

The calf age X PG interaction reveals a highly significant ($P<.001$) negative effect of grazing activity on ADG. Each percentage point increase in PG reduced growth rate by 0.0097±0.0018 kg/day. Although appearing to be inconsequential, a 10% change in PG produces an effect

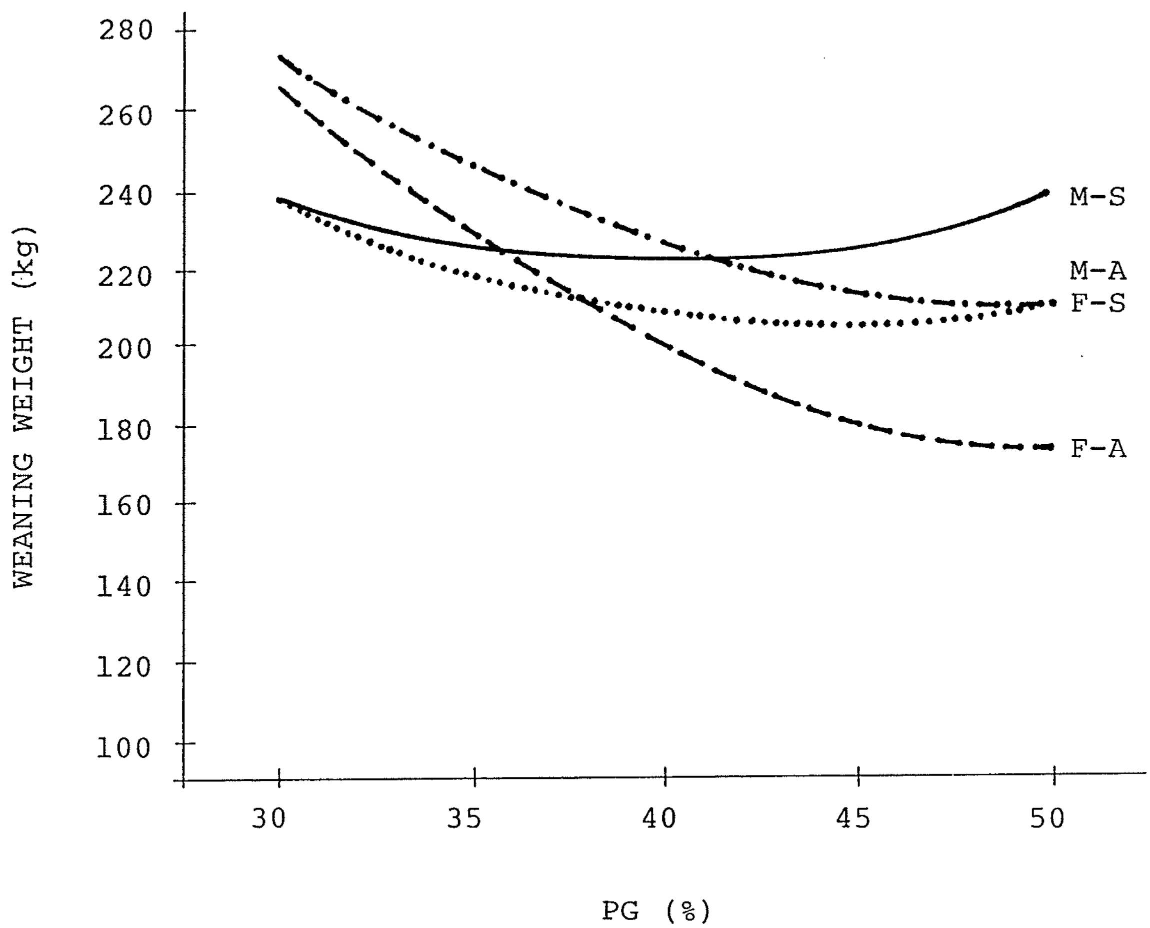

Figure 13. Plots of predicted calf weight at weaning against calf grazing activity by sex - breed of sire of calf combination (M=male, F=female; S=Simmental, A=Angus) for Group 1 calves with mature dams.

equal in magnitude but in the opposite direction of that seen for sex of calf. Grazing activity had a negative influence on preweaning calf growth. Koots and Crow (1983) found grazing time had a nonsignificant but positive association with weaning weight. Very little research has been done on this subject. Adams (1984) noted that grazing time and rate of intake determines forage intake. Boggs et al. (1980) found grass intake and ADG were negatively related during the calves' first two months of life. Calf age and dam's milk yield may have confounding effects on intake and grazing activity. More work is needed to determine the relationship between grazing and calf preweaning performance.

Grazing activity and milk consumption. Model IVd found a quadratic effect of PG on yield of milk. Illustrated in Figure 14, as grazing activity increases, yield improves reaching a maximum at PG=39.47%, then declines. PG possibly reflects vitality of the calf such that grazing activity is related to suckling activity. Prior to the peak, more active calves are able to extract larger amounts of dam's milk. At high levels of grazing activity calves may consume declining amounts because their dams are low producers. These calves are forced to seek nutrients elsewhere, consequently spending more time grazing. Arnold (1985a) concluded that increased grazing times occur as dam's yield declines and calves become older. Baker et al. (1976) found a negative relationship between level of milk and grazing time only in the last month prior to weaning, but in a second study (LeDu et al., 1976a) this was detected only in the first month of life. A negative relationship between herbage intake and level of milk has been established by Boggs et al. (1980), LeDu et al. (1976a), LeDu et al. (1976b), and Lusby et al. (1976). Baker et al. (1981a) noted that dam's milk acts as a buffer

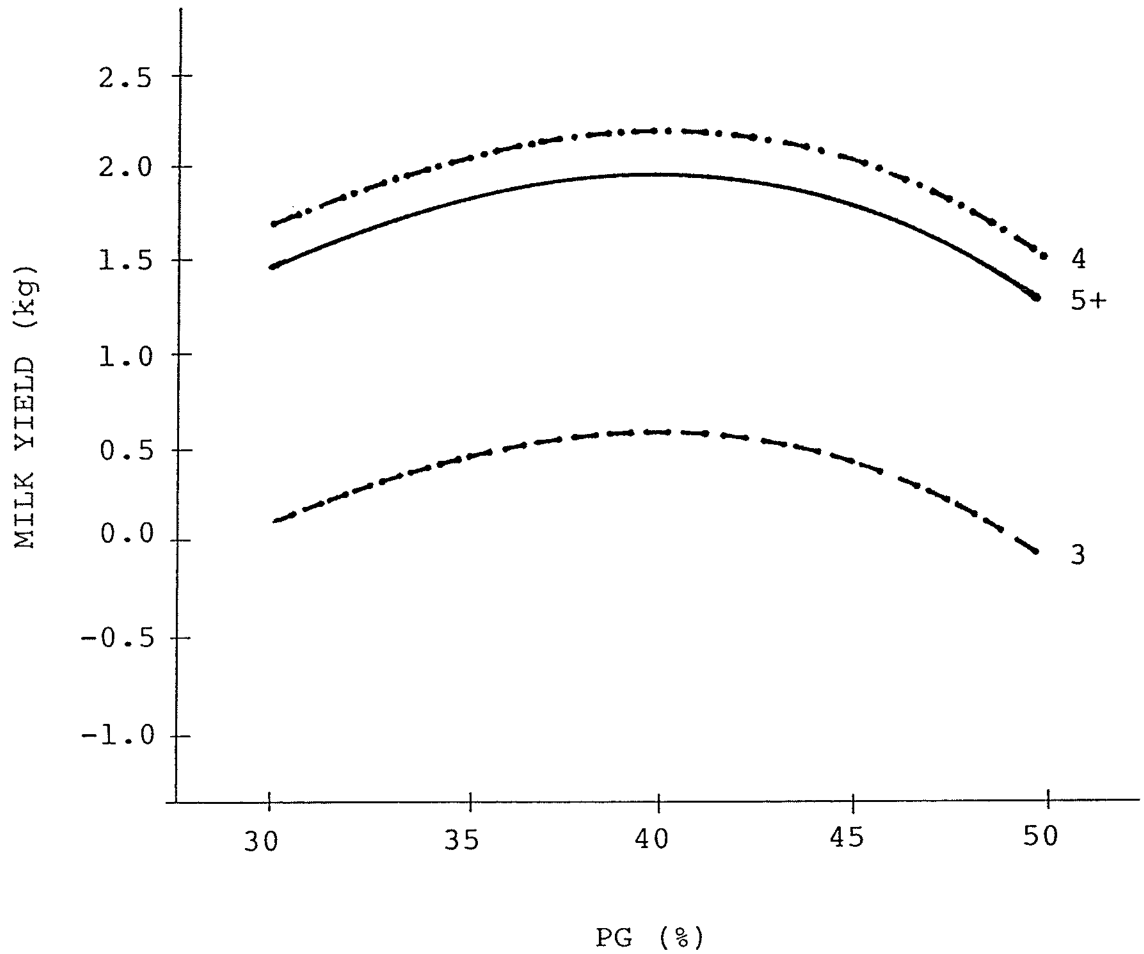

Figure 14. Plots of predicted milk yield on the last day of estimation (146 days) against calf grazing activity by age of dam (years) for Group 1.

against poor grazing conditions.

No interactions with PG were detected by Model IVd. The effect of grazing activity on yield of milk was independent of the other variables and did not influence persistency of lactation.

Yield of milk and weaning weight of calves differed in their response to PG. With below-average levels of grazing activity, an increase in frequency resulted in greater consumption of milk but not enough to maintain calf weight. It is unknown why a greater amount of milk did not benefit weight. In contrast, calves with high grazing activity exhibited declining consumption and weight. Here frequency of grazing had a negative association with both dam's milk production and calf performance.

CONCLUSIONS

The regression models accounted for 94-97% of the variation in calf weight. Although 91% was explained by calf age alone, the additional variables also made significant contributions.

A majority of the factors investigated affected calf performance by influencing both birthweight and growth rate. An effect on ADG produces a cumulative advantage throughout the preweaning period, and a subsequent effect on weaning weight. Sex, breed of sire, and EBV_D of the calf influenced growth rate. Age, EBV_M, and milk yield of the cow were maternal influences on ADG. Further, behavioral traits of the calf, suckling and grazing activity, were associated with growth rate.

Calves with a higher growth potential experience more rapid rates of gain. This was seen for males compared to females, and Simmental-sired calves compared to those sired by Angus. The genetic potential for growth, estimated by EBV_D of calf, had an additional influence: ADG improved by approximately 0.01 kg/day for each unit increase in EBV_D. The relationship between genetic potential for growth (genotype) and weight at weaning (phenotype) was positive and linear. Genotype was expressed in weaning weight. Current methods of calculating EBVs (Chesnais, 1980; Willham, 1982) assume additive effects of EBV and age of dam. However, this study found that the relationship between weaning weight and EBV_D of calf depended on age of dam in one of three years.

Cow age, weight, EBV_M, and milk yield were connected to the pre-weaning performance of the calves. Effects of cow age on weaning weight reflected milk yields. Following adjustment for cow age, the variables, cow weight, EBV_M, and milk yield were also associated with calf performance. A negative linear relationship between cow weight and calf weight was determined; lighter cows were suspected of producing more milk at the expense of body condition. Genetic potential for the maternal contribution to growth was closely related to milk production. Each unit increase in EBV_M resulted in an improvement in ADG of calves that was similar in amount to that seen for EBV_D of calf. The relationship between calf weight at weaning and EBV_M of dam was curvilinear but generally positive. In the two earlier years, the relationship was linear and positive. Expression of EBV_M in calf weight depended on factors related to growth potential of the calf, that is, sex and breed of sire, but there were differences among years. This further suggests that assumptions of current methods of calculation of EBVs (linear and additive effects of breeding value) are not satisfied. Yield of milk, a component of maternal ability, had a positive linear effect on calf weight that was independent of sex and breed of sire of the calf. This provides evidence that EBV_M and milk yield are not the same trait.

Of the behavioral variables studied, only cow-calf distance was not related to growth rate. There was an association with birthweight and subsequently a small effect on weaning weight that is comparatively inconsequential. The small pens probably prevented normal cow-calf behavior and distances so it is unknown if this variable has the potential to exert a substantial influence on calf performance.

Frequency of suckling activity had a positive effect on growth rate whereas the frequency of grazing activity had a negative effect. The quadratic relationship between suckling activity and weaning weight was relatively linear and positive suggesting that heavier calves were more active and able to procure more milk; there were differences between the sexes. The relationship between grazing activity and weaning weight was also quadratic. Overall trends were difficult to detect because of confounding interactions. Weaning weights of low growth potential calves (females and Angus-sired calves) were more adversely affected by increased grazing, as were calves of older and thus higher-yielding dams. Relationships between calf weight and these behavioral traits varied with age of calf; as the calf became older nutritional requirements increased and dam's milk yield declined. Little work has been conducted in this subject area therefore the association of calf suckling and grazing activity with performance is not well established.

A small amount of the variation in yield of milk, 11-20%, was explained by the regression models. Of the variables which were found to influence yield, only separation interval and age of cow affected the slope of the lactation curve, or persistency of production. Usually the y-intercept of the lactation curve was affected, that is, there was an influence on yield that was constant across all days of the study.

Age, weight, and EBV_M of the cow influenced yield of milk. Effects of cow age on late lactation yields were curvilinear and typical except for an unusually high performance in the small sample of two-year-olds. Cow weight had a quadratic effect on yield that depended on separation interval; it was suspected that the ideal weight for maximum yields was related to udder capacity. Genetic potential for the maternal contribution to calf growth, estimated by EBV_M, had a positive influence on yield that tended to diminish at superior levels of EBV_M but varied with age of the cow. There were differences among years. Realization of EBV_M in yield of milk depended on cow age and the diminishing effect indicates further limitations. Calf growth did not appear to be restricted with dams of high EBV_M thus the maternal contribution to calf performance is not straight forward. Behavior and other factors, in addition to milk yield, may determine the maternal environment.

Calf growth potential with regard to sex and breed of sire did not affect yield of milk. The estimated genetic potential for growth, EBV_D of calf, was associated with yield, however. The nature of the relationship was not clear since there were large differences among years. The role of calf genotype in yield of dam's milk is not established. The phenotypic value for calf growth, weight, had a slight positive effect on yield that varied with separation interval. Most often calf performance is considered an independent variable which is affected by dam's milk production. It is unknown which variable actually causes a response in the other.

All behavioral traits studied had curvilinear relationships with yield of milk that were independent of other variables. An ideal level of each behavior, occurring within the middle range of values, maximized yields. It was difficult to explain these effects of cow-calf distance, and calf suckling and grazing activity. Although the behavioral traits were associated with milk yields further work is needed to understand the contribution of behavior to performance of the dam.

A proportion of the variation in the behavioral traits was explained by the factors investigated in this study. None of the factors were related to cow-calf distance, however. Variables of the dam, age and EBV_M, had a positive association with calf suckling activity although there were differences between groups of calves and periods of observation. This indicates that calf suckling activity reflected maternal environment. Calf grazing activity differed with day, a result of age effects or variation due to the day since there were only two days of observation. Factors associated with calf growth potential, breed of sire and EBV_D, were negatively related to grazing activity; calves that grazed less often had more rapid rates of gain. A larger sample of calves observed over a number of days throughout the preweaning period is recommended to minimize variation which may obscure relationships between factors studied and behavioral traits.

SUMMARY

Forty-six cow-calf pairs were used to investigate factors affecting calf preweaning growth and dam's milk production. The dams were Selkirk Reds, a synthetic beef breed. The average dates of birth of Group 1 (n=24) and Group 2 (n=22) calves were 8 April (SD=4 days) and 13 April (SD=18 days), respectively. Groups were balanced for the two breeds of sire of calf: Simmental (high growth potential) and Angus (low growth potential). Beginning on 30 April-2 May, calf weights, milk consumption, cow weights, and behavioral data were obtained from Group 1 weekly for seven weeks. Milk consumed by the calf, an estimate of dam's milk yield, was measured with a calf-suckling method. The actual time interval of separation was calculated for each estimate. Behavioral data, animal position and activity within pens, were recorded on scaled diagrams at 15-minute intervals from 12 noon to 3 p.m., one day each week. Distances between the cow and calf of each pair were averaged across all observations. The percent of observations in which each calf exhibited suckling activity was determined. Animals were moved to pasture in mid-June, and data collection continued monthly for three months using both Group 1 and Group 2 cow-calf pairs. Behavioral data obtained on only two occasions, consisted of calf activity recorded at 15-minute intervals from sunup to sundown. The percent of observations in which each calf was classed as suckling, and grazing, were calculated. A final calf weight record was obtained at weaning when calves

were, on average, 188 days of age (SD=13 days).

Calf weight data were analyzed using multiple regression models for effects of age, sex, breed of sire, and EBV_D of calf; and age, weight, EBV_M, and milk yield (adjusted for separation interval) of the dam. Male calves gained 0.092±0.022 kg/day (P<.001) more than females, and Simmental-sired calves gained 0.076±0.023 kg/day (P<.01) more than those with Angus sires. Genetic potential of the calf, estimated by EBV_D, also influenced growth rate by 0.012±0.001 kg/day/ unit EBV_D (P<.001). The shape of the relationship between weaning weight (phenotype) and EBV_D (genotype) was linear and positive but varied with age of dam (P<.05). Older dams appeared to provide a more favourable environment allowing full expression of calf genetic potential. Age of dam affected ADG of calves by 0.032±0.014 kg/day/year of age (P<.05). Weight of dam had a slight negative effect on calf weight of -0.023±0.013 kg calf/kg dam (P<.10). Genetic potential of the dam for the maternal contribution to calf weight, estimated by EBV_M, had a highly significant (P<.001) influence of 0.009±0.002 kg/day/unit EBV_M on calf growth rate. The relationship between calf weaning weight and EBV_M of dam was curvilinear but generally positive. The curve varied with breed of sire of calf (P<.001) becoming flatter for Simmental calves. Milk yield, a factor contributing to the maternal environment, averaged 2.2 kg (SD=1.4). Adjusted for separation interval, it had an effect of 0.036±0.011 kg/day/kg milk (P<.001) on calf ADG.

Milk production data were analyzed with multiple regression models for effects of days in lactation, separation interval; age, weight, and EBV_M of the cow; and sex, breed of sire, EBV_D, and weight of calf. Curvilinear effects of days in lactation were not significant (P>.10).

Separation interval averaged 5.64 hours (SD=0.65) and had a negative influence on slope of lactation curves ($P<.05$), or persistency of production. Cow age had a positive effect on persistency ($P<.05$). There was a quadratic ($P<.05$) association between cow weight and yield, with a peak occurring within the middle range of weights, depending on separation interval ($P<.10$). The relationship between EBV_M and yield was quadratic but varied with cow age ($P<.10$). In general, expression of EBV_M in yield of milk diminished as EBV_M approached the highest levels, particularly in younger dams. Sex and breed of sire of calf did not affect yield ($P>.10$). The relationship between genetic potential of the calf for growth and dam's yield was quadratic ($P<.05$): yields reached a maximum within the middle range of values of EBV_D. However, the phenoypic value, calf weight, had a positive linear influence on yield that was greater with longer separation intervals ($P<.10$).

Cow-calf distance, and calf suckling and grazing behavioral data, were analyzed using one-factor analyses of variance or Chi-square tests for effects of sex and breed of sire of calf, and simple regression models for effects of EBV_D of calf, age of cow, and EBV_M of cow. None of these factors influenced cow-calf distance ($P>.10$). Cow age had a positive linear effect ($P<.05$) on suckling activity of Group 1 calves during confinement. Suckling activity of these calves during the later pasture period was unaffected ($P>.10$) by all variables tested. EBV_D of calf had a positive linear influence ($P<.10$) on suckling activity of Group 2 calves during the pasture period, and there was a similar EBV_M of dam effect ($P<.05$). Grazing activity of Group 1 calves was 10.77% ($P>.001$) greater on the second observation day. Simmental-sired calves grazed 3.22% ($P<.10$) less often than Angus calves, and EBV_D was found to influence grazing activity by -0.46±0.17 percentage points/unit EBV_D (P<.05). Grazing also increased (P<.001) on the second day of observation in Group 2 calves. EBV_D had a quadratic (P<.05) but generally negative relationship with grazing activity in these calves. EBV_M had a negative linear effect (P<.05).

Calf weight and dam's milk production data of Group 1 animals were analyzed by multiple regression models for effects of the behavioral traits. Cow-calf distance averaged 6.02 m (SD=1.00), and was not associated (P>.10) with rate of gain of calves although there was a slight quadratic effect (P<.001) on weight. On average, calves suckled during 5.74% (SD=2.01) of observations. Suckling activity influenced ADG by 0.030±0.006 kg/day/percentage point (P<.001). Suckling activity had a quadratic relationship with weight that varied with with sex of calf (P<.10); calves heavier at weaning tended to spend more time suckling. Grazing averaged 37.67% (SD=9.86) of observations. This variable influenced growth rate by -0.0097±0.0018 kg/day/percentage point (P<.001). The relationship between grazing activity and weight was quadratic and depended on sex (P<.001), breed of sire (P<.001), and age of dam (P<.001). None of these behavioral traits influenced persistency of dam's milk yield (P>.10). Cow-calf distance, and calf suckling and grazing activity, all had curvilinear effects (P<.05) on yield, independent of other factors included in the models. In all three cases, maximum yields were achieved within the middle range of values for the behavior.

LITERATURE CITED

ABADIA, D., and BRINKS, J.S. 1972. Milk production of Hereford heifers. J. Anim. Sci. 34: 886 (Abstract).

ADAMS, D.C. 1984. Grazing behavior of cattle in a range environment. In: Terry C. Nelson and Robert A. Bellows (Editors), Breeding Beef Cattle in a Range Environment. Fort Keogh Research Symposium, Miles City, Montana. p.39-48.

AHUNU, B., and MAKARECHIAN, M. 1986. Influence of birth date, sex of calf, breed group and age of dam on preweaning performance of range beef calves. Can. J. Anim. Sci. 66: 381-388.

ANDERSON, J.H., and WILLHAM, R.L. 1978. Weaning weight correction factors from Angus field data. J. Anim. Sci. 47: 124-130.

ARNOLD, G.W. 1985a. Ingestive behavior. In: A.F. Fraser (Editor), Ethology of Farm Animals. Elsvier Science Publishers B.V., New York. p.183-200.

ARNOLD, G.W. 1985b. Nursing and maternal care. In: A.F. Fraser (Editor), Ethology of Farm Animals. Elsvier Science Publishers B.V., New York. p.349-360.

ARNOLD, G.W., and DUDZINSKI, M.L. 1978. Ethology of Free-Ranging Domestic Animals. Elsvier Scientific Publishing Co., New York.

ARNOLD, G.W., WALLACE, S.R., and MALLER, R.A. 1985. Some factors involved in natural weaning processes in sheep. In: A.F. Fraser (Editor), Reproductive and Developmental Behavior in Sheep. Elsvier Science Publishers B.V., New York. p.385-392.

BAKER, R.D., ALVAREZ, F., and LeDU, Y.L.P. 1981a. The effect of herbage allowance upon the herbage intake and performance of suckler cows and calves. Grass and Forage Sci. 36: 189-199.

BAKER, R.D., LeDU, Y.L.P., and ALVAREZ, F. 1981b. The herbage intake and performance of set-stocked suckler cows and calves. Grass and Forage Sci. 36: 201-210.

BAKER, R.D., LeDU, Y.L.P., and BARKER, J.M. 1976. Milk-fed calves. 1. The effect of milk intake upon the herbage intake and performance of grazing calves. J. Agri. Sci. (Camb.) 87: 187-196.

BARTLE, S.J., MALES, J.R., and PRESTON, R.L. 1984. Effect of energy intake on the postpartum interval in beef cows and the adequacy of the cow's milk production for calf growth. J. Anim. Sci. 58: 1068-1074.

BELCHER, C.G., and FRAHM, R.R. 1979. Productivity of two-year-old crossbred cows producing three-breed cross calves. J. Anim. Sci. 49: 1195-1206.

BOGGS, D.L., SMITH, E.F., SCHALLES, R.R., BRENT, B.E., CORAH, L.R., and PRUITT, R.J. 1980. Effects of milk and forage intake on calf performance. J. Anim. Sci. 51: 550-553.

BOWDEN, D.M. 1981. Feed utilization for calf production in the first lactation by 2-year-old F_1 crossbred beef cows. J. Anim. Sci. 51: 304-315.

BUDDENBERG, B.J., BROWN, C.J., JOHNSON, Z.B., and HONEA, R.S. 1986. Maternal behavior of beef cows at parturition. J. Anim. Sci. 62: 42-46.

BUTSON, S., and BERG, R.T. 1984a. Lactation performance of range beef and dairy-beef cows. Can. J. Anim. Sci. 64: 253-265.

BUTSON, S., and BERG, R.T. 1984b. Factors influencing lactation performance of range beef and dairy-beef cows. Can. J. Anim. Sci. 64: 267-277.

BUTSON, S., BERG, R.T., and HARDIN, R.T. 1980. Factors influencing weaning weights of range beef and dairy-beef calves. Can. J. Anim. Sci. 60: 727-742.

CARTWRIGHT, T.C., and CARPENTER, J.A., Jr. 1961. Effects of nursing habits on calf weights. J. Anim. Sci. 20: 904 (Abstract).

CHENETTE, C.G., and FRAHM, R.R. 1981. Yield and composition of milk from various two-breed cross cows. J. Anim. Sci. 52: 483-492.

CHESNAIS, J.P. 1980. Computation of EBV for calves, dams, and sires in the Beef Herd Test Program. Agriculture Canada mimeograph.

CHOW, G., RIGGS, J.K., and SCHAKE, L.M. 1967. Fequency of milking and milk yield of beef cows. J. Anim. Sci. 25: 202 (Abstract).

CHRISTIAN, L.L., HAUSER, E.R., and CHAPMAN, A.B. 1965. Association of preweaning and postweaning traits with weaning weight in cattle. J. Anim. Sci. 24: 652-659.

COMPTON, T.L., and BRUNDAGE, A.L. 1971. Cattle behavior on subalpine range in southcentral Alaska. J. Anim. Sci. 32: 339-342.

CRAIG, J.V. 1981. Domestic Animal Behavior. Prentice Hall, Inc., Englewood Cliffs, N.J.

CUNDIFF, L.V., GREGORY, K.E., SCHWULST, F.J., and KOCH, R.M. 1974. Effects of heterosis on maternal performance and milk production in Hereford, Angus and Shorthorn cattle. J. Anim. Sci. 38: 728-745.

DAWSON, W.M., COOK, A.C., and KNAPP, B., Jr. 1960. Milk production of beef Shorthorn cows. J. Anim. Sci. 19: 502-508.

DEUTSCHER, G.H., and WHITEMAN, J.V. 1971. Productivity as two-year-olds of Angus-Holstein crossbreds compared to Angus heifers under range conditions. J. Anim. Sci. 33: 337-342.

DREWRY, K.J., BROWN, C.J., and HONEA, R.S. 1959. Relationships among factors associated with mothering ability in beef cattle. J. Anim. Sci. 18: 938-946.

ECONOMIDES, S.J., TOPPS, J.H., MILLER, T.B., and PRATT, G. 1976. Effect of level of feeding and of single versus double suckling on milk production and weight changes of the suckler cow and on growth of the calf. Br. Vet. J. 132: 576-587.

EDWARDS, S.A., and BROWN, D.M. 1982. Behavioral interactions of dairy cows with their newborn calves and the effects of parity. Anim. Behav. 30: 525-535.

FRANKE, D.E., BURNS, W.C., and KOGER, M. 1975. Milk yield and preweaning growth in beef cattle. J. Anim. Sci. 41: 267 (Abstract).

FREDEEN, H.T., WEISS, G.M., RAHNEFELD, G.W., LAWSON, J.E., and NEWMAN, J.A. 1982. Environmental and genetic effects on preweaning performance of calves from first-cross cows. II. Growth traits. Can. J. Anim. Sci. 62: 51-67.

FURR, R.D., and NELSON, A.B. 1964. Effect of level of supplemental winter feed on calf weight and on milk production of fall-calving range beef cows. J. Anim. Sci. 23: 775-781.

GARY, L.A., SHERRITT, G.W., and HALE, E.B. 1970. Behavior of Charolais cattle on pasture. J. Anim. Sci. 30: 203-206.

GASKINS, C.T., and ANDERSON, D.C. 1980. Comparison of lactation curves in Angus-Hereford, Jersey-Angus and Simmental-Angus cows. J. Anim. Sci. 50: 828-832.

GLEDDIE, V.M., and BERG, R.T. 1968. Milk production in range beef cows and its relation to calf gains. Can. J. Anim. Sci. 48: 323-333.

GODLEY, W.C., and TENNANT, C.O. 1969. The influence of dam's weight on calf performance. J. Anim. Sci. 28: 129 (Abstract).

GREGORY, K.E., SWIGER, L.A., KOCH, R,M., SUMPTION, L.J., ROWDEN, W.W., and INGALLS, J.E. 1965. Heterosis in preweaning traits of beef cattle. J. Anim. Sci. 24: 21-28.

HINCH, G.N., THWAITES, C.J., and LYNCH, J.J. 1982. A note on the grazing behavior of young bulls and steers. Anim. Prod. 35: 289-291.

HOHENBOKEN, W.D., HAUSER, E.R., CHAPMAN, A.B., and CUNDIFF, L.V. 1973. Phenotypic correlations between dam traits expressed during development and lactation and traits of progeny in cattle. J. Anim. Sci. 37: 1-10.

HOLLOWAY, J.W., STEPHENS, D.F., WHITEMAN, J.V., and TOTUSEK, R. 1975. Performance of 3-year-old Hereford, Hereford X Holstein and Holstein cows on range and in drylot. J. Anim. Sci. 40: 114-125.

HOUPT, K.A., and WOLSKI, T.R. 1982. Domestic Animal Behavior for Veterinarians and Animal Scientists. Iowa State Univ. Press, Ames, Ia.

JEFFERY, H.B., and BERG, R.T. 1971. Evaluation of milk variables as measures of milk effect on preweaning performance of beef cattle. Can. J. Anim. Sci. 51: 21-30.

JEFFERY, H.B., and BERG, R.T. 1972a. Influence of cow size and other factors on weight gain of beef calves to 365 days of age. Can. J. Anim. Sci. 52: 11-21.

JEFFERY, H.B., and BERG, R.T. 1972b. An evaluation of several measurements of beef cow size as related to progeny performance. Can. J. Anim. Sci. 52: 23-37.

JEFFERY, H.B., BERG, R.T., and HARDIN, R.T. 1971a. Factors influencing milk yield of beef cattle. Can. J. Anim. Sci. 51: 551-560.

JEFFERY, H.B., BERG, R.T., and HARDIN, R.T. 1971b. Factors affecting preweaning performance in beef cattle. Can. J. Anim. Sci. 51: 561-577.

KELLER, D.G. 1980. Milk production in cattalo cows and its influence on calf gains. Can. J. Anim. Sci. 60: 1-9.

KEMP, R.A., SCHAEFFER, L.R., and WILTON, J.W. 1984. Breed of dam, age of dam and sex of calf effects in the Canadian Simmental Young Sire Proving Program. Can. J. Anim. Sci. 64: 1-8.

KILGOUR, R. 1985. Imprinting in farm animals. In: A.F. Fraser (Editor), Ethology of Farm Animals. Elsvier Science Publishers B.V., New York. p.133-148.

KLETT, R.H., MASON, T.R., and RIGGS, J.K. 1965. Milk production of beef cows and its relationship to the weaning weight of their calves. J. Anim. Sci. 24: 586 (Abstract).

KOCH, R.M. 1972. The role of maternal effects in animal breeding: VI. Maternal effects in beef cattle. J. Anim. Sci. 35: 1316-1323.

KOOTS, K., and CROW, G.H. 1983. Pasture behavior of beef calves and its relation to dam milk production and calf performance. Can. J. Anim. Sci. 63: 1007-1008 (Abstract).

KRESS, D.D., and ANDERSON, D.C. 1974. Milk production in Hereford cattle. J. Anim. Sci. 38: 1320 (Abstract).

KRESS, D.D., DOORNBOS, D.E., and ANDERSON, D.C. 1984. Performance of crosses among Hereford, Angus, and Simmental cattle with different levels of Simmental breeding. II. Effect of calf breed on cow productivity. J. Anim. Sci. 58: 1329-1336.

KROPP, J.R., HOLLOWAY, J.W., STEPHENS, D.F., KNORI, L., MORRISON, R.D., and TOTUSEK, R. 1973a. Range behavior of Hereford, Hereford X Holstein and Holstein non-lactating heifers. J. Anim. Sci. 36: 797-802.

KROPP, J.R., STEPHENS, D.F., HOLLOWAY, J.W., WHITEMAN, J.V., KNORI, L., and TOTUSEK, R. 1973b. Performance on range and in drylot of two-year-old Hereford, Hereford X Holstein and Holstein females as influenced by level of winter supplementation. J. Anim. Sci. 37: 1222-1231.

LAMOND, D.R., HOLMES, J.H.G., and HAYDOCK, K.P. 1969. Estimation of yield and composition of milk produced by grazing beef cows. J. Anim. Sci. 29: 606-611.

LAMPKIN, K., and LAMPKIN, G.H. 1960. Studies on the production of beef from zebu cattle in East Africa. II. Milk production in suckled cows and its effect on calf growth. J. Agri. Sci. 55: 233-239.

LASLEY, J.F. 1972. Genetics of Livestock Improvement. Prentice Hall, Inc., Englewood Cliffs, N.J.

LAWLOR, T.J., Jr., KRESS, D.D., DOORNBOS, D.E., and ANDERSON, D.C. 1984. Performance of crosses among Hereford, Angus and Simmental cattle with different levels of Simmental breeding. I. Preweaning growth and survival. J.Anim. Sci. 58: 1321-1328.

LAWSON, J.E. 1981. Milk production and weight of cows of the Hereford and Highland breeds and their reciprocal crosses. Can. J. Anim. Sci. 61: 861-869.

LeDU, Y.L.P., BAKER, R.D., and BARKER, J.M. 1976a. Milk-fed calves. 2. The effect of length of milk feeding period and milk intake upon herbage intake and performance of grazing calves. J. Agri. Sci. (Camb.) 87: 197-204.

LeDU, Y.L.P., BAKER, R.D., and BARKER, J.M. 1976b. Milk-fed calves. 3. The effect of milk intake, herbage intake, and performance of suckled calves. J. Agri. Sci. (Camb.) 87: 205-211.

LEIGHTON, E.A., WILLHAM, R.L., and BERGER, P.J. 1982. Factors influencing weaning weight in Hereford cattle and adjustment factors to correct records for these effects. J. Anim. Sci. 54: 957-963.

LENT, P.C. 1971. Mother-infant relationships in ungulates. In: V. Geist and F. Walther (Editors), The Behavior of Ungulates and its Relation to Management. I.U.C.N. Publ., Morges, Switzerland. p.14-55.

LEWANDROWSKI, N.M., and HURNIK, J.F. 1983. Nursing and cross-nursing behavior of beef cattle in confinement. Can. J. Anim. Sci. 63: 849-853.

LICKLITER, R.E. 1984. Mother-infant spatial relationships in domestic goats. Appl. Anim. Behav. Sci. 13: 93-100.

LUSBY, K.S., STEPHENS, D.F., and TOTUSEK, R. 1976. Effects of milk intake by nursing calves on forage intake on range and creep intake and digestibility in drylot. J. Anim. Sci. 43: 1066-1071.

MARLOWE, T.J., MAST, C.C., and SCHALLES, R.R. 1965. Some nongenetic influences on calf performance. J. Anim. Sci. 24: 494-501.

MARSHALL, D.A., PARKER, W.R., and DINKEL, C.A. 1976. Factors affecting efficiency to weaning in Angus, Charolais and reciprocal cross cows. J. Anim. Sci. 43: 1176-1187.

McGINTY, D.D., and FRERICHS, W.G. 1971. Milk yields and calf performance from crossbred and Hereford cows. J. Anim. Sci. 33: 210 (Abstract).

MELTON, A.A., RIGGS, J.K., NELSON, L.A., and CARTWRIGHT, T.C. 1967. Milk production, composition and calf gains of Angus, Charolais and Hereford cows. J. Anim. Sci. 26: 804-809.

MINYARD, J.A., and DINKEL, C.A. 1965. Weaning weight of beef calves as affected by age and sex of calf and age of dam. J. Anim. Sci. 24: 1067-1071.

MONDRAGON, I., WILTON, J.W., ALLEN, O.B., and SONG, H. 1983. Stage of lactation effects, repeatabilities and influences on weaning weights of yield and composition of milk in beef cattle. Can. J. Anim. Sci. 63: 751-761.

MONTANO, M., CLUTTER, A.C., and NIELSON, M.K. 1986. Effect of level of beef cow milk production on calf growth and cow reproduction. In: G.E. Dickerson and R.K. Johnson (Editors), Third World Congress on Genetics Applied to Livestock Production. Vol. XI. Genetics of Reproduction, Lactation, Growth, Adaptation, Disease, and Parasite Resistance. University of Nebraska, Lincoln, Nebraska. p.113-118.

MORRIS, C.A., and WILTON, J.W. 1976. Influence of body size on the biological efficiency of cows: a review. Can. J. Anim. Sci. 56: 613-647.

NEIDHARDT, R., PLASSE, D., WENIGER, J.H., VERDE, O., BELTRAN, J. and BENAVIDES, A. 1979. Milk yield of Brahman cows in a tropical beef production system. J. Anim. Sci. 48: 1-6.

NELSON, L.A., BEAVERS, G.D., and STEWART, T.S. 1982. Beef X beef and dairy X beef females mated to Angus and Charolais sires. II. Calf growth, weaning rate and cow productivity. J. Anim. Sci. 54: 1150-1159.

NELSON, T.C., and KRESS, D.D. 1981. Additive and multiplicative correction factors for sex and age of dam in beef cattle weaning weight. J. Anim. Sci. 53: 1217-1224.

NEVILLE, W.E., Jr. 1962. Influence of dam's milk production and other factors on 120- and 240-day weight of Hereford calves. J. Anim. Sci. 21: 315-320.

NEVILLE, W.E., Jr., WARREN, E.P., and GRIFFEY, W.A. 1974. Estimates of age effects on milk production in Hereford cows. J. Anim. Sci. 38: 1-5.

NOTTER, D.R., CUNDIFF, L.V., SMITH, G.M., LASTER, D.B., and GREGORY, K.E. 1978. Characterization of biological types of cattle. VII. Milk production in young cows and transmitted and maternal effects on pre-weaning growth of progeny. J. Anim. Sci. 46: 908-921.

ODDE, K.G., KIRACOFE, G.H., and SCHALLES, R.R. 1985. Suckling behavior in range beef calves. J. Anim. Sci. 61: 307-309.

PRESTON, T.R., and WILLIS, M.B. 1970. Intensive Beef Production. Pergamon of Canada Ltd., Toronto.

RANDEL, R.D. 1981. Effect of once-daily suckling on postpartum interval and cow-calf performance of first-calf Brahman X Hereford heifers. J. Anim. Sci. 53: 755-757.

REYNOLDS, W.L., DeROUEN, T.M., and BELLOWS, R.A. 1978. Relationships of milk yield of dam to early growth rate of straightbred and crossbred calves. J. Anim. Sci. 47: 584-594.

RICHARDSON, F.D., OLIVER, J., and CLARKE, G.P.Y. 1977. Analysis of some factors which affect the productivity of beef cows and of their calves in a marginal rainfall area of Rhodesia. 2. The yield and composition of milk of suckling cows. Anim. Prod. 25: 359-372.

ROBISON, O.W., YUSUFF, M.K.M., and DILLARD, E.U. 1978. Milk production in Hereford cows. I. Means and correlations. J. Anim. Sci. 47: 131-136.

RUGH, M.C., and WILSON, L.L. 1971. Influence of energy intake, cow body size and calf sex on certain behavioral traits of Angus-Holstein cows and their progeny. J. Anim. Sci. 32: 727-731.

RUTLEDGE, J.J., ROBISON, O.W., AHLSCHWEDE, W.T., and LEGATES, J.E. 1971. Milk yield and its influence on 205-day weight of beef calves. J. Anim. Sci. 33: 563-567.

RUTLEDGE, J.J., ROBISON, O.W., AHLSCHWEDE, W.T., and LEGATES, J.E. 1972. Estimating milk yield of beef cows. J. Anim. Sci. 34: 9-13.

SAS Institute Inc. 1982. SAS User's Guide: Statistics, 1982 Edition. SAS Institute Inc., Cary, N.C.

SCHAKE, L.M., and RIGGS, J.K. 1969. Activities of lactating beef cows in confinement. J. Anim. Sci. 28: 568-572.

SCHAKE, L.M., RIGGS, J.K., McGINTY, D.D., and MARION, P.T. 1966. Effects of feed intake levels upon yield and composition of milk from confined beef cows. J. Anim. Sci. 25:248-249 (Abstract).

SCHWULST, F.J., SUMPTION, L.J., SWIGER, L.A., and ARTHAUD, V.H. 1966. Use of oxytocin for estimating milk production of beef cows. J. Anim. Sci. 25: 1045-1047.

SELLERS, H.I., WILLHAM, R.L., and DeBACA, R.C. 1970. Effect of certain factors on weaning weight of beef calves. J. Anim. Sci. 31: 5-12.

SHARMA, A.K., WILLMS, L., HARDIN, R.T., and BERG, R.T. 1982. Sex of calf and age of dam adjustments for some performance traits in two populations of beef cattle. Can. J. Anim. Sci. 62: 699-708.

SINGH, A.R., SCHALLES, R.R., SMITH, W.H., and KESSLER, F.B. 1970. Cow weight and preweaning performance of calves. J. Anim. Sci. 31: 27-30.

SLIWORSKY, G.E., and CROW, G.H. 1984. Effect of calf breed on milk production of beef cows. Can. J. Anim. Sci. 64: 1099-1100 (Abstract).

SMITH, S.P., POLLAK, E.J., and ANDERSON, G.B. 1982. Maternal influences on growth of twin and single calves. J. Anim. Sci. 55: 533-542.

SNEVA, F.A. 1970. Behavior of yearling cattle on eastern Oregon range. J. Range Manage. 23: 155-158.

SOMERVILLE, S.H., and LOWMAN, B.G. 1980. A comparison of machine-milking and the calf-suckling technique as methods of measuring the milk yield of beef cows. Anim. Prod. 30: 365-372.

TANNER, J.E., COOPER, R.J., and KRUSE, W.E. 1965. Relationships between weaning weights of calves and weights and measurments of their dams. J. Anim. Sci. 24: 280 (Abstract).

THRIFT, F.A., GALLION, S.R., and ABSHER, C.W. 1978. Breed of sire and dam comparisons for preweaning traits under commercial beef cattle conditions. J. Anim. Sci. 46: 977-982.

TONG, A.K.W., and NEWMAN, J.A. 1980. Additive age of dam adjustment factors for weaning weight of beef cattle. Can. J. Anim. Sci. 60: 11-19.

TOTUSEK, R., ARNETT, D.W., HOLLAND, G.L., and WHITEMAN, J.V. 1973. Relation of estimation method, sampling interval and milk composition to milk yield of beef cows and calf gain. J. Anim. Sci. 37: 153-158.

WILLHAM, R.L. 1972. Beef milk production for maximum efficiency. J. Anim. Sci. 34: 864-869.

WILLHAM, R.L. 1982. Predicting breeding values of beef cattle. In: R.A. Barton and W.C. Smith (Editors), Proceedings of the World Congress on Sheep and Beef Cattle Breeding. Vol. I. Technical. The Dunmore Press Ltd., Palmerston North, New Zealand. p.209-216.

WILLIAMS, J.H., ANDERSON, D.C., and KRESS, D.D. 1979a. Milk production in Hereford cattle. I. Effects of separation interval on weigh-suckle-weigh milk production estimates. J. Anim. Sci. 49: 1438-1442.

WILLIAMS, J.H., ANDERSON, D.C., and KRESS, D.D. 1979b. Milk production in Hereford cattle. II. Physical measurements: repeatabilities and relationships with milk production. J. Anim. Sci. 49: 1443-1448.

WILSON, L.L., GILLOOLY, J.E., RUGH, M.C., THOMPSON, C.E., and PURDY, H.R. 1969. Effects of energy intake, cow body size and calf sex on composition and yield of milk by Angus-Holstein cows and preweaning growth rate of progeny. J. Anim. Sci. 28: 789-795.

WISTRAND, G.C., and RIGGS, J.K. 1966. Milk production of Santa Gertrudis cows as measured by calf nursing and machine milking methods. J. Anim. Sci. 25: 263-264 (Abstract).

WOOD-GUSH, D.G.M., HUNT, K., CARSON, K., and DENNISON, S.G.C. 1984. The early behavior of suckler calves in the field. Biol. Behav. 9: 295-306.

WYATT, R.D., GOULD, M.B. and TOTUSEK, R. 1977a. Effects of single vs simulated twin rearing on cow and calf performance. J. Anim. Sci. 45: 1409-1414.

WYATT, R.D., GOULD, M.B., WHITEMAN, J.V., and TOTUSEK, R. 1977b. Effect of milk level and biological type on calf growth and performance. J. Anim. Sci. 45: 1138-1145.

WYATT, R.D., LUSBY, K.S., WHITEMAN, J.V., GOULD, M.B., and TOTUSEK, R. 1977c. Performance of 4- and 5-year-old Hereford, Hereford X Holstein and Holstein cows on range and in drylot. J. Anim. Sci. 45: 1120-1130.

APPENDIX I

Computer Program 1. Calculation of EBV_D for animals with all five sources of information available.

```
PROC MATRIX;
  FETCH NEW DATA=ADJUST1;
  JJJ=NROW(NEW);
  DO I=1 TO JJJ;
     CALF=NEW(I,1);
     YEAR=NEW(I,2);
     AWWR=NEW(I,3);
     AWWRP=NEW(I,4);
     AWWRM=NEW(I,5);
     AWWRD=NEW(I,6);
     AWWRO=NEW(I,7);
     D1=NEW(I,8):
     D2=NEW(I,9);
     D3=NEW(I,10);
     X=4 .25 .25 .5 .5/
       .25 1 0 0 .125/
       .25 0 1 .5 .125/
       .5 0 .5 4 .25/
       .5 .125 .125 .25 1;
     X(2,2)=D1;
     X(3,3)=D2;
     X(5,5)=D3;
     Y=1/.25/.25/.5/.5;
     E=INV(X)*Y; B1=E(1,); B2=E(2,); B3=E(3,); B4=E(4,); B5=E(5,);
       C1='B1';
       OUTPUT B1 COLNAME=C1 OUT=DATA1B1;
       C2='B2';
       OUTPUT B2 COLNAME=C2 OUT=DATA1B2;
       C3='B3';
       OUTPUT B3 COLNAME=C3 OUT=DATA1B3;
       C4='B4';
       OUTPUT B4 COLNAME=C4 OUT=DATA1B4;
       C5='B5';
       OUTPUT B5 COLNAME=C5 OUT=DATA1B5;
     EBV=100+(B1*AWWR)+(B2*AWWRP)+(B3*AWWRM)+(B4*AWWRD)+(B5*AWWRO);
       C6='EBV';
       OUTPUT EBV COLNAME=C6 OUT=DATA1EBV;
     ACC=SQRT(B1+(.25*B2)+(.25*B3)+(.5*B4)+(.5*B5));
       C7='ACC';
       OUTPUT ACC COLNAME=C7 OUT=DATA1ACC;
  END;
DATA A;
  MERGE ADJUST1 DATA1B1 DATA1B2 DATA1B3 DATA1B4 DATA1B5
        DATA1EBV DATA1ACC;
  KEEP CALF YEAR B1 B2 B3 B4 B5 EBV ACC;
```

Computer Program 2. Calculation of EBV_M for cows with all three sources of information available.

```
PROC MATRIX;
  FETCH NEW DATA=COW1;
  JJJ=NROW(NEW);
  DO I=1 TO JJJ;
     CALF=NEW(I,1);
     YEAR=NEW(I,2);
     M1=NEW(I,3);
     AWWRI=NEW(I,4);
     N3=NEW(I,5);
     M3=NEW(I,6);
     AWWRDMGS=NEW(I,7);
     N4=NEW(I,8);
     M4=NEW(I,9);
     AWWRDS=NEW(I,10);
     V1=NEW(I,11);
     V3=NEW(I,12);
     V4=NEW(I,13);
     X=1 .125 .25/
       .125 1 0/
       .25 0 1;
     X(1,1)=V1;
     X(2,2)=V3;
     X(3,3)=V4;
     Y=1/.125/.25;
     E=INV(X)*Y; B1=E(1,); B3=E(2,); B4=E(3,);
       C1='B1';
       OUTPUT B1 COLNAME=C1 OUT=DATA1B1;
       C3='B3';
       OUTPUT B3 COLNAME=C3 OUT=DATA1B3;
       C4='B4';
       OUTPUT B4 COLNAME=C4 OUT=DATA1B4;
     EBV=100+(B1*AWWRI)+(B3*AWWRDMGS)+(B4*AWWRDS);
       C5='EBV';
       OUTPUT EBV COLNAME=C5 OUT=DATA1EBV;
     ACC=SQRT(B1+(.125*B3)+(.25*B4));
       C6='ACC';
       OUTPUT ACC COLNAME=C6 OUT=DATA1ACC;
  END;
DATA A;
  MERGE COW1 DATA1B1 DATA1B3 DATA1B4 DATA1EBV DATA1ACC;
  KEEP CALF YEAR B1 B3 B4 EBV ACC;
```

Computer Program 3. Calculation of EBV_M for calves with all three sources of information available.

```
PROC MATRIX;
  FETCH NEW DATA=CALF1;
  JJJ=NROW(NEW);
  DO I=1 TO JJJ;
     CALF=NEW(I,1);
     YEAR=NEW(I,2);
     M2=NEW(I,3);
     AWWRD=NEW(I,4);
     N3=NEW(I,5);
     M3=NEW(I,6);
     AWWRDMGS=NEW(I,7);
     N4=NEW(I,8);
     M4=NEW(I,9);
     AWWRDS=NEW(I,10);
     V2=NEW(I,11);
     V3=NEW(I,12);
     V4=NEW(I,13);
     X=1 .25 0/
       .25 1 0/
       0 0 1;
     X(1,1)=V2;
     X(2,2)=V3;
     X(3,3)=V4;
     Y=.5/.125/.25;
     E=INV(X)*Y; B2=E(1,); B3=E(2,); B4=E(3,);
       C2='B2';
       OUTPUT B2 COLNAME=C2 OUT=DATA1B2;
       C3='B3';
       OUTPUT B3 COLNAME=C3 OUT=DATA1B3;
       C4='B4';
       OUTPUT B4 COLNAME=C4 OUT=DATA1B4;
     EBV=100+(B2*AWWRD)+(B3*AWWRDMGS)+(B4*AWWRDS);
       C5='EBV';
       OUTPUT EBV COLNAME=C5 OUT=DATA1EBV;
     ACC=SQRT((.5*B2)+(.125*B3)+(.25*B4));
       C6='ACC';
       OUTPUT ACC COLNAME=C6 OUT=DATA1ACC;
  END;
DATA A;
  MERGE CALF1 DATA1B2 DATA1B3 DATA1B4 DATA1EBV DATA1ACC;
  KEEP CALF YEAR B2 B3 B4 EBV ACC;
```

APPENDIX II

1984 and 1983 Materials and Methods

To provide further insight into relationships between the EBVs calculated and the traits calf weight and dam's milk production, data from 1984 and 1983 calf crops of the University of Manitoba beef herd were analyzed.

Herd management and data collection in these two years was similar to 1985. Data were collected by a MSc student, G. Sliworsky, and the farm staff. There were two sire breeds each year: Simmental and Angus in 1984, and Simmental and Selkirk Red Line in 1983. Two groups of 24 and two groups of 30 cow-calf pairs were chosen for study in 1984 and 1983, respectively. An attempt was made to balance groups for sex and breed of sire of calf, and all ages of dam were well represented. Measurement of calf weight and milk consumption began in June once animals were on pasture. In 1984, data were collected five times at three-week intervals; in 1983 there were four or three samplings, depending on group, at monthly intervals. Method of estimating milk consumption was the same as in 1985 except separation interval was overnight for twelve hours and not exactly determined for each estimate. Weaning in late October again provided a final calf weight.

Multiple regression models similar to Model Ib, Ie, IIb, and IIe were used to analyze 1984 and 1983 calf weight and dam's milk production data for the effects of EBV_D of calf and EBV_M of dam. Results are illustrated in the following figures. Regression lines are plotted at the same calf age or stage of lactation as the corresponding 1985 figures, to permit comparisons among years.

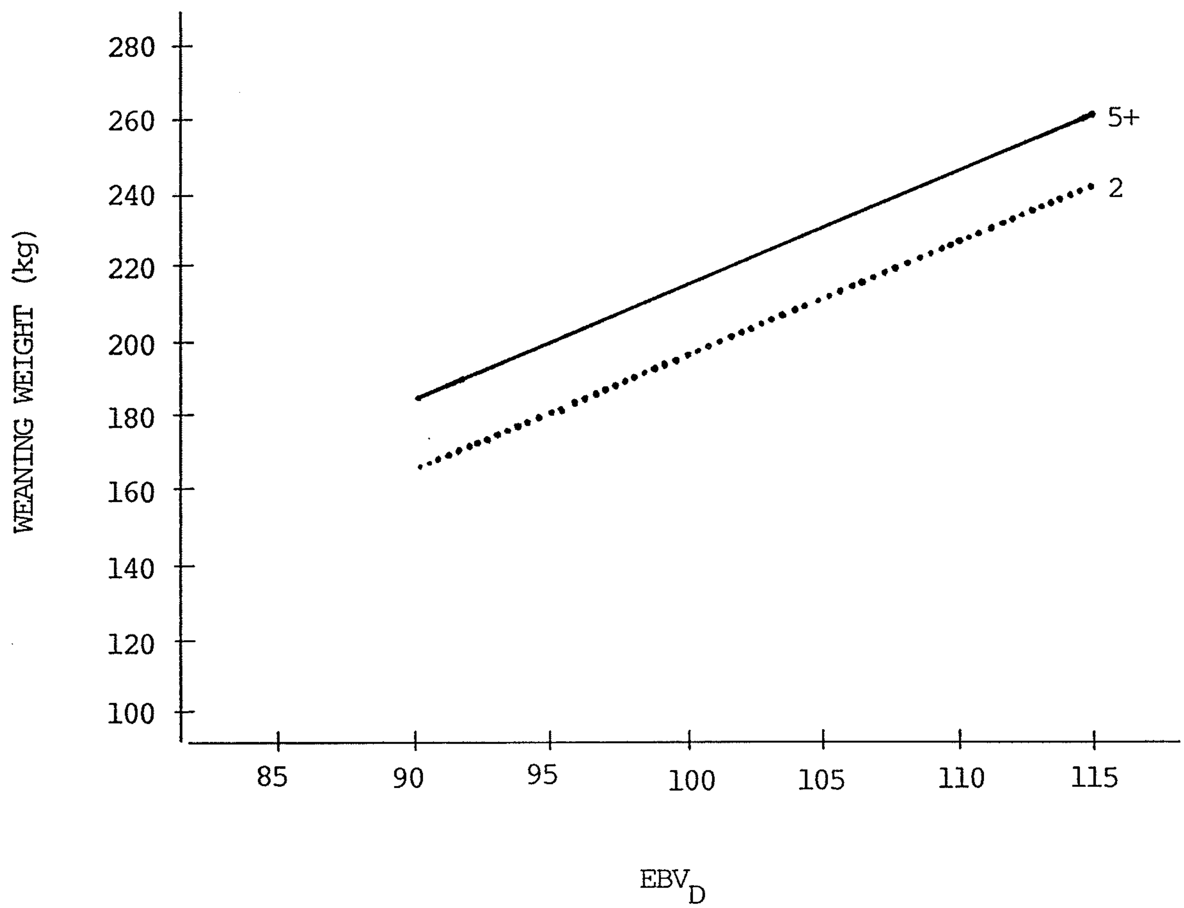

Figure A-1. Plots of predicted weight of male calves at weaning against EBV_D of calf by age of dam (years) for 1984 data.

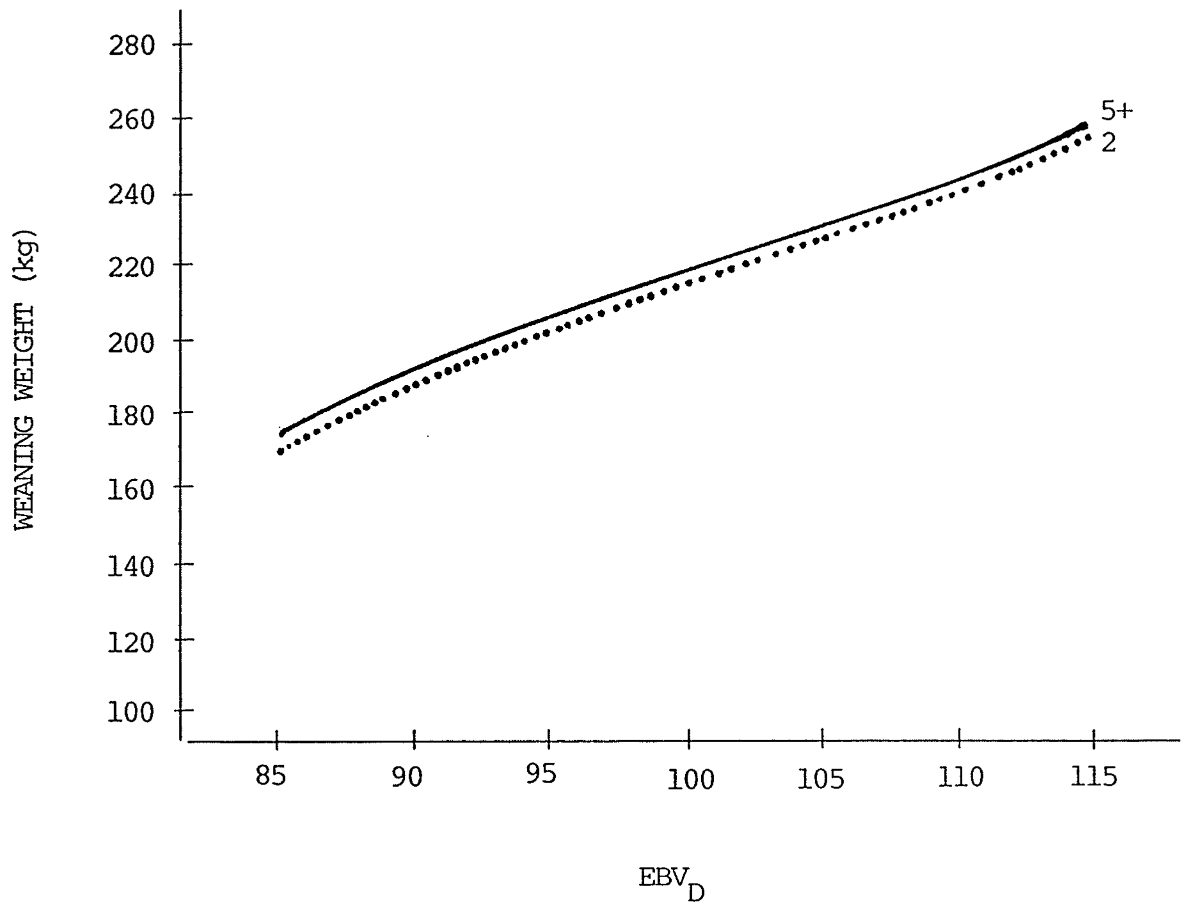

Figure A-2. Plots of predicted weight of male calves at weaning against EBV$_D$ of calf by age of dam (years) for 1983 data.

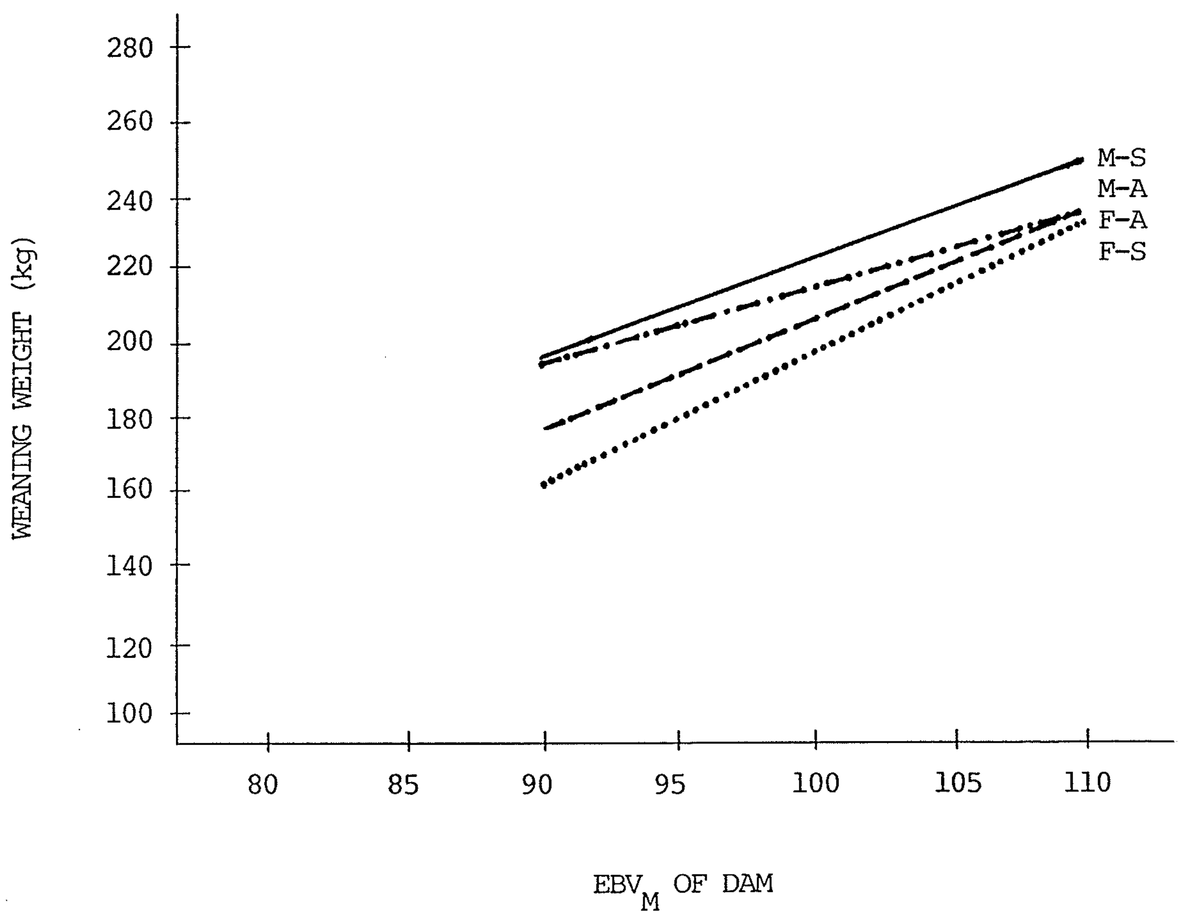

Figure A-3. Plots of predicted calf weight at weaning against EBV_M of dam by sex - breed of sire of calf combination (M=male, F=female; S=Simmental, A=Angus) for calves with mature dams (1984 data).

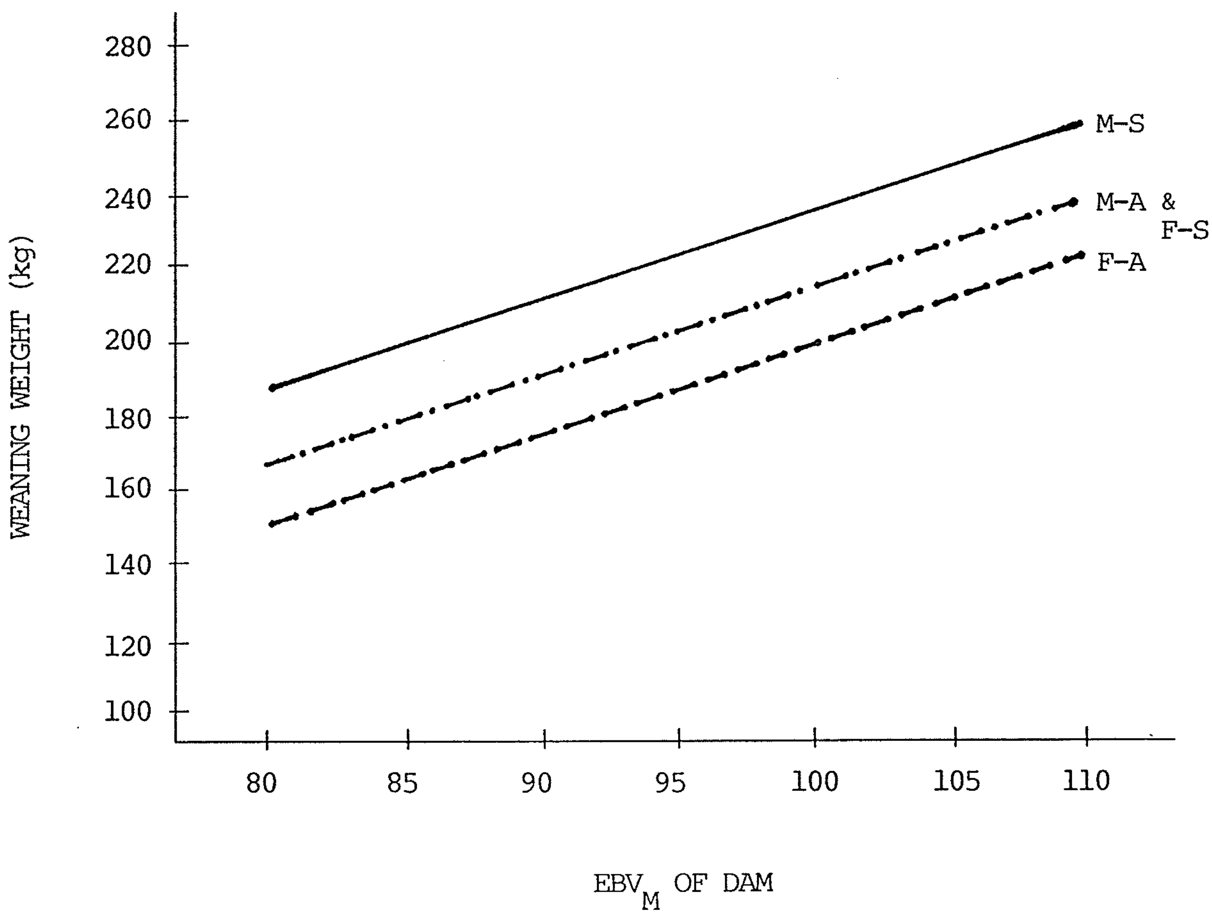

Figure A-4. Plots of predicted calf weight at weaning against EBV_M of dam by sex - breed of sire of calf combination (M=male, F=female; S=Simmental, A=Angus) for calves with mature dams (1983 data).

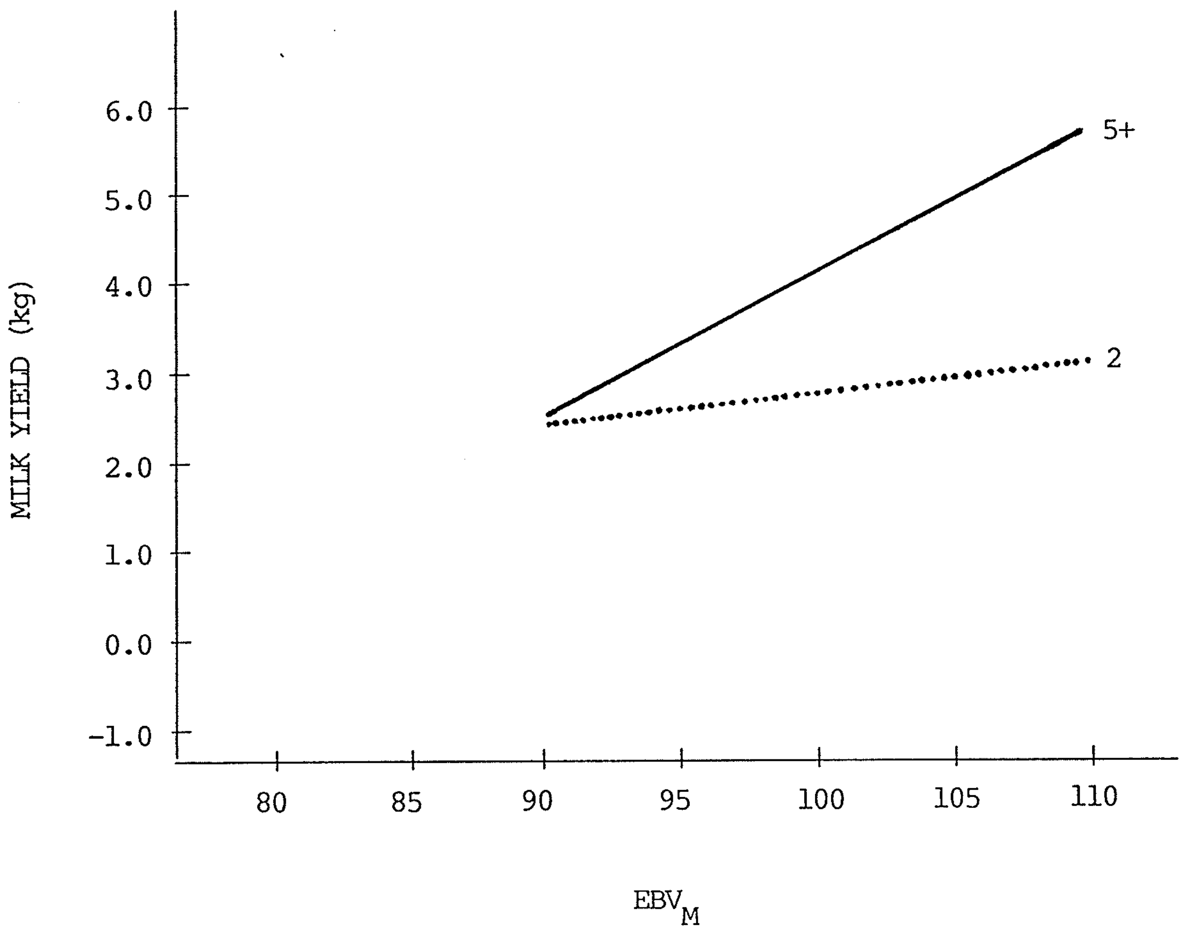

Figure A-5. Plots of predicted milk yield on day 146 of lactation against EBV_M of cow by age of cow (years) for 1984 data.

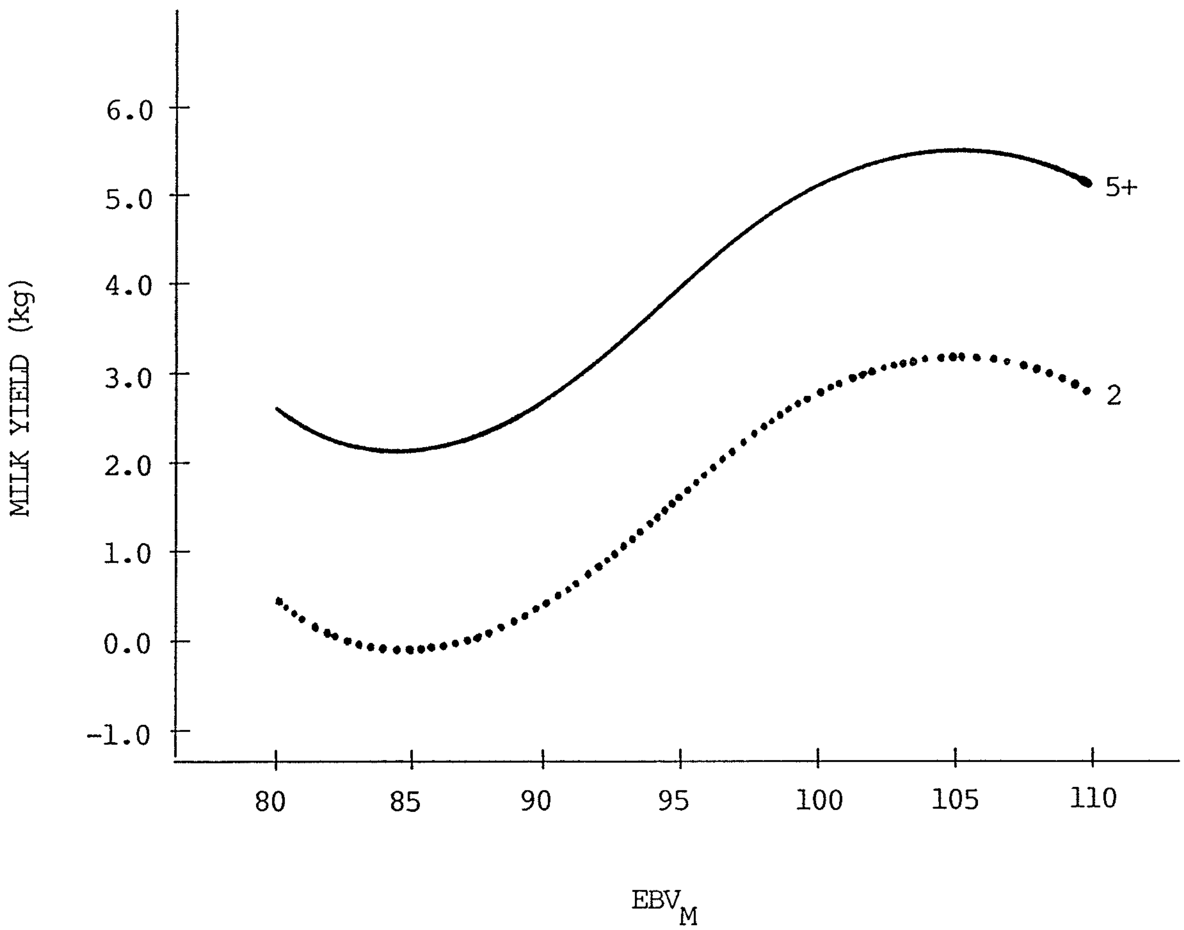

Figure A-6. Plots of predicted milk yield on day 146 of lactation against EBV_M of cow by age of cow (years) for 1983 data.

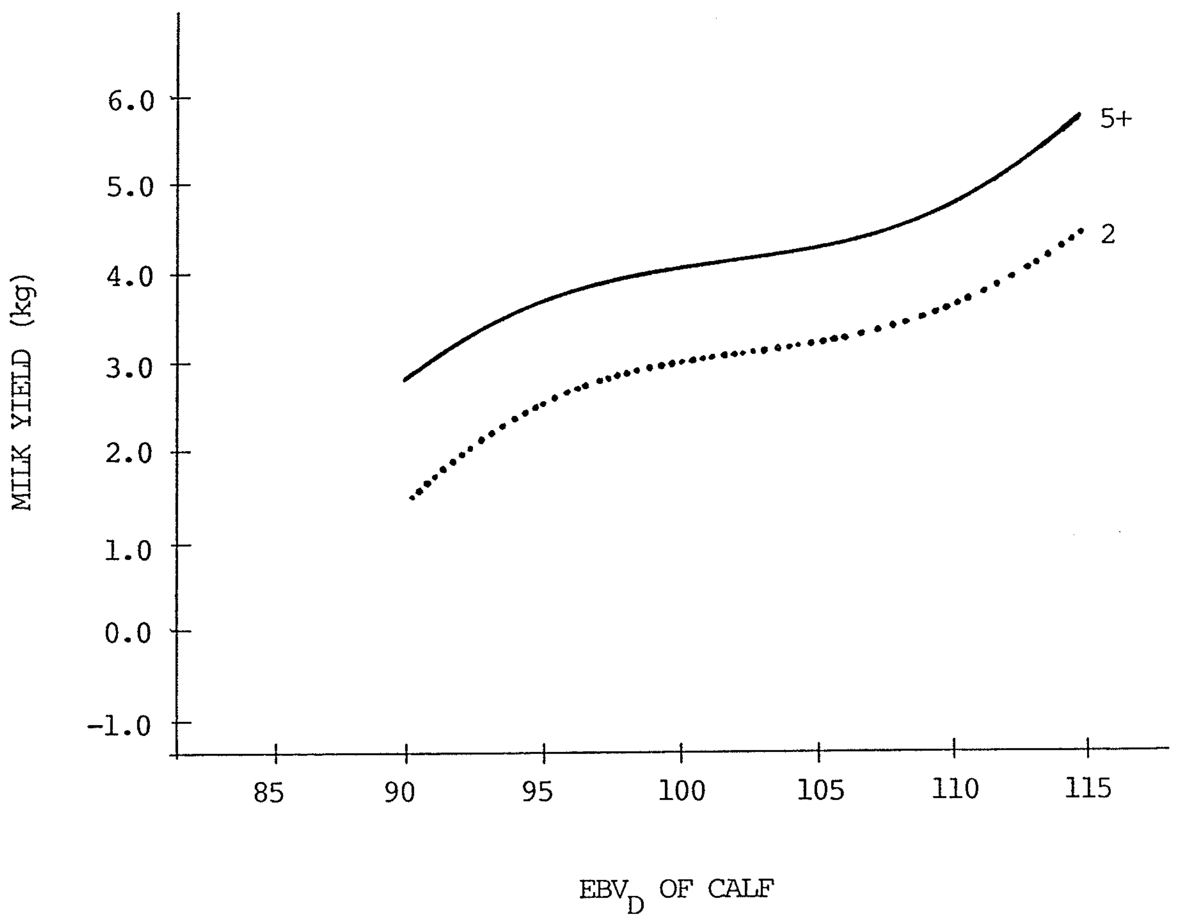

Figure A-7. Plots of predicted milk yield on day 146 of lactation against EBV_D of calf by age of cow (years) for 1984 data.

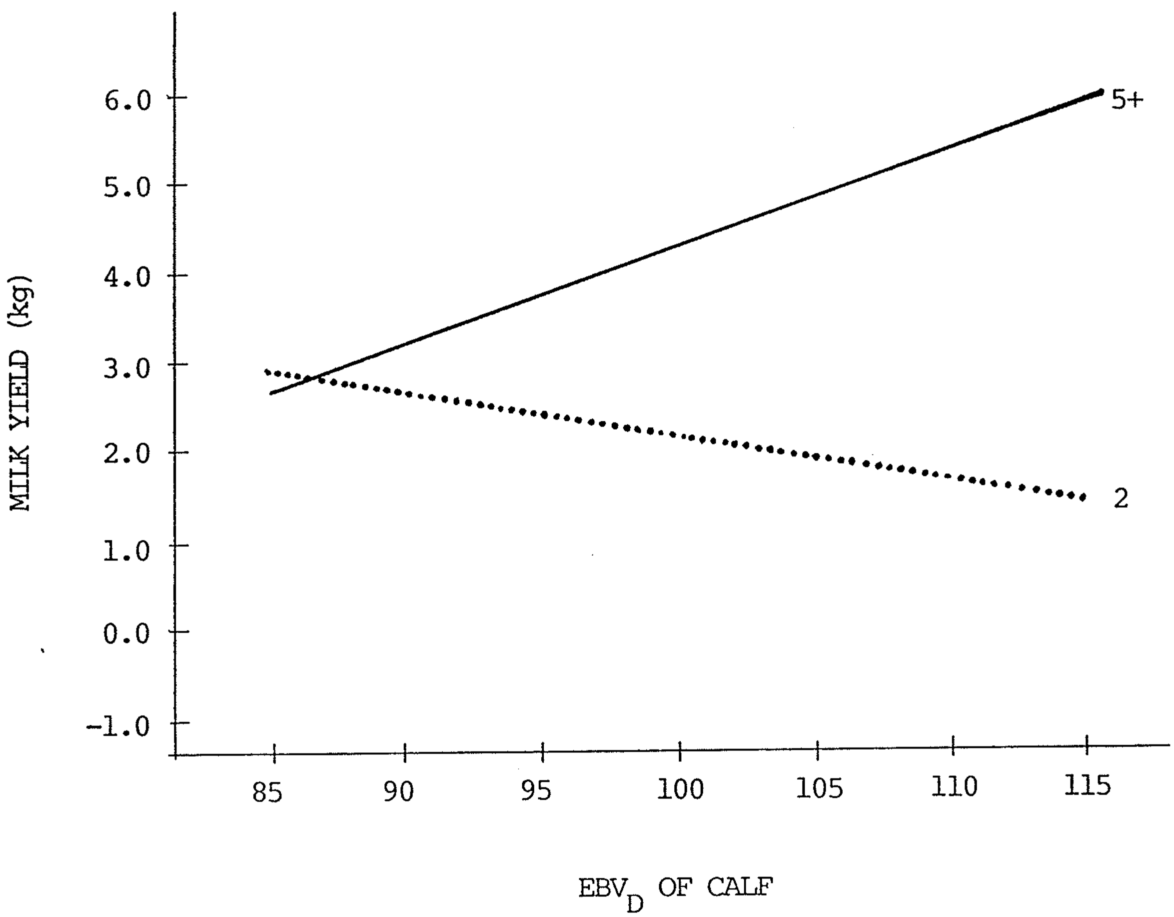

Figure A-8. Plots of predicted milk yield on day 146 of lactation against EBV_D of calf by age of cow (years) for 1983 data.

Table A-1. Final models, regression coefficients, and results of hypothesis tests in multiple regression analysis of 1985 calf weight data.

Variable[a]	Model Ia	Model Ib	Model Ic	Model Id	Model Ie
Intercept	238.3***	278.7***	223.8**	-4106.4***	147.3+
Age of calf	0.621***	-0.585***	0.644***	-0.254ns	0.736***
Sex of calf	10.5***	2.7ns	9.1***	5.0*	8.8***
Age of dam	-180.1**	-157.0***	-160.8**	-174.8***	-109.4*
Age of dam squared	52.80**	37.42**	48.95**	48.44***	35.00*
Age of dam cubed	-4.899**	-3.347**	4.689**	-4.311**	-3.438*
Brsire[b]	9.0**		-7.2ns	118.1***	-4.4ns
EBV_D of calf		-0.765+			
Weight of dam			-0.023+		
EBV_M of dam				138.120***	
EBV_M of dam squared				-1.45784***	
EBV_M of dam cubed				0.0051190***	
Adj. milk consumption[c]					-1.0ns
Age of calf X sex of calf	0.092***	0.088***	0.111***	0.088***	0.101***
Age of calf X age of dam	0.032*	0.049***	0.031+	0.039**	
Age of calf X brsire	0.076**		0.081**	0.068**	0.077**
Age of calf X EBV_D of calf		0.01152***			
Age of calf X EBV_M of dam				0.00858***	
Age of calf X adj. milk consumption					0.036***

continued.....

Table A-1. (continued)

Sex of calf X brsire	-16.5***		-16.1***	-8.4***	-15.6***
Age of dam X brsire			3.4*		2.8+
Age of dam X EBV_D of calf		0.230*			
Brsire X EBV_M of dam				-1.114***	
Residual df	330	330	280	325	282
Model F value	616.60***	1052.52***	380.43***	604.63***	409.42***
% R^2	94.92	96.96	94.22	96.54	94.57

[a] df=1 for all variables in the models
[b] breed of sire of calf
[c] milk consumption adjusted for separation interval
ns, +, *, **, and *** indicate (P>.10), (P<.10), (P<.05), (P<.01), and (P<.001), respectively.

Table A-2. Final models, regression coefficients, and results of hypothesis tests in multiple regression analyses of 1985 milk production data.

Variable[a]	Model IIa	Model IIb	Model IIc	Model IId	Model IIe
Intercept	20.3*	24.1+	2.0ns	-22.8ns	22.5*
Days in lactation	0.002ns	0.007ns	0.002ns	0.005ns	0.056ns
Separation interval	1.1**	-1.3ns	1.0**	1.1***	0.3ns
Cow age	-20.7**	-22.4**	-22.9**	-17.5*	-18.5*
Cow age squared	6.03**	6.44**	5.88**	5.04*	5.15*
Cow age cubed	-0.563**	-0.595**	-0.556**	-0.471*	-0.468*
Cow weight		0.020ns			
Cow weight squared		-0.00004*			
EBV_M of cow			0.436ns		
EBV_M of cow squared			-0.00266+		
EBV_D of calf				0.767*	
EBV_D of calf squared				-0.00373*	
Calf weight					-0.064ns

continued.....

Table A-2. (continued)

Days in lactation X separation interval	-0.006*	-0.007*	-0.006*	-0.007*	-0.019*
Days in lactation X cow age	0.006*	0.006*	0.006*	0.006*	0.005*
Separation interval X cow weight		0.004+			
Separation interval X calf weight					0.015+
Cow age X EBV_M of cow			0.030+		
Residual df	287	281	284	285	285
Model F value	7.097***	6.009***	7.183***	6.367***	7.442***
% R^2	14.76	17.62	20.19	16.74	19.03

[a] df=1 for all variables in the models
ns, +, *, **, and *** indicate (P>.10), (P<.10), (P<.05), (P<.01), and (P<.001), respectively.

Table A-3. Final models, regression coefficients, and results of hypothesis tests in multiple regression analyses of Group 1 calf weight data (1985).

Variable[a]	Model IIIa	Model IIIb	Model IIIc	Model IIId
Intercept	-84.5*	-245.6***	-84.2+	320.4***
Age of calf	0.794***	0.795***	0.662***	1.075***
Sex of calf	10.0***	-13.1ns	26.7**	-14.2**
Age of dam	61.4**	102.5***	66.4**	-18.2ns
Age of dam squared	-7.10**	-12.45***	-7.78**	8.12**
Breed of sire of calf	9.8***	6.5*	12.6***	-90.7***
CCDO		56.37***		
CCDO squared		-8.564***		
PSO			-3.61+	
PSO squared			0.316+	
PG				-11.91***
PG squared				0.173***
Age of calf X sex of calf	0.094***	0.094***	0.066**	0.096***
Age of calf X age of dam				0.026+
Age of calf X breed of sire of calf	0.053*	0.052*		
Age of calf X PSO			0.0303***	
Age of calf X PG				-0.0097***

continued.....

Table A-3. (continued)

Sex of calf X age of dam		4.2*		
Sex of calf X breed of sire of calf	-16.7***	-10.7***	-18.1***	-9.1***
Sex of calf X PSO			-2.81+	
Sex of calf X PG				1.31***
Age of dam X breed of sire of calf				-6.8***
Age of dam X PG				-0.92***
Breed of sire of calf X PG				3.25***
Residual df	244	241	241	233
Model F value	551.33***	429.20***	468.40***	486.17***
% R^2	94.76	95.14	95.53	96.90

[a] df=1 for all variables in the models
ns, +, *, **, and *** indicate (P>.10), (P<.10), (P<.05), (P<.01), and (P<.001), respectively.

Table A-4. Final models, regression coefficients, and results of hypothesis tests in multiple regression analyses of Group 1 milk production data (1985).

Variable[a]	Model IVa	Model IVb	Model IVc	Model IVd
Intercept	-12.1*	1.5ns	-14.3**	-21.2***
Days in lactation	-0.030*	-0.033**	-0.029*	-0.035**
Separation interval	0.4*	0.5**	0.4*	0.5**
Cow age	6.8**	9.2**	7.1**	7.0**
Cow age squared	-0.87**	-1.15**	-0.89**	-0.90**
CCDO		-20.69+		
CCDO squared		7.151*		
CCDO cubed		-0.7825*		
PSO			0.53**	
PSO squared			-0.038**	
PG				0.44**
PG squared				-0.006**
Days in lactation X cow age	0.005+	0.006*	0.005+	0.006*
Residual df	223	220	221	217
Model F value	5.236***	5.430***	5.864***	5.280***
% R^2	10.51	16.49	15.66	14.55

[a] df=1 for all variables in the models

ns, +, *, **, and *** indicate (P>.10), (P<.10), (P<.05), (P<.01), and (P<.001), respectively.

APPENDIX IV

Table A-5. List of abbreviations.

ADG=average daily gain

n=number

df=degrees of freedom

SD=standard deviation

EBV_D=estimated breeding value for the direct contribution to growth

EBV_M=estimated breeding value for the maternal contribution to growth

CCD=cow-calf distance

CCDD=average cow-calf distance within observation day

CCDO=overall average cow-calf distance

PSC=calf suckling activity during the confinement period expressed as a percent of observations

PSP=calf suckling activity during the pasture period expressed as a percent of observations

PSO=calf suckling activity over all periods expressed as a percent of observations

PG=calf grazing activity expressed as a percent of observations.