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THE EFFECTS OF WITHIN BREED SELECTION
FOR YEARLING WEIGHT AND
CROSSBREEDING ON THE COW-CALF UNIT
presented by

Bruce E. Cunningham

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of the requirements for

M.S. degree in Animal Science


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**THE EFFECTS OF WITHIN BREED SELECTION FOR YEARLING WEIGHT AND
CROSSBREEDING ON THE COW-CALF UNIT**

By

Bruce E. Cunningham

A THESIS

**Submitted to
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ABSTRACT

THE EFFECTS OF WITHIN BREED SELECTION FOR YEARLING WEIGHT AND CROSSBREEDING ON THE COW-CALF UNIT

By

Bruce E. Cunningham

The genetic improvement of cow-calf production is dependent upon the effective utilization of selection and crossbreeding by the cow-calf producer. Data collected at the Lake City Experiment Station at Lake City, Michigan were analyzed to determine the effects of within breed selection for yearling weight and crossbreeding on traits associated with cow-calf production.

Selection for yearling weight within the Hereford breed dramatically increased birth weight and calving difficulty, along with increased weaning weight and cow size. Cow productivity was not significantly improved by yearling weight selection when compared to the control group.

Crossbreeding with beef and dairy breeds resulted in noticeable improvement in most cow-calf traits. The use of a dairy breed, Holstein-Friesian, decreased the incidence of calving difficulty, and improved weaning growth and cow productivity through increased milk production.

The direct and maternal breed effects were significant for most traits, reflecting breed differences for economically

important traits. Individual and maternal heterosis effects were generally non-significant for the traits analyzed in this study.

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INTRODUCTION

The commercial beef cattle industry is in a phase where optimal production is replacing maximum production, especially in the cow-calf industry. In the past, the cow-calf industry has been accustomed to relatively inexpensive inputs which allowed production to be maximized by increasing the input per unit of output. During the mid-1970's to the mid-1980's, emphasis has been placed on optimal production along with the minimization of inputs in order to increase production efficiency. The problem lies in the inherent inefficiency of the beef animal. Dickerson (1978) pointed out this situation clearly in comparing the total life cycle energy intake per unit of edible meat protein output for various meat animal species. The chicken ranked first as the most efficient while the beef animal ranked last in this measure of efficiency. We must realize that the ruminant animal is the only species available that can effectively utilize forages, particularly grass, which the other species are unable to do. Production efficiency can be influenced by the manipulation of additive and non-additive genetic effects, and by various management techniques. Future success in the cow-calf industry will be dependent upon the ability of researchers to disseminate the information concerning the use of animal breeding and management techniques to the producers and producers' ability to

effectively utilize this information to optimize production and minimize inputs in the production system.

Two methods exist which a commercial cattleman can use to make effective genetic change in his cow herd. The first method is the use of mass selection performed in the seedstock industry. This selection performed in the seedstock industry is used by the commercial industry to genetically improve economically important traits of concern to the cow-calf producer. To use this genetic improvement, commercial breeders purchase bulls, or semen if artificial insemination (AI) is used, to incorporate the genetic improvement received from the purebred sector. Secondly, crossbreeding schemes are used in commercial herds to utilize additive and non-additive genetic effects for increased productivity in the short term.

Magee (1971) and Nielsen (1978) have shown, on an industry basis, the seedstock industry is responsible for all genetic change in the commercial sector. National sire evaluation, if effectively used, could be a real asset to the purebred industry. It would allow breeders to identify those sires with outstanding performance which would improve genetic levels in commercial herds.

Crossbreeding is not a new concept as pointed out by Mather (1955) who said: "Appreciation of the practical value of hybrid vigor is as old as the mule, but its scientific investigation began only relatively recently." Hill (1971) said two important aspects of crossbreeding exist:

1) The choice of breeds and methods of utilizing them in a crossbreeding scheme in order to maximize economic performance is of extreme importance.

2) After crossbreeding has been used, how can future improvement be made in order to increase performance over a period of a few years?

Numerous breeds exist in North America and commercial cattlemen are faced with decisions as to which breeds they should use to maximize their economic performance in the short run. Also, the commercial industry must decide which crossbreeding schemes are the most useful in effectively utilizing resources and increasing potential economic benefits. Willham (1979) concerning crossbreeding said: "Economics justifies its use but the reproductive potential of cattle makes its application difficult." In the commercial industry today, the rotational crossbreeding system seems to be the most feasible at the present time because the separate herds required by other schemes do not have to be maintained when a rotational system is used. Breeds used in the rotational system must be similar in type and performance, forcing selection pressure to be placed on the same traits within each breed used.

Crossbreeding over the short run is an effective means of improving performance but after the initial response of heterosis, the maintenance of heterosis at the present level becomes important because it occurs only once. Any further improvement of production characters must come through selection

for these characters in the bull producing herds. Selection in the purebred population should be effective in improving performance in crossbreeding programs for most traits as shown by Dunn et al. (1969) in beef cattle, McLaren et al. (1983) in swine, and Salah et al. (1970) in sheep. This point further emphasizes the importance of the seedstock industry in the genetic improvement of the commercial beef cattle industry.

The importance of the beef female is quite obvious since she is responsible for raising the product sold in the cow-calf industry, pounds of calf at weaning time. Willham (1972) discussed the importance of the beef female and said the beef cow contributes 1/2 of the genes and provides the early nutritional environment of her calf. This early nutritional environment is also partly genetically determined in the cow. Cundiff (1984) showed the importance of the crossbred female in providing the genetic potential for growth and the nutritional environment required to express this growth. The use of the crossbred female is an advantage for the cow-calf producer because of the maternal heterosis expressed by these females. The nature of this heterosis is for increased fertility and milk production in the beef female.

A simple way to improve weaning performance is to increase the milk production of the beef female. In his discussion of milk production in the beef female, Willham (1972) provided two important warnings concerning increased lactational performance:

1) The increased milk production without increasing rate of lean tissue growth could lead to increased fat deposition at weaning time which would result in increased maintenance costs in the feedlot; 2) The ceiling for milk production in the commercial cow-calf herd is the natural selection for reproductive performance. The use of dairy breeds in the commercial sector has gained interest due to the fact that milk production can be increased beyond any increase obtained from crossing beef breeds. In a dairy intensive state like Michigan, the use of dairy breeds such as Holstein-Friesian in beef herds has recieved considerable interest in past several years. In his discussion of the role of dairy genes in beef production, Cartwright (1983) said the simple averaging of breeding values for milk production alone would significantly increase weaning weight but nutritional stress on the initiation of post partum cycling could be a serious problem. The use of dairy breeding has been very useful in the improvement of the level of production by the cow-calf unit but nutritional requirements of these beef x dairy females must be met or the usefulness of the dairy cross female could be limited in the cow-calf industry.

OBJECTIVES

The data used in this study were collected at the Lake City Experiment station from a long term selection and crossbreeding study conducted by W. T. Magee as a contribution to NC-1. The objectives of this study were:

- 1) Evaluate the effect of using sires from the seedstock herds selecting for yearling weight on traits from birth to weaning and on the performance of the beef female in Hereford cattle.
- 2) Evaluate the use of crossbreeding using a four breed rotational scheme compared to a group with straight Hereford breeding.
- 3) Compare beef x beef rotational scheme to a beef x dairy rotational crossbreeding scheme for several traits of the cow-calf unit.
- 4) Estimate additive and non-additive genetic effects for Hereford, Angus, Charolais, Holstein-Friesian, and Simmental breeds of cattle.
- 5) Evaluate the Holstein-Friesian breed for several traits of beef production in relation to British and Continental beef cattle breeds.

LITERATURE REVIEW

Literature from beef cattle selection studies reviewed in this thesis dealt only with correlated responses of cow-calf traits to yearling weight selection. The crossbreeding literature reviewed included only those studies using *Bos Taurus* cattle such as the British and Continental breeds.

Correlated response to yearling weight selection:

Birth and survival traits.

Brinks et al. (1964) evaluated 25 years of data obtained from Hereford females raised at the U. S. Range and Livestock Experiment Station, Miles City, Montana, to determine the genetic relationships between several traits measured from birth to maturity. A genetic correlation of .56 for birth weight (BW) with yearling weight (YWT) was obtained. The correlated response to YWT selection for BW was .78 kg or .22 standard deviation units per generation.

The effect of selection for YWT on phenotypic change was studied by Nelms and Stratton (1967). They determined a correlated response to YWT selection should be expected for BW. The secondary selection differential, expressed as a deviation from the sex-year mean, was positive for BW, being .06 standard deviations. To obtain a phenotypic change per year, the data were

regressed on year and adjusted for calf sex, age of dam, and calf age. A significant change of $.3 \pm .07$ kg per year ($P < .05$) for BW in response to YWT selection was obtained. Actual change in BW in response to YWT selection exceeded the indirect selection applied to BW with the responses being 1.2 and .8 kg for the actual response and the selection practiced, respectively. They suggested the exceeded selection could be due to a large environmental variance combined with a large genetic correlation between BW and YWT.

Koch et al. (1973) studied data obtained from three selection lines of Hereford breeding from 1961 to 1970. The three lines were selection for 1) 200-day weaning weight (WWL), 2) 452-day yearling weight for males and 550-day yearling weight for females (YWL), and 3) an index of YWT and muscling score equally weighted in standard measure (IXL). The genetic correlations between BW and YWT were .53 and .45 for males and females, respectively. These genetic correlations were adjusted for differences between selection lines. The authors concluded that selection for YWT would result in a significant increase in all growth traits from birth to yearling age.

Canadian workers reported (Anderson et al., 1974) that intensive selection for YWT resulted in a significant correlated response in BW. Data were collected from two herds of Shorthorn cattle located at Brandon, Manitoba, and Lacombe, Alberta. The correlated response in BW to intensive YWT selection was significant at both locations. The difference between the control

and selection lines was adjusted for age, birth year of dam, and time. For the two locations, Brandon and Lacombe, the differences in BW due to YWT selection ($P < .01$) were 3.0 and 3.6 kg, respectively.

In a further analysis of the Nebraska selection project, Koch et al. (1974) analyzed data from 1963 to 1970 to evaluate the response to WWT (WWL), YWT (YWL), or YWT and muscling score index (IXL) selection. For both male and female calves, the genetic correlations between BW and YWT were $.70 \pm .11$ and $.50 \pm .11$. The correlated response to YWT selection for BW was .28 standard deviations or 3.75 kg. The authors believed BW should be expected to change genetically since BW is a direct component of YWT.

Stanforth and Frahm (1975) studied the amount of selection applied and the response to selection in two lines of Hereford cattle. The lines were selected for WWT and YWT, respectively. The response to selection was determined by calculating for an individual a cumulative selection differential (CSD). These quantities were obtained by calculating the average CSD for an individual's sire and dam, then adding the individual's selection differential expressed as a deviation from its contemporary group average. The CSD is an expression of the total selection pressure applied to a selected animal relative to the foundation animals. A positive secondary selection differential for birth weight was obtained in the YWT line. The selection differential was 11.2 kg for BW after nine years of selection for YWT. These data

suggested YWT selection would increase BW in a positive direction.

Nelsen and Kress (1979) used data obtained from field records to estimate genetic parameters for growth traits measured from birth to final test weight. The data were obtained from the Montana Beef Performance Association and consisted of records from Angus and Hereford herds collected from 1958 to 1973. The genetic correlation between BW and final test weight for Hereford bulls was $.60 \pm .13$.

Thrift et al. (1981) analyzed data from three selection projects located in Kentucky, North Carolina, and Tennessee, that were selecting for characteristics of growth at approximately one year of age. Each project maintained a control line in which no selection was practiced. The correlated responses to YWT selection were positive for both lines but these estimates exhibited large standard errors. The genetic correlations between BW and YWT were positive within a sex-line subclass, with the correlations being larger in the control line. The genetic correlations are listed below:

MALES		FEMALES	
SELECTED	CONTROL	SELECTED	CONTROL
$.17 \pm .35$	$.20 \pm .30$	$.20 \pm .34$	$.44 \pm .43$

The large standard errors associated with these estimates made interpretation of the correlations difficult.

Chenette et al. (1982a), in a further study of the project reported in Stanforth and Frahm (1975), showed a positive genetic increase in BW in response to YWT selection. The average correlated CSD for BW was 7.3 kg or 1.7 standard deviations when expressed in standard measure. The regression of the average correlated cumulative selection differentials (CSD) on year was positive with an accumulation per year of $.49 \pm .07$ kg. BW CSDs accumulated at approximately 50% of the YWT selection pressure.

A negative phenotypic trend for BW in response to YWT selection was found over a 15-year span by Chenette et al. (1982b). When expressed as a deviation from a control line, the genetic response per year was positive. This situation clearly shows the need and use of control lines in selection studies to monitor year to year environmental fluctuations. The genetic trend for birth weight in response to yearling weight selection was .23 kg per year.

Koch et al. (1982), in a summary of the Nebraska selection study, analyzed data from three selection lines and a control line collected from 1963 to 1978. The control line was established in 1971. In all selection lines, BW increased because of indirect selection since BW is a component of WWT and YWT and due to correlated responses associated with increased gains from birth to yearling age. The amount of selection applied and the response to selection for BW in the control line, YWL, and IXL are listed below:

LINE	CSD ^a	$\bar{x}$ (77-79)	RESPONSE
CONTROL	0	34.8	0
YWL	6.7	37.5	2.8
IXL	6.6	39.0	4.2

a- cumulative selection differential

As BW increased due to selection for YW, the incidence of fetopelvic incompatibility (FPI) increased in first-calf two-year-old heifers. An analysis of calving difficulty data indicated increased BW could not account for the increased FPI observed in the male calves. The authors suggested the extra difficulty at calving time could be due the result of calf shape or bone structure. The means for BW (kg) and % assisted births (%AB) in line-sex subclasses for two-year-old heifers are listed below:

LINE	MALES		FEMALES	
	BW	%AB	BW	%AB
CONTROL	32.2	50	30.0	19
YWL	35.4	64	32.7	43
IXL	37.2	77	34.0	39

Selection for growth resulted in correlated responses in birth weight and the incidence of FPI. When selection was practiced for both YWT and muscling score, these increased responses became more evident.

Bourdon and Brinks (1982) studied data from Angus, Hereford, and Red Angus herds to determine the genetic relationships between gestation length (GL), BW, prenatal gain (PRNG), growth

traits, and age at first calving (AFC). The genetic correlations between BW and YWT were $.69 \pm .08$ and $.55 \pm .11$ for male and female calves, respectively. The expected correlated response per generation for BW was 1.8 kg or .39 standard deviations in response to YWT selection. BW should increase in response to YWT selection pressure. Further analysis determined that a calf's genotype was more important than maternal influences in determining BW. Additive effects accounted for 39% of the variance while maternal influences accounted for 12% of the total variance. When expressed as a trait of the dam, the repeatability of BW was $.22 \pm .02$.

Buchanan et al. (1982) analyzed data collected from 1960 to 1977 from three selection lines described by Koch et al. (1973). Genetic correlations within a sex between BW and YWT were $.63 \pm .13$ and $.58 \pm .12$ for male and female calves, respectively. The average predicted responses were obtained by summing sire and dam responses averaged across sex of calf. These predicted responses indicated sire selection accounted for 80 to 88% of the total response to selection.

The use of open line selection was evaluated by Hough et al. (1985) to determine the efficacy of this selection method to improve performance traits in beef cattle. The sires used in the selection line were listed in the top 1% of the sires ranked in the American Hereford Association's National Sire Evaluation (NSE) on the basis of their YWT expected progeny differences (EPD). A base herd of Hereford cows was equally divided into a

control and a selection line. Repeat matings were made in the control line to more accurately monitor environmental trends. The genetic change was estimated as differences between the selection and control lines regressed on years. The correlated responses to yearling weight selection were $1.4 \pm .3$ kg ($P < .01$), $.14 \pm .04$ units ($P < .01$), and $-2.3 \pm 1.7\%$ for BW, calving difficulty score (CD), and % born alive (%BL), respectively. The genetic changes per year were $.16 \pm .16$ kg, $-.51 \pm .39\%$, and $.04 \pm .03$ units for BW, %BL, and CD, respectively. Selection for YWT only slightly increased pelvic area ($P < .01$) by $11 \pm 2 \text{ cm}^2$. If selection for YWT would increase BW substantially and not significantly affect pelvic area, the authors conclude the incidence of calving difficulty or dystocia could be increased.

Preweaning and weaning traits.

Data collected from 1934 to 1959 were analyzed by Brinks et al. (1964) to determine the genetic relationships between several performance traits in Hereford females. The genetic correlations between preweaning average daily gain (PWDG) and WWT with YWT were .67 and .71. Positive correlated responses to YWT selection were obtained with the responses for PWDG and WWT being 4.42 and 5.31 kg per generation, respectively.

Nelms and Stratton (1967) reported a phenotypic change in WWT in response to YWT selection. The secondary selection differential for WWT was .12 standard deviation units. The phenotypic change per year for WWT was positive, with WWT

increasing $.7 \pm .35$ kg per year ($P < .05$) in response to YWT selection. The data suggest significant phenotypic change can be made in small, closed herds by selecting for yearling weight.

Large, positive genetic correlations between PWDG and WWT with YWT were reported by Koch et al. (1973). Data from three selection lines from 1961 to 1970 were analyzed. The genetic correlations for PWDG and WWT with YWT within calf sex are listed below:

	MALES	FEMALES
PWDG	.76	.76
WWT	.79	.76

These correlations suggest large increases in weaning performance should be expected when selection pressure is placed upon YWT in beef cattle.

Data from two Shorthorn herds were analyzed to determine the correlated responses in birth weight, growth traits, and carcass merit to intense yearling weight selection by Anderson et al. (1974). The difference between the selection and control lines for WWT were 16.2 and 7.8 kg at Lacombe and Brandon, respectively. These differences represented 5 years of intensive selection for YWT.

The response to selection was evaluated in three lines selected for WWT (WWL), YWT (YWL), or an index of YWT and muscling score (IXL) (Koch et al., 1974). Genetic correlations of PWDG and WWT with YWT were $.56 \pm .15$ and $.72 \pm .11$ for male calves,

and $.61 \pm .10$ and $.70 \pm .08$ for female calves. The correlated responses in standard measure in response to YWT selection were for PWDG and WWT .13 and .17, respectively.

Kennedy and Henderson (1975) studied data from 61,688 Hereford and 22,333 Angus records obtained from the Canadian Record of Performance program. The genetic correlations were calculated within a breed and management system subclass. Estimates of the genetic correlations for PWDG and WWT with YWT are presented in the table below:

	WWT	PWDG
NCF H	.75	.74
CF H	.75	.75
NCF A	.84	.80
CF A	1.31	1.22

NCF,CF - NON-CREEP FEED, CREEP FEED
H,A - HEREFORD, ANGUS

Alteration of the growth curve genetically was investigated by Smith and Cundiff (1976) in which the genetic relationships between relative growth rate and certain growth characters were evaluated. Preweaning relative growth rate (RGR) was expressed mathematically as $\{\ln(\text{WWT}) - \ln(\text{BW})\} / \text{DAYS OF AGE}$. RGR represents the percentage increase in body weight per day relative to body weight already accumulated. Further discussion can be found in Fitzhugh and Taylor (1971) and Fitzhugh (1976). The genetic correlation between preweaning RGR and YWT in straightbred and crossbred Angus, Hereford, and Shorthorn steers was $.28 \pm .70$. Even

though the standard error of the correlation was very large, YWT selection could make an improvement in the growth rate from birth to weaning age.

Nelsen and Kress (1979) analyzed field data and obtained large genetic correlations for PWDG and WWT with final test weight. For Hereford bulls, the genetic correlations were $.73 \pm .12$ and $.84 \pm .09$ for PWDG and WWT, respectively.

Thrift et al. (1981) determined WWT was highly correlated genetically with YWT. The genetic correlations of WWT with YWT within a sex-line subclass are listed below:

MALES		FEMALES	
S	C	S	C
$1.01 \pm .57$	$.85 \pm .40$	$.68 \pm .62$	$.77 \pm .53$
S,C - SELECTION, CONTROL			

In a summary of sixteen years of selection data, Koch et al. (1982) found selection for YWT significantly increased growth up to weaning age. The correlated increase in WWT was due to WWT being a component of the direct selection of YWT and due to correlated responses of increased gain from birth to weaning. Means and selection responses for the control, YWL and IXL selection lines are shown below:

	$\bar{x}$ (77-79)	SELECTION RESPONSE
CONTROL	180.6	0
YWL	189.9	9.3
IXL	195.8	15.3

Selection on an index of YWT and muscling score resulted in a greater increase than selection for YWT alone.

Chenette et al. (1982a) reported significant increases in WWT can be made by selection for YWT. The correlated mean cumulative selection differential (MCSD) were .28 and 65.1 kg for PWDG and WWT, respectively. When expressed in standard measure, the MCSDs for PWDG and WWT were 2.81 and 2.98 standard deviations. The MCSDs were regressed on years with the MCSD accumulating at $4.89 \pm .21$ kg per year for WWT and $.02 \pm .00$ kg per year for PWDG.

The genetic trends for PWDG and WWT in response to YWT selection were estimated by Chenette et al. (1982b). WWT and PWDG increased genetically in response to YWT selection .93 kg per year for WWT and .004 kg per year for PWDG.

Bourdon and Brinks (1982), in studying Angus, Hereford, and Red Angus data, found the genetic correlations between PWDG and WWT with YWT were approximately equal to .9. The genetic correlations between PWDG and WWT with yearling weight are listed below by sex of calf:

	MALES	FEMALES
PWDG	$.89 \pm .03$	$.90 \pm .03$
WWT	$.87 \pm .04$	$.88 \pm .04$

The expected correlated response to YWT selection for WWT was .60 standard deviations or 19.7 kg. The data suggest selection for YWT will result in large increases in a calf's weaning performance.

Buchanan et al. (1982) found large genetic correlations for PWDG and WWT with YWT. The correlations reported are listed below by sex of calf:

	MALES	FEMALES
PWDG	.52 $\pm$.14	.67 $\pm$.13
WWT	.61 $\pm$.11	.74 $\pm$.11

The average predicted response to YWT selection was found to be .21 and .24 standard deviations for WWT and PWDG, respectively.

Hough et al. (1985), in a further study of open line selection using Hereford sires ranked in the top 1% of the Hereford NSE, found the use of bulls with high YWT EPDs can result in significant improvement in weaning performance. The estimated correlated response in 205-day adjusted WWT was 15 $\pm$ 2 kg ($P < .01$) and the genetic change per year was 4.6 $\pm$.7 kg ($P < .01$).

Cow traits.

Brinks et al. (1964) reported a genetic correlation between YWT and mature fall weight of .62 for Hereford females. The correlated response to YWT selection for mature fall weight was 11.60 kg or .30 standard deviations.

In a study of the effectiveness and response to selection, Brinks et al. (1965) reported the effect and response to selection for several performance traits in a closed Hereford line over a 25-year period. The genetic correlation between YWT and a cow's most probable producing ability (MPPA) for Hereford females was .14.

The effect of selection for growth rate on mature cow size was investigated by Karlsson (1979). Data were collected from two dual-purpose breeds used in Sweden, Swedish Red and White (SRB) and Swedish Friesian (SLB). Growth rate data on young bulls of each breed undergoing progeny testing were collected from 1967 to 1975. Mature cow size data was recorded by measuring the chest girth and height at the withers of cows in milking herds. Estimation of genetic correlations were possible since bulls in progeny testing and cows in the milking herds were sired by common sires. The genetic correlation was calculated as:

$$r_{GxGy} = r_{PxPy} / b_x^{1/2} b_y^{1/2}$$

where r_{PxPy} - correlation between progeny group means

$b_x^{1/2}$, $b_y^{1/2}$ - accuracies of progeny test for two traits.

The genetic correlations between chest girth and weight at one year of age were .85 and .62 for SRB and SLB, respectively. Between height at the withers and weight at one year of age, the correlations were .55 and .34 for SRB and SLB, respectively. The author noted selection for weight at one year of age would increase mature cow size.

Effects of crossbreeding:

Birth and survival traits.

Pahnish et al. (1969) crossed Hereford (H), Charolais (Ch), and Angus (A) breeds to produce straightbred and all possible two-way cross calves. Also, H, Ch, and A sires were mated to Brown Swiss (BS) dams to evaluate beef x dairy crossbreeding systems. Ch sired calves had the highest birth weights (BW) when compared to H and A sired calves. Heterosis for BW in male calves was 1.6 kg ($P < .01$) or 4.4% but heterosis was non-significant for heifer calves. When compared to beef breeds, H, A, and Ch, calves from BS dams were heavier at birth by 5.4 kg for male calves and 6.7 kg for female calves. The authors attributed this increase in BW of calves from BS dams to an increased skeletal size at birth.

The relationship between BW and dystocia in reciprocally crossed Ch, H, and A cattle was studied by Sagebiel et al. (1969). Purebred, all possible F_1 and reciprocal three breed crosses among the three breeds used were produced. Dystocia was scored as listed in Table 1. Percent difficulties (%AB) was defined as the number of calves with a dystocia score greater or equal to 3. The differences between crossbred and straightbred groups for dystocia score and %AB are listed below:

	DYSTOCIA		%AB	
	M	F	M	F
CROSSBRED	1.70	1.43	16.0	14.0
STRAIGHTBRED	1.68	1.03	14.7	5.3
DIFFERENCE	.02	.43*	1.3	8.7*

*P < .05

When compared to the other breeds as a sire breed, Ch sired calves had greater difficulty and required more assistance at birth than H and A sired calves. Moreover, calves from Ch dams had the least amount of difficulty and calves from A dams exhibited the most difficulty at parturition and requiring the most assistance at birth. The breed means are listed in Table 2. Correlations of dystocia score with BW, cow weight (CW), a ratio of BW to CW were .11*, -.24**, and .32**, respectively (* P<.05, ** P<.01). The data would suggest calf size in relation to the dam's body size at calving is a cause of dystocia. Crossbred calves sired by Ch bulls were heavier at birth and required more assistance at birth, whereas calves from A dams had the most difficulty and calves from Ch dams required the least amount of assistance.

Smith et al. (1976) collected data on 2,368 calves from H and A dams and sired by H, A, Jersey (J), South Devon (SD), Limousin (L), Ch, and Simmental (Sm) sires. When compared to H-A crosses, Ch and Sm cross calves had heavier BW, greater incidence of dystocia, and a higher percentage of early mortalities. The breeds possessing greater growth potential such as Ch and Sm were

TABLE 1. DEFINITION OF CALVING EASE SCORES

Degree of assistance	Calf alive or dead	Cow alive or dead	Assigned score
No assistance	alive	alive	1
No assistance	dead	alive	2
Pulled-not difficult	alive	alive	3
Pulled-not difficult	dead	alive	4
Pulled-difficult	alive	alive	5
Pulled-difficult	dead	alive	6
Pulled-very difficult	alive	dead	7
Pulled-very difficult	dead	dead	8
a - Sagebiel et al. (1969)			

TABLE 2. SIRE AND DAM BREED MEANS FOR DYSTOCIA AND % DIFF^a

SIRE BREED	DYSTOCIA SCORE		% DIFFICULTIES	
	M	F	M	F
ANGUS	1.28	1.16	6.2	5.7
HEREFORD	1.54	1.53	14.6	16.3
CHAROLAIS	2.28	1.60	32.9	21.1
DAM BREED				
ANGUS	2.38	1.92	32.4	30.5
HEREFORD	1.61	1.28	18.7	11.1
CHAROLAIS	1.10	1.10	2.6	1.6

^a - Sagebiel et al. (1969)

heavier at birth which resulted in greater calf mortality and increased the incidence of dystocia. Heterosis for BW was $.9 \pm .3$ kg ($P < .01$), but was not significant for % dystocia and % early mortality. The means for the crosses and straightbreds are listed Table 3. When calving difficulty was included as a main effect in the analysis of % early mortality, calving difficulty had a significant effect.

Calving data from 2- and 3-year old females were studied by Notter et al. (1978a) to determine transmitted and maternal genetic effects on birth and survival traits. The two age groups were analyzed separately due to the differences in sire breeds used in each age group. The females were the result of mating H, A, J, SD, Sm, L, and Ch sires to H and A females. Calves from the 2-year old cows were sired by H, A, Brahman (Br), Holstein (Hl), or Devon (D) bulls. The three year old dams were mated to produce progeny from H, A, Maine-Anjou (MA), Chianina (C), and Gelbvieh (G) sires. Cows sired by Ch and Sm sires dropped heavier calves when compared to H-A females. The authors noted crossbred females in the 2-year group with heavier BW tended to have a greater incidence of calving difficulty even though these females possessed greater body size, whereas, in the 3-year group, the crossbred females tended to have a lower incidence of dystocia and calf mortality. Hl sired calves had heavier BW than H-A sired calves. When adjusted for BW, the difference in % dystocia between Hl and H-A remained significant with the difference

TABLE 3. HETEROSIS AND BREED GROUP MEANS^a

BREED GRP ^b	BW	% DYSTOCIA	% EARLY MORT.
HH	34.7	18	3.7
AA	31.0	12	4.8
HETEROSIS	.9 $\pm$.3**	-4 $\pm$ 3	-3.0 $\pm$ 1.8
HA	33.7	11	1.3
Chx	38.6	34	9.6
Smx	38.0	29	6.8

** - $P < .01$

a - Smith et al. (1976)

b - HH = Hereford, AA = Angus, HA = Hereford-Angus,
Chx = Charolais cross, Smx = Simmental cross

being 17%. Means for cow sire and calf sire for each age group are listed in Table 4.

Gregory et al. (1978) studied data from calves by BS, H, A, MA, C, G, and Red Poll (RP) sires mated to H and A dams to evaluate sire and dam breed effects on birth and weaning traits. The use of large framed, Continental breeds such as MA, C, and G breeds increased the incidence of calving difficulty when compared to H-A, with the BS being an intermediate. BW was increased through the use of dairy or the large framed, Continental breeds but the difference between the BS and large framed, Continental breeds was not significant. Calves by MA, C, and G sires had the greatest amount of perinatal mortality (%PM) and the BS sired calves had the least number of deaths after birth. The sire breed means are listed below:

	CD	%PM	BW ^a
HA	2.9 $\pm$ 1.9	2.7 $\pm$ 1.5	36.8 $\pm$.6
BS	8.4 $\pm$ 1.8	1.7 $\pm$ 1.5	39.9 $\pm$.6
G	8.0 $\pm$ 2.0	4.6 $\pm$ 1.7	40.1 $\pm$.7
MA	20.4 $\pm$ 1.9	7.3 $\pm$ 1.5	42.2 $\pm$.6
C	11.8 $\pm$ 1.9	4.5 $\pm$ 1.4	41.6 $\pm$.6

a - CD: calving difficulty
 %PM: percent perinatal mortality
 BW: birth weight (kg)

The incidence of dystocia increased with use of large framed, high growth rate breeds when compared to BS sired calves but the differences in BW were insignificant. These data suggest

TABLE 4. BREED GROUP MEANS FOR TWO AND THREE YEAR OLD COWS^a:

TWO YEAR OLD DAMS:

COWSIRE	BW	% DYSTOCIA	% EARLY MORTALITY
Sm	33.0 $\pm$.4	46 $\pm$ 4	4 $\pm$ 2
Ch	33.9 $\pm$.4	44 $\pm$ 5	6 $\pm$ 3
HA	30.4 $\pm$.4	40 $\pm$ 5	6 $\pm$ 3

CALFSIRE

HA	30.7 $\pm$.4	27 $\pm$ 4	4 $\pm$ 2
HI	32.0 $\pm$.4	47 $\pm$ 4	9 $\pm$ 2

THREE YEAR OLD DAMS:

COWSIRE

Sm	38.1 $\pm$.4	27 $\pm$ 4	3 $\pm$ 2
Ch	39.1 $\pm$.4	29 $\pm$ 4	3 $\pm$ 2
HA	34.1 $\pm$.4	31 $\pm$ 5	6 $\pm$ 12

a - Notter et al. (1978)

b - HA = Hereford-Angus, HI = Holstein, Ch = Charolais
Sm = Simmental

differences in calving difficulty were not due to increases in BW but due to anatomical differences among the sire breeds used in the study.

Records of straightbred and crossbred cows of A, H, and Sh breeding were analyzed by Gaines et al. (1978) to determine the amount of heterosis for weaning and cow performance traits. Data from heifer and steer calves were analyzed separately and in both sexes the difference between crossbred and purebred cows for BW was significant. The means for cow breed type within a sex are listed below:

kg	HEIFERS	STEERS
PUREBRED	31.1 $\pm$.32	33.3 $\pm$.28
CROSSBRED	32.1 $\pm$.32	34.1 $\pm$.28

In another analysis in which data of both sexes were pooled and cow weight was included as a covariate, the differences in BW between crossbred and purebred females were insignificant and CW was a significant source of variation ($P < .01$) in birth weight. This result was an indication that cow size and heterosis were important factors in determining the size of the calf at parturition.

Belcher and Frahm (1979) studied traits relating to cow-calf production and how these traits were affected by breed type in two-year old crossbred females producing three-breed cross calves. The cows used in the study were the result of mating H, A, Sm, BS, and J sires to H and A cows. The two-breed cross

females were mated to RP and Sh bulls to calve at 24 months of age. Breed group means for BW (kg), calving difficulty score (CD), % assisted births (%AB), and % born alive (%BL) are listed below:

BREED GROUP ^a	BW	CD	%AB	%BL
HA	28.1	1.92	31.2	76.9
Smx	30.7	2.23	42.9	64.0
BSx	30.5	1.83	23.2	81.6
Jx	27.0	1.65	19.3	89.8

 a - HA = Hereford-Angus, Smx = Simmental cross,

BSx = Brown Swiss cross, J = Jersey cross

Dairy x beef females had lower CD and required less assistance at calving time than beef x beef females. BS sired females, when compared to Sm sired females, did not differ in BW but possessed a lower CD and a lower incidence of calving difficulty by 19.7%. The degree and incidence of dystocia for BS crosses was much lower than HA , even though the BS crosses had heavier BW. Calves born to Sm cross females were heavier at birth, and fewer were born alive than calves born to HA females.

Rahnfeld (1980) summarized data from a crossbreeding project conducted by Agriculture Canada. H, A, and Sh cows were mated to Ch, Sm, and L bulls to produce F1 females which were then mated to terminal sire breeds to produce three-breed cross calves. A control group of HA crosses was also maintained. The project was conducted at two locations, Brandon, Manitoba and Manyberries,

Alberta. Ch sired calves exhibited greater calving difficulty, preweaning mortality, and heavier BW than Sm sired calves. The sire breed means are presented below:

	BW (kg)	%CD	%PW ^a
Ch	42.9	5.9	13.1
Sm	42.2	3.4	5.7

a - %CD:percent calving difficulty
 %PW:percent preweaning mortality

In further analysis of data presented by Pahnish et al. (1969), Knapp et al. (1980) evaluated maternal heterosis effects from three breed cross progeny of H, A, and Ch females and contemporary reciprocal cross females. Moreover, maternal performance of BS x beef females was compared to beef x beef maternal performance. The overall maternal heterosis percentage for BW was 1.4%. To obtain the total amount of heterosis, the estimate of individual heterosis was obtained from Pahnish et al. (1969), then added to the estimate of maternal heterosis. The overall estimate of heterosis for BW was 4.3%. The difference for birth weight between progeny of BS x beef and beef x beef crosses was 3.4 kg. The results indicate crossing conventional beef breeds or including dairy type breeds into a crossbreeding scheme will increase BW.

Long (1980), in a comprehensive review of crossbreeding literature, compiled heterosis estimates and maximum differences among breed diallels, sire breeds, and cow breeds for several

traits of economic importance in the beef cattle industry. The heterosis estimates and average maximum differences are listed in Table 5.

Urlick et al. (1981) studied records from straightline (SL), two-way cross (2W), three-way cross (3W), and synthetic variety (SV) calves to determine the merit of crossing inbred lines in the Hereford breed. The rotational cross groups showed significant increases over the straightline calves for BW. Birth weight means were 34.6, 36.6, and 36.3 kg for SL, 2W, and 3W systems, respectively. Large amounts of heterosis were obtained for the rotational crosses ($P < .01$) over the SL average. Heterosis estimates for BW were 5.8% and 4.9% for 2W and 3W crossbreeding systems, respectively. The data set suggests heterosis for BW can be generated by crossing inbred lines of Hereford cattle.

In an effort to evaluate the merit of using dairy breeding in beef herds, Nelson and Beavers (1982) studied data from four female breed types mated to two male breed types. Straightbred Hereford (HH), Angus x Hereford (AH), Charolais x Hereford (CH), and Brown Swiss x Hereford (SH) cows were mated to A and Ch bulls. Traits measured and studied were BW, dystocia (CD), % difficulty (%DIFF), and conception rate. Least square means for birth traits are presented in Table 6. Calves by Ch bulls were heavier at birth, required more assistance at calving, and had higher CD scores than calves sired by A bulls. Dairy x beef (SH) dropped heavier calves than beef x beef females (CH, AH, and HH) but they required less assistance at parturition and had lower CD

TABLE 5. ESTIMATES OF HETEROSIS AND MAXIMUM DIFFERENCES^a

TRAIT	AVE. HET. ^b	MAXIMUM DIFFERENCES	
		BREED DIALLELS	SIRE BREEDS
CALF SURVIVAL (birth)	2%	2%	7%
CALVING DIFFICULTY	0-7%	3-19%	7-29%
BIRTH WEIGHT	4%	20%	17%
COW TRAITS			COW BREEDS
CALF SURVIVAL	-1%	2%	2.6%
CALVING DIFFICULTY	-.06%	- -	68.4%

a - Long (1980)

b - average heterosis

TABLE 6. LEAST SQUARE MEANS FOR SIRE AND DAM BREED TYPES^a

	BW	CD	% DIFF
SIRE BREED^b			
A	33.2	1.20	15.2
Ch	38.1	1.41	25.7
DAM BREED^c			
HH	33.4	1.48	31.2
AH	34.2	1.36	22.5
CH	35.9	1.24	15.4
SH	39.1	1.17	12.8

a - Nelson and Beavers (1982)

b - A = Angus, Ch = Charolais

c - HH = Hereford, AH = Angus x Hereford, CH = Charolais x Hereford, SH = Brown Swiss x Hereford

scores. HH cows were at a distinct disadvantage in the incidence of calving difficulty, with HH females having higher dystocia scores even though they had the lightest BW. When adjusted for CW linearly and quadratically, the effects of sire and dam breed remained significant for BW, CD, and %DIFF. The sire breed x dam breed interaction was not significant for any of the traits with the exception of %DIFF when adjusted for calf BW and dam's postcalving weight quadratically.

Lawlor et al. (1984) analyzed data from H, 1/2 Angus-1/2 Hereford (1/2A1/2H), 1/4 Simmental-3/4 Hereford (1/4S3/4H), and 1/2 Simmental-1/2 Hereford (1/2S1/2H) calves to determine the effect of varying levels of Simmental (Sm) breeding upon calf preweaning performance. Breed group least square means for BW, CD, and % early survival (%ES) are listed below:

BREED GROUP	BW (kg)	CD	%ES
H	37.9 $\pm$.4a	1.00 $\pm$.03a	97.9 $\pm$ 1.0
1/2A1/2H	37.2 $\pm$.4a	1.07 $\pm$.04a	99.0 $\pm$ 1.2
1/4S3/4H	37.9 $\pm$.4a	1.06 $\pm$.03a	98.9 $\pm$ 1.3
1/2S1/2H	41.4 $\pm$.4b	1.19 $\pm$.03b	97.4 $\pm$ 1.2

a,b - unlike subscripts in a column differ $P < .05$

1/2 Sm calves had heavier BW and higher CD ($P < .05$) than H and the other crossbred groups. Although not significant, 1/2 Sm calves had the lowest %ES. The data indicated crossing with a high growth rate breed such as Simmental resulted in increased stress due to calving difficulty which was a cause in the decreased early survival of newborn calves.

The effect of sire breed when mated to A dams was investigated by Marlowe et al. (1984). Angus females were mated to A, Ch, and HI sires from 1969 to 1974. Breed of sire was divided orthogonally to compare small straightbred versus large crossbred types (A vs. Ch and HI) and to contrast large crossbred types (Ch vs. HI). Breed of sire did not have a significant effect on perinatal mortality. Ch sired calves were the heaviest at birth with the HI sires calves being intermediate.

Cundiff (1984), in a review of results from the Beef Cattle Germ Plasm Evaluation Program conducted at the U. S. Meat Animal Research Center (USMARC), Clay Center, Nebraska, reported significant differences among breeds for output and input components of beef production. An antagonistic relationship exists between retail product growth, birth weight, calving difficulty, and calf mortality. Breeds excelling in retail product growth experienced the heaviest birth weights and greatest calving difficulty. The incidence of calving difficulty appeared to be lowered by the use of large F1 cross females even though birth weight was increased as a result.

Prewaning and weaning traits.

Prewaning data from 751 calves of a three breed diallel with the breeds being Hereford (H), Angus (A), and Shorthorn (Sh) were analyzed by Gregory et al. (1965) to determine the effects of heterosis on preweaning traits of economic importance in beef cattle. Estimates of average heterosis were significant ($P < .01$)

for BW, daily gain (DG), WWT, and conformation score (CS). The estimates of average heterosis were $1.22 \pm .23$ kg, $.04 \pm .01$ kg*d⁻¹, 8.8 ± 1.3 kg, and $.17 \pm .06$ of one-third of a grade for BW, DG, WWT, and CS, respectively.

Pahnish et al. (1969) found heterosis effects for WWT and preweaning average daily gain (PWDG) to be significant for steers while the heterosis effects were non-significant in the heifer data. The heterosis estimates are listed below:

	WWT	%	PWDG	%
STEERS	8.3**	3.8	.033*	3.7
HEIFERS	4.0	1.9	.017	2.0
** P .01 * P .05				

The Charolais (Ch) breed ranked above the H and A breeds for preweaning growth and WWT. This result was probably indicative of the superior growth potential and adequate maternal ability of the Ch breed when compared to H and A. The utilization of Brown Swiss (BS) dams over H, A, and Ch dams resulted in increased growth of crossbred calves of both sexes. This growth superiority was attributed to a favorable maternal environment provided by the BS cows assuming dairy x beef heterosis effects to be the same as beef x beef heterosis effects. The BS superiority for preweaning gain was due to the high level of milk production contributed by the dairy breed. The differences between BS dams and beef dams in growth traits in their crossbred progeny are listed below by sex:

	WWT	PWDG
STEERS	33.6	.138
HEIFERS	32.5	.126

Preweaning growth for several biological types of cattle was investigated by Smith et al. (1976). Sire breed differences and heterosis estimates were determined from data collected from 2,368 calves. Heterosis for preweaning relative growth rate (RGR) was not significant while heterosis for PWDG and WWT were significant ($P < .01$). When compared to HA, Ch and Simmental (Sm) cross calves possessed much higher growth rates to weaning but were later maturing as illustrated by a lower RGR ($P < .05$). The sire breed means and heterosis estimates are listed on Table 7. The sire breed x age of dam interaction was significant which indicated the sire breeds with high genetic growth potential responded more to the increased milk production of the older females.

Data from cows produced from a three breed diallel mating system using H, A, and Sh breeds were analyzed by Smith et al. (1976) to estimate heterosis and reciprocal differences for immature weights, mature weights, degree of maturity, average growth rate (AGR) which is equal to PWDG, average maturing rate (AMR), RGR, and age at puberty. Preweaning RGR heterosis was not significant. Heterosis estimates were $1.7 \pm .5$ kg ($P < .01$), 10 ± 2 kg ($P < .01$), $.04 \pm .01$ kg*d⁻¹ ($P < .01$), and $-.001 \pm .007\%$ for BW, 200-day WWT, AGR, and RGR, respectively.

TABLE 7. BREED GROUP MEANS AND HETEROSIS ESTIMATES^a

BG ^b	RGR ^c	PWDG	200-d WWT
HH	.83	.74	182
AA	.91	.79	190
HETEROSIS	.01	.05**	8**
HA	.88f	.80f	194f
Ch	.84h	.84h	207h
Sm	.84h	.83h	204h

** P < .01

f,h - unlike letters in a column differ (P<.05)

a - Smith et al. (1976)

b - HH = Hereford, AA = Angus, HA = Hereford - Angus, Ch = Charolais cross, Sm = Simmental cross

c - RGR * 100

Gregory et al. (1978) evaluated data from calves by BS, H, A, Maine-Anjou (MA), Chianina (C), Gelbvieh (G), and Red Poll (RP) sires mated to H and A dams. The use of BS breeding for maternal improvement had a significant direct effect in which weaning performance as measured by PWDG and WWT was increased but RGR from birth to weaning was decreased when compared to HA. Large framed, Continental breeds (MA, C, and G) increased the growth potential from birth to weaning age but RGR and the number of calves weaned were decreased as a result. MA, C, and G sired calves attained higher PWDG and heavier WWT than BS sired calves but the BS sired calves were earlier maturing as indicated by a higher RGR and a greater number of BS sired calves were alive at weaning. For PWDG and WWT, the breed of sire x breed of dam interaction was significant. The authors concluded calves from the high growth rate breeds were better able to express their full growth potential when they were nursing Angus dams. Breed group means are listed on Table 8.

Weaning maternal ability for purebred and crossbred cows of H, A, and Sh breeding was evaluated by Gaines et al. (1978). Cow weight was related linearly to weaning weight in the straightbred females but no effect could be detected in the crossbred females. When cow weight was included as a covariate in the analysis of WWT, differences between purebred and crossbred cows due to cow weight accounted for 20% of the differences in weaning weight. The inclusion of cow size could be misleading to producers if differences in cow size were removed in the statistical analysis

TABLE 8. BREED GROUP MEANS FOR PREWEANING AND WEANING TRAITS^a

	PWDG	RGR ^b	WT	CCW
HA	.76	.86	188	96.3
BS	.79	.84	198	96.1
G	.81	.85	202	90.4
MA	.79	.82	199	89.7
C	.79	.83	200	90.0

^a - Gregory et al. (1978)

^b - RGR * 100

HA = Hereford - Angus, BS = Brown Swiss sired, G = Gelbvieh sired

MA = Maine - Anjou sired, C = Chianina sired

since inferences in maternal performance could be altered if differences in cow size and subsequent differences in nutritional requirements were removed. Breed means for WWT and % calves weaned were 207 and 198 kg, and 87.5 and 88.2% for crossbred and purebred females, respectively.

In a further analysis of the performance of two and three-year old females described by Notter et al. (1978a), Notter et al. (1978b) studied preweaning growth of their progeny when mated to a third breed of sire. Sire breed means are listed in Table 9. Progeny from Simmental cross (Smx) females were superior in their weaning performance ($P < .05$) than HA or Charolais cross (Chx) females at both ages. The rank of the cow sire breeds did not change at either age. Holstein sired calves from two-year old females did not differ significantly in preweaning growth from HA calves but they were heavier at weaning time ($P < .05$). At both ages, Smx females produced calves with higher RGR than HA or Chx, especially at three years of age. This magnitude of difference at three years of age for the Smx females reflected the relationship between high milk production and high birth weights of the Smx compared to HA or Chx. At three years of age, the ranking of maternal ability corresponded closely to the ranking for milk production.

Data from crossbred two-year old females mated to Sh and RP sires were analyzed by Belcher and Frahm (1979) to determine the effects of crossbreeding on preweaning traits. Brown Swiss cross (BSx) females weaned heavier calves that possessed faster

TABLE 9. BREED GROUP MEANS FOR TWO AND THREE YEAR OLD COWS^a

TWO YEAR OLD FEMALES:

COW SIRE BREED	PWDG	200-d WWT	RGR
HA	.67 $\pm$.01d	164 $\pm$ 2.3d	.85 $\pm$.01cd
Sm	.74 $\pm$.01b	181 $\pm$ 1.9b	.86 $\pm$.01c
Ch	.71 $\pm$.01c	175 $\pm$ 2.2b	.83 $\pm$.01cd

CALF SIRE BREED

HA	.67 $\pm$.01	165 $\pm$ 2.2d	.87 $\pm$.01c
HI	.71 $\pm$.01	174 $\pm$ 1.9c	.83 $\pm$.01d

THREE YEAR OLD FEMALES:

COW SIRE BREED

HA	.76 $\pm$.01d	188 $\pm$ 2.3d	.83 $\pm$.01d
Sm	.84 $\pm$.01b	206 $\pm$ 1.9b	.87 $\pm$.01c
Ch	.77 $\pm$.01d	193 $\pm$ 2.0cd	.82 $\pm$.01d

^a - Notter et al. (1978b)

HA = Hereford - Angus, HI = Holstein, Ch = Charolais, Sm = Simmental

b,c,d, - unlike letters in a column differ P < .05

preweaning growth and they weaned a greater percentage of calves than beef x beef females. When compared to HA, Smx females weaned fewer calves that possessed greater preweaning growth and heavier 205-day WWT. Smx and BSx females increased weaning performance in two ways: 1) direct genetic effects for growth and size; and 2) increased maternal ability. Breed group means are listed below:

COW GROUP ^a	PWDG ^b	205-D WWT ^c	% WEANED
HA	.68	168	72.0
Smx	.78	189.5	62.9
BSx	.81	197.5	78.6
Jx	.79	189.0	89.8

a - breed of cow			
b - kg*d ⁻¹			
c - kg			

Knapp et al. (1980) reported positive but nonsignificant maternal heterosis estimates from the analysis of data obtained from three breed cross progeny and reciprocal cross females of H, A, and Ch breeds. The heterosis estimates were .002 kg*d⁻¹ (.3%) and .7 kg (.4%) for PWDG and WWT, respectively. Overall heterosis estimates were 3.8 and 3.9% for PWDG and WWT, respectively. The nonsignificant estimates of maternal heterosis could be due to maternal environment for preweaning performance was negatively influenced by maternal effects in the previous generation. BS x beef females produced faster gaining and heavier calves at weaning than beef x beef females. The differences between BS x

beef females and beef x beef females were $.11 \text{ kg} \cdot \text{d}^{-1}$ and 25.2 kg for PWDG and WWT, respectively.

Long (1980) in an intensive review of crossbreeding literature summarized average heterosis, maximum differences among breed diallels, sire breeds, and cow breeds. Compiled estimates are listed below:

	heterosis	breed diallels	sire breeds
CALF SURVIVAL (weaning)	3	7	9
PWDG	4	19	7
WWT	5	16	9
COW TRAITS			
WWT	8	8	10

The use of European breeds was evaluated by Rahnfeld (1980) to determine the effect of these breeds on traditional beef production concepts. Ch and Sm sired calves did not differ in WWT but a greater number of Ch sired calves were weaned than Sm sired calves. Percent weaned for HA, Chx, and Smx females were 75.1, 76.6, and 74.1%.

Heterosis estimates for PWDG and WWT were obtained by crossing inbred lines of Hereford cattle in two-way (2W), three-way (3W), and synthetic variety (SV) crossing schemes. Urick et al. (1981) reported heterosis for PWDG and WWT of 7.2 and 8.15 kg for 2W calves, and 10.5 and 11.7 kg for 3W calves. Means for SL, 2W, and 3W calves are listed below:

	PWDG (kg)	WWT (kg)
SL	127.2	166.5
2W	136.3	180.1
3W	140.5	185.8

Dairy x beef and beef x beef females were evaluated by Nelson et al. (1982) to determine the merit of using dairy breeding in beef cattle production. The traits investigated were average daily gain from birth to 130 days (ADG1), calf weight at 130 days (CW130), average daily gain from 130 days to 210 days (ADG2), and calf weight at 210 days (CW210). The mating plans were the same as described by Nelson and Beavers (1982). Progeny from beef x beef females (AH, CH) possessed greater preweaning growth and heavier weaning weights than HH. Sire breed and dam breed least square means are listed on Table 10. The incorporation of dairy breeding increased weaning performance when compared to beef x beef females. The authors suggested continued growth from 130 days to 210 days from SH females was a function of calf's genotype and maternal environment supplied by its dam. Dam weight and dam weight change were significant effects, linearly and quadratically, in the analysis of ADG and CW.

Weaning performance data collected from a mating scheme in which varying levels of Simmental breeding were used were analyzed by Lawlor et al. (1984). Weaning traits included % weaned (%W), WWT and net kilograms weaned (NKW). Breed group means are presented below:

TABLE 10. LEAST SQUARE MEANS FOR TRAITS OF COW PRODUCTIVITY^a

BREED GROUP ^b	% WN	% CONC	CW/CE	WWT ^b
HH	66.4	96.8	122.3	184
AH	76.8	95.7	157.3	197
CH	77.7	93.0	165.5	213
SH	83.4	97.1	196.0	235

a - Nelson et al. (1982)

b - HH = Hereford, AH = Angus x Hereford, CH = Charolais x Hereford, SH = Brown Swiss x Hereford

c - % WN : % weaned; % CONC : % conception; CW/CE : calf weight per cow exposed; WWT : weaning weight

GROUP ^a	%W	WWT (kg)	NKW (kg)
H	95.6 $\pm$ 1.9ab	185 $\pm$ 2a	177 $\pm$ 4a
1/2A1/2H	99.5 $\pm$ 2.1b	192 $\pm$ 2b	194 $\pm$ 5b
1/4S3/4H	97.4 $\pm$ 2.0b	192 $\pm$ 2b	184 $\pm$ 5ab
1/2S1/2H	91.6 $\pm$ 2.0a	201 $\pm$ 2c	182 $\pm$ 5a

unlike subscripts differ $P < .05$

a - H = Hereford, 1/2A1/2H = 1/2 Angus 1/2 Hereford,
 1/4S3/4H = 1/4 Angus 3/4 Hereford, 1/2S1/2H = 1/2
 Simmental 1/2 Hereford

The use of A and percentage Sm bulls resulted in increased WWT ($P < .05$) and improved NKW, especially when A sires were used in the crossbreeding scheme. As indicated by the data, any increase in growth rate can be offset by a decreased survival and weaning rate. Even though, 1/2 SM calves were the heaviest at weaning, they had the lowest %W thus the lowest NKW while 1/2 A calves had the highest NKW.

Marlowe et al. (1984) analyzed weaning data collected from progeny of Ch, H1, and A sires mated to A females. Weaning traits studied were weaning rate (WR), PWDG, and WWT. For WR, sire breed differences were insignificant while significant differences existed for growth traits. The differences due to crossbreeding were .3%, .04 kg*d⁻¹, and 14 kg for WR, PWDG, and WWT, respectively. Sire breed means are listed below:

	WR	PWDG	WWT
A	81.8 $\pm$ 3.1	.76 $\pm$.01	193 $\pm$ 2
H1	83.9 $\pm$ 3.2	.77 $\pm$.01	200 $\pm$ 2
Ch	80.5 $\pm$ 3.2	.83 $\pm$.01	213 $\pm$ 2

Ch sired calves were faster gaining and heavier at weaning time than H1 or A sired calves.

Cundiff (1984) in a summary of data collected at USMARC reported weaning performance could be increased by crossbreeding utilizing breeds which excel in retail product growth. The use of large framed dual purpose breeds improved weaning performance through direct genetic effects for growth and increased milk production in the crossbred female.

Cow traits.

The relationship between cow weight and weaning weight was investigated by Urlick et al. (1971) using data collected from Angus (A), Hereford (H), and Charolais (Ch) cows. Cow size was measured as fall weight and fall weight to the .73 power. Within each breed, cow weight and weaning weight appeared to be linearly related in a positive manner ($P < .01$) with weaning weight increasing 1.93 kg for every unit (45.4 kg) increase in fall weight. The correlation between fall weight and weaning weight was .16. An inverse relationship was noted between cow weight and calf weight per 45.4 kg of cow weight with the correlation being -.56 with smaller cows having tended to have more kg of calf weight per unit cow weight than H and A cows.

Rutledge et al. (1971) examined certain sources of environmental variation in milk yield and evaluated the magnitude of the influence of milk yield and several other variables on 205-day weaning weight. Cow size as measured by weight was a significant source of variation ($P < .05$) with the linear regression of total milk yield (TMY) on cow weight being $.104 \pm .05$ kg. The single most important influence in determining 205-day WWT on a within herd-year-sex basis was the lactational status of the dam. Milk yield accounted for 60% of the variation accounted for by the regression variables in WWT with milk quantity rather than quality being a more important influence in the weaning performance in Hereford calves.

Records from 406 straightline and crossline Hereford females were examined by Burfening and Kress (1973) to estimate heterosis for a female's maternal ability. Maternal ability was measured by most probable producing ability (MPPA) as defined by Lush (1945) for 180-day weaning weight. Crossline females were produced by topcrossing 3 inbred lines designated lines 1, 2, and 3 on a common tester line 4 to produce lines 5, 6, and 7. Heterosis estimates were obtained for each crossline using the formula: $CL_j - (L_1 + L_4)/2$. Heterosis for MPPA(180W) in kg+SE(%) were 6.3 ± 1.7 (3.5%), $.40 \pm 1.6$ (.21%), and 2.2 ± 1.8 (1.2%) for lines 5, 6, and 7, respectively.

Significant heterosis was obtained for reproductive traits by comparing Shorthorn (Sh), H, and A females to reciprocal cross females when mated to produce crossbred progeny with equal

additive and nonadditive genetic makeup. Cundiff et al. (1974) reported significant heterosis estimates for several measures of reproductive performance. Crossbred females weaned 6.4% more calves ($P<.01$) than straightbred females with differences being due to increased pregnancy and first service conception rates in crossbred females. The differences in weaning weight per cow exposed (WWT/CE) was 23 kg ($P<.01$) in favor of the crossbred females when compared the the straightbred females. The total effect of individual and maternal heterosis was 23% for pounds of calf weaned per cow.

Maternal heterosis was estimated by Cundiff et al. (1974) using data from straightline and reciprocal cross cows of H, A, and Sh breeding. Maternal heterosis was estimated from the difference between progeny obtained from crossbred and straightbred females mated to the same bulls of a third breed. When adjusted for breed, age, and management regimes, estimates of maternal heterosis were 1.7% ($P<.05$) and 4.7% ($P<.01$) for BW and WWT, respectively. Crossbred females possessed greater and more persistent milk production than straightbred females which resulted in a greater weaning performance in progeny of crossbred females. The authors noted a tendency for maternal heterosis to decrease as the cow age increased for preweaning growth.

Notter et al. (1978b) estimated milk production using 59 2-year old and 125 3- and 4-year old crossbred cows to determine the quantity and persistancy of milk production in crossbred beef females. Milk production was measured as kg per 12 hours and

samples were collected at 128, 156, and 184 days of lactation. For two year old females, cow sire breeds were ranked similarly across stage of lactation with Simmental cross (Smx) cows producing more milk than Hereford-Angus (HA) or Charolais cross (Chx) cows. The same situation held true for 3- and 4-year old females. The data indicated breeds with high average milk production levels were less persistent in their milk production as average milk production levels increased. Heterosis at day 128 was significant and decreased over time as time of lactation progressed. The average milk production heterosis was 15% or .4 kg per 12 hr. Average estimates of milk production (kg) for each breed are presented below:

BREED	2-YEAR OLDS ^a	3 & 4 YEAR OLDS ^b
HA	4.4 $\pm$.3	3.0 $\pm$.2
Smx	4.7 $\pm$.3	4.0 $\pm$.3
Chx	4.1 $\pm$.4	2.7 $\pm$.2

a - 24 hr production
b - 12 hr production

Production data from 2 year-old crossbred cows were analyzed by Belcher and Frahm (1979). In several measures of cow productivity, they determined dairy x beef females were strikingly superior to beef x beef females, especially in kg of calf weaned per cow exposed (WWT/CE). Brown Swiss (BSx) females when compared to HA and Smx females were more productive in terms

of kg of calf weaned and in numbers of calves weaned. In a comparison of beef x beef females, Smx cows weaned calves possessing greater preweaning growth and heavier weaning weights but weaned fewer calves. Smx females were the heaviest compared to the other breed crosses. BSx females were intermediate in size being larger than HA and smaller than Smx. Least-square means for measures of cow productivity for each breed cross are listed below:

BREED ^a	% CC	CW	RATIO	WWT/CE ^b
HA	86.5	321	.53	124
Smx	69.5	349	.55	120
BSx	85.8	335	.59	156
Jx	92.4	301	.63	170

a - HA = Hereford - Angus, Smx = Simmental cross
BSx = Brown Swiss cross, Jx = Jersey cross

b - % CC : % cows calving
CW : cow weight (kg)
RATIO : WWT/CW
WWT/CE : weaning weight per cow exposed (kg)

Even though, the large crossbred cows were more productive, the crossbred females required more feed for maintenance and needed to produce heavier calves to offset their extra input into the cow-calf enterprise.

Gaines et al. (1978) analyzed records from straightbred and crossbred cows of A, H, and Sh breeding and determined the crossbred females to be heavier but also more productive in terms

of kg of calf weight per kg of cow weight. Crossbred females gave birth to a greater number of calves but fewer calves were weaned when compared to purebred females. Using a measure of cow productivity, $\% CW * (WWT / CW)$ (percent calves weaned * (weaning wt/cow weight), the purebred cows were more productive with the main difference being due to a greater number of calves weaned by purebred females.

Significant heterosis for mature size was obtained by Smith et al. (1976) using data of cows produced in a three breed diallel using H, A, and Sh. The heterosis for mature size was 12+5 kg ($P < .01$). The authors noted advantages could exist for matching maturing rate of a crossbred cow to a given management system.

Gregory and Cundiff (1980) noted that because of the improved reproductive performance and maternal ability, crossbred cows produced 14.8% more calf weight per cow exposed. The cumulative effects of heterosis on traits that contribute to weight of calf per cow exposed was shown to be 23.3%.

Long (1980) in a review of crossbreeding literature found the heterosis estimates for cow weight ranged from -1 to 7% and the maximum differences between breeds were from 7 to 34%.

Differences in cow productivity were investigated by Nelson et al. (1982) in which cow performance data were collected from beef x beef and dairy x beef females. Weaning rate is a product of calving rate and calf survival, and a trait of significant economic importance in which dairy x beef females excelled. Breed

group means are presented in Table 10. The difference between % weaned and conception rate was the greatest for Hereford (HH) and the smallest for Brown Swiss x Hereford (SH). This difference included all possible losses after conception. CW/CE is an indicator of differences in total production per cow to weaning and a reflection of differences in calf survival and growth. Also, CW/CE is a measure of differences in reproductive and maternal performance of the cows. In general, crossbred females were more productive than straightbred HH and dairy x beef females were more productive than beef x beef females. The advantage in favor of dairy x beef females was due to the greater maternal performance as indicated by heavier weaning weights and more calves weaned per cow.

Cundiff (1984) showed increasing mature weight increases output per cow but increases the nutritional needs in order to meet the cow's maintenance requirements. The output per cow was the greatest for large size dual purpose breeds that excelled in milk production and greater growth potential if feed resources are available to meet growth, maintenance, lactation, and support high reproductive levels.

In an analysis of data collected from a four breed diallel using A, H, Holstein (HI), and BS, McInerney (1984) found crossbred cows to be 3.4% heavier at maturity than straightbred cows. The maturing rate was 3.7% greater for crossbred females than straightbred females. The leaner breed combinations were usually associated with a larger mature size. When comparing

larger cows of dairy breeding to smaller beef breed crosses, the maintenance mass of the larger cows appeared to be underestimated. The differences in the mass of metabolically active tissue were greater than indicated by mature cow weight alone.

Estimation of genetic effects:

In order to evaluate which breeds to use in a given crossbreeding scheme, it is important to evaluate these breeds with respect to their direct and maternal additive genetic effects. Heterosis effects, both individual and maternal, must be estimated in order to determine the nonadditive components that exist for the set of breeds being evaluated for their potential use in crossbreeding schemes.

Theory and estimation procedures.

Dickerson (1969) described that the effective use of breed resources available is dependent upon the estimation of direct and maternal additive breed effects and heterosis effects for a set of given breeds. The genetic components were defined as a mean deviation in offspring performance from the average performance for purebreds. Experimental designs and planning of crossbreeding experiments were discussed in detail in order that breeds could be accurately evaluated. While defining the theory of genetic components, the estimation of these additive and nonadditive components was not discussed.

The utilization of breed differences were discussed by Dickerson (1973) and comparisons among different crossbreeding systems were also described for each of the livestock species. The expected average gain in performance for a rotational crossbreeding scheme using a set of n sire breeds over the weighted mean of n purebreds was a function of the number of breeds in the rotational cross, individual and maternal heterosis, and individual and maternal recombination effects. Advantages of the rotational crossbreeding scheme are the requirement of only male replacements from purebred matings and the utilization of a high proportion of the heterozygosity available.

Dillard et al. (1980) used a multiple regression approach to estimate breed additive, breed maternal, direct heterosis, and average maternal heterosis effects from data collected from purebred and crossbred Angus, Charolais, and Hereford cattle for birth and weaning traits. The multiple regression approach (MLR) was compared to fitting least-square constants for each breed group. The differences between the breed group analysis and the MLR for each trait analyzed in terms of R^2 were not significantly different which suggested the MLR adequately accounted for the variation in the data set. The MLR technique had three advantages over the fitting of constants:

- 1) provides a clearer way of separating the component parts;
- 2) can be used to predict performance of various crosses of interest not available in the data set;
- 3) utilizes all information from the breed groups in the estimation of genetic effects.

Genetic and maternal effects were estimated by Alenda et al. (1980) by using linear functions of breed means to separate the component parts. The genetic effects estimated were 1) breed additive effects, 2) individual and maternal heterosis effects, and 3) total maternal effects. The total maternal effect was decomposed into maternal and grand maternal effects. The equations used to estimate these genetic effects were designed to analyze data from crossbreeding experiments using a diallel mating design in which all possible crosses among a set of breeds are obtained.

Robison et al. (1980) further described the multiple regression procedure used to estimate additive and nonadditive genetic effects. A genetic model was derived to describe the underlying genetic model assumed for the particular data set involving crosses among Holstein, Ayrshire, and Brown Swiss cattle. The genetic model is described below:

$$C_{ij} = u + k_1 a_i + k_2 a_j + k_{1j} h_{ij} + k_{2j} m_j + e$$

where C is the ijth cross and represents any combination of breeds in either male or female parent;

- k_i - percentage of genes contributed by breed i through the sire;
- k_j - percentage of genes contributed by breed j through the dam;
- a_i - average breed effect for the i th breed;
- a_j - average breed effect for the j th breed;
- k_{ij} - percentage of loci in the individual with one gene from the i th breed and one gene from the j th breed;
- h_{ij} - heterosis expressed for the ij th breed combination;
- k_{j1} - percentage of genes in the dam from the j th breed;
- m_{j1} - average breed maternal effect for the j th breed as a female.

Using this genetic model, an analytical model was derived to estimate the a_i , a_j , h_{ij} , and m_{j1} . These values can be considered as partial regression coefficients. Since k_i and k_j for an individual sum to 1.0, restrictions were imposed in order to obtain solutions. This procedure provided results that were identical to techniques which estimate each breed group mean, equating it to its genetic expectation, weighting by the number of observations, and solving the system of equations. Comparisons of the error sum of squares for the regression approach and the breed group model yielded no significant differences between the two estimation techniques.

Fimland (1983) describes the multiple regression procedure used to estimate crossbreeding parameters and presented guidelines for designing experiments in order to estimate these components. Assuming the crossbreeding variance components are unknown, a fixed model must be used in the estimation procedure. If the variances were known, the prediction efficiency could be improved. In order to use the best model for prediction of specific crosses, the quadratic loss function must be minimized. Alternative models should be compared so the smallest average square error of prediction can be found. The effect of ignoring some factors is negligible if the true value for these ignored effects are equal to zero. Some of the factors which are ignored are actually non-estimable due to confounding with other effects and the crossbreeding design used in the experiment.

Estimation of genetic effects:

Estimates from crossbreeding experiments.

Gaines et al. (1970) estimated general combining ability (GCA) and maternal effects for Hereford (H), Angus (A), and Shorthorn (Sh) breeds used to produce two breed, three breed, and backcross combinations. GCA was defined as the additive genetic effect of a line or breed in combination with other lines or breeds. The estimates of GCA for birth weight (BW) were significantly different among the breeds used. The additive effect for A regarding BW was significantly less than H or Sh. No effect on birth weight could be attributed to maternal effects.

Maternal effects on weaning weight (WWT) for the three breeds differed ($P .01$). GCA and maternal effects for each breed are listed below:

	A	H	Sh
BW (kg)			
GCA	-2.40 $\pm$.54	1.36 $\pm$.54	1.04 $\pm$.54
MATERNAL	1.13 $\pm$.72	-.54 $\pm$.68	-.59 $\pm$.72
WWT (kg)			
GCA	-4.22 $\pm$ 3.81	8.03 $\pm$ 3.76	-3.81 $\pm$ 3.76
MATERNAL	8.44 $\pm$ 4.85	-15.10 $\pm$ 4.72	6.67 $\pm$ 4.85

The relationship between GCA and maternal effects appeared to negative since GCA is a combination of sire and dam effects, while the maternal effect was estimated by subtracting the sire effect from the dam effect.

Transmitted and maternal effects were estimated by Notter et al. (1978a) using linear combinations of breed group least-square means obtained using progeny from two and three year old crossbred dams. These estimates were expressed as deviations from Hereford-Angus (HA). For birth weight, the deviations from HA were positive for Simmental (Sm) and Charolais (Ch), both as calf sires and as cow sires. Also, positive maternal deviations were obtained for Sm and Ch. Effects for Sm and Ch were positive for % dystocia and when considered as calf sires, positive deviations for % total mortality were obtained for both dam age groups. In the three year old group, Sm and Ch, when considered as cow

sires, were negatively deviated from HA for % dystocia and % total mortality. The maternal effects were also negative for % dystocia and % total mortality. Estimates are presented in Table 11.

Notter et al. (1978b) estimated transmitted and maternal effects on preweaning average daily gain (PWDG), weaning weight (WWT), and preweaning relative growth rate (RGR) from progeny of two and three year old dams. The estimates are presented in table 11. Maternal effects for Sm and Ch were positive for all three traits except for Ch in the three year old dam group. The positive maternal effects for PWDG coincide with positive maternal effects for RGR. Also, the ranking for maternal ability corresponds to the ranking for milk production in the three year old females.

Kress et al. (1979) in an analysis of data to determine the heterotic response from crossing closed lines of Hereford cattle estimated transmitted and maternal genetic effects for each the five lines used in the study. Correlations between the transmitted and maternal effects for BW, 180-day weight (180W), percentage born (%BORN), percentage weaned (%WN), and net kilograms weaned (NKW) were calculated using the estimates obtained. Negative correlations were obtained for BW, 180W, and NKW which suggests an antagonistic relationship exists between the direct and maternal line effects for these growth traits.

Genetic and maternal effects were estimated for A, H, and Ch breeds by Alenda et al. (1980) using linear functions of breed

TABLE 11. DEVIATIONS OF BREED MEANS FROM HEREFORD-ANGUS AND
ESTIMATES OF MATERNAL EFFECTS^a

BREED	BW	%DYS	%TM	PWDG	WWT	RGR
Two year old dams:						
Simmental						
Calf sire	3.7	25.5	6.7	-.03	-2.4	-.05
Cow sire	2.6	6.1	-5.7	.08	17.7	.01
Maternal	1.3	-6.7	-9.1	.09	18.9	.04
Charolais						
Calf sire	3.4	33.5	26.9	.07	9.5	-.02
Cow sire	3.5	4.0	-.1	.04	11.6	-.02
Maternal	1.8	-12.8	-13.6	.01	6.9	-.01
Three year old dams:						
Simmental						
Calf sire	5.1	18.7	19.4	.05	15.4	-.03
Cow sire	2.0	-4.4	-1.7	.08	18.2	.04
Maternal	-.6	-13.8	-11.4	.06	10.5	.05
Charolais						
Calf sire	5.3	26.4	17.6	.06	17.4	-.02
Cow sire	3.0	-2.0	-2.2	.02	5.5	-.01
Maternal	.4	-15.2	-11.0	-.02	-3.2	.00

^a - compiled from Notter et al. (1978a,1978b)

means. Effects estimated were additive effects for each breed, individual and maternal heterosis for each two breed combination, and maternal and grand maternal breed effects. Ch additive effects were 8 to 12 kg ($P < .01$) and 17 to 21 kg ($P < .01$) higher than H and A additive effects for BW and WWT, respectively. The total maternal effect (maternal and grand maternal) of Ch were 12 kg greater than H ($P < .05$) in WWT. Angus maternal effects were intermediate to Ch and H effects. Maternal and grand maternal effects were negatively related for each breed which supports evidence that rearing environment of the dam influences a cows' own maternal ability.

Using a multiple regression procedure, Dillard et al. (1980) estimated additive and nonadditive genetic effects for H, A, and Ch. $\hat{\mu}$ was used to represent the H least square mean since additive effects were expressed as deviations from the H breed. Specific individual heterosis for each two breed combination was estimated while only the average maternal heterosis was estimated due to the lack of maternal breed combinations in the data set. BW was influenced by additive and maternal breed effects but the effects of individual and maternal heterosis were not significant. Weaning traits, average daily gain and WWT, were significantly influenced by additive and nonadditive genetic effects.

MacNeill et al. (1982) used performance data from the South Dakota Beef Cattle Improvement Association to estimate breed individual and maternal effects and heterosis for 205-day WWT.

Records from 47,652 calves in 371 contemporary groups were analyzed using a mixed model with the genetic effects being considered fixed and contemporary groups representing the random effect. The data represented 12 different beef breeds in a variety of breed combinations but only seven breeds could be evaluated for maternal effects because not all breeds were used in the dam breed groups. Estimates are listed below for H, A, Polled Hereford (PH), Ch, and Sm along with average individual and maternal heterosis:

BREED	INDIVIDUAL	MATERNAL
H	-19.0 <u>±</u> 1.1	-6.4 <u>±</u> 1.0
A	-12.2 <u>±</u> 0.9	.3 <u>±</u> 0.9
PH	-11.5 <u>±</u> 3.1	-18.9 <u>±</u> 2.9
Ch	12.4 <u>±</u> 1.2	6.3 <u>±</u> 1.3
Sm	14.6 <u>±</u> 1.2	16.9 <u>±</u> 2.0
heterosis	4.4 <u>±</u> 0.4	6.8 <u>±</u> 0.4

The European breeds, Ch and Sm, possessed much greater additive effects for 205-day WWT than the three British breeds. The maternal effect for the Sm breed was substantially larger when compared to the other breeds, particularly the PH breed.

MATERIALS AND METHODS

Base population.

In the year 1967, the Ford brothers, Henry and Edsel, donated to Michigan State University a herd of grade Hereford females which were typical of the Hereford cattle found in northern Michigan during the late 1960's. Most of the females were five years of age or older. Two hundred cows were selected to form the base population of a breeding project to be conducted at the Lake City Experiment Station. The cows were stratified by age and randomly assigned into four breeding groups of fifty cows each. The first matings were made in 1967 and the first crossbred females entered production in 1970.

Breeding project.

The breeding project consists of four breed groups with each group representing different selection criteria and mating systems. The four breed groups are 1) a unselected, random mating Hereford control line, 2) a Hereford group which uses sires from Hereford seedstock herds which are selecting for yearling weight, 3) a rotational crossbreeding system using Angus, Hereford, Charolais, and Simmental, and 4) another rotational cross with the Holstein-Friesian breed replacing the Charolais breed. The sires in their respective breeds used in the two crossbred groups

were also obtained from herds selecting for yearling growth. Three to four bulls of each breed were used per year in groups 2, 3, and 4. The Holstein-Friesian bulls were evaluated on their estimated breeding values for yearling weight which were calculated by personnel at Michigan Animal Breeding Cooperative (M.A.B.C.) Semen from the beef sires were obtained from the various A.I. studs. M.A.B.C-Select Sires has been very helpful and cooperative in the processing and supplying semen used in the project. A table describing the breeding project is listed below:

DESCRIPTION OF THE LAKE CITY BREEDING PROJECT

GROUP	SELECTION CRITERIA	MATING SYSTEM
1	NONE	RANDOM
2	YEARLING WEIGHT	STRAIGHTBRED
3	YEARLING WEIGHT	CROSSBREEDING ^a
4	YEARLING WEIGHT	CROSSBREEDING ^b
a - beef x beef crossing with Angus, Hereford, Charolais, and Simmental		
b - beef x dairy crossing with Angus, Hereford, Holstein-Friesian, and Simmental		

Group 1 was used to monitor environmental trends which allows for the estimation of genetic change free from environmental effects. The bulls chosen as replacements were not selected for yearling weight. The first four bull calves born each from a different sire were chosen to be replacements. In their first year of service, these bulls were used for clean-up

purposes. After their first breeding season, semen was collected from these yearling sires and used the following breeding season. In an attempt to avoid unintentional selection for yearling weight, the ten heifers with the earliest birth dates were kept as replacement females. The only deviations from random mating were performed in order to keep inbreeding to a minimum level.

Fifteen percent of the females in groups 2, 3, and 4 were retained based upon their actual yearling weight. The number of heifers retained was reduced to ten based upon 1) pregnancy status and 2) yearling weight. Any open females that were 4 years of age and older were culled and in groups 2, 3, and 4. Any additional culling was done on the basis of calf performance. Each year, 20% of the females were replaced by 2 year old females in each group.

Management of breeding project:

Cow herd.

The cow herd was weighed at weaning time in September and at the start of the pasture season during the middle part of May. The breeding season began on the middle of April and lasted 90 days with the cows being bred artificially the first 45 days. All females were kept in one herd except for the last 45 days of the breeding season when the females were assigned to their respective clean-up bulls.

During the winter season, the two groups of females, straightbred Hereford and crossbred females, recieved alfalfa-

grass hay as well as sorghum-sudan silage until the start of the calving season. During and after the start of the calving season, the straightbred Herefords recieved a mixture of haylage and corn silage while the crossbred females were fed a full-feed of corn silage. The pasture season usually lasted from 160 to 180 days with the females grazing upon improved and unimproved pastures. In the latter stages of the pasture season prior to the onset of calving, the cow herd did recieve limit-fed feed stuffs such as haylage and green chop. At weaning time, the cows were weighed and their pregnancy status was determined by veterinarians from the Michigan State University College of Veterinary Medicine. The cows recieved treatment for lice and grubs and tested for brucellosis.

Each female, prior to parturition, was given an yearly injection of Vitamin A and D. They were inoculated for leptospirosis and vibriosis, and given a wormer at this time before calving.

Replacement helpers.

The replacement helpers, at weaning time, were grouped and fed together. The helpers recieved corn silage and adequate amounts of grain to insure the reproductive performance of these helpers was not impaired by nutritional deficiencies. Prior to the breeding season, booster immunizations for infectious bovine rhinotracheitis (IBR), bovine virus diarrhea (BVD), and para-influenza (PI₃) were given to the replacement helpers.

Following the first 45 days of the breeding season during which the heifers were bred using artificial insemination (AI), they were grouped with the mature cows of their respective breed groups in pasture with the clean-up bulls corresponding to their particular breed groups.

Calf management.

Each calf, shortly after birth, was weighed, given a calving difficulty score, ear-tagged with an identification tag, and given injections of Vitamins A and D and a selenium-alpha tocopherol complex. The selenium-alpha tocopherol injections were given to prevent white muscle disease which is associated with a selenium-Vitamin E deficiency. All male calves were castrated with the exception of the bull calves in group 1 chosen to replacement bulls. Also, all horned calves were dehorned. Before the start of the pasture season, the calves recieved vaccinations against blackleg and malignant edema. At approximately six months of age, all helper calves were vaccinated against brucellosis. At weaning, all calves were weighed and given immunization shots for IBR, BVD, and PI.

In most years, some growth stimulating hormone implants were tested by assigning the treatments equally across all breeding groups for the steer calves.

The steer calves after weaning were transported to the Beef Cattle Research Center (BCRC) located at Michigan State University in East Lansing which is about 150 miles south of the Lake City station.

Management of steers in feedlot phase.

The steers were weighed and sorted upon arrival at the BCRC into eight pens with two pens belonging to each breed group. The cattle were weighed about every 28 days from start to the finish of the feeding trials. While at the BCRC, the steers were subjected to various nutritional and management regimes which involved differences in diet and/or hormonal implants. The treatments were imposed across breeding groups in order to determine if genotype-nutritional interactions existed. Treatments were randomized in each breed group in order for a balanced design to exist.

From the start of the project until 1980 the cattle were slaughtered when 80% of them were expected to reach the U.S.D.A. Choice grade. Starting in 1981, the cattle were slaughtered when they were determined to reach the Choice grade. This procedure has resulted in two to three distinct slaughter groups each year.

The cattle were slaughtered at a commercial packing plant where hot carcass weights were obtained and the carcasses allowed to chill for 24 hours. Personnel from Michigan State University obtained rib eye area, external fat thickness, and % kidney, heart, and pelvic fat data while a government grader determined marbling score and carcass maturity. Rib eye area, fat thickness, and marbling score was determined at the twelfth rib.

Statistical Analysis.

Data consisting of 1,232 cow records were collected from 1978 to 1982 at the Lake City Experiment Station, Lake City, Michigan. Data editing criteria and the number of observations for each of the traits analyzed are described in Table 12.

Two statistical models were used to analyze the data. The breed group analysis compared different selection criteria and mating systems. Different direct and maternal effects for each breed used in the crossbreeding portion of the study were analyzed using the genetic effect analysis.

Breed group analysis.

For birth weight (BW), % born alive (%BL), % calves weaned (%WEANED), preweaning average daily gain (PWDG), and preweaning relative growth rate (RGR), the following linear model was examined:

$$Y_{ijklm} = \mu + YR_i + BG_j + AGE_k + SEX_l + (YR*BG)_{ij} + (BG*AGE)_{jk} + E_{ijklm}$$

where: Y_{ijklm} is the m th observation of the trait of interest of the l th sex, in the k th age of dam group, in the j th breed group, and in the i th year;

μ is a constant common to all observations;

YR_i is the fixed effect of the i th year with $i=1,2,\dots,5$ which represents the years 1978 to 1982;

BG_j is the fixed effect of the j th breed group with $j=1,2,3,4$ which represents BG1, BG2, BG3, and BG4 as defined in an earlier section;

TABLE 12. DATA EDITING CRITERIA AND NUMBER OF OBSERVATIONS
FOR EACH TRAIT

TRAIT	EDIT CRITERIA ^a	NUMBER OF OBSERVATIONS	
		I ^b	II ^c
Birth weight (BW)	no record	948	693
% born alive (%BL)	no BW record	948	693
% weaned	no BW record	948	693
Calving difficulty ^d (CD)	no record or abnormal presentation	923	692
% assisted births ^e (%AB)	no record or abnormal presentation	923	692
Weaning weight (WWT)	no record	827	616
Prewaning average daily gain (PWDG)	no BW, WWT, or age record	820	612
Relative growth rate (RGR)	no BW, WWT, or age record	822	614
Dam weight (DAMWT)	no record	931	711
% fertility (%BRED)	no record	1226	908
% wintered (%winter)	no record	1232	- -
Weaning weight-cow weight ratio (WW/CW)	no WWT, DAMWT, or age record	812	614

a - reason for edit;

b - number of observations in breed group analysis;

c - number of observations in genetic effect analysis;

d - coded 1 = no assistance, 2 = easy pull, 3 = hard pull,
4 = Caesarean section;

e - coded 0 = no assistance, 1 = assistance required ($CD \leq 1$);

AGE_k is the fixed effect of the k th age of dam with $k=1,2,3,4$ which represents 2, 3, and 4 years of age, and 5 years of age and older;

SEX_l is the fixed effect of the l th calf sex with $l=1,2$ which represents male and female calves;

$(YR*BG)_{ij}$ is the interaction of the i th year and j th breed group;

$(BG*AGE)_{jk}$ is the interaction of the j th breed group and k th age of dam;

E_{ijklm} is the random residual effect peculiar to the m th observation.

Relative growth rate was calculated from birth to weaning. It is an expression which describes the percentage increase in body weight per day or the growth rate relative to the current size of the animal (Smith et al. (1976)).

The model used for calving difficulty score (CD) and % assisted births (%AB) is described below:

$$Y_{ijklm} = \mu + YR_i + BG_j + AGE_k + SEX_l + (YR*BG)_{ij} + (BG*AGE)_{jk} + b_1BW + b_2BW^2 + E_{ijklm}$$

where: b_1 is the regression coefficient for the linear term of birth weight (BW);

b_2 is the regression coefficient for the quadratic term of BW.

Weaning weight (WWT) and weaning weight to cow weight ratio (WWT/CW) were analyzed using the following model:

$$Y_{ijklm} = \mu + YR_i + BG_j + AGE_k + SEX_l + (YR*BG)_{ij} + (BG*AGE)_{jk} + b_1 DAYS + E'_{ijklm}$$

where: b_1 is a partial regression coefficient for calf's age in days at weaning (DAYS).

The model used to describe cow weight (DAMWT), % cows bred (%BRED), and % cows wintered (%WINTER) is described below:

$$Y_{ijkl} = \mu + YR_i + BG_j + AGE_k + (YR*BG)_{ij} + (BG*AGE)_{jk} + E'_{ijkl}$$

A general expresion in matrix notation is now written to represent the models above:

$$y = Xb + e$$

where: y is a column vector containing n observations pertaining to the trait being analyzed;

b is a column vector of unknown constants which correspond to the fixed effects of classes and regression coefficients described in a given model;

X is a matrix of 0's and 1's which represent the presence or absence of an observation in a fixed class;

e is a column vector of random residuals pertaining to observations in y .

The following assumptions were made:

- 1) y 's were normally distributed with mean Xb and variance $I\sigma^2$;
- 2) e 's were normally distributed with mean 0 and variance $I\sigma^2$;
- 3) other interactions concerning the main effects were assumed to be non-significant sources of variation;
- 4) $E(y) = Xb$;
- 5)
$$\text{Var} \begin{bmatrix} y \\ e \end{bmatrix} = \begin{bmatrix} V & R \\ R & R \end{bmatrix}$$
 where $V = R = I\sigma^2$.

The statistical analysis was performed using a generalized least square program, GLM, described by Goodnight et al. (1982). Since the linear models analyzed were fixed classification models, the coefficient matrix, $X'X$, was singular and as a result, a generalized inverse was used to solve the set of equations. Solutions obtained were not unique but estimable functions of the solutions are unique. Estimable functions which satisfied the requirement, $k'(X'X)^-X'X = k'$ where k' is a row vector defining the estimable function, were constructed to estimate:

- 1) the effects of within breed selection for yearling weight, BG1 versus BG2;
- 2) the effects of crossbreeding, BG2 versus BG3 and BG4;

- 3) the use of dairy x beef crossbreeding versus beef x beef crossbreeding, BG3 versus BG4.

Least square means or as termed by Goodnight et al. (1982), population marginal means, were obtained for each class within the main effects and subclass within the interactions of the main effects.

Genetic effect analysis.

The model used to estimate additive and non-additive genetic effects is described below:

$$Y_{ijklmn} = \mu + g_i^I f_i + \sum g_j^I f_j + \sum g_{j'}^M f_{j'} + h_{ij}^I f_{ij} + h_{jj'}^M f_{jj'} + YR_k + AGE_l + SEX_m + \text{covariates} + E_{ijklmn}$$

where: μ is a constant common to all observations;

g_i^I is the direct (I) genetic effect of the i th sire breed where $i=1,2,\dots,5$ which represents Angus (A), Hereford (H), Charolais (Ch), Holstein-Friesian (Hl), and Simmental (Sm);

g_j^I is the direct (I) genetic effect of the j th dam breed where $j=1,2,\dots,5$ which represents A, H, Ch, Hl, and Sm;

$g_{j'}^M$ is the maternal (M) genetic effect of the j' th dam breed where $j'=1,2,\dots,5$ which represents A, H, Ch, Hl, and Sm;

h_{ij}^I is the average individual heterosis effect for the given set of breeds;

h_{jj}^M , is the average maternal heterosis effect for the given set of breeds;

f_i is the fraction of genes attributed to the i th sire breed;

f_j is the fraction of genes attributed to the j th dam breed;

$f_{j'}$ is the fraction of genes attributed to the j' th dam breed;

f_{ij} is the fraction of loci with one gene from one breed and one gene from another breed;

$f_{jj'}$ is the fraction of loci with one gene from one dam breed and one gene from another dam breed;

YR, AGE, SEX, and E have been discussed in the previous section.

The covariates used for calving difficulty score and % assisted birth were linear and quadratic terms of birth weight. Days of age at weaning was used as a covariate for weaning weights and weaning weight-cow weight ratio. In order to obtain meaningful estimate of μ , the covariates were expressed as deviation from their means in the construction of the normal equations.

The terms, f_i and f_j are equal to .5 each. When summed together to equal 1.0, they describe the total breed makeup of the animal in question. Since crossbred sires were not used in the breeding project, the portion of genes coming from a

particular sire breed is equal to .5. Estimates of specific combining ability were not estimated since a mating scheme based upon rotational crossbreeding was used. Females in the two crossbred groups were mated to the sire breed they were least related to based upon pedigree. Also, estimates of average heterosis were deemed more important in a rotational crossbreeding scheme. The g^I and g^M represent the phenotypic effect of substituting A, Ch, Hl, or Sm genes for H genes, both directly and maternally.

The f_i , f_j , f_{ji} , f_{ij} , and f_{jj} coefficients were obtained by determining the fraction of genes attributable to a given breed and fraction of loci with genes from different breeds. A example of a crossbred pedigree is described below:

8	7	1	7	2
(1)	(2)	(3)	(4)	(5)

1 - Sire

2 - Maternal Grandsire

3 - Maternal Great Grandsire

4 - Maternal Great Great Grandsire

5 - Hereford base

where 1 = Angus, 2 = Hereford, 6 = Charolais,

7 = Holstein - Friesian, 8 = Simmental.

A subroutine was written to calculate the coefficients used in the estimation of the genetic effects. Examples of the coefficients used for the estimation of the breed and heterosis effects are listed in Table 13.

TABLE 13. EXAMPLE OF COEFFICIENTS USED FOR BREED AND HETEROSIS EFFECTS

PDGR ^b	DIRECT (f_i and f_j)					MATERNAL (f_{ji})					HET ^a	
	1	2	6	7	8	1	2	6	7	8	I	M
87172	1/8	1/16	0	5/16	1/2	1/4	1/8	0	5/8	0	1	3/4
8612	1/8	1/8	1/4	0	1/2	1/4	1/4	1/2	0	0	1	1
712	1/4	1/4	0	1/2	0	1/2	1/2	0	0	0	1	1
1872	1/2	1/8	0	1/8	1/4	0	1/4	0	1/4	1/2	1	1
28717 ^c	1/16	17/32	0	5/32	1/4	1/8	1/16	0	5/16	1/2	15/16	1
22222	0	1	0	0	0	0	1	0	0	0	0	0

a - Heterosis for direct and maternal effects (f_{ij} and f_{ji})

b - Pedigree of individual in data set

c - Hereford base not included in pedigree, extra 1/32 Hereford breeding

The model expressed in matrix notation is described below:

$$y = Fg + Xb + e$$

where: y is a $n \times 1$ column vector of observations which pertain to the trait being analyzed;

g is a $p \times 1$ column vector of unknown fixed constants for direct and maternal breed effects (g^I and g^M), and individual and maternal heterosis effects (h^I and h^M);

F is a $n \times p$ matrix which contains f_i , f_j , f_{ji} , f_{ij} , and f_{jj} , needed to estimate additive and non-additive genetic effects;

b is a $q \times 1$ column vector which contains unknown fixed quantities from classes of the classification factors and covariates;

X is a $n \times q$ matrix which contains 0's and 1's to denote the presence of an observation in the classes of the classification factors and observations on covariates when included in the analysis;

e is a $n \times 1$ column vector which contains unknown random effects peculiar to observations in **y**.

Assumptions made for the genetic effect analysis are listed below:

$$1) E(y) = Fg + Xb;$$

$$2) \text{Var} \begin{bmatrix} y \\ e \end{bmatrix} = \begin{bmatrix} V & R \\ R & R \end{bmatrix}$$

$$3) y \sim N(Fg + Xb, I\sigma^2)$$

$$4) e \sim N(0, I\sigma^2)$$

5) interactions among genetic effects and fixed environmental factors were assumed to be non-significant.

The normal equations thus become:

$$\begin{bmatrix} F'F & F'X \\ X'F & X'X \end{bmatrix} \begin{bmatrix} g \\ b \end{bmatrix} = \begin{bmatrix} F'y \\ X'y \end{bmatrix} .$$

Due to confounding with year and age of dam with a pedigree containing Sm as a maternal grandsire, dams with this particular

pedigree were removed from the data set. The maternal effects were estimated for A, H, Ch, and Hl breeds in the analysis of cow traits because of the confounding problem.

The design of the statistical model resulted independencies occurring in the genetic equations and in the fixed classification equations. The dependencies in the genetic effect equations were due to the sum of the coefficients for breed direct and maternal effects being equal to one. Also, dependencies existed in the fixed classification portion due to the fact that the equations are dependent upon the number of observations in the factors included in the model. The sum of the observations in each factor or interaction is equal to the total number in the data set being analyzed at the time.

To remove the dependencies in the breed direct and maternal equations, the g^I and g^M for A, Ch, Hl, and Sm were expressed as deviations from H since the direct and maternal H equations were set to zero. The H breed was chosen since every animal in the data set had some H breeding in their respective pedigrees. One must remember that g^I and g^M partial regression coefficients are not estimates but are solutions which are dependent on the restrictions imposed on the system of equations. Regardless of the restrictions imposed on the set of equations, estimable functions of the solutions are unique estimates. Estimates of h^I and h^M are unique since they are determined by the fractions of loci with genes from different breeds so they do not necessarily equal one. This results in the h^I and h^M partial regression

coefficients being unique estimates. With the restrictions imposed upon the set of genetic effect equations, $\hat{\mu}$ becomes the H least square mean for the trait of interest. Further discussion of the estimation procedures can be found in Jungst and Kuhlbers (1984).

Because the classes in a fixed classification factor sum to the equation, the number of fixed classification equations actually solved was the rank of $X'X$, $r(X'X)$. When the coefficient matrix was constructed, only the number of equations for the fixed classification factors equal to the $r(X'X)$ were included along with pertinent covariates in the construction of the coefficient matrix.

Absorption of the classification effects and covariates.

Absorption can be used to reduce the number of equations to be solved in the case of a very large set of equations or used to delete equations that are not of immediate interest to the researcher. The two absorption techniques known are block absorption and loop absorption. Block absorption was used in this analysis since the number of equations was relatively small which permitted direct inversion of the coefficient matrices. The technique of block absorption is described by Searle (1971) and Mao (1982) as

$$\begin{bmatrix} F'F & F'X \\ X'F & X'X \end{bmatrix} \begin{bmatrix} g \\ b \end{bmatrix} = \begin{bmatrix} F'y \\ X'y \end{bmatrix}$$

$$[F'F - F'X(X'X)^{-1}X'F] g = [F'y - F'X(X'X)^{-1}X'y].$$

The entire coefficient matrix and right hand side do not have to be constructed for block absorption. Parts of the coefficient matrix, $F'F$, $F'X$, and $X'X$ can be constructed separately. Also, $F'y$ and $X'y$ can be constructed separately. The following steps were performed in the block absorption routine used in the program written to analyze the data:

- 1) find the generalized inverse of $X'X$ which is designated $(X'X)^-$;
- 2) pre and post multiply $(X'X)^-$ by $F'X$ and its transpose $X'F$. This product will be unique because of the following theorems of the generalized inverse quoted by Mao (1982):
 - a) $X(X'X)^-X'$ is unique regardless of which $(X'X)^-$ is used.
 - b) $X(X'X)^-X'$ will be symmetric whether $(X'X)^-$ is or not.

Pre-multiply $(X'X)^-$ by $F'X$ and post-multiply by $X'y$.

- 3) subtract $F'X(X'X)^-X'F$ from $F'F$ and subtract $F'X(X'X)^-X'y$ from $F'y$. The genetic effect equations and right hand side have now been adjusted for the classification and covariate effects.
- 4) obtain a generalized inverse of $[F'F - F'X(X'X)^-X'F]$ then multiply by $[F'y - F'X(X'X)^-X'y]$ to obtain the solution vector, $\hat{g}$.

In order to obtain sums of squares due to fitting the model (SSM) and error sum of squares (SSE), solutions for both $\mathbf{g}$ and $\mathbf{b}$ are needed. Therefore, the following technique was used to back solve for $\tilde{\mathbf{b}}$:

- 1) post-multiply $\mathbf{X}'\mathbf{F}$ by $\tilde{\mathbf{g}}$;
- 2) post-multiply $(\mathbf{X}'\mathbf{X})^{-}$ by $\mathbf{X}'\mathbf{y}$;
- 3) take product of (1) and pre-multiply by $(\mathbf{X}'\mathbf{X})^{-}$, and
- 4) to obtain a solution vector for fixed classification factors and pertinent covariates, subtract product of 3) from product of 2), i.e.,

$$\tilde{\mathbf{b}} = (\mathbf{X}'\mathbf{X})^{-}\mathbf{X}'\mathbf{y} - (\mathbf{X}'\mathbf{X})^{-}\mathbf{X}'\mathbf{F}\tilde{\mathbf{g}} = (\mathbf{X}'\mathbf{X})^{-}\mathbf{X}'(\mathbf{y} - \mathbf{F}\tilde{\mathbf{g}}).$$

The entire inverse of the coefficient matrix does not have to be constructed since all hypothesis testing was confined to the genetic portion of the coefficient matrix. This situation is true if one compares block absorption and inversion of a partitioned symmetric matrix. If a partitioned symmetric matrix is represented as follows:

$$\begin{bmatrix} \mathbf{A} & \mathbf{B} \\ \mathbf{B}' & \mathbf{C} \end{bmatrix} \text{ and it's inverse by } \begin{bmatrix} \mathbf{P} & \mathbf{Q} \\ \mathbf{Q}' & \mathbf{R} \end{bmatrix}.$$

The different parts of the inverse can be attained by parts as shown in Searle (1966):

$$\mathbf{P} = (\mathbf{A} - \mathbf{BC}^{-}\mathbf{B}')^{-}, \mathbf{Q} = -\mathbf{A}^{-}\mathbf{BR}, \text{ and } \mathbf{R} = \mathbf{C}^{-} - \mathbf{C}^{-}\mathbf{BQ}'.$$

As a result, the inversion of a partitioned matrix and the procedure of block absorption achieve the same end result if we are interested only in the inverse of A or in this particular application. This can be shown below:

First, define the inverse of the coefficient matrix as

$$\begin{bmatrix} c^{11} & c^{12} \\ c^{21} & c^{22} \end{bmatrix} = \begin{bmatrix} F'F & F'X \\ X'F & X'X \end{bmatrix}^{-1}$$

a) Inverting a partitioned matrix -

$$c^{11} = [F'F - F'X(X'X)^{-1}X'F]^{-1}$$

b) absorption of $X'X$ -

$$c^{11} = [F'F - F'X(X'X)^{-1}X'F]^{-1}.$$

As shown above, inversion of a partitioned symmetric matrix and absorption achieve the same end result.

Estimable functions and Q - values.

Since solutions obtained for the additive and non-additive genetic effects were not unique, estimable functions were constructed in order to obtain estimates of the genetic effects. In order to check for estimability, H as defined by Searle (1971) was expressed as:

$$H = c^{11}(F'F - F'X(X'X)^{-1}X'F).$$

The resulting matrix will contain 0's, 1's, and -1's if y is normally distributed with variance-covariance matrix of $I\sigma^2$. If k' is defined as a row vector describing an estimable function,

k' would be estimable if $k'H = k'$. This test showed that all solutions were estimable with the exception of g^I and g^M for the Hereford breed which were set to zero in order to solve the set of equations. These estimable functions of g^I and g^M can be regarded as partial regression coefficients with μ being defined as the Hereford least square mean. Estimates of h^I and h^M are unique because of the design of the coefficient matrix and coefficients used for h^I and h^M . For each partial regression coefficient, the following hypothesis was tested: $H:k'\beta = 0$. The standard error for each estimable function was $(k'C^{-1}k)^{1/2}\hat{\sigma}$ where:

$$\hat{\sigma}^2 = SSE/(n - r(F'F) - r(X'X)).$$

The error sum of squares (SSE) was obtained as shown below:

$$SSE = y'y - \tilde{g}'F'y - \tilde{b}'X'y$$

where: $y'y$ is the total sum of squares;

$\tilde{g}'F'y$ is the sum of squares for genetic effects;

$\tilde{b}'X'y$ is the sum of squares for classification effects and covariates.

Simple t-tests were performed to test the significance of each effect.

Sums of squares for μ , g^I , g^M , h^I , and h^M were obtained by computing numerator sum of squares or Q - values. Q - values were constructed as shown below:

$$Q = \tilde{g}'K(K'C^{11}K)^{-1}K'\tilde{g}$$

where: $\tilde{g}$ is a vector of solutions;

K is a matrix defining estimable functions;

C^{11} is a generalized inverse for the genetic effects after absorption.

Since $K'\tilde{g}$ is estimable and K has full rank, $K'C^{11}K$ is invariant to the C^{11} used and thus has a unique inverse. For each genetic effect class, μ , g^I , g^M , h^I , and h^M , a Q - value was calculated with s being equal to the degrees of freedom for each class. The F - statistic for Q is $F(H) = Q/s \hat{\sigma}^2$. If the Q - value for each class has the maximum number of linearly independent estimable functions or $r(K)$ is equal to the degrees of freedom for that factor, Q is equal to the reduction sum of squares for that factor. In order to maintain programming ease, the Q - value approach was used in order to obtain sum of squares for each effect for analysis of variance purposes.

RESULTS AND DISCUSSION

The contrasts describing the effects of selection are listed in Table 14. Least-square means for BG1 and BG2 are listed in Table 15. Contrasts describing the effects of crossbreeding and comparisons of beef x beef and beef x dairy crossbreeding are in Tables 16 and 17, respectively. Least-square means for BG2, BG3, and BG4 are in Table 18.

Effects of within breed selection for yearling weight:

Birth and survival traits.

As indicated on Table 14, the use of bulls selected for YWT in the Hereford breed greatly increased the size of the calf at birth along with an increased incidence of calving difficulty. Selection for YWT in BG2 increased BW 8.9 kg ($P < .01$) as compared to BG1. BW should be expected to increase in response to YWT selection pressure since BW is a direct component of YWT. Data from several selection studies summarized by Koch et al. (1984) indicated BW will increase genetically in response to selection for weights at other ages.

A change in BW of this magnitude between BG1 and BG2 implies the genetic correlation between BW and YWT is greater than 1.0. A large positive genetic correlation between BW and YWT is expected

TABLE 14. EFFECTS OF WITHIN BREED SELECTION FOR YEARLING WEIGHT:

BG1 vs BG2

TRAIT	CONTRASTS
BW (kg)	-8.9 $\pm$.5**
%BL (%*100)	1.2 $\pm$ 1.8
CD	-.18 $\pm$.04**
%AB (%*100)	-13.8 $\pm$ 3.6**
RGR (%*100)	.05 $\pm$.01**
PWDG (kg*d ⁻¹)	-.10 $\pm$.01**
WWT (kg)	-28.1 $\pm$ 2.5**
% WEANED (%*100)	.60 $\pm$ 3.1
% BRED (%*100)	2.4 $\pm$ 2.9
% WINTER (%*100)	-1.5 $\pm$ 3.5
DAMWT (kg)	-71.6 $\pm$ 5.3**
WW/CW (%*100)	-.95 $\pm$.64

**P < .01

TABLE 15. LEAST-SQUARE MEANS FOR BG1 AND BG2.

TRAIT	BG1	BG2
BW (kg)	28.7 $\pm$.35	37.6 $\pm$.38
%BL (*100)	96.5 $\pm$ 1.3	95.3 $\pm$ 1.4
CD	1.22 $\pm$.04	1.40 $\pm$.03
%AB (*100)	20.4 $\pm$ 3.4	34.2 $\pm$ 2.7
RGR (*100)	.844 $\pm$.006	.795 $\pm$.007
PWDG (kg*d ⁻¹)	.613 $\pm$.009	.713 $\pm$.009
WWT (kg)	148.9 $\pm$ 4.0	176.5 $\pm$ 4.3
% WEANED (*100)	88.1 $\pm$ 2.3	87.5 $\pm$ 2.4
DAMWT (kg)	425.2 $\pm$ 3.8	496.8 $\pm$ 4.0
% BRED (*100)	86.1 $\pm$ 2.2	83.7 $\pm$ 2.2
% WINTER (*100)	81.4 $\pm$ 2.6	82.9 $\pm$ 2.6
RATIO (*100)	35.9 $\pm$.5	36.9 $\pm$.5

TABLE 16. EFFECTS OF CROSSBREEDING: BG2 vs BG3 and BG4

TRAIT	CONTRASTS
BW (kg)	-3.5 $\pm$.5**
%BL (%*100)	-1.2 $\pm$ 1.7
CD	.17 $\pm$.04**
%AB (%*100)	13.5 $\pm$ 3.3**
RGR (%*100)	-.06 $\pm$.01**
PWDG (kg*d ⁻¹)	-.19 $\pm$.01**
WWT (kg)	-41.6 $\pm$ 2.4**
%WEANED (%*100)	-.5 $\pm$ 2.9
% BRED (%*100)	-3.8 $\pm$ 2.7
% WINTER (%*100)	2.2 $\pm$ 3.2
DAMWT (kg)	-19.2 $\pm$ 4.9**
RATIO (%*100)	-6.8 $\pm$.6**

**P < .01

TABLE 17. BEEF x BEEF vs. DAIRY x BEEF CROSSBREEDING:

BG3 vs. BG4

TRAIT	CONTRASTS
BW (kg)	-.76 $\pm$.50
%BL (%*100)	-1.4 $\pm$ 1.8
CD	.15 $\pm$.04**
%AB (%*100)	12.2 $\pm$ 3.6**
RGR (%*100)	-.04 $\pm$.01**
PWDG (kg*d ⁻¹)	-.12 $\pm$.07**
WWT (kg)	-24.8 $\pm$ 2.6**
% WEANED (%*100)	-3.5 $\pm$ 3.2
% BRED (%*100)	1.0 $\pm$ 3.0
% WINTER (%*100)	.7 $\pm$ 3.6
DAMWT (kg)	-3.5 $\pm$ 5.5
RATIO (%*100)	-4.5 $\pm$.7**

**P < .01

TABLE 18. LEAST-SQUARE MEANS FOR BG2, BG3, AND BG4

TRAIT	BG2	BG3	BG4
BW (kg)	37.6 $\pm$.38	40.8 $\pm$.36	41.5 $\pm$.35
%BL (*100)	95.3 $\pm$ 1.4	95.8 $\pm$ 1.3	97.2 $\pm$ 1.3
CD	1.40 $\pm$.03	1.30 $\pm$.03	1.15 $\pm$.03
%AB (*100)	34.2 $\pm$ 2.7	26.8 $\pm$ 2.7	14.6 $\pm$ 2.7
RGR (*100)	.795 $\pm$.007	.834 $\pm$.006	.870 $\pm$.006
PWDG (kg*d ⁻¹)	.713 $\pm$.009	.849 $\pm$.009	.963 $\pm$.009
WWT (kg)	176.5 $\pm$ 4.3	205.7 $\pm$ 1.9	230.5 $\pm$ 1.8
% WEANED (*100)	87.5 $\pm$ 2.4	86.2 $\pm$ 2.3	89.7 $\pm$ 2.3
DAMWT (kg)	496.8 $\pm$ 4.0	514.2 $\pm$ 3.9	517.8 $\pm$ 3.9
% BRED (*100)	83.7 $\pm$ 2.2	86.9 $\pm$ 2.2	87.9 $\pm$ 2.2
% WINTER (*100)	82.9 $\pm$ 2.6	80.4 $\pm$ 2.6	81.1 $\pm$ 2.5
RATIO (*100)	36.9 $\pm$.5	41.5 $\pm$.5	45.9 $\pm$.4

but such a large correlated response is not possible given knowledge of literature estimates. A possible cause for such an increase in BW could be due to a positive covariance between the direct and maternal effects for BW. Koch et al. (1974) reported that genetic correlations estimated from the regression of offspring on midparent in an unselected population could be equal to or greater than 1.0 if significant maternal effects were present. In a review on maternal effects in beef cattle, Koch (1972) reported a genetic correlation between direct and maternal components for BW equal to .07. Dickerson (1947) indicated the realized selection differential could be increased if a positive covariance between direct and maternal components existed.

Because of the large increase in BW due to selection, the incidence of feto-pelvic incompatibility (FPI) was increased as a result. Calving difficulty score (CD) was increased .18 units ($P < .01$) in response to within breed selection. Percent assisted births (%AB) was also analyzed since it is more meaningful to producers who are interested in the occurrence of CD rather than the degree. The incidence of calving difficulty (%AB) was increased 14% ($P < .01$) in BG2 as compared to BG1. The increase in FPI has been attributed to the increased size of the calf at parturition. Koch et al. (1984) reported selection for weight increased the frequency of dystocia and calf mortality in two year old first calf heifers. Me'nissier (1976), in an analysis of Charolais data in France, said selection for growth and muscling

caused increased dystocia by increasing the size of the calf while the dam's pelvic area did not increase proportionally.

To further define the relationship between FPI, BW, and dams' body size at calving, a within breed group regression analysis was performed. The estimated regression equations are listed on Table 19 and mean squares for each breed group are listed on Table 20. In BG1 and BG2, BW, either linearly or quadratically, did not have a significant effect on %AB. Spring dam weight (SDW) which was used as a measure of body size at calving time was a significant source of variation in %AB, linearly and quadratically. In examining the regression equations, the relationship between %AB and SDW was curvilinear in both BG1 and BG2. This result indicated as SDW increased, %AB decreased until a minimum threshold level was reached which suggests the incidence of FPI is dependent upon BW in relation to dams' body size at calving within BG1 and BG2.

A greater but nonsignificant percentage of calves were alive 24 hours after birth in BG1 than in BG2. .01% more calves were alive in BG1 than in BG2 24 hours after parturition. The increased death loss after birth in BG2 was due to the increased calving difficulty and associated stress on the calf at birth. Koch et al. (1984) reported increases in calf mortality for calves born to two year old females in all three selection lines when compared to the control group.

Prewaning and weaning traits.

The use of within breed selection for yearling weight increased preweaning average daily gain (PWDG) and actual weaning weight (WWT) ($P < .01$) by $.11 \text{ kg} \cdot \text{d}^{-1}$ and 28.1 kg, respectively. Since WWT is a direct component of yearling weight and PWDG is a correlated trait to both WWT and yearling weight, the use of sires selected for yearling weight should increase weaning performance. In an earlier analysis of data from the Lake City breeding project, McPeake (1977) reported that selection for yearling weight within the Hereford breed increased unadjusted WWT by 17 kg or 9%.

Relative growth rate (RGR) as described by Fitzhugh and Taylor (1971) from birth to weaning was decreased by selection for yearling weight with the difference between BG1 and BG2 being $.05\% \cdot \text{d}^{-1}$ ($P < .01$). The decreased RGR indicated calves sired by bulls selected for yearling weight were later maturing than calves from the control group at weaning time. The high birth weights in BG2 were responsible for the decrease in RGR. Smith et al. (1976) estimated the genetic correlation between RGR from birth to 200 days and BW to be equal to $-.66 \pm .57$.

No significant difference existed between BG1 and BG2 for % weaned per 100 cows wintered. Apparently, most calves stressed by difficult births and other factors in BG2 were able to survive the stressful period following parturition and were present at weaning time in the fall.

Cow traits.

The effects of within breed selection for yearling weight on cow traits is of interest since daughters of the sires used would be going back into the cow herd as replacements. Me'niesser (1976) said, in his discussion of beef cattle breeding schemes for the European Economic Community, the most obvious genetic antagonism exists between selection for muscling and maternal ability. Also, numerous studies have indicated the existence of a negative relationship between direct and maternal effects. This genetic antagonism could impair the maternal ability of females raised in very favorable environments.

The utilization of selection for yearling weight increased the average cow size measured by weight substantially. Dam weight (DAMWT) measured in the fall at weaning time increased 71.6 kg in BG2 compared to BG1. The increase in cow size was to be expected since selection for weight at any age would result in increases in weight at other ages. McPeake (1977) reported selection for yearling weight within the Hereford breed increased cow weight measured in the fall by 59.6 kg.

Weaning weight to cow weight ratio (WW/CW) was used as an indicator of cow productivity. The ratio expresses the amount of weaning weight as a percentage of cow weight. Since feed intake data was not available for this study, WW/CW was used to measure cow efficiency or productivity, realizing this ratio does not actually account for differences in nutritional intake. No significant difference between BG1 and BG2 could be detected for

WW/CW. In examining the least square means for WWT and DAMWT for BG's 1 and 2, the relationship between WWT and DAMWT was further defined. The increase in DAMWT due to selection in relation to the increase in WWT was much greater.

Several reasons could account for this relationship: 1) Selection for yearling weight resulted in large increases in cow size but it did not improve the maternal ability of the females in BG2. Dim (1977) found the genetic correlation between yearling growth and milk production to be not significantly different from zero in Swedish Red and White and Swedish Friesian cattle; 2) The existence of a negative covariance between the direct and maternal effects for WWT has been reported in the literature. Studies have reported if helpers are subjected to a favorable environment prior to weaning or their growth has been increased genetically, their subsequent maternal ability will be impaired; and 3) The exact relationship between cow weight and weaning weight may not be linear. Benyshek and Marlowe (1973) found a significant curvilinear relationship between progeny weaning weight and dam weight. The relationship indicated WWT increased as DAMWT increased but the magnitude of the increase decreased over the range of cow weights in the data set.

Fertility was defined as % bred in the fall. Even though the difference between BG1 and BG2 was nonsignificant, the difference was notable. The number of females determined to be pregnant in the fall was higher in BG1 than in BG2. This decreased fertility in BG2 has been noticeable for several years. Brinks et al.

(1973) reported females which experienced calving difficulty weaned fewer calves who weighed less at weaning than females that experienced no difficulty at parturition. A negative correlation between birth weight and number of calves per year equal to $-.20$ ($P < .01$) was obtained by Singh et al. (1970). Me'nissier (1976) reported, within the Charolais breed in France, selection for growth and muscling has decreased fertility and adaptation traits.

The decreased fertility in BG2 was a result of increased post-partum anestrous caused by increased dystocia. Given a 90-day breeding period, the delay in the initiation of post partum cycling by the BG2 females reduced their chances of becoming pregnant during this time period. Also, the fertility of the clean-up bulls used would have to be questioned since few females in the past few years have been settled by the clean-up bulls used.

Effects of crossbreeding:

Birth and survival traits.

The use of crossbreeding with A, H, Ch, Sm, and Hl in rotational crossbreeding systems resulted in a large increase in BW, when compared to straightbred H (BG2). Utilization of large breeds such as Ch, Sm, and Hl provided increased breeding values for BW and individual and maternal heterosis contributed to the increase in BW. Within breed selection for yearling weight was confounded within each breed used in the two crossbred groups.

Thus, correlated responses to yearling weight selection accounted for part of the increase in BW. Crossbreeding increased BW by 3.5 kg ($P<.01$) compared to BG2. Cundiff (1984) indicated the use of large framed, high growth breeds would increase the size of the calf at birth.

Rotational crossbreeding using a dairy breed compared to all beef x beef crossbreeding did not significantly increase BW. The difference between BG3 and BG4 was -.76 kg. BG3 and BG4 differ with respect to the breeds used in the two groups. BG3 used Ch whereas BG4 used H1, even though the two breeds differed in type, they did not differ in size.

Crossbreeding decreased the incidence and degree of fetopelvic incompatibility (FPI) even though BW was increased as compared to BG2. CD and %AB were decreased by crossbreeding by .17 units ($P<.01$) and 13.5% ($P<.01$), respectively. The decrease in calving difficulty could be directly attributed to the use of large crossbred females, realizing BW was increased as a result. Price and Wiltbank (1978) in a review of the literature concerning dystocia in cattle indicated crossbred calves were heavier at birth than straightbred calves but crossbred calves did not experience more dystocia. Also, the maternal effects of birth weight and dystocia are dependent upon the size differential between sire and dam breeds used in the matings. Laster (1974) determined larger cows tended to have larger pelvic areas but with the increased cow size, BW increased as well.

Correlations obtained by Sagebiel et al. (1969) suggest calf size in relation to cow size is the major determinant in the cause of dystocia.

Holstein-Friesian breeding in a crossbreeding system did not significantly increase calf size but decreased significantly the incidence of calving difficulty. In comparing BG3 and BG4, the use of dairy breeding decreased CD and %AB by .15 units ($P < .01$) and 12.2% ($P < .01$), respectively. Data reported by McPeake (1977) indicated a similar relationship between BG3 and BG4 with the least-square means being equal to 1.36 and 1.24 for BG3 and BG4, respectively. These data suggested differences in calf shape and/or anatomical characteristics of the cow at calving were the cause of decreased dystocia in the beef x dairy cross compared to the beef x beef cross.

Hassig (1979) measured calving performance score, several measures of calf shape such as height, width, and circumference, and muscling score for calves by Fleckvieh heifers. None of the estimated correlations were greater than the correlation between birth weight and calving performance score. Differences in dystocia among breeds of similar body weight at birth implied differences in calf shape could exist thus exerting an influence on the incidence in calving difficulty. Measures of calf shape when adjusted for birth weight, as shown by Laster (1974), were not significant sources of variation in the frequency of dystocia. After birth weight was accounted for, calf shape accounted for less than 1% of the total variation in dystocia. In

data obtained from various beef x dairy crosses, Dufour et al. (1981) found circumferences of a calf's head and nose to be 1.6 and 1.3 cm larger in calves from difficult births than calves from unassisted births ($P < .01$).

Belcher and Frahm (1979) hypothesized beef x dairy cross females possessed a biological advantage for ease of calving over the beef x beef crosses such as less exterior fat, decreased muscling, or a more flexible pelvic area. Hassig (1979) obtained a low correlation of .12 between dystocia score and thigh muscularity score in Fleckvieh heifers. Differences in hormonal levels that affect the cow's ability to prepare for parturition such as adequate dilation of the cervix, strength of uterine contractions, and motility of lumbosacral joints in the pelvis have been implicated but little experimental evidence exists.

Relationship between birth weight, dam weight, and calving difficulty.

In the analysis of %AB and CD, BW was included as a linear and quadratic regression coefficient to determine if a curvilinear relationship existed between BW and the incidence of calving difficulty as suggested by several papers. As shown on Table A1, BW had a significant quadratic effect but the linear term was not significant. This suggests a curvilinear relationship between %AB and BW in which as BW increases, %AB increases at an increasing rate and a point exists where calving difficulty is minimized. Moreover, the curvilinear relationship implicates the existence of a threshold range in BW where %AB is

relatively tolerant to small increases in calf size at birth. Once this threshold is crossed, %AB increases almost exponentially.

Notter et al. (1978a) indicated in 2-year old cows, dystocia increased at an increasing rate as BW increased whereas in three-year old females, dystocia was at a minimum when BW equaled 32.4 kg. For both purebred and crossbred lambs, Smith et al. found a significant curvilinear relationship between BW and dystocia ($P < .01$). Lawlor et al. (1984) obtained a significant quadratic relationship between BW and calving difficulty ($P < .05$).

A within breed group analysis was performed to further define the relationship between BW, dam weight, and calving difficulty. Estimated regression equations and mean squares are listed in tables 19 and 20, respectively. In each breed group, BW, when included as linear and quadratic terms did not account for significant portions of variation in %AB. In BG1, BG2, and BG4, cow weight as a linear and quadratic term accounted for significant portions of the variation in %AB. This data suggests within a breed and/or mating system, the incidence of calving difficulty is dependent upon BW in relation to cow size at calving than BW alone. The linear and quadratic regression of dystocia score and % difficulty on postcalving cow weight ($P < .01$) by Nelson and Beavers (1982) indicated calving difficulty was dependent upon calf size in relation to cow size at time of birth.

TABLE 19. WITHIN BREED GROUP ANALYSIS OF CALVING DIFFICULTY

SOURCE	BG1	BG2	BG3	BG4
MEAN SQUARES				
BW	.002	.202	.104	.002
BW ²	.003	.133	.324	.000
CW	.369*	1.209**	.093	.624*
CW ²	.286+	.937**	.029	.477+
SEX	.210+	1.072**	.090	.670*
ERROR	.078	.190	.163	.135
df	229	210	232	232

**P<.01, *P<.05, +P<.10

TABLE 20. WITHIN BREED GROUP REGRESSION EQUATIONS FOR % AB

SOURCE	BG1	BG2	BG3	BG4
INTERCEPT	1.684	2.823	2.209	3.301
BW	-.006	.061	-.030	.006
BW ²	.000	-.001	.001	-.000
CW	-.612*	-1.386**	-.479	-1.117*
CW ²	.059+	.119**	.025	.090+
SEX	.032+	.073**	.020	.056*

**P<.01, *P<.05, +P<.10

Preweaning and weaning traits.

Rotational crossbreeding using A, H, Ch, Sm, and H1 improved weaning performance compared to straightbred H cattle. This increased preweaning and weaning performance was accomplished by 1) direct genetic effects for growth, 2) improved maternal ability in the crossbred female, and 3) individual and maternal heterosis. Crossbreeding increased PWDG and WWT ($P < .01$) $.19 \text{ kg} \cdot \text{d}^{-1}$ and 41.6 kg, respectively, compared to BG2. These results agree with Nelson et al. (1982) who indicated crossbred females possessed greater advantages in preweaning growth and weaning weight when compared to straightbred females. McPeake (1977) determined the increased weaning performance in BG3 and BG4 was due to the introduction of larger breeds coupled with a large breed whose sole purpose is milk production.

The introduction of dairy breeding into a rotational crossbreeding system compared to an all beef system resulted in increases ($P < .01$) of $.12 \text{ kg} \cdot \text{d}^{-1}$ and 24.8 kg for PWDG and WWT, respectively. Using dairy breeding resulted in a large scale increase in milk production while at the same time maintaining adequate direct effects for growth up to weaning. In an evaluation of type crosses within BG3 and BG4, McPeake (1977) found WWT favored calves sired by Ch bulls from British cross cows in BG3 while in BG4, calves with H1 cross dams were heavier at weaning but this difference was only 5 kg. The difference between beef x beef and beef x dairy crossing agree with Cartwright (1983) who said averaging breeding values for body

size to enhance or maintain present growth while improving lactational performance can be done.

Relative growth rate (RGR) from birth to weaning was used as an indicator of maturing rate and growth curve shape. Crossbreeding with beef and dairy breeds increased the % change in body weight per day (RGR) compared to BG2 by .058 (%*100) ($P<.01$). Calves from the two crossbred groups were larger and growthier from birth to weaning thus were able to increase body weight to body weight already attained at a greater rate than BG2 calves. Since Fitzhugh and Taylor (1971) determined RGR and relative maturing rate to be equal, the crossbred calves for their body size were maturing at a faster rate than straightbred Hereford calves. Smith et al. (1976) indicated when compared to Hereford-Angus (HA), Charolais and Simmental sired calves, even though they were heavier and faster growing, possessed lower values for RGR ($P<.05$). Sm cross females produced progeny that had higher RGR values ($P<.05$) than HA or Ch crosses (Notter et al., (1978b)). They attributed these large differences to the relationship between high milk production and high BW for the Sm cross females compared to HA and Ch crosses.

Beef x dairy cross calves possessed higher preweaning RGR than beef x beef crosses ($P<.01$) with the difference being .036 (% * 100) in favor of BG4. This would suggest beef x dairy crosses were earlier maturing than beef x beef crosses, realizing part of the increase in RGR was due to the increased growth stimulated by the improved milking ability of BG4 cows. In a

study comparing weight, height, and maturing rate in Angus (A), Hereford (H), Brahman (Br), Holstein (Hl), and Jersey (J) breeds in a diallel cross system, Nelsen et al. (1982a) found purebred Hl cows when compared to purebred cows of the other breeds were maturing at a faster rate when maturing rate was estimated by Brody's equation fitted for each individual. The Hl breed was younger at the onset of puberty than A, H, Br, and J cattle (Nelsen et al., (1982b)).

Crossbreeding did not significantly increase the number of calves alive at weaning time. The difference due to crossbreeding was -.46%. The decreased % weaned in BG3 compared to BG2 and BG4 was the main reason for the insignificant difference attributed to crossbreeding. McPeake (1977) reported crossbreeding significantly improved calf livability to weaning, particularly for Ch sired calves from British cross cows ($P < .01$).

Including dairy genes into a crossbreeding system increased % weaned noticeably. Percent weaned was increased 3.5% due to the use of Hl breeding. An increase of 8.2% was obtained by using a beef x dairy cross female but this difference was non-significant (McPeake (1977)).

Cow traits.

Crossbreeding increased cow size when measured as cow weight in the fall compared to straightbred H. DAMWT was increased 19.2 kg ($P < .01$) as a result of using A, H, Ch, Sm, and Hl breeds in crossbreeding systems. This increased cow size was attributed to the use of large breeds such as Sm, Ch, and Hl, and to heterotic

effects for cow weight. The use of crossbreeding with larger breeds increased cow size at weaning by 30 kg (McPeake (1977)). Along with the increased size, the nutritional requirements of the crossbred female are increased due to the increase in maintenance requirements associated with the larger cow size. Ferrell and Jenkins (1982) reported large mature size crossbred females' (Ch and Sm cross) annual metabolizable energy requirements were 11 to 30% greater than HA. The Sm cross had the highest energy requirements because of its large size and high milking ability. Marshall et al. (1984) determined that HA crossbred females were heavier than Sm and BS crosses but Sm and BS crosses had higher TDN intakes than HA. Cundiff (1984) indicated heavier cow weights increased output per head when cows were sold but also increased energy requirements for maintenance.

The use of dairy breeding did not significantly increase cow size compared to beef x beef females. BG4 females weighed 3.53 kg more at weaning time than BG3 females. These results agree with McPeake (1977) who indicated dairy breeding did not change cow weight. Lemenager et al. (1980) found Brown Swiss x Hereford cows were not different in weight than Charolais x Hereford cows but required 20 to 25% more lbs. of $\text{TDN} \cdot \text{d}^{-1}$ than the Charolais cross. Their results indicated energy requirements for large breeds with high milk production cannot be predicted accurately by cow weight alone.

Weaning weight to cow weight ratio (WW/CW) was used as a measure of cow productivity since feed intake data was not readily available to estimate cow efficiency. Crossbreeding by using direct genetic effects for growth, increased breeding values for maternal ability, and individual and maternal heterosis improved cow productivity, even though cow size was increased. Rotational crossbreeding systems improved WW/CW by 6.8% ($P < .01$) compared to BG2. Bartlett and Ritchie (1981) showed crossbred females weaned 3% more kg of adjusted weaning weight as a percent of their own body weight than straightbred H cows. The same relationship was true for two year old crossbred and Hereford females. Nelson et al. (1982) determined that dam weight and weaning weight were significantly related in a positive curvilinear manner ($P < .01$), indicating as cow size increases weaning weight will increase until a maximum point is reached.

WW/CW increased due to the improved milking ability of the beef x dairy cross female. The difference due to dairy breeding was 4.5% higher ($P < .01$) than BG3 dams. This increased cow productivity can be accounted for by the increased maternal ability of the beef x dairy cow since cow size did not change significantly. These results indicate that cow productivity can be improved by manipulating direct effects for cow size, calf growth, and milking ability, and maternal effects by crossbreeding with a dairy breed. This can be done as long as the nutritional requirements of the dairy cross female can be

adequately met to insure reproductive performance. Cartwright (1983) pointed out the use of dairy breeding in beef cow-calf operations can provide breeding values for desired large or small size and high milk production but maintenance requirements are increased by approximately 10%.

The use of the WW/CW ratio assumes the maintenance requirements are accounted for by cow weight. Dinkel and Brown (1978) questioned the use of WW/CW since it did not account for feed consumption. The ratio would overestimate cow efficiency if cow weight underestimated the nutritional requirements. Realizing these points, the ratio was used since feed consumption data was not available to any degree.

An interesting trend existed between WWT and DAMWT when comparing the different age groups. In examining the least-square means for age of dam, WW/CW decreased as the cow became older. The least-square means for WW/CW, WWT, and DAMWT are listed below:

AGE OF DAM:	2	3	4	5+
WW/CW ^a	42.1 $\pm$.5	40.3 $\pm$.5	39.6 $\pm$.5	38.2 $\pm$.3
WWT (kg)	178 $\pm$ 2	192 $\pm$ 2	194 $\pm$ 2	196 $\pm$ 1
DAMWT (kg)	441 $\pm$ 4	493 $\pm$ 4	503 $\pm$ 5	517 $\pm$ 3
a - % * 100				

The data indicates as the cow becomes more mature, her own weight increases at a greater rate proportional to her calf's weaning weight. In other words, cow productivity decreased as the age of

dam increased. This same relationship was noticed in data analyzed by Bartlett and Ritchie (1981) who reported for both crossbred and Hereford females, 2-year-old females were more productive in terms of adjusted weaning weight as a percentage of cow weight. Bourdon (1984) using data obtained from the Colorado State University beef production model determined that a 2-year-old female required less energy from birth to the weaning of her first calf than a mature cow raising two calves during this two year period. The maintenance of mature cows is biologically inefficient since the heifer is gaining weight and the mature cow is only maintaining weight. A maturing cow becomes more inefficient since more energy is required for maintenance and less is available for production purposes. The cow herd in order to remain biologically efficient should be kept young and not allowed to become too mature.

A greater percentage of crossbred females were diagnosed pregnant in the fall than BG2 females. Crossbreeding increased %BRED by 3.7% which approached significance ($P < .10$). McPeake (1977) used % weaned as a measure of fertility and found crossbred cattle to be more fertile than BG2 cows. The literature indicates fertility to be controlled by non-additive gene actions thus crossbreeding should be expected to improve fertility due to heterosis. No significant difference existed between BG3 and BG4 with the difference being less than 1%.

Percent wintered represented the number of cows saved to enter the wintering pasture and contains a collection of management criteria for culling that may be difficult to determine. Culling decisions were made concerning cow performance, soundness, fertility, and other criteria. It is an important trait since it represents the number of females saved for production next year. No significant differences existed due to crossbreeding and using a dairy breed. A greater percentage of BG2 cows were saved because few replacement heifers were available due to the fertility problems experienced during the past few years. In order to maintain herd numbers, females in BG2 that would have been normally culled were saved.

Additive and non-additive genetic effects on the cow-calf unit:

Estimates of the genetic effects for birth and survival traits are listed on Table 21, preweaning and weaning traits on Table 22, and cow traits on Table 23. The numerator sum of squares for each trait are on Table 24.

The additive genetic effects contain within breed dominance and epistatic effects that cannot be separated unless inbreeding is present, so the effects are totaled and called the breed additive effects. Average individual and maternal heterosis effects for the set of five breeds used in this study were estimated since the data set was not sufficient to allow estimation of specific components.

TABLE 21. ADDITIVE AND NON-ADDITIVE BREED EFFECTS:
BIRTH AND SURVIVAL TRAITS^a

Effect	BW	CD	%AB	%BL
μ^b	37.1 $\pm$.6	1.18 $\pm$.05	.153 $\pm$.043	.997 $\pm$.020
Direct ^c	-----			
A	-9.5 $\pm$ 2.6**	.05 $\pm$.23	.049 $\pm$.185	-.114 $\pm$.090
Ch	-2.3 $\pm$ 2.7	.03 $\pm$.23	.006 $\pm$.187	.006 $\pm$.092
Hl	-2.6 $\pm$ 2.9	-.08 $\pm$.25	-.070 $\pm$.208	.019 $\pm$.102
Sm	-.04 $\pm$ 2.2	.37 $\pm$.19*	.296 $\pm$.156+	-.163 $\pm$.076*
Maternal ^d	-----			
A	8.0 $\pm$ 2.1**	-.24 $\pm$.18	-.173 $\pm$.143	.041 $\pm$.070
Ch	4.4 $\pm$ 2.5	-.29 $\pm$.21	-.303 $\pm$.175+	.027 $\pm$.086
Hl	8.2 $\pm$ 2.4**	-.56 $\pm$.21**	-.533 $\pm$.170**	.019 $\pm$.082
Sm	4.3 $\pm$ 2.4+	-.51 $\pm$.20**	-.422 $\pm$.167*	.092 $\pm$.082
h^le	4.9 $\pm$ 2.7+	-.33 $\pm$.24	-.233 $\pm$.192	.166 $\pm$.094+
h^M	-3.2 $\pm$ 2.5	.29 $\pm$.22	.215 $\pm$.178	-.105 $\pm$.087

a - BW = birth weight (kg), CD = Calving difficulty score,
%AB = Percent assisted births, %BL = Percent born alive

b - μ = Hereford least-square means.

c - A, Ch, Hl, and Sm = breed direct effects for Angus, Charolais, Holstein-Friesian, and Simmental breeds, respectively.

d - A, Ch, Hl, and Sm = breed maternal effects for Angus, Charolais, Holstein-Friesian, and Simmental breeds, respectively.

e - Average direct and maternal heterosis.

** $P < .01$, * $P < .05$, + $P < .10$

TABLE 22. ADDITIVE AND NON-ADDITIVE BREED EFFECTS:
PREWEANING AND WEANING TRAITS^a

EFFECT	PWDG	WWT	RGR	%WEANED
μ^b	.656 $\pm$.013	168.7 $\pm$ 2.7	.753 $\pm$.009	.96 $\pm$.03
Direct ^c -----				
A	-.002 $\pm$.062	-8.5 $\pm$ 12.8	.065 $\pm$.043	-.31 $\pm$.16*
Ch	.010 $\pm$.060	10.6 $\pm$ 12.5	-.048 $\pm$.042	.07 $\pm$.16
Hl	.239 $\pm$.071**	48.5 $\pm$ 14.6**	.099 $\pm$.049**	-.33 $\pm$.18+
Sm	.002 $\pm$.054	18.8 $\pm$ 11.6	-.127 $\pm$.037**	-.03 $\pm$.13
Maternal ^d -----				
A	.190 $\pm$.049**	46.3 $\pm$ 10.1**	.019 $\pm$.034	.28 $\pm$.13*
Ch	.026 $\pm$.058	7.4 $\pm$ 12.0	.007 $\pm$.041	-.03 $\pm$.15
Hl	.237 $\pm$.057**	60.0 $\pm$ 11.6**	.017 $\pm$.039	.34 $\pm$.14*
Sm	.110 $\pm$.058	30.6 $\pm$ 12.0*	-.009 $\pm$.040	.33 $\pm$.14*
h^{le} -----				
h^M	.164 $\pm$.063*	26.3 $\pm$ 12.9*	.086 $\pm$.044*	.14 $\pm$.16
h^M	-.095 $\pm$.058	-21.9 $\pm$ 11.9+	-.003 $\pm$.040	-.22 $\pm$.15

a - PWDG = Prewaning average daily gain ($\text{kg} \cdot \text{d}^{-1}$), WWT = Weaning weight (kg), RGR = relative growth rate, %WEANED = percent calves weaned per 100 cows wintered.

b - Hereford least-square means.

c - A, Ch, Hl, and Sm = breed direct effects for Angus, Charolais, Holstein-Friesian, and Simmental breeds, respectively.

d - A, Ch, Hl, and Sm = breed maternal effects for Angus, Charolais, Holstein-Friesian, and Simmental breeds, respectively.

e - Average direct and maternal heterosis.

** $P < .01$, * $P < .05$, + $P < .10$

TABLE 23. ADDITIVE AND NON-ADDITIVE BREED EFFECTS:

COW TRAITS ^a			
Effect	DAMWT	WW/CW	%BRED
μ^b	502.6 $\pm$ 5.7	.336 $\pm$.007	.86 $\pm$.03
Direct ^c			
A	38.7 $\pm$ 20.5+	.075 $\pm$.023**	.26 $\pm$.11*
Ch	128.5 $\pm$ 25.1**	-.028 $\pm$.028	.29 $\pm$.13*
Hl	73.1 $\pm$ 23.5**	.158 $\pm$.026**	.34 $\pm$.12**
Sm	83.7 $\pm$ 22.9**	-.002 $\pm$.055	.41 $\pm$.12**
Maternal ^d			
A	75.1 $\pm$ 21.2**	-.008 $\pm$.025	-.36 $\pm$.11**
Ch	90.5 $\pm$ 20.1**	-.005 $\pm$.023	-.21 $\pm$.11**
Hl	114.1 $\pm$ 19.0**	-.056 $\pm$.021**	-.25 $\pm$.10*
h^{le}	-27.8 $\pm$ 12.0*	.023 $\pm$.013+	-.08 $\pm$.06
h^M	-58.0 $\pm$ 11.9**	.015 $\pm$.014	.07 $\pm$.07

a - DAMWT = Cow weight in the fall (kg), WW/CW = weaning weight to cow weight ratio, %BRED = percent pregnant in the fall.

b - Hereford least-square means.

c - A, Ch, Hl, and Sm = breed direct effects for Angus, Charolais, Holstein-Friesian, and Simmental breeds, respectively.

d - A, Ch, and Hl = breed maternal effects for Angus, Charolais, and Holstein-Friesian breeds, respectively.

e - Average direct and maternal heterosis.

**p<.01, *p<.05, +p<.10

TABLE 24. SUMS OF SQUARES FOR ADDITIVE AND NON-ADDITIVE
GENETIC EFFECTS.

EFFECT ^b	df	Trait ^a			
		BW	CD	%AB	%BL
μ	1	105585	97.3	1.64	76.43
Direct	4	421**	.8	.53	.20
Maternal	4	913**	1.7+	1.36*	.07
Ind. Het.	1	87	.4	.19	.10+
Mat. Het.	1	42	.3	.19	.05
Error	c	17825	131.8	87.60	21.35

a - BW = birth weight (kg²), CD = calving difficulty score, %AB = percent assisted births, %BL = percent born alive.

b - μ = Hereford purebred mean, Direct = breed direct effect, Maternal = breed maternal effect, Ind. Het. = individual heterosis, Mat. Het. = maternal heterosis.

c - Error degrees of freedom : 674, 671, 671, 674.

Effect ^b	df	Trait ^a			
		PWDG	WWT	RGR	%WEANED
μ	1	29.96	1965006	39.784	70.72
Direct	4	.19*	10395**	.146**	.90
Maternal	4	.53**	30146**	.016	1.41**
Ind. Het.	1	.08**	2130*	.022+	.07
Mat. Het.	1	.03	1709+	.000	.20
Error	c	7.19	306664	3.475	65.61

a - PWDG = preweaning average daily gain, WWT = weaning weight(kg²), RGR = relative growth rate, %WEANED = percent weaned.

b - same as above table.

c - Error degrees of freedom: 593, 596, 595, 674.

TABLE 24. SUM OF SQUARES CONT.

Effect ^b	df	Trait ^a		
		DAMWT	WW/CW	%BRED
μ	1	21221921	7.63	79.31
Direct	4	90576**	.44**	1.35*
Maternal	3	104381**	.04**	1.08*
Ind. Het.	1	14446*	.01+	.16
Mat. Het.	1	64327**	.00	.10
Error	c	1864964	1.70	95.75

a - DAMWT = Dam weight (kg^2), WW/CW = weaning weight-cow weight ratio, %BRED = percent bred in the fall.

b - same as above tables.

c - Error degrees of freedom: 694, 595, 891.

** $P < .01$, * $P < .05$, + $P < .10$.

Birth and survival traits.

As shown on Table 21, BW was significantly influenced by direct and maternal breed effects ($P < .01$). The direct breed effect for Angus (A) was lower than Hereford (H) ($P < .01$) but the rest of the direct effects were not significantly different from the H breed. Maternal effects for A and Holstein (H1) were positively deviated from H ($P < .01$) while the Simmental (Sm) maternal effect was greater than H ($P < .10$). The Charolais (Ch) maternal effect was positive but not significantly different from zero. These data agree with Dillard et al. (1980) that birth weight is significantly influenced by breed direct and maternal effects.

Individual heterosis for BW equaled 4.92 ± 2.72 kg which indicated some individual inter- and intra- loci interactions increased BW but maternal heterosis was not an important influence on calf size at birth.

A correlation between the breed direct and maternal effects, $r_{g|gM}$, was estimated and it indicated a negative relationship between the direct and maternal breed components for birth weight. The $r_{g|gM}$ was equal to $-.67$. The relationship suggests using breeds to decrease birth weight directly would result in increased maternal effects causing birth weight to increase. Burfening et al. (1981) reported a negative correlation between direct and maternal effects for birth weight in Simmental data of $-.24$. An average literature estimate of $-.44$ was presented by Koch (1972).

Calving difficulty score (CD) was significantly influenced by breed maternal effects but direct effects were not significant with the exception of the direct effect for the Sm breed. The Sm direct deviation was equal to $.37 \pm .19$ units ($P < .05$). The other breed direct effects were not significantly different from H. Each of the maternal breed effects were negatively deviated from g_H^M with Sm and Hl being the largest deviations ($P < .01$). The correlation between g^I and g^M was negative indicating an antagonistic relationship exists between the direct and maternal effects. The data suggests large breeds such as Sm and Hl be used in a rotational cross in order to take advantage of the maternal superiority in calving ease possessed by these breeds. These results support the maternal grandsire model which indicates to decrease calving difficulty, breeds or sires known for above average calving difficulty should be used and the resulting daughters should be retained to decrease calving difficulty in future generations. Heterosis, individual and maternal, did not significantly affect CD or % AB. Calving difficulty appears to be influenced by breed direct and maternal effects.

The inferences made concerning CD are the same for %AB with one exception, the breed maternal effect for Ch was negatively deviated from H ($P < .10$). Estimates of the direct and maternal breed effects indicate calving difficulty can be reduced by using large breeds on the maternal side of the pedigree, realizing CD could be increased by the direct breed effects on the calf.

Calf mortality at 24 hours after birth (%BL) was not affected by breed direct and maternal effects. The direct effect for the Sm breed was negatively deviated from the H breed ($P<.01$). Lawlor et al. (1984) indicated the greatest death loss after birth was found in calves sired by Sm bulls.

Individual heterosis for %BL was equal to $.16 \pm .09\%$ ($P<.10$) which indicates non-additive gene action is important for calf survival. Crossbreeding with the five breeds used in this study should improve calf survival after birth. Long (1980) reported average heterosis was important for calf survival and estimates in the literature ranged from 3 to 15%.

Preweaning and weaning traits.

Preweaning average daily gain (PWDG) was influenced by breed direct ($P<.05$) and maternal effects ($P<.01$) which indicated direct and maternal breed differences were important for preweaning growth. The H1 direct effect was deviated positively from the H breed ($P<.01$). None of the other direct breed effects were of importance. Maternal effects for A and H1 were significant and positively deviated from the H effect ($P<.01$). These estimates reflect the superior maternal ability of these two breeds compared to the H breed. The estimated maternal effects for A and H1 agree with Nelson et al. (1982) who indicated that AH and SH dams were superior to HH dams in terms of calf preweaning growth. Individual heterosis was equal to $.16 \pm .06 \text{ kg} \cdot \text{d}^{-1}$ ($P<.01$) while maternal heterosis was not significant. The h^1 estimate agrees

with other crossbreeding studies which show individual heterosis to be important in improving calf growth from birth to weaning time.

The insignificance of the estimates of g^I and g^M for the Sm breed was surprising given the fact that the Sm breed is a large, high growth rate, heavy milking breed. Sampling errors were probably the cause for the insignificant estimates. Also, the matings represented in the data set could be a cause since most calves were sired by Sm bulls from 1978 to 1982 which did not allow for adequate comparisons with the other breeds.

Maternal effects were the primary genetic influence on weaning weight in this data set with differences in breed maternal ability being significant ($P < .01$). The breed direct effect for H1 was equal to 48 ± 14 kg ($P < .01$) while the other direct effects were non-significant. A, H1, and Sm maternal effects were positively deviated from H reflecting the superior milking ability of these breeds. WWT was significantly influenced by individual and maternal heterosis. Individual and maternal heterosis estimates were equal to 26 ± 13 kg and -21 ± 12 kg, respectively. The estimate for h^I agrees with other studies reviewed in Long (1980) which indicated WWT is increased due to individual non-additive gene action. The maternal heterosis estimate is negative which is contrary to other studies that show maternal heterosis for WWT to be positive.

Estimates of the H1 direct genetic effect for PWDG and WWT were unusually large compared to H. From 1978 to 1982, most

calves in BG4 were sired by Sm bulls with relatively few being sired by H1 bulls. During this period, the H1 breeding was concentrated in the dam side of the pedigree. The estimates of the H1 direct effect for PWDG and WWT reflect the maternal effects of the H1 breed and are overestimated to some degree as a result.

Prewaning relative growth rate (RGR) was influenced by direct breed effects ($P < .01$) and individual heterosis ($P < .10$). Maternal breed effects were not significantly deviated from the g_H^M . The H1 and Sm direct breed effects were significant ($P < .01$) but of opposite signs from the H direct effect. The H1 direct estimate was equal to $.100 \pm .049$ while the Sm direct estimate was equal to $-.127 \pm .037$. These estimates reflect the differences in maturing rate of two breeds of comparable body size compared to the H breed. The H1 breed would appear to be earlier maturing while the Sm breed was later maturing compared to the H breed. Gregory et al. (1978) determined BS sired calves had an increased maturing rate than Maine-Anjou (MA) or Chianina (C) sired calves but BS calves were later maturing when compared to HA calves. Smith et al. (1976) determined Sm sired calves possessed lower RGR values than HA calves while Notter et al. (1978b) indicated H1 sired calves were later maturing than HA sired calves. Individual heterosis was significant for RGR being equal to $.086 \pm .044 (\% \times 100)$ ($P < .05$). No significant heterosis could be detected by Smith et al. (1976) in HA calves for RGR.

Percent WEANED was influenced by maternal breed deviations ($P < .01$) while direct breed and heterosis effects were not significant sources of variation. Maternal effects for A, H1, and Sm were positively deviated from the H breed effect ($P < .01$). The maternal effects for % WEANED were in general agreement with the estimates for %BL and CD. The maternal effects which decreased calving difficulty increased the number of calves born alive and the number of calves alive at weaning. The fact that heterosis was not significant is surprising since several studies summarized in Long (1980) reported positive heterosis for calf survival at weaning.

Cow traits.

Breed direct and maternal effects were important for DAMWT and reflect breed differences, directly and maternally, for cow size. The direct effects for Ch, H1, and Sm exceeded the H effect ($P < .01$) and were indicative of the increased size of these three breeds. Maternal deviations for A, Ch, and H1 were positive ($P < .01$) and indicated large maternal differences in size between the A, Ch, and H1 breeds with the H breed. The data indicates the utilization of these three breeds in crossbreeding systems would result in increased cow size, especially if Ch, H1, or Sm breeding was used in a rotational crossbreeding scheme.

Estimates for individual and maternal heterosis were significant, ($P < .05$) and ($P < .01$), respectively, but each estimate was negative. The estimates were -27.8 ± 12.0 kg and -58.0 ± 11.9 kg for h^I and h^M , respectively. When the additive and

non-additive estimates were used to predict means for different breed combinations, the individual and maternal heterosis effects did not allow cow size to become extremely large. The biological significance of these heterosis estimates, if any, is not clear to the author at this time.

Direct breed effects for WW/CW were important ($P < .01$) and are a reflection of differences in cow productivity between the breeds used in this study. A and HI direct effects were significant and positively deviated from the H breed ($P < .01$). The breed direct effects for A and HI were indicators of the superior maternal ability possessed by these two breeds compared to the H breed. Maternal effects on WW/CW were influential ($P < .10$) and the HI maternal effect was equal to $-.056 \pm .021$ ($P < .01$) which indicates using females from HI cross dams could decrease cow productivity in terms of % of body weight expressed as calf weight at weaning.

The relationship between the direct and maternal effects for HI indicate an antagonism between the direct and maternal contributions to cow productivity. Using daughters from HI cross females could result in decreased productivity for these retained daughters. The data suggests the improved milking ability of the HI breed as indicated by the direct breed effect could be detrimental to the future productivity of crossbred heifers nursing these HI cross females as shown by the negative maternal effect. McPeake (1977) determined the extra milk received by crossbred heifers may have decreased their productivity as cows.

Individual heterosis was significant ($P < .10$) for WW/CW while maternal heterosis was not of any significance. The estimates indicate some individual heterosis exists for cow productivity but direct and maternal breed differences were the major sources of variation in WW/CW.

Direct and maternal breed effects were significant sources of variation in % BRED ($P < .01$) The direct effects for A, Ch, Hl, and Sm were positive deviations while the maternal effects were negative for A, Ch, and Hl. The negative maternal effects for % BRED correspond to the positive deviations for the maternal effect in WWT, particularly for A and Hl. Improving the maternal ability for WWT could result in decreased fertility maternally for crossbred cows, yet the direct effects for %BRED were positive indicating improved fertility for this same set of breeds. Individual and maternal heterosis did not have a significant effect on %BRED in this data set. Cundiff et al. (1974) reported a 5.2% increase ($P < .01$) in diagnosed pregnancies in the fall due to crossbreeding.

For each trait analyzed, the individual and maternal heterosis estimates were of opposite sign in each case. The crossbreeding system used may have imposed a negative correlation between individual and maternal heterosis. During 1978 to 1982, a fourth breed was being introduced into BG3 and BG4 while maternal breed composition remained relatively the same. This could have

increased individual heterosis while maternal heterosis remained the same since the composition of breeds making up the maternal pedigree was not changed noticeably.

CONCLUSIONS

Data comprising of 1232 cow records obtained from the Lake City breeding project were used to evaluate the use of within breed selection for yearling weight, rotational crossbreeding, and utilization of dairy breeding in beef production. Also, direct and maternal breed effects, and individual and maternal heterosis effects were estimated for the five breeds used in this study.

Within breed selection for yearling weight increased birth weight significantly and as a result, increased the incidence and degree of calving difficulty. Weaning and preweaning growth was increased by selection for yearling weight but calves sired by bulls selected for yearling growth were later maturing as indicated by a decreased RGR. Selection within the Hereford breed for yearling weight increased cow weight but did not improve cow productivity as measured by WW/CW ratio. Also, the number of selected Hereford females diagnosed pregnant in the fall was reduced compared to the control group.

The use of rotational crossbreeding using the five breeds in the study increased birth weight but utilization of large crossbred females resulted in decreased calving difficulty compared to the straightbred Hereford group. Crossbreeding improved preweaning growth and weaning weight by increased

breeding values for preweaning growth and improved maternal ability of the crossbred cow. The number of calves alive at weaning was not improved by crossbreeding compared to BG2. Cow size was increased by rotational crossbreeding with large breeds such as Charolais, Holstein, and Simmental but cow productivity was increased due to the improved maternal ability of these crossbred females. Furthermore, the number of pregnant females in the fall was increased by crossbreeding.

Crossbreeding with the Holstein breed decreased the incidence of calving difficulty and did not significantly increase calf size at birth. The superior milking ability of the beef x dairy cross female increased preweaning growth and weaning weight while increasing the RGR of the beef x dairy cross calf. The number of calves alive after birth and at weaning was increased compared to beef x beef crossbreeding. Using a dairy breed in a crossbreeding system did not increase cow size but the infusion of genes for increased milk production improved cow productivity.

Calving difficulty was more dependent upon calf size in relation to cow size at birth than on calf size alone. Within each breed group, the quadratic regression of birth weight on cow weight was an important source of variation in calving difficulty. In the breed group analysis, a curvilinear relationship existed between BW and calving difficulty suggesting the existence of a threshold point in BW where calving difficulty starts to increase significantly. Differences in calving

difficulty between BG3 and BG4 suggest differences in calf shape and/or anatomical characteristics of the cow at calving were responsible since no difference in birth weight was found.

Birth weight was influenced by direct and maternal breed effects and was not significantly affected by heterosis effects. For calving difficulty score and percent assisted births, maternal breed effects were the most important source of genetic differences. The estimates for Ch, H1, and Sm maternal effects indicated using these breeds in the maternal pedigree would reduce feto-pelvic incompatibility. Estimates of the direct and maternal effects for Sm suggest the use of Sm breeding in crossbreeding programs would increase calving difficulty directly but would decrease dystocia from the maternal side. Also, the use of H1 breeding would decrease calving difficulty due to maternal effects. The direct and maternal effects for %BL were not significant except the direct effect for the Sm breed which decreased %BL.

Weaning weight (WWT) and preweaning average daily gain (PWDG) were influenced mostly by the breed maternal effects. the maternal effects for A and H1 reflected their superior maternal ability compared to the H breed. Individual heterosis was important for WWT and PWDG. The direct effect of Sm and H1 were significant for RGR but were opposite in sign. Direct effects for RGR of the Sm and H1 breeds suggested differences in maturing rates compared to the H breed up to weaning age. Maternal effects

for %WEANED were important with the maternal effects for A, H1, and Sm being positively deviated from the H breed.

Direct and maternal effects for cow weight were important with all breeds used in this study possessing positive deviations for cow size compared to the H breed. Anomalous results were obtained for individual and maternal heterosis in which the biological implications could not be determined.

The number of females diagnosed pregnant in the fall was influenced by direct and maternal breed effects. The H breed possessed greater maternal effects for %BRED but the other breeds were superior in terms of their direct contributions to fertility.

The Holstein-Friesian breed in this study appeared to complement the other breeds used in the rotational crossbreeding systems. Estimates of the direct and maternal breed effects for H1 indicate increases in birth weight maternally but calving difficulty could be reduced by using beef x Holstein cross females. The single greatest contribution to the cow-calf unit by the H1 breed was a large, positive maternal effect for calf growth from birth to weaning. RGR was increased using the H1 breed directly which indicated that increased maturing rates upto weaning could obtained compared to the other breeds in this study. Cow size was increased directly and maternally by using the H1 breed in crossbreeding systems with recognized beef breeds but cow productivity would also be increased. The utilization of the H1 breed could have a detrimental maternal effect on the

maternal performance of replacement heifers from beef x HI cross cows. The direct use of the HI breed to improve cow productivity could result in impaired productivity of heifers saved from these beef x HI cross cows when these heifers enter production because of the negative maternal effect for cow productivity.

APPENDIX

TABLE A1. ANALYSIS OF VARIANCE FOR BREED GROUP ANALYSIS:

BIRTH AND SURVIVAL TRAITS					
SOURCE	DF	BW(kg ²)	% BL	CD	% AB
MEAN SQUARES					
YR	4	38	.03	.2	.1
BG	3	6640**	.02	1.9**	1.2**
AGE	3	640**	.10**	10.4**	8.8**
SEX	1	1408**	.05	1.6**	1.5**
(YR*BG)	12	36	.05	.2	.2
(BG*AGE)	9	34	.03	.6**	.4**
BW	(1)	--	--	.4	.2
BW ²	(1)	--	--	1.1*	.7*
ERROR	N ^a	24	.03	.2	.1

**P<.01, *P<.05

^aN: 915 915 888 888

TABLE A2. ANALYSIS OF VARIANCE FOR BREED GROUP ANALYSIS:

PREWEANING AND WEANING TRAITS

SOURCE	DF	PWDG	WWT(kg ²)	RGR	%WEANED
MEAN SQUARES					
YR	4	.224**	55413**	.202**	.092
BG	3	3.889**	208051**	.152**	.040
AGE	3	.178**	9380**	.059**	1.066**
SEX	1	.691**	32046**	.008	.362+
(YR*BG)	12	.020	655	.012*	.084
(BG*AGE)	9	.024*	7561**	.009	.104
DAYS	(1)	--	63974**	--	--
ERROR	N ^a	.012	551	.006	.099

**P<.01, *P<.05, +P<.10

^aN: 787 793 789 915

TABLE A3. ANALYSIS OF VARIANCE FOR BREED GROUP ANALYSIS:

COW TRAITS					
SOURCE	DF	DAMWT(kg ²)	WW/CW	%BRED	%WINTER
MEAN SQUARES					
YR	4	63005**	.008	.652**	.377*
BG	3	355250**	.337**	.074	.026
AGE	3	256776**	.058**	.289+	.356+
SEX	1	--	.197**	--	--
(YR*BG)	12	10861**	.006*	.078	.007
(BG*AGE)	9	3264	.009**	.294*	.292+
DAYS	(1)	--	.261**	--	--
ERROR	N ^a	2847	.003	.122	.157

**P<.01, *P<.05, +P<.10

^aN: 899 778 1194 1200

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