THE EFFECT OF CROSSBREEDING ON LENGTH OF GESTATION PERIOD AND BIRTH WEIGHT OF DAIRY CATTLE

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ABSTRACT

THE EFFECT OF CROSSBREEDING ON THE LENGTH OF GESTATION PERIOD AND BIRTH WEIGHT OF DAIRY CATTLE

The effects of crossbreeding upon duration of gestation and birth weight were analyzed from data collected over a period of 11 years from a crossbreeding project utilizing the University of Manitoba dairy herd. The project involved four breeding groups of calves: purebred Holstein-Friesian (H x H), two-breed cross (BS x H), three-breed cross A(BS x H) and three-breed backcross to Holstein, H.A(BS x H). The symbols H, BS and A represent Holstein, Brown Swiss and Ayrshire, respectively.

Estimates of the pooled effects upon gestation length and birth weight of two non-genetic sources of variation _viz._ sex and parity (calving sequence) were obtained. The magnitude of the effects expressed as weighted mean differences ($\bar{d}$) were:

Gestation Length (Days)	$\bar{d}$ ± SE
Sex: Male - female	0.93 ± 0.44
Calving Sequence: Parities 2 and subsequent - Parity 1	0.88 ± 0.52
Birth Weight (Kg)	
Sex: Male - female	2.76 ± 0.48*
Calving Sequence: Parities 2 and subsequent - Parity 1	2.68 ± 0.52*

* $p < 0.05$

Data were adjusted for the effects of sex and calving sequence. The adjusted means were:

Breeding Group	Gestation Length (days)	Birth Weight (kg)
H x H	283.27	42.79
BS x H	289.21	45.79
A (BS x H)	285.37	41.39
H.A (BS x H)	284.64	41.34

The comparisons among the adjusted means showed significant breeding effects. These comparisons were:

Comparison	$\bar{d} \pm SE$ Gestation Length	$\bar{d} \pm SE$ Birth Weight
(BS x H) vs. (H x H)	5.72 ± 0.70*	3.29 ± 0.68*
A(BS x H) vs. (H x H)	3.01 ± 0.78*	-1.81 ± 0.63
H.A(BS x H) vs. (H x H)	3.18 ± 0.90*	-3.15 ± 0.81*
(BS x H) vs. A(BS x H)	2.44 ± 0.89	7.35 ± 0.92*
(BS x H) vs. H.A(BS x H)	3.11 ± 1.77	5.68 ± 1.72
A(BS x H) vs. H.A(BS x H)	-0.75 ± 0.79	-3.04 ± 0.98

The observed values of gestation length agreed closely with expectations based on additive gene action indicating no manifestation of heterosis. No such agreement was observed for birth weight indicating the presence of non-additive gene action in birth weight.

* $p < 0.05$

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I. INTRODUCTION

Relatively little crossbreeding is practiced in commercial dairy production in North America or Europe. Several reasons can be advanced to explain the reluctance of dairy cattle producers to adopt a breeding system which has materially benefited producers of other types of livestock. Perhaps one of the main reasons is that research stations have not found conclusive evidence of the merits of crossbreeding dairy cattle. Few projects have been conducted with adequate numbers of animals over a sufficient duration of time to permit reasonably unqualified recommendations.

Experimental evidence from both laboratory species and economic species in both plants and animals does suggest that the exploitation of heterosis could contribute to the improvement of the dairy industry. Heterosis has been defined (Lush,1948) as the superiority of the hybrid over the mean of its parental breeds. The degree of superiority has been found to vary with the trait. Thus lowly heritable traits i.e. those which give little or no response to selection, show the greatest degree of heterosis. Examples of such traits include litter size in swine and egg production in poultry. In general, traits associated with reproduction have low heritabilities but respond well to crossbreeding. Highly heritable traits e.g. carcass characteristics in meat animals, show little or no heterosis from crossbreeding.

The present study consists of an investigation of the effects of crossbreeding upon certain aspects of reproductive performance in dairy cattle. Specifically the traits were duration of gestation and birth weight. The data for the study were obtained from a crossbreeding project conducted at the University of Manitoba.

II. REVIEW OF LITERATURE

A. Gestation Length

An accurate knowledge of the time to expect the birth of a calf enables preparation of the cow to be made for subsequent parturition and lactation e.g. drying off the cow and getting her in the proper physical condition. The length of the gestation period becomes of concern to the dairyman when the calves are carried for an extremely long time and calving difficulties result, or when calves are born prematurely (Knott, 1932; Brackel et al, 1952; and Touchberry and Bereskin, 1966).

It is believed by many stockmen that calves born following a gestation period considerably shorter than the average are not likely to develop into animals of good merit. This may be due to the greater chance in getting an immature calf after a short pregnancy. At one time a cow could not obtain an official Record of Performance (R.O.P.) if the calving interval (period in days between successive calvings) exceeded a specified maximum period (Brackel et al,1952). The purpose of this requirement was to assist in determining the duration of pregnancy during the official testing period, and for this purpose the need to determine the "normal length of gestation" has been the subject of much research work (Brackel et al, 1952).

1. The Normal Length of the Gestation Period

Mumford (1917) defined the gestation period as: "The period of development from fertilization of the egg by the sperm cell until the birth of the fully developed offspring capable of independent existence outside the body of the mother is known as the period of gestation".

This definition is a theoretical one, for the time of fertilization cannot be known, hence, for practical purposes the gestation period in cattle is understood to include the period of time from service of the cow by the bull or by A.I. until the birth of the calf (Knott, 1932).

An "average" gestation period is not applicable to all cattle because of well recognized breed differences as well as certain environmental influences upon the duration of pregnancy. Brackel et al (1952), reviewed the studies of many workers and outlined estimates of "average" gestation length (Table 1). The estimates from several sources were averaged to obtain overall breed means.

2. Causes of Variation in Gestation Length

As is the case with most traits, variation in gestation length is controlled by both genotype and environmental factors. Lush (1948) defined heritability as "the fraction of the observed or phenotypic variance which is caused by differences between the genes or genotypes of individuals". Alim (1965), using the Holstein-Friesian breed, reported a heritability of .29 as estimated from the paternal half sib correlation. This estimate was in agreement with that reported by De Fries et al (1959,) but less than that reported by Wheat et al (1959) of .50. In general, the heritability of gestation length falls in the "medium" range of values.

Table 1. Mean length of gestation period for various breeds, (Brackel *et al*, 1952).

Breed	Period	No. of Observations	Average Gestation Length
Ayrshire	1922-1950	1,171	279.8
Brown Swiss	1938-1950	10,745	289.6
Guernsey	1922-1950	744	282.9
Friesian	1943-1947	1,291	276.2
Holstein-Friesian	1922-1950	6,164	279.3
Black Pied	1944-	311	279.7
Jersey	1922-1950	3,313	279.5
Aberdeen-Angus	1945-1948	384	279.9
Hereford	1944-1948	500	283.5
Red Poll	1934-	788	285.0
Shorthorn-Beef	1908-1944	1,400	281.2
Shorthorn-Milking		170	281.8

Various reports have shown that sex of calf, age of dam, sire and interaction among these variables can affect gestation length in cattle (Jafar et al, 1950; and Tandon, 1951). Brackel et al (1952) showed that breed and season of calving affect the gestation length, in addition to previously mentioned factors. McDowell et al (1959) showed that crossbreeding had a pronounced effect on the gestation length in a Jersey-Sindhi crossbreeding project.

a. Sex of Calf

Research workers agree that the sex of calf contributes a part of the variation in gestation length (Knott, 1932; Jafar et al, 1950; Livesey and Bee, 1945; Brackel et al, 1952; Herman and Spaulding, 1947; Alim, 1965; and Touchberry and Bereskin, 1966).

Knott (1932) found from a study of 1438 gestation periods, that bull calves in the Holstein-Friesian are carried one day longer than heifer calves. A later report by Jafar et al (1950) on the same breed showed that the difference between gestation periods of cows depended significantly on the sex of the calf.

Burris and Blunn (1952) reported that sex differences were associated with some breeds, while in other breeds the differences were not significant (Table 2). They stated: "Hereford and Angus bull calves were carried for longer gestation periods than heifer calves, while the Shorthorn heifers were carried longer than the bull calves. The difference in gestation length of the sexes was significant only for the Angus breed".

Table 2. Sex differences in gestation length. (Burris and Blunn, 1952).

Breed	Sex: Males	Sex: Females	Difference (Days)
Angus	282.9	280.7	2.2*
Hereford	286.8	285.4	1.4
Shorthorn	284.2	284.3	-0.1
All breeds	284.7	283.4	1.3

*: $P < .05$

The findings of Knapp <u>et al</u> (1940) were contradictory to those reported by Burris and Blunn (1952); their results showed that male calves were carried 2 days longer than female calves in the Shorthorns. Livesey and Bee (1945) agreed with Burris and Blunn (1952) on the significant differences in the Hereford cattle but found that differences between sexes in the Angus were not significant.

Brackel <u>et al</u> (1952) studied 1256 gestations in five major dairy breeds and reported the results shown in Table 3.

The Guernsey and Holstein-Friesian breed showed highly significant ($P < .01$) sex effects, while the Jersey, the Ayrshire and the Brown Swiss did not show any significant differences due to sex. These effects were significant when all the breeds were combined.

In general, previous studies show that sex of calf has an effect on the length of gestation period, but the effects may vary with breeds.

Table 3. Mean gestation length of male and female calves. (Brackel et al, 1952).

Breed	Male		Female		D (Days)
	No.	d	No.	d	
Guernsey	131	283.44	146	281.97	1.47**
Holstein-Friesian	191	279.25	163	277.77	1.48**
Jersey	117	278.30	132	277.49	.81
Ayrshire	172	278.31	159	278.01	.30
Brown Swiss	20	287.95	25	288.68	-.73
All 5 Breeds	631	279.96	625	279.19	.77**

*: $P < .05$

**: $P < .01$

d = gestation length

D = male - female

b. Effect of Calving Sequence and Age of Dam on Gestation Length

The word "parity" is defined as the state or fact of having borne offspring. The number which is prefixed to the word parity describes the order of parity in relation to the reproductive life of a cow. This can be described as the sequence of calving. Hence, the words parity and calving sequence are often used interchangeably.

The age of dam is associated with the parity order; a cow which has had four calvings is likely to be at least six years of age, and a cow which is only two years old could not have had more than one calving. Hence, parity to a marked extent, is an indicator of age and the effect of one is included with the other; this assumes that a cow calves normally each year and that she calves first at two years of age.

Investigators are not entirely in agreement regarding the effect of age of dam on gestation length. Copeland (1930), Jakubec (1941), Knapp et al (1940), McCandlish (1922), Weaver et al (1947), Burris and Blunn (1952), Jafar (1950), Alim (1965), McDowell et al (1959) and Herman and Spaulding (1947) reported that the age or the sequence of calving has no effect on the length of gestation period, or that the effects are too small to be significant. On the other hand, Jordao et al (1943, 1938 and 1939); Johansson (1928) and Davis et al (1954), reported that age of cow has an effect on gestation length. The work by Johansson (1928) showed that calves of first parity are carried 1.1 days less than the average of all the consecutive gestations; the difference was significant. Touchberry and Bereskin (1966) reported parity effects in the Holstein-Friesian, but the magnitude of these effects was in the opposite direction to those reported by Johansson (1928); they stated that calves of first parity were carried 1.4 days longer than the average gestation length, whereas the second and third gestation were not different than the mean gestation length. In other words, only the first gestation period was longer than the breed mean gestation period.

Brackel et al (1952) found that the length of gestation period appears to increase slightly until the dam is five years old.

c. The Sire Effect on Gestation Length

Burris and Blunn (1952) detected sire effects on gestation length, but these effects were not significant. The results of Gerlaugh et al (1951), showed that the sire as well as the dam influenced gestation length.

Touchberry and Bereskin (1966) reported that calves by Holstein sires were carried 4.49 days less than those by Guernsey sires, when the dams were purebred Guernseys. McDowell et al (1959) reported that Jersey-Sindhi crossbred calves carried by Jersey dams are carried 5 - 8 days longer than the purebred Jersey calves. This is generally the crossbreeding effect which includes the effects of breed of dam, breed of sire and breed of foetus, together with all other random effects.

d. The Effect of Breed on Gestation Length

It is stated by most workers who have compared various breeds in regard to gestation length, that breeds contribute to the variation in gestation length.

Table 1 presented the mean gestation length for a number of breeds; Brackel (1952). Herman and Spaulding (1947) estimated the mean gestation length in Holstein-Friesian, Jersey and Guernsey dairy cattle as 278.11, 280.36 and 284.00 days respectively. The differences among these estimates were significant.

Porter _et al_ (1965) reported that the difference between the gestation length of the Holstein cattle (279 days) is one day longer than that of the Ayrshire cattle (278 days), and the gestation length of the Brown Swiss cattle (290 days) is 11 days longer than the Holstein cattle.

Brackel _et al_ (1952) reported an average gestation length for the Holstein-Friesian similar to that reported by Herman and Spaulding (1947) and found that the average gestation length for the Holstein, the Ayrshire and the Jersey did not significantly differ; however, the difference between Brown Swiss and Guernsey and the other three breeds was significant.

McDowell (1959) reported in crosses involving Jerseys and Sindhis that for each 25 percent of Sindhi inheritance, there was an increase of approximately three days in length of gestation period.

The report by Touchberry and Bereskin (1966) on crossbreeding Holstein-Friesian and Guernsey cattle showed that for each increase of 1/8 Holstein in breeding of the dam the gestation period of the calf decreased by .33 days and the Guernsey dams carried their calves 2.6 days longer than the Holstein-Friesian dams.

e. Effect of Season on Gestation Length

There are conflicting reports in the literature concerning differerences in gestation length due to seasonal effects.

Herman and Spaulding (1947) and Alexander (1950) working with dairy cattle, agreed that in most cases, gestation length based on date of calving was shorter for winter calves than it was for summer calves, where winter is defined to include the months of December, January, and February and summer includes the months of June, July, and August. The report by Herman and Spaulding showed a significant difference of 1 - 3 days due to seasonal effects. Alim (1965) reported a difference of 2.7 days in western breeds of dairy cattle in Sudan, during the summer season.

Brackel <u>et al</u> (1952) grouped the gestations of three dairy breeds, Holstein, Ayrshire, and Jersey cattle from the Ohio State University herd for the period 1922-1949, according to the month of calving. They found that the longest mean was for April calvings and the shortest was for November; the difference was 3.29 days and highly significant ($P < .01$).

Jafar <u>et al</u> (1950) reported that neither the year nor the season affected gestation length.

f. Interaction of Factors Affecting Gestation Length

Most workers assume the independence of the factors affecting the gestation length, and that interactions among these factors either do not exist or are of little importance and negligible.

Burris and Blunn (1952) reported that the interaction between the sex of calf and breed was not significant, while the report by McDowell <u>et al</u> (1959) found that this interaction as well as the interaction between sire effect and sex effect were significant.

Jafar et al (1950) working with the Holstein-Friesian breed reported that the interaction between sex of calf and calving sequence has a significant effect on the gestation length. (Table 4)

Table 4. Analysis of variance of gestation periods for sex and calving sequence, (Jafar et al, 1950).

Source of Variation	Degrees of Freedom	Mean Square
Between Sexes (A)	1	323.8**
Between Calving Sequence (B)	4	33.8
Sex X Calving Sequence (A X B)	4	53.0*

**P < .01

*P < .05

B. Birth Weight

The size of calf at birth expressed as weight, has at times been a problem to the dairyman. His aim is to get calves as large as possible but with minimum calving problems.

Everett and Magee (1965) reported that, in the state of Michigan, about 20% of the artificially bred dairy heifers were mated to Angus bulls, in order to produce smaller calves and thus reduce calving problems.

They reported that some dairy bulls sire larger calves than others, resulting in a greater incidence of calving problems, and on occasion, a reduction in subsequent milk production of the dam.

Beef cattle research workers have shown that birth weight can be used to predict weaning weight, (Gregory et al 1950; Koch and Clark, 1955), weight at one year (Koch and Clark, 1955), rate of gain to weaning, rate of gain during fattening, or rate of gain from birth to slaughter (Dawson et al, 1947; Gregory et al, 1950; Knapp et al, 1940; Koch and Clark, 1955; and Martin, 1956), fattening performance and final weight (Pierce et al, 1954.)

In spite of the fact that birth weight is a body characteristic, some dairy research workers have tried to correlate birth weight of a calf and milk production of the dam following the birth. Legault and Touchberry (1962) found a non-significant correlation between birth weight and the immediate lactation of the dam; these results agree with those reported by Blackmore et al (1958) and Martin (1956).

1. Variability in Birth Weight

Birth weight is only partly the result of heredity, as environmental effects collectively contribute a major proportion of the variability.

Various estimates show that the heritability of birth weight ranges between .22 and .51 (Burris and Blunn, 1952; Koch and Clark, 1955; Legault and Touchberry, 1952; and Everett and Magee, 1965). In general the heritability of birth weight is considered to be of medium value.

Birth weight is a variable, and its variability depends on several factors. These factors can be classified as genetic and environmental.

In order to demonstrate the variability in birth weights, Table 5 was adapted from various literature reports.

Table 5. Birth Weight of Certain Breeds of Cattle.

Breed	Average Birth Weight (kg)	Reference
Holstein	44.27	Everett and Magee (1965)
Holstein	41.65	Touchberry and Bereskin (1966)
Guernsey	30.60	Touchberry and Bereskin (1966)
Crossbreds (Guernsey x Holstein)	37.56	Touchberry and Bereskin (1966)
Hereford	30.58	Burris and Blunn (1952)
Angus	29.18	Burris and Blunn (1952)
Shorthorn (Beef)	29.19	Burris and Blunn (1952)

2. Factors Affecting Birth Weight

Specific factors which have been found to affect birth weight are:

1. Sex of calf
2. Parity sequence
3. Age of dam
4. Season of calving

5. The breed of foetus and breed of dam

6. Sire

7. Gestation length

8. Interactions among the above factors

9. Random effects.

a. The Effect of Sex of Calf

Various authors (Eckles, 1919; Espe et al, 1932; Fitch et al, 1924; Fohrman, 1939; McCandlish, 1922; Ragsdale, 1933; Tyler et al, 1947; Willard, 1948) reported a range in birth weights from 92.9 to 101.0 pounds for males, and from 85.5 to 94.0 pounds for females. The estimates of Davis et al (1954) agree with these ranges and the difference between the means of males and the females were significant at the 1% level of probability. Males were heavier than females by an average of 6.4 pounds. Table 6 shows the estimates of Davis et al (1954).

Burris and Blunn (1952) stated that the adjustment of birth weight records for sex effects should be done before any comparison can be made among the means of birth weight of the various groups of cattle. They reported highly significant differences in all the beef breeds studied ($P < .01$). The differences are shown in Table 7. Porter et al (1965) reported significant sex differences in the three dairy breeds, Ayrshire, Holstein, and Brown Swiss. His estimates are as follows:

	Birth Weight (lb)		
Breed	Male (M)	Female (F)	M-F
Ayrshire	78	71	7
Brown Swiss	101	93	8
Holstein	99	93	6

Table 6. Effects of Sex and Calving Sequence on the Birth Weight of Holstein-Friesian Calves (Davis et al, 1954).

Calving Sequence	Average Birth Weight (lb.) Male	Female	Differences (Male-Female)
1	92.0	85.7	6.3
2	99.3	90.7	8.6
3	100.7	93.3	7.4
4	99.5	95.7	3.8
5	94.6	95.4	-0.8
6	99.9	92.4	7.5
7	92.1	94.7	-2.6
8	103.7	85.2	18.5
All Calvings	96.7	90.3	6.4

The work of Brinks et al (1961) reported that in the Hereford breed males are heavier than female calves by 5.3 pounds at birth, which agrees with those of Burris and Blunn 1952; Knapp et al, 1944; Gregory et al, 1950, and Koch and Clark, 1955.

Touchberry and Bereskin (1966), McDowell et al (1959), and Legault and Touchberry (1962), working with dairy breeds reported that sex of calf has a pronounced effect on the birth weight. The report by Touchberry and Bereskin (1966) stated that male calves are heavier than female calves by 2.48 kg at birth. The difference was found to be highly significant ($P < .01$).

Table 7. Average Birth Weight of Calves (lb.) for each Breed and Sex. (Burris and Blunn, 1952).

Breed	Breed Average	Male(M) Mean ± SE	Female (F) Mean ± SE	M-F	M-F Adjusted For Gestation Length
Angus	64.2	67.1 ± 1.95	61.8 ± .79	5.3	4.5
Hereford	67.4	69.9 ± .97	65.4 ± .92	4.5	3.9
Shorthorn	64.3	66.7 ± .26	61.8 ± .26	4.9	5.0
All breeds	65.4	68.0 ± .57	63.2 ± .51	4.8	4.3

b. Age of Dam and Parity Effects

Davis et al (1954); Legault and Touchberry (1962); Touchberry and Bereskin (1966); and McDowell et al (1959), showed that parity sequence has an effect on the birth weight of the calf, and stated that the first calf is more likely to be the lightest among its maternal sibs.

Braude and Walker (1949); Venge (1948) and Knapp et al (1940), found that age of dam had an influence on the birth weight of the calf, with the heaviest calves being born to relatively young cows, from four to six years of age; this means that the first calf is lightest on the average, the second or the third are the heaviest among all the sibs, and calves of later parities are average, findings which agree with the report of Touchberry and Bereskin (1966).

The work by Burris and Blunn (1952) with beef breeds showed the same trend but on a different scale, the maximum birth weight of calves is not reached until the cow is nine to ten years of age. The coefficient of regression of birth weight of the calf on the age of dam was 1.043 pounds per year and the coefficient of correlation among these traits was .970; both coefficients are significant ($P \leq .05$).

c. The Effect of Sire and Breed of Sire on Birth Weight

Working with beef breeds of cattle, Piam (1944) did not detect any influence of the sire on the birth weights of calves, while Rhoad et al (1945) reported quite definite sire effects on weight of the calf at birth.

Touchberry and Bereskin (1966) reported that calves sired by Holstein bulls were 2.54 kg heavier than those by Guernsey bulls, when the dams in both cases were Holstein-Friesian purebreds. This difference might be caused by the genotype of the breed of foetus, to which the sire contributed 50%. Hence, the breed of sire might have directly affected the birth weight of the foetus.

McDowell et al, (1959) and Gregory et al, (1950) are in agreement with Touchberry and Bereskin (1966) about the effects of breed of sire. The report of McDowell et al, (1959) showed that crossbred Sindhi calves from Jersey dams were heavier than purebreds from the same dams. This difference might be explained in the same manner mentioned before.

d. The Effects of Breed on the Birth Weight

Burris and Blunn (1952) reported that the average birth weight for the Angus, Hereford and Shorthorn cattle were 64.2,67.4 and 64.3 pounds respectively. The Hereford was significantly heavier than both the Shorthorn and the Angus, while there was no difference between the last two breeds in average birth weights. Davis (1954) reported a mean birth weight of 93.5 pounds for the Holstein-Friesian breed of cattle, and the report by Touchberry and Bereskin (1966) stated that the Holstein-Friesian calves at birth are heavier than the Guernsey calves by 9.62 kg. This difference was observed after adjustment of records was done for the effects of parity, sex, weight of dam and age of dam. Besides the differences among purebreds, it seems that there are also effects of the various combinations of breeds when they are present in the genetic composition of crossbreds.

Naidu and Desai (1965) found from their study of crossbreds (H x Sahiwal) that the ratio of the Holstein-Friesian genetic pool present in the crosses has a pronounced effect on the birth weights of calves. The report showed that the ratios 12/32 - 15/32 and 16/32 - 19/32 had the highest birth weights among all crosses, with birth weights of 57.3 and 63.0 lbs. respectively which are heavier than those of the purebred Sahiwal.

Ellis et al, (1965), reported that breeds and crosses were highly significant sources of variation and heterosis occurred in crosses and backcrosses involving the Brahman and Hereford breeds. Their results, shown in Table 8, are in agreement with those reported by Cartwright et al, (1958), and Baker and Black (1950), which indicated some degree of heterosis in birth weight.

Table 8. Comparisons among means of birth weight (lb.) for Purebreds and Crossbreds (Ellis et al, 1965).

Group	Mean	% Advantage over Mean of Purebreds
H x H and B x B	66.51	Standard
H x B and B x H	73.72	10.8
BH x H and BH x B	70.14	5.5
H x BH and B x BH	71.96	8.2
B x BH and BH x BH	67.83	2.0

B: Brahman
H: Hereford

It was reported by Foote et al, (1959), that sire line has a significant effect on the birth weights of linebred Holstein calves. The amount of inbreeding in the dam or the offspring did not show any significant effects on the birth weight of calves when the average inbreeding in the dam was 24.7% and in the calf was 24.9%. Table 9 shows the means of the six sire lines.

Table 9. The birth weight means of calves from six sire lines of Holstein cattle.

Sire Line[a]	Line Means[b]	N
Hartog	83.3	85
Netherland	77.6	82
Mooie	85.7	75
Lalaur	80.2	96
Ollie	75.1	100
Belmont	81.1	98

(a) Data are from the Holstein-Friesian herd at the University of Wisconsin (Foote *et al*, 1959).

(b) Females of first parity adjusted records

e. Heterosis in Birth Weight

Gregory *et al*, (1950), reporting on the Nebraska crossbreeding project, stated that crossbreds showed significant heterotic effects, the crossbreds averaged a difference of 2.7 $\pm$ 0.5 pounds heavier than the purebreds in birth weights. The project dealt with crosses of Hereford, Angus and Shorthorn breeds of cattle.

Ellis *et al*, (1965), reported on the heterosis in birth weight resulting from Brahman-Hereford crosses at the Texas Experimental Station; the heterotic effects were estimated to be 10.8 percent in first cross calves. Backcross calves from crossbred cows, exhibited 5.5 per cent heterosis and calves from purebred cows but sired by first cross bulls, exhibited 8.2 per cent heterosis. The F_2 calves exhibited about 2 per cent heterosis. These results are in agreement with the results of Cartwright et al, (1959) and Baker and Black (1950), which indicate some degree of heterosis in birth weight of various crosses of beef cattle.

f. The Effect of Year and Season of Calving on Birth Weight

The effects of year and season are often not measured in an analysis of the factors affecting birth weight. Their effects can be reduced by analyzing on a within season and year basis. However, some workers have estimated these effects and their results are contradictory.

Burris and Blunn (1952), found that the year of calving has no effect on the calves' birth weights. This might be due to the relatively uniform environment which might have reduced the variation to a minimum.

Gregory et al, (1965), at the Nebraska Experimental Farm, estimated the year effects from three breeds; namely, Hereford, Angus and Shorthorn, brought to the station from Nebraska, Montana and Colorado. The herd was left on pasture during the time of the experiment. The results showed highly significant effects of the year of calving on the birth weights.

g. The Effects of Gestation Length on Birth Weight

There is evidence that gestation length has a definite effect on the birth weight of calves. Davis et al, (1954), found these effects to be highly significant ($P < 0.01$) and accounted for 8.2 per cent of the variance in birth weight. Burris and Blunn (1952) reported that the effects of gestation period counted for 7.3 per cent of the variance in birth weight.

Braude and Walker (1949), found in Shorthorns an average increase of .91 lbs. in birth weight of calf for each day it was carried beyond the normal term (expected day).

Alim (1965) reported a coefficient of correlation of .26 between the gestation length and birth weight. Burris and Blunn (1952), reported a coefficient of correlation ($r = .24$) close to that reported by Alim (1965). Both estimates were significant at the 1% level of probability.

III. MATERIALS AND METHODS

The data for this study were collected from a crossbreeding project with dairy cattle which was initiated at the University of Manitoba in 1957. The data used were obtained during the years 1957 to 1968 inclusive.

The basic plan of the project was to utilize the purebred Holstein female herd to produce both purebred and crossbred daughters, the latter to be sired by Brown Swiss bulls. Crossbred daughters were mated to Ayrshire sires to produce three-breed cross offspring. These in turn were bred to Holstein sires to complete one cycle of what is known as a three-breed rotational crossbreeding system. The following symbols are used to designate breeding groups:

Breeding Group	Breed of Sire	Breed of Dam
H x H	Holstein	Holstein
BS x H	Brown Swiss	Holstein
A(BS x H)	Ayrshire	BS x H
H.A(BS x H)	Holstein	A(BS x H)

The Holstein herd was maintained throughout the experimental period by breeding some females each year to produce purebred offspring. Artificial insemination was used almost exclusively; each bull in the program sired a limited number of daughters, the maximum number not exceeding ten. The herd consisted of two basic groups (purebreds and crossbreds (in the latter there were two types of crossbreds).

Records of performance and production were kept throughout the project. Birth weights were recorded in pounds within twenty-four hours from the time of birth. The gestation length was taken as the number of days between the last service date and the date of calving.

The number of gestation periods, birth weights and sires for the calves included in this study are listed in Table 10.

The use of a large number of sires of each breed was undertaken to obtain a representative sample of the breed in question. In the early years of the project little information was available as to the genetic merits of the sires: thus the sires could have been considered a random sample of the breeds. In the later years with the Holstein breed, sires were normally selected on the basis of their contemporary proof for milk production.

A very high proportion - at least 80% - of the female calves, both purebred and crossbred, were saved for breeding purposes. Culling of females was done on the basis of their own performance rather than on a pedigree analysis.

Due to the fact that the records did not indicate birth weights prior to December 1957, and because of some missing data, the number of birth weight records is not equal to the numbers of gestation period records. This difference would not affect the results, for each trait was analysed separately.

Only the birth weights and gestation periods of live single birth calves were included; i.e. data involving twin birth or dead calves at birth were excluded.

The objective of the present study was to determine the effects of crossbreeding upon gestation length and birth weight of dairy cattle. To obtain unbiased estimates of these effects, it was necessary

Table 10. Numbers of Birth Weights, Gestation Periods and Sires in Project classified by Breeding Group.

Breeding group	Year	N (Birth Weight)	N (Gestation Length)	N (Sire)
H x H	1957-1968	216	235	34
BS x H	1957-1965	110	114	16
A(BS x H)	1960-1967	101	104	-15
H.A(BS x H)	1962-1968	64	68	19*
Total	1957-1968	491	521	65

*The sires for the group H.A(BS x H) were excluded from the total, because they are included previously in group H x H.

first to estimate the effects of certain "environmental" factors upon the traits under study. The literature review suggested that the "environmental" factors likely to have the greatest effect on the traits were parity of cow and sex of calf. (Sex is not "environmental" in the usual sense of the word, but can be considered as such in the present context). The effects of both sex and parity were estimated for gestation length and birth weight. The material to follow indicates the statistical procedure employed to estimate the effect of sex upon gestation length, using the method described by Seale (1965)

1. Method of computing sex differences for gestation length:

The average difference in gestation length between the two sexes was computed for each year within a calving sequence (parity), and breeding group.

In symbolic form:

The Model:

$$X_{kfjin} = \mu_{fji} + s_{kfji} + e_{kfjin}$$

where:

X_{kfjin} = The gestation length of the n^{th} calf, of the k^{th} sex, of the f^{th} calving sequence, of the j^{th} breeding group, raised in the i^{th} year.

μ_{fji} = The population mean of gestation length, of the f^{th} calving sequence of the j^{th} breeding group, raised in the i^{th} year.

s_{kfji} = An effect common to all individuals of the k^{th} sex of the f^{th} calving sequence of the j^{th} breeding group raised in the i^{th} year.

e_{kfjin} = a residual effect on gestation length, of the n^{th} calf, of the k^{th} sex, of the f^{th} calving sequence, of the j^{th} breeding group, raised in the i^{th} year.

k = 1 or 2 (male or female)

f = 1 or 2 (first or subsequent calving)

j = 1, 2, 3, or 4, where:

1: H x H

2: BS x H

3: A(BS x H)

4: H.A(BS x H)

i = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.

1: 1957

2: 1958

3: 1959

4: 1960

5: 1961

6: 1962

7: 1963

8: 1964

9: 1965

10: 1966

11: 1967

12: 1968

The reason for grouping the data into two calving sequence (parity) groups, first and subsequent, is that most research workers have found that second and latter calvings were both considered to have almost the same effects on gestation length and birth weight, (Johanson, 1928; Touchberry and Bereskin, 1966; Brackel et al, 1952; Braude and Walker, 1949; Venge, 1948; and Knapp et al, 1940).

Let $\overline{X}_{1fji}$ and $\overline{X}_{2fji}$ represent mean gestation lengths for males and females respectively of the f^{th} parity of the j^{th} breeding group raised in the i^{th} year.

Then:

$$d_{fji} = \overline{X}_{1fji} - \overline{X}_{2fji}$$

provides an estimate of $s_{1fji} - s_{2fji}$ (the mean difference between sex effects of the f^{th} calving sequence of the j^{th} breeding group raised in the i^{th} year).

The weighted mean difference between sexes within a parity and breeding group for all years, was obtained as:

$$\overline{ds}_{fj} = \frac{\sum_i (W_{fji} \cdot d_{fji})}{\sum_i W_{fji}}$$

Where:

$$W_{fji} = \frac{N_{1fji} \cdot N_{2fji}}{N_{1fji} + N_{2fji}}$$

N_{1fji} = number of male calves of the f^{th} parity of the j^{th} breeding group raised in the i^{th} year.

N_{2fji} = number of female calves of the f^{th} parity of the j^{th} breeding group raised in the i^{th} year.

Variances were estimated assuming:

1. Independence of all e's; (the residual effects) and,
2. Homogeneity of variances of the residual effects over sexes, parities, breeding groups and years.

Let V_{fj} = variance of the residual effects for the f^{th} parity of the j^{th} breeding group.

Then:

$$V(d_{fji}) = \frac{V_{fj}}{N_{1fji}} + \frac{V_{fj}}{N_{2fji}}$$

$$= V_{fj}\left(\frac{1}{N_{1fji}} + \frac{1}{N_{2fji}}\right)$$

$$= V_{fj}\left(\frac{N_{1fji} + N_{2fji}}{N_{2fji} \cdot N_{2fji}}\right)$$

$$= \frac{1}{W_{fji}} \cdot V_{fj}$$

and: $V(\overline{ds}_{fj})$: the pooled variance of the weighted mean difference

$$V(\overline{ds}_{fj}) = \frac{\sum_i W^2_{fji}\ V(d_{fji})}{(\sum_i W_{fji})^2}$$

but: $V(d_{fji}) = \frac{1}{W_{fji}} \cdot V_{fj}$

then: $V(\overline{ds}_{jf}) = \frac{V_{fj} \sum_i W_{fji}}{(\sum_i W_{fji})^2}$

$$= \frac{V_{fj}}{\sum_i W_{fji}}$$

V_{fj} was estimated as follows:

$$\hat{V}_{fj} = \frac{\sum_i \sum_n (X_{1fjin} - \overline{X}_{1fji})^2 + \sum_i \sum_n (X_{2fjin} - \overline{X}_{2fji})^2}{\sum_i (N_{1fji} + N_{2fji} - 2)}$$

then:

$$\hat{V}(\overline{ds}_{fj}) = \frac{\hat{V}_{fj}}{\sum_{i} W_{fji}}$$

$\overline{ds}_{fj}$ is an unbiased estimate of the mean difference between sexes of the calves of the f^{th} parity of the j^{th} breeding group, raised in all the years of the project. It is assumed that there is no interaction between sex and calving sequences in both traits, birth weight and gestation length. The assumption of no interaction was implicit in the assumption of independence among residual effects (Snedecor, 1956; Steel and Torrie, 1960).

The same method was used to estimate the difference in gestation length resulting from effects of parity. The effects of sex and parity upon birth weights were also estimated by the same procedure.

The effects of sex upon gestation length were estimated within parity and breeding groups. Similarly the effects of parity upon gestation length were estimated within sex and breeding groups. The analysis of variance indicated that there were significant differences for each sex and parity. In adjusting to reduce the effects of sex upon gestation length, the estimates specific for a parity and breeding group were used. In the case of sex, records were adjusted to a male basis by adding or subtracting the appropriate difference to each female record. For parity effects, all records were adjusted to a second and subsequent parity basis. The same methodology was used to adjust birth weight records.

IV. RESULTS

The effects of sex of calf and parity sequence on each of the traits studied i.e. gestation length and birth weight, are indicated in Tables 11 - 14 .

A. Gestation Length

The weighted mean differences ($\bar{d}s_{fj}$) between sexes of calf in gestation period computed within parity and breeding groups are indicated in Table 11. The pooled estimate of the effect of sex upon length of gestation period was .93 ± .44 days, males having the longer period. The pooled estimate of the effect of parity upon gestation length was .88 ± .52 days, (Table 12). In this instance, calves born in second and subsequent parities have longer gestation periods than those born in the first parity.

Records of gestation length were adjusted to reduce the effects of sex and parity upon the estimates of duration of gestation. Adjustments reduce or eliminate sources of bias and thereby facilitate comparisons between and among breeding groups. In the present study all records pertaining to gestation length were adjusted to a male birth and second and later parity basis. In the process of adjustment coefficients corresponding to the pertinent breeding group, sex and parity were computed (Table 15). The coefficients were added to or subtracted from individual records for gestation length.

In adjusting records, the parity and sex effect for specific breeding groups were used in preference to the overall differences. The effects of sex upon gestation length (Table 11) were significantly different among breeding groups; similarly, breed differences were apparent in the effects of parity (Table 12).

Table 11. the weighted mean difference ($\bar{d}s_{fj}$ in days) between sexes in gestation length computed within calving sequence (parity) , breeding group and year.

Group	Parity	N	$\sum_i W_{fji}$	$\bar{d}s_{fj}$ male-female	$SE(\bar{d}s_{fj})$	$\hat{V}(\bar{d}s_{fj})$	df*
H x H	1	63	14.71	1.76	1.17	29.60	47
	2	169	38.98	-0.78	.78	23.98	145
BS x H	1	17	3.67	1.69	.70	1.79	7
	2	91	20.22	1.83	1.13	25.65	75
A(BS x H)	1	41	7.60	2.47	.84	5.37	27
	2	56	13.08	0.65	1.22	19.27	46
H.A(BS x H)	1	40	9.85	3.39	1.21	14.29	30
	2	25	2.26	0.32	3.45	26.84	17
Pooled		502	110.37	0.93	0.44	22.17	394

*d.f. = $\sum(N_{1fji} + N_{2fji} - 2)$

Where: N_{1fji}= the number of male calves, of f^{th} calving sequence, of the j^{th} breeding group, raised in the i^{th} year.

N_{2fji}= the number of female calves, of the f^{th} calving sequence, of the j^{th} breeding group, raised in the i^{th} year.

Table 12. The mean difference ($\bar{d}p_{kj}$ in days) between calving sequences in gestation length computed within sex, breeding group and year.

Group	Sex	N	$\sum_i W_{kji}$	$\bar{d}p_{kj}$	$SE(\bar{d}p_{kj})$	$\hat{V}(\bar{d}p_{kj})$	df*
H x H	M	114	23.85	-1.16	1.09	28.39	94
	F	84	18.12	0.63	1.26	28.86	64
BS x H	M	36	6.21	3.37	1.86	20.66	28
	F	53	9.56	3.72	1.75	29.15	39
A(BS x H)	M	45	9.02	0.79	1.25	14.14	31
	F	50	10.41	0.05	1.22	15.48	40
H.A(BS x H)	M	32	6.65	1.99	1.45	14.59	22
	F	33	7.35	3.93	1.75	22.11	25
Pooled		447	91.17	0.88	0.52	24.65	343

*d.f. = $\sum(N_{1kji} + N_{2kji} - 2)$

Where: N_{1kji} = number of first parity calves of the k^{th} sex, of the j^{th} breeding group, raised in the i^{th} year.

N_{2kji} = number of second parity calves of the k^{th} sex, of the j^{th} breeding group, raised in the i^{th} year.

$\bar{d}p_{kj}$ = parities 2 and subsequent - parity 1

Table 13. The weighted mean difference($\bar{d}s_{fj}$ in kg.) between sexes in birth weight computed within calving sequence (parity), breeding group and year.

Group	Parity	N	$\sum_i W_{fji}$	$\bar{d}s_{fj}$ male − female	SE($\bar{d}s_{fj}$)	$\hat{V}(\bar{d}s_{fj})$	*df
H x H	1	58	14.02	2.72	0.99	13.74	42
	2	146	33.67	2.43	0.85	24.55	124
BS x H	1	18	3.72	5.33	4.36	70.60	8
	2	85	19.10	2.84	1.30	32.37	69
A(BS x H)	1	41	7.40	1.09	1.58	18.49	27
	2	54	12.55	3.92	1.44	26.03	44
H.A(BS x H)	1	37	9.06	3.60	1.28	14.82	29
	2	24	4.93	1.06	2.31	26.30	16
Pooled		463	104.45	2.76	0.48	24.25	359

$*df = \sum(N_{1fji} + N_{2fji} - 2)$

Where: N_{1fji} = number of male calves, of the f^{th} calving sequence, of the j^{th} breeding group, raised in the i^{th} year.

N_{2fji} = number of female calves, of the f^{th} calving sequence, of the j^{th} breeding group, raised in the i^{th} year.

Table 14. The weighted mean difference ($\bar{d}p_{kj}$ in kg.) between calving sequences in birth weight computed within sex, breeding group and year.

Group	Sex	N	$\sum_i W_{kji}$	$\bar{d}p_{kj}$	$SE(\bar{d}p_{kj})$	$\hat{V}(\bar{d}p_{kj})$	*df
H x H	F	76	16.09	3.29	1.17	22.36	58
	M	110	22.47	2.14	1.02	23.15	90
BS x H	F	50	10.03	3.05	1.56	24.39	38
	M	35	6.15	3.17	2.43	26.23	27
A(BS x H)	F	49	10.37	0.98	1.63	27.44	39
	M	34	8.54	5.30	1.55	20.58	29
H.A(BS x H)	F	32	7.58	3.06	1.63	20.06	24
	M	29	5.62	0.08	1.71	16.43	21
Pooled		424	86.85	2.68	0.52	23.88	326

*d.f. = $\sum(N_{1kji} + N_{2kji} - 2)$

Where: N_{1kji} = number of first parity calves of the k^{th} sex, of the j^{th} breeding group, raised in the i^{th} year.

N_{2kji} = number of second parity calves of the k^{th} sex, of the j^{th} breeding group, raised in the i^{th} year.

$\bar{d}s_{kj}$ = parities 2 and subsequent - parity 1

The use of weighted mean differences to estimate effects may require some elaboration. In the present study data were not available for all breeding groups in all years. The only breeding group present in all years was the purebred Holsteins (H x H); this breed could thus be used as a standard for comparisons. The two-breed cross, BS x H, was not present during the period 1966 - 68. The other groups A(BS x H) and H.A(BS x H) were born first in 1960 and 1962 respectively.

In the classification of data into subgroups of breed, parity, sex and years, some of the cells contained no information or such few observations that an accurate estimate of differences was not possible. Combining the observations from cells in which the same differences (either sex or parity) could be estimated yields an estimate of the particular difference. Weighting according to numbers within a subclass provides a more precise estimate of the overall mean differences (Steel and Torrie, 1960).

Weighting eliminates errors arising from the disproportionality of numbers within subclasses (Seale, 1965). For example, in certain years within a parity and breeding group, the frequency of males may have been less than that of females. An unweighted difference determined over all years would be biased because year effects could be present. Similarly in estimating parity effects, disproportionality of numbers in first as opposed to second parity classes could lead to a biased estimate of the effect of parity.

Confounding may arise from the disproportionality of the subclass number (Seale, 1965). For example, in certain years within a parity and a breeding group the frequency of males was less than females, or vice versa. Additionally one of the sexes may not have been present in a particular year. Then the unweighted differences determined over all the years would be biased and unreliable. Similarly, in estimating parity effects disproportionality of numbers in first as opposed to second parity classes could lead to a biased estimate of the effect of parity.

Table 15. Coefficients for adjustment of gestation length for sex and parity effects.*

Breeding group	H x H				BS x H				A(BS x H)				H.A(BS x H)			
Sex	M		F		M		F		M		F		M		F	
Parity	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
$\bar{d}_{sfj}$ (sex effect)			1.76	-.78			1.69	1.83			2.47	.65			3.39	.32
$\bar{d}_{pkj}$ (parity effect)	-1.16		.63		3.37		3.72		.79		.05		1.99		3.93	
Total = coefficient of Adjustment	-1.16		2.39	-.78	3.37		5.41	1.83	.79		2.52	.65	1.99		7.32	.32

* See Tables 11 and 12 for origin of coefficients.

Table 16 shows the unadjusted and the adjusted gestation lengths for the four breeding groups. Comparisons among breeding groups by using unadjusted means are not valid because the means include all data; no attempt has been made to account for year effects. As noted previously, only the H x H group was represented in all years. Of note however is the fact that the H x H group recorded the shortest gestation periods. The differences between this group and the (BS x H), A(BS x H) and H.A(BS xH) groups were 5.94, 2.10 and 1.37 days respectively.

Table 17 shows the results of comparisons made among breeding groups computed on a within year basis: individual year differences are pooled over years. In effect, breeding groups were compared for only those years in which observations were recorded for the two groups being compared.

The duration of gestation was shorter in Holstein purebred matings than in any of the crossbred matings. The differences between (H x H) and (BS x H), A(BS x H) and H.A(BS x H) are 5.72, 3.01 and 3.72 days respectively. These estimates of differences in gestation period vary to a limited degree from those derived from Table 16. The differences among crossbred groups, while not statistically significant, are of a magnitude that would be expected from a knowledge of the comparisons with the H x H group.

There are no significant differences among the crossbreds, hence they are considered to have the same gestation length.

Table 16. The mean gestation lengths (days) of the four breeding groups adjusted for sex and parity; also indicated are the unadjusted means.

	Unadjusted					Adjusted
Sex	Males		Females		All sexes and parities pooled	Mean of gestation length
Parity	1	2	1	2		
H x H	285.00	283.01	282.95	283.24	283.38	283.27
N	38	93	38	66	235	235
BS x H	284.55	288.21	283.78	286.62	286.75	289.21
N	9	46	14	45	114	114
A(BS x H)	283.61	285.70	283.38	284.42	284.35	285.37
N	18	27	26	33	104	104
H.A(BS x H)	283.69	284.00	279.74	284.00	282.70	284.64
N	23	10	19	16	68	68

Table 17. The estimated effects of crossbreeding on length of gestation period (days).

Comparison	N	$\sum_i W$	$\bar{d}$ (days)	$SE(\bar{d})$	$\hat{V}(\bar{d})$	df[a]
(BS x H) vs (H x H)	293	65.86	5.72*	.70	32.11	275
A(BS x H) vs (H x H)	251	55.67	3.02*	.78	34.19	235
H.A(BS x H) vs (H x H)	192	37.32	3.18*	.90	30.42	178
(BS x H) vs A(BS x H)	159	32.05	2.44	.89	25.54	147
(BS x H) vs H.A(BS x H)	72	7.94	3.11	1.77	24.99	64
A(BS x H) vs H.A(BS x H)	144	27.86	- .75	.79	17.21	132

a) $df = \sum(N_1 + N_2 - 2)$
*: $P < .05$

N = number of calves which are included in each comparison

$\bar{d}$ = weighted mean difference between breeding groups in length of gestation period (days).

B. The Birth Weight

Weighted mean differences($\bar{d}s_{fj}$) between sexes in birth weights computed on a within breeding group, parity and year basis are indicated in Table 13. The pooled estimate of the effect of sex was 2.76 ± .48 kg. males being heavier at birth than females. The effects of parity upon birth weight (second and subsequent parity vs first parity) are indicated in Table 14. The pooled estimate was 2.68 ± .52 kg. in favor of calves born to second and subsequent pregnancies.

Adjustment of birth weight records was conducted by the same technique as was used to adjust gestation lengths. All birth weights were adjusted to a male, second and later parity basis. The weighted mean differences computed within breeding groups were used in adjusting records rather than the pooled estimate involving all breeding groups. Coefficients used in adjusting records are summarized in Table 18.

As in the adjustment of gestation records, the adjustments to birth weight records were undertaken to reduce the overall variance and to reduce the portion of variation due to sex and parity effects. More reliable estimates of differences between breeding groups can be obtained from adjusted records.

Overall means of birth weights (both adjusted and unadjusted) for the four breeding groups are indicated in Table 19. Neither sets of means have taken year effects into account. More accurate estimates of the effects of breeding group upon birth weights are shown in Table 20. Mean differences were computed within years and pooled to provide the estimates ($\bar{d}$) of differences between groups. The records used in the computation had been adjusted for sex and parity effects.

Table 18. Coefficients for adjustment of birth weights for sex and parity effects.*

	H xH				BS x H				A(BS x H)				H.A(BS x H)			
Sex	F		M		F		M		F		M		F		M	
Parity	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Parity Effects	3.29		2.14		3.05		3.17		.98		5.30		3.06		.08	
Sex Effects	2.72	2.43			5.33	2.84			1.09	3.92			3.60	1.06		
Total	6.01	2.43	2.14		8.38	2.84	3.17		2.07	3.92	5.30		6.66	1.06	.08	

* See Tables 13 and 14 for origin of coefficients

The analysis of variance was carried out on the records adjusted for sex and parity effects in the manner described in the material s and methods section.

Table 19 shows the unadjusted mean gestation periods of the four breeding groups ; also indicated are the means adjusted for sex and parity effects.

Table 20 shows the computation of the weighted mean difference ($\bar{d}$) between paired breeding groups and was computed by the same method as used to determine the effect of sex and parity on birth weight. Computations were made within years on records adjusted for sex and parity effects. The cross BS x H was significantly heavier than the H x H and A(BS x H) by 3.29 ± .68 kg. and 7.35 ± .92 kg. respectively. The group H x H was significantly heavier than the H.A(BS x H) by 3.15 ± .81 kg. The cross H.A(BS x H) was significantly heavier than the A(BS x H) group by 3.04 ± .98 kg. The difference between the H x H and A(BS x H) birth weights was not significant nor was the difference between the BS x H and H.A(BS x H) when both were tested at the 5% level of probability.

Table 19. Mean birth weight (kg.) of the four breeding groups adjusted for sex and parity; also shown are unadjusted means.

	Unadjusted Means				All sexes and parities (unadjusted)	Adjusted for sex and parity
Sex	Males		Females			
Parity	1	2	1	2		
Breeding Group						
H x H	40.49	42.46	36.97	39.96	40.57	42.79
N	37	84	33	62	216	
BS x H	43.59	45.75	38.88	42.95	43.57	45.79
N	9	44	15	42	110	
A(BS x H)	37.21	43.36	36.45	39.36	39.28	41.39
N	17	26	26	32	101	
H.A(BS x H)	39.34	39.78	36.13	39.33	38.49	41.34
N	22	8	18	16	64	

Table 20. The estimated effects of crossbreeding on birth weight in dairy cattle (kg).

Comparison	N	$\sum_{i} W$	$\bar{d}$ (kg)	$SE(\bar{d})$	$\hat{V}(\bar{d})$	df[a]
(BS x H) vs (H x H)	262	59.68	3.29*	.68	27.20	244
A(BS x H) vs (H x H)	242	53.68	-1.81	.63	21.38	226
H.A(BS x H) vs (H x H)	132	33.85	-3.15*	.81	22.05	118
(BS x H) vs A(BS x H)	145	28.83	7.35*	.92	24.17	133
(BS x H) vs H.A(BS x H)	19	5.11	5.68	1.72	15.15	11
A(BS x H) vs H.A(BS x H)	103	24.36	-3.04*	.98	23.28	85

a: $df = \sum (N_1 + N_2 - 2)$

*: $P < .05$

N = Number of calves which are included in each comparison.

$\bar{d}$ = Weighted mean difference between breeding groups in birth weight (kg).

V. DISCUSSION

A. Sex differences

The analysis of the data showed that sex effects were present in both traits under study, namely gestation length and birth weight. The records adjustments were then necessary in order to exclude these effects before any comparisons between breeding groups could be made. Since the sex differences computed within parity, breeding group and years showed significant differences among groups at the 5 per cent level of probability, the adjustment on the basis of the pooled sex difference estimate $\bar{d}_S \pm SE$, would be biased; the use of the weighted mean differences for sexes computed within a parity and breeding group would exclude the bias.

B. Parity effects

The data were classified according to the birth sequence into two groups: first parity, and second and subsequent parities. This classification was chosen to avoid the relatively small numbers that would result from increasing the parity subclasses; in any case most of the literature reports agree on the similar effects of the second and subsequent parities (Touchberry and Bereskin, 1966).

The adjustment for parity effects was similar in its procedure and assumptions to the sex adjustment discussed previously.

It can be noticed in Table 11 that the sex differences for the various subclasses vary from a negative value to a positive one. In the (H x H) group the females from the first parity are carried longer than the males, by almost one day. However, the standard error (SE) tend to be large and the "real" difference may not favor females over males.

C. Gestation length

The pooled estimate of the effect of parity ($\bar{d}p$) showed that calves from the first parity are carried approximately one day longer than those from second and subsequent parities. The estimated mean difference was .88 ± .52 days, which is not different from zero at the 5% level of probability.

Each sex subclass showed a different estimated difference of the parity effects. The second parity Holstein females were carried .78 ± .78 days longer than the first parity Holstein-Friesian females. Again this difference is not different from zero at the five per cent level of probability

The weighted mean difference for parity within sexes within breeding groups ranged between -0.78 and 3.39 days. This variation is affected by the small number of observations which gave a decline to the "weights", which are considered to be the effective number of observations.

The overall difference due to parity sequence is in agreement with that of Touchberry and Bereskin, 1966.

The pooled estimate of the sex differences (male - female) showed that male calves were carried 0.93 ± 0.44 days longer than female calves.

Each parity subclass showed a different estimated difference of sex effects. In the (BS x H) breeding group the sex differences were approximately the same in both parity subclasses, and the classification into parity subclasses had little or no effect. These differences were 1.69 ± .70 days and 1.83 ± 1.13 days for the first parity subclass and the second and subsequent parity subclass respectively.

In the groups H x H, A(BS x H) and H.A(BS x H) it was found that the sex differences within the first parity were 2.54 days, 1.82 days and 3.07 days respectively longer than those of the second and subsequent parity. The estimated sex effects are shown in table 11.

The overall estimate of the sex differences in gestation length is in agreement with the estimate of Brackel et al (1952).

The results from all the possible comparisons showed that the breeding method has some significant effects on the length of gestation period.

The differences between the Holstein-Friesian purebreds gestation length and some of the crosses (the Holstein as a base) were significantly different.(Table 17). This suggests that the genetic makeup of the foetus has a significant effect on the length of gestation period. These results agree with the results of Touchberry and Bereskin (1966) and Herman and Spaulding (1947).

When the various crosses were compared with each other, however, the differences were not significant at the 5 per cent level of probability; in other words, the comparisons (BS x H) vs. A(BS x H), (BS x H) vs. H.A(BS x H) and A(BS x H) vs. H.A(BS x H) showed no significance. Hence, they may have the same gestation length.

The weighted mean differences between H x H group and the three crossbred groups for gestation length as reported in Table 17 are compared with those calculated from the adjusted means reported in

Table 16. These comparisons summarized in Table 21 show a reasonable agreement between the weighted and adjusted mean differences indicating that year effects and unequal sample sizes did not have a great effect on the results.

Table 21. Differences in gestation length between H x H group and three groups of crossbreds. Differences determined from adjusted means (Table 16) and weighted mean difference (Table 17).

Group	Mean* Gestation Length	(Cross) - (H x H)	$\bar{d}$**
H x H	283.27		
BS x H	289.21	5.94	5.72
A(BS x H)	285.37	2.10	3.02
H.A(BS x H)	284.64	1.37	3.18

* Table 16

** Table 17

The mean gestation length for the Holstein breed determined in this study (approximately 283 days) is about four days longer than that reported in other studies (Brackel et al , 1952; Porter et al,1965) This difference is due to a combination of factors including herd differences, environmental conditions and sampling errors.

D. Heterosis in gestation length

The design of the present study does not facilitate the determination of a reliable estimate of the degree of heterosis associated with gestation length. For such an estimate to be determined, information would have been required from purebreds of the Ayrshire and Brown Swiss breeds. However, through use of literature reports of the gestation lengths of the breeds involved, an indication can be obtained as to the presence or absence of heterosis.

Porter et al (1965) reported that the gestation period for the Ayrshire breed is one day shorter, and for the Brown Swiss breed 11 days longer, than the Holstein gestation period. On this basis the expected gestation periods for the Ayrshire and the Brown Swiss breeds under the conditions of this study would be 282.2 and 294.2 days respectively.

The expected values for the three crosses studied were calculated as the midparental values of the breeds involved in each cross (some of the dams are crossbreds) and are shown together with the observed gestation periods in Table 22. The assumption in making these calculations was that gestation length was determined by additive gene action.

It is noted that the observed values agree closely with the expectations based on additive gene action. The results of this study do not provide any evidence to suggest that heterosis is a significant factor affecting length of the gestation period.

Table 22. Observed and expected* mean gestation lengths in days for each of the three breeding groups.

Breeding Group	Observed Means (Table 16)	Expected Means	O - E
H x H	283.2		
(BS x H)	289.2	288.7	0.5
A(BS x H)	285.4	285.4	0.0
H.A(BS x H)	284.6	284.3	0.3

* Expected values are calculated on the basis of additive gene action (no heterosis)

Breed of Sire and Dam Effects

The comparison H x H vs. (BS x H) is an indication of the confounded effects of the breed of sire and breed of foetus. In both groups the dams are purebred Holstein-Friesian, while the sires differed. The weighted mean difference in this comparison was 5.72 $\pm$ .70 days. This difference is not likely attributable entirely to the breed of sire and breed of foetus effects, for it may include some maternal and random effects which cannot be separated by the design of this experiment. It would appear that the major part of this difference is due to the effects of the breed of sire and breed of foetus, assuming that matings between the dams and the sires within a group were at random.

Likewise, the comparison H.A(BS x H) vs. H x H, is an example of the confounded effects of breed of dam and breed of foetus. In both groups the sires are purebred Holstein-Friesian, while the dams are of different genetic background. The weighted mean difference in this comparison was 3.18 ± .90 days. This difference is attributed to the confounded effects of breed of dam and breed of foetus, in addition to the paternal and other effects which have not been separated.

Since breed of sire (or breed of dam) and breed of foetus are confounded in their effects, it is not possible to say which is the factor affecting the trait: for that matter both factors may interact to produce the difference. This interaction is really heterosis.

E. <u>Birth Weight</u>

The pooled estimate of the effect of parity showed that calves from the second and subsequent parities are significantly heavier at birth than those from first parity. The estimated difference was 2.68 ± 0.52 kg .

Each sex subclass showed a different estimate of the effect of parity (Table 14). These estimated differences ranged between 0.08 and 5.30 kg. In the (H x H) and (BS x H) groups the differences between parities were almost equal in both sexes and the classification into sex subclasses had no significant effects.

However, in the group A(BS x H), the male subclass showed little effects of 0.98 ± 1.6 kg .

In the group H.A(BS x H) the female subclass showed significant parity effects of 3.04 ± 1.63 kg. while the males showed little effects, the difference being 0.08 ± 1.71 kg.

The overall difference due to parity (2.68 kg.) is higher in its magnitude than those reported in the literature. This difference is due to a combination of factors including herd differences, environmental conditions and sampling errors.

The pooled estimate of the sex differences (males - females) showed that male calves were 2.76 ± 0.48 kg. heavier at birth than female calves.

Each parity subclass showed a different estimated difference of the sex effects. In the H x H group the sex differences were approximately the same in both parity subclasses, and the classification into parity subclasses had little or no effect. These differences were 2.72 ± .99 kg. and 2.43 ± .85 kg, for the first parity subclass and the second and subsequent parity subclass respectively.

In the groups (BSxH) and H.A(BS x H), it was found that the sex differences within the first parity are approximately 2.5 kg. larger than those of second and subsequent parity subclass.

In the group A(BS x H) the estimated difference between sexes within second and subsequent parity subclass was 3.92 ± 1.44 kg. compared with 1.09 ± 1.58 kg. for the first parity subclass.

The overall estimate of the sex difference in birth weight is in agreement with those reported Burris and Blunn (1952), Touchberry and Bereskin (1966), McDowell et al (1959) and Legault and Touchberry (1962).

The weighted differences for the birth weights of each of the three crosses from the H x H group reported in Table 20 are compared with those calculated from the adjusted means reported in Table 19.

These comparisons are summarized in Table 23 which shows a fair agreement between the weighted and the unweighted (adjusted) mean differences indicating that unequal sample size and year effects did not have a great effect on the results.

Table 23. Differences in birth weight between (H x H) group and three groups of crossbreds. Differences determined from adjusted means (Table 19) and weighted mean difference (Table 20)

Breeding Group	Adjusted Means (kg) (Table 19)	Crossbreds - (H x H)	Weighted Mean differences (Table 20)
H x H	42.79		
BS x H	45.79	3.00	3.29
A(BS x H)	41.39	-1.40	-1.81
H.A(BS x H)	41.34	-1.45	-3.15

The comparison (H x H) vs. (BS x H) is an illustration of the confounded effects of the breed of sire and breed of foetus. In both groups the dams are purebred Holstein-Friesian, while the sires differed. The mean difference in this comparison was 3.29 ± .68 kg. This difference is not attributable entirely to the breed of sire and breed of foetus effects, for it includes some effects which cannot be separated by the design of this experiment. But it appears the major part of this difference is due to the effects of the breed of sire and breed of foetus, assuming random mating between the dams and the sires within each group.

Likewise, the comparison H.A(BS x H) vs. H x H, is a indication of the confounded effects of breed of dam and breed of foetus. In both groups the sires were purebred Holstein-Friesian, while the dams were of different genetic background. The weighted mean difference in this comparison was $-3.15 \pm .81$ kg. This difference is mainly attributable to the effects of breed of dam and breed of foetus; in addition these may be paternal and random effects which cannot be separated.

These results indicate that either breed of sire (or dam) or breed of foetus may have a significant effect on birth weight. Confounding of the effects does not permit a statement to be made as to which factor is affecting birth weight. It is possible that both effects may be interacting (i.e. heterosis) .

Birth weight records were adjusted for the effects of sex and parity by the same method used in the gestation length adjustments.

After the adjustments were made for sex and parity, the birth weights of the various crosses and Holstein-Friesian purebreds were compared with each other. The results showed significant differences in birth weights among breeding groups. These results are in agreement with the results reported by Naidu and Desai (1965), Ellis _et al_ (1965), Foote _et al_ (1959), Gregory _et al_ (1965), and McDowell _et al_ (1959).

F. Heterosis in birth weight

The crossbreeding project utilized only females of one pure breed, the Holstein-Friesian; thus it was not possible to measure heterotic effects on birth weight directly by the conventional methods involving reciprocal crosses between breeds. (The conventional method involves comparing the means of reciprocal crossbreds with the averages of the parental breeds).

The results of the project do however provide data which can be used to estimate - admittedly not precisely - the likelihood of a heterotic effect.

Literature reports indicate the following birth weights for the three purebreeds in question (Porter, *et al*, 1965)

	Male
Holstein	99
Brown Swiss	101
Ayrshire	78

The birth weight adjusted to a male basis are thus 99, 101 and 78 pounds respectively for the three breeds. Assuming that the gene action involving birth weight is entirely additive, ie. no heterosis, the following weights should be expected from crossbreeding:

Group	Calculation	Pounds	Kg.
H x H		99	45.0
BS x H	(101 + 99)/2	100	45.5
A(BS x H)	(78 + 100)/2	89	40.5
H.A(BS x H)	(99 + 89)/2	94	42.7

The deviations of these values from the Holstein group would provide adjustment values to obtain the expected theoretical (no heterosis) mean birth weights. This is shown in the following:

Group	Expected Birth Weight (kg)	Deviation from H x H	Present study (Table 19)
H x H	45.0		42.8
BS x H	45.5	.5	45.8
A(BS x H)	40.5	-4.5	41.4
H.A(BS x H)	42.7	-2.3	41.3

Then the theoretical (no heterosis) values are:

Group	Theoretical (No Heterosis)
H x H	42.8
BS x H	42.8 + 0.5 = 43.0
A(BS x H)	42.8 - 4.5 = 38.3
H.A(BS x H)	42.8 - 2.3 = 40.5

Then:

Group	Expected birth Weight (kg)	Observed Birth Weight (kg)	Estimate of Heterosis	% Heterosis
H x H	42.8	42.8		
BS x H	43.0	45.8	2.8	6.5
A(BS x H)	38.3	41.4	3.1	8.1
H.A(BS x H)	40.5	41.3	.8	1.9

$$* \ \% \text{ heterosis} = \frac{\text{Estimate of heterosis}}{\text{Expected birth weight}} \times 100$$

The methodology above, while primarily a computional exercise does result in "estimates" of heterosis comparable with those reported by Gregory *et al* (1965), Ellis *et al* (1965) for dairy and beef breeds . Certainly the present evidence is consistent with what might be expected from a knowledge of heterosis observed in well designed experiments in which heterosis could be reliably determined. Birth weight is a trait in which non-additve gene action is present i.e. heterosis is present.

VI. SUMMARY

A study was conducted on data which included 491 birth weights and 521 gestation lengths of purebred and crossbred dairy calves in the University of Manitoba herd. The calves were of four types of breeding; purebred Holstein-Friesian (H x H), two-breed cross (BS x H), three-breed cross A(BS x H) and three-breed backcross H.A(BS x H), where H, BS and A designate the Holstein, Brown Swiss and Ayrshire respectively.

The objective of this study was to estimate the effects of crossbreeding on the duration of gestation period and birth weight in dairy cattle. Preliminary to the estimation of the genetic effects of crossbreeding, the effects upon birth weight and gestation period of two sources of non-genetic variation were determined within each breeding group, and records were adjusted in accordance with the magnitude of the effect. The two sources of the non-genetic variation were: sex (two classes; males and females) and calving sequence(two classes; first parity calves and second and subsequent parities calves). The method of comparison was to determine a weighted mean difference ($\bar{d}$) between the classes. In the determination, analysis were made within subgroups (breeding group, years, sex of calf and parity). The weighted mean differences were:

	$\bar{d} \pm$ SE	Range
Gestation length (days):		
Males vs. Females	0.93 ± 0.44	-0.78 to 3.39
Parities 2 and subsequent - parity 1	0.88 ± 0.52	-1.16 to 3.93
Birth Weight (kg):		
Males vs. Females	2.76 ± 0.48 *	1.06 to 5.33
Parities 2 and subsequent - parity 1	2.68 ± 0.52 *	0.08 to 5.30

* $P < .05$

The overall means of gestation lengths and birth weights, both adjusted for sex of calf and parity effects, were:

Breeding Group	Gestation Length (days) Adjusted	Gestation Length (days) Unadjusted	Birth Weight (kg) Adjusted	Birth Weight (kg) Unadjusted
H x H	283.27	283.38	42.79	40.57
N	235	235	216	216
BS x H	289.21	286.75	45.79	43.51
N	114	114	110	110
A(BS x H)	285.37	284.35	41.39	39.28
N	104	104	101	101
H.A(BS x H)	284.64	282.70	41.34	38.49
N	68	68	64	64

Comparisons of adjusted records, by again using the method of weighted mean differences, were made in order to estimate the net crossbreeding effects. These comparisons were:-

Comparison	$\bar{d} \pm SE$ Gestation length	$\bar{d} \pm SE$ Birth Weight
(BSxH) vs. (HxH)	5.72 ± 0.70*	3.29 ± 0.68*
A(BSxH) vs. (HxH)	3.01 ± 0.78*	-1.81 ± 0.63
H.A(BSxH) vs. (HxH)	3.18 ± 0.90*	-3.15 ± 0.81*
(BSxH) vs. A(BSxH)	2.44 ± 0.89	7.35 ± 0.92*
(BSxH) vs. H.A(BSxH)	3.11 ± 1.77	5.68 ± 1.72
A(BSxH) vs. H.A(BSxH)	-0.75 ± 0.79	-3.04 ± 0.98

*: $< P$ 0.05

The results showed significant breed effects. The comparison (BS x H) vs. (H x H) is an indication of the confounded effects of breed of sire and breed of foetus, while the comparison H x A (BS x H) vs. H x H indicates the confounded effects of breed of dam and breed of foetus.

Heterosis in gestation length and birth weight was estimated by an indirect method. It was noted that the observed values of gestation length agree closely with expectations based on additive gene action indicating no manifestation of heterosis in gestation length.

In birth weight the expected values did not agree with the observed values.This presents evidence of the non-additive gene action on birth weight. These deviations expressed as per cent heterosis were:

Breeding of Calf	% Heterosis
BS x H	6.5
A(BS x H)	8.1
H.A(BS x H)	1.9

Heterosis was measured as the extent in % by which the observed birth weight of a calf exceeded the expected mean of the parental breeds.

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