CHAPTER 8

Postweaning growth and carcase traits of Devon, Hereford and reciprocal cross steers

The four steer breedtypes (straightbred Devon and Hereford and the Devon *x* Hereford and Hereford *x* Devon crossbreds) produced in Phase 1 of the trial were evaluated for postweaning growth in two different environments. Carcase studies were performed to examine differences between the four breedtypes for several carcase traits and the impact of the environment on these traits.

8.1 Materials and Methods

The four steer breedtypes used in this study were the male progeny from the base mating of Devon and Hereford cows to Devon and Hereford sires as described in Chapter 7.

8.1.1 Animals and Management

A total of 89 steers from the 1985 calf drop were grown from weaning to slaughter in two different environments. The steers were all weaned at the same time and occurred when the average age was six months (average weight 150 kgs). Two months after weaning the steers were divided into two representative groups. Group 1 (52 steers) were grown out at Gunnedah (north-west NSW) on good quality pasture

(**Environment A**) for eight months, until food quality began to decline, whereupon they were placed in a feedlot for two months prior to slaughter. The second group (37 steers) was transported to Wards River on the mid-north coast of N.S.W. and grown out to slaughter on low quality native pastures (**Environment B**). The number of steers of each breedtype for the high nutrition group was 12 straightbred Devons (DD), 22 Devon *x* Herefords (DH), 9 Hereford *x* Devons (HD) and 9 straightbred Herefords (HH), and for the low nutrition group 9 DD, 9 DH, 9 HD and 10 HH.

A second calf drop of 21 steers born in 1986 remained on high nutrition (Environment A) after weaning. The number of steers in each breedtype was 9 DD, 4 DH, 4 HD and 4 HH. The data from these steers (Group 3) was treated as a separate group in the analysis and was not pooled with high nutrition group steers due to the confounding effects of years.

A summary of the number of steers of each of the four breedtype per group is presented in Table 8.1. The total number of steers of each of the breedtypes are also presented.

Within each group all steers were grazed together at all times and were subjected to the same management practices. Bimonthly weights were recorded on all steers. The initial criteria set for time of slaughter of all the animals at each site involved the Devon steers having an average estimated fat depth of 6mm at the 12/13th rib site. This criteria was modified to 3-4mm of fat because of economic and management considerations. When the decision was made to slaughter, all the steers in the group were weighed, assessed for fatness and at slaughter individual carcase measurements were recorded.

Table 8.1: Number of steers per breedtype for each of the three postweaning groups.

Group#	DD	DH	HD	HH	Total
1	12	22	9	9	52
2	9	9	9	10	37
3	9	4	4	4	21
Total	30	35	22	23	110

\# Group 1 1985 drop High nutrition
Group 2 1985 drop Low nutrition
Group 3 1986 drop High nutrition

8.1.2 The Environments

Two nutritionally different environments were selected to grow the steers postweaning to examine breedtype differences for growth and carcase traits. A high nutrition site (Environment A) and a low nutrition site (Environment B) were used for the study, and a description of each site follows.

8.1.2.1 Environment A (High nutrition)

This field site was located at Gunnedah, on the Liverpool Plains in North-Western New South Wales, 31° S 153° 15' E. The property was primarily alluvial plain, altitude ranging from 260 to 300m. Climate corresponds to Cfa of Koeppen's classification (hot summer, mild winter).

The annual median rainfall of 550 to 600mm is often ineffective due to variability and high evapotranspiration rates in the summer and can thus limit pasture production. The herd groups were grazed together at all times on a mixture of natural pasture (Stipa aristiglumis based), improved irrigated pasture (Medicago sativa), summer fodder crop (Sorghum spp hybrid) and winter fodder crops (Hordeum vulgare and Avena sativa). In the final two months the steers entered a feedlot which was located at this site. Steers were fed ad libitum a grain (barley) based ration. The 1986 steers were also finished in the feedlot for a 90 day period.

8.1.2.2 Environment B (Low nutrition)

This field site was located at Wards River on the Mid-North Coast of New South Wales, 32^{o} 13'S, 151^{o} 56'E and at an altitude of approximately 200m. Climate corresponds to Cfa of Koeppen's classification (hot, humid summer, mild winter). The annual median rainfall is 1000mm, with a predominantly summer distribution. The property was hilly, with shale based soils of low to medium fertility, deficient in nitrogen, phosphorus, molybdenum and copper. These deficiencies are due to the considerable leaching of the soils in periods of heavy rainfall and are a major limit to pasture production. The herd was run together and grazed on a mixture of low quality natural grasses in which the main species were summer growing Themeda australis, Axonopus affinus and Pennisetum clandestinum, often resulting in serious winter feed shortages.

8.1.3 Experimental techniques

8.1.3.1 Body weight

Bimonthly steer liveweights were measured to the nearest 1kg using electronic cattle scales. Steers at both sites were weighed after three hours fasting.

8.1.3.2 External body fat scoring (condition scoring)

The technique used to manually estimate fat cover on the live animal was developed by the East Scotland College of Agriculture (ESCA) (Lowman et al. 1976). The technique is a semi-objective method of scoring live cattle for subcutaneous fat cover, and involves palpating key areas on the animal, viz. the loin area (particularly the short ribs), the ribs and hip, with reference to the areas on either side of the tail head. A 0 to 5 scale was employed with Fat score 0= very thin (0mm fat over rib eye), Fat score 1 (0 to 1 mm of fat), Fat score 2 (2 to 5 mm of fat), Fat score 3 (6 to 10 mm of fat), Fat score 4 (11 to 16 mm of fat) and Fat score 5= very fat (17mm, or more, over the rib eye).

8.1.3.4 Slaughter procedures

All the steers were slaughtered at commercial abattoirs. By special arrangement kidney and channel fat was removed and weighed. All carcases were trimmed to the same standard at each of the abattoirs. Hot carcase weight was recorded for each animal at the slaughter chain end. After 24 hours cooling at 4^{0}C the carcases were quartered at the 12/13th rib, and fat depth and eye muscle area were recorded. Fat thickness (to an accuracy of 0.1 mm) was measured directly on both sides of the carcase using vernier calipers; measurements were made at nine sites. A description of each site follows and its location on a carcase is shown on Figure 2.

Round - In a horizontal plane from the caudal edge of the pubic symphisis to a point perpendicular to the distal extremity of the hock. The measurement is made over the *M. vastus lateralis.*

Silverside - In the same horizontal plane. One third of the distance from the round site (as above) to the caudal edge of the pubic symphisis. The measurement is made over the *M. biceps femoris.*

Topside - Located over the proximal insertion of the *M. semimembraneous.*

Rump - Located over the *M. biceps femoris* two thirds of the distance from the caudal edge of the exposed sacral bone to the anterior edge of the tuber coxae.

Sirloin - Located at the junction between the third and fourth lumbar vertebrae, over the last quarter of the *M. longissimus.*

Forequarter - 12/13th - located at the junction between the 12th and 13th thoracic vertebrae over the last quarter of the *M. longissimus.*

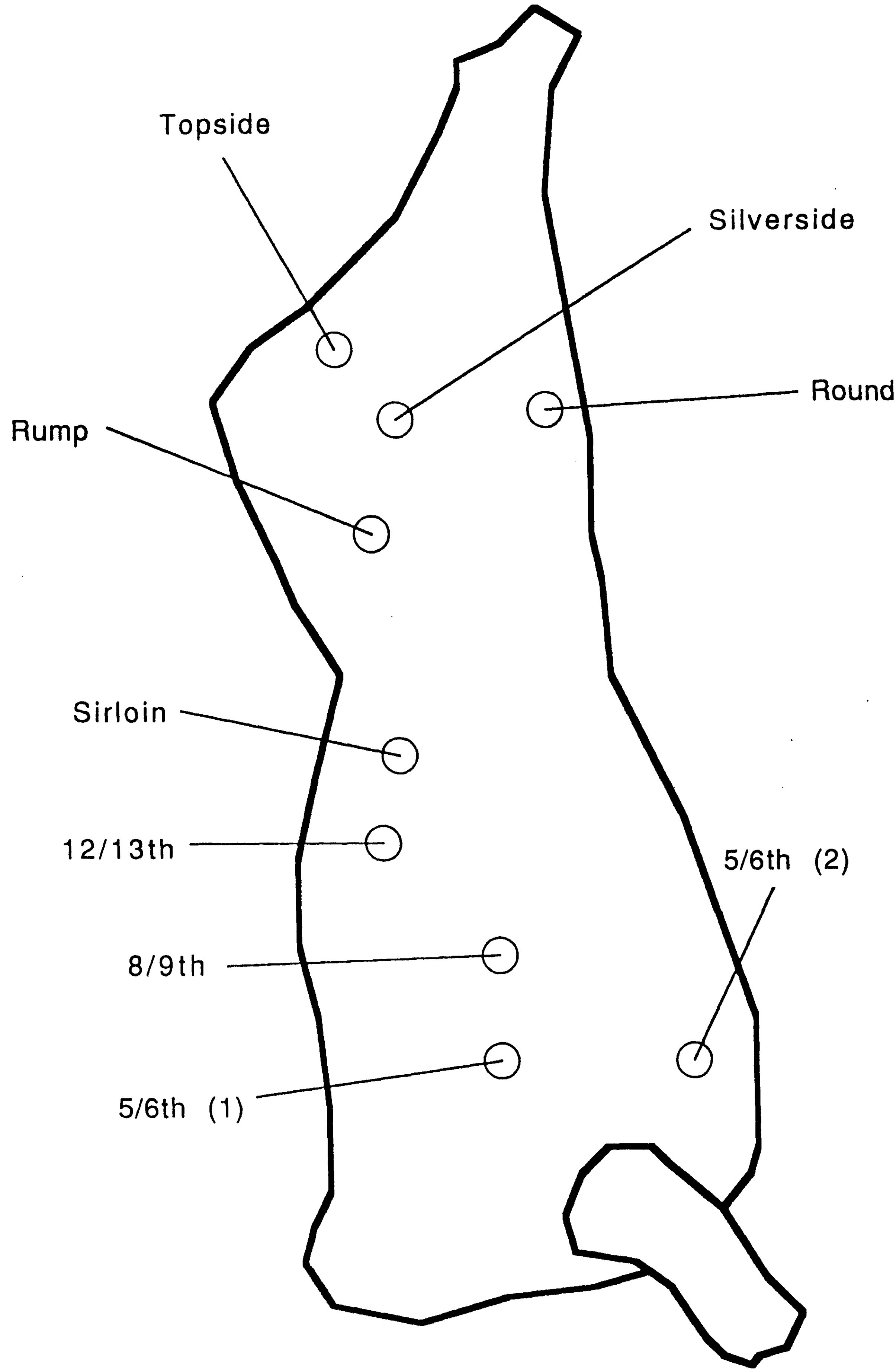
8/9th - located at the mid-point between the distal edge of the 8th rib and the ventral process of the 8th thoracic vertebrae. This measurement is made over the *M. lattissimus dorsi*.

5/6th (1) - located over the *M. lattissimus dorsi* at the junction of the caudal edge of the 5th rib and the ventral edge of the scapulae (this site is located by pushing the pin through the carcase from the thoracic cavity).

5/6th (2) - located at the distal edge of the 5th rib.

Eye muscle (*longissimus dorsi*) tracings were made at the 12/13th rib. The individual tracings were then analysed by an electronic planimeter (plant leaf area machine) to determine their area to the nearest cm^2.

Figure 2: The location of the 9 fat sites on the carcase



8.1.4 Data analysis

All data was analysed by generalised least squares procedures. All first order interactions were included in the initial models and non-significant (P>0.05) interactions were sequentially removed to produce the final models. All variables were tested using the residual term. A description of the variables included in the final models for each trait is given below.

The breedtype term in all analyses was constrained into 3 single degree of freedom contrasts, viz.

- Heterosis, calculated as the crossbred mean minus the straightbred mean i.e. [(DH+HD)-(DD+HH)]/2
- Straightbred additive effect, the difference between the straightbred means i.e. DD-HH; and
- Maternal additive effect, the difference between the reciprocal cross means i.e. DH-HD#

this estimate may also contain reciprocal differences generated if any sex linkage occurred for traits, but this will be assumed to be negligible.

Steer growth:

Weaning weight and slaughter weight data from the three groups of steers were combined and analysed in a univariate model which contained terms for breedtype, group and weaning age. Models for slaughter weight were also fitted with weaning weight and the group *x* weaning weight interaction. Weaning weight was included in the model as a covariate to obtain estimates for breed effects for postweaning growth. A term for sires within breedtype was not included in the model as the average number of calves per A.I. sire was only 1.4.

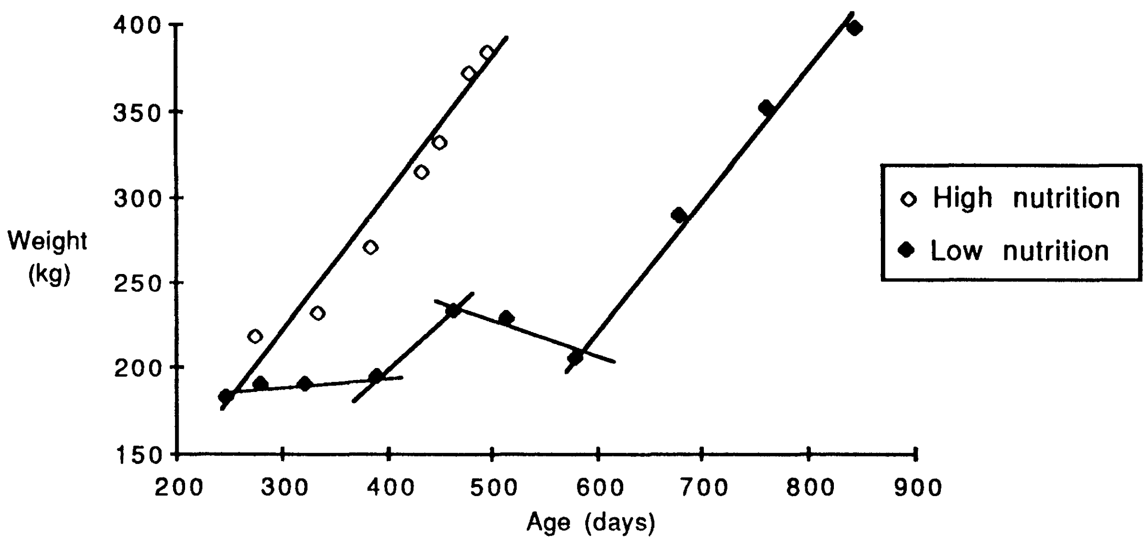


Figure 3: Mean postweaning weights and regression lines for growth rate of the 1985 Devon steers grown out in high and low nutrition environments.

Plots of liveweight against time showed a linear pattern of growth for steers at Gunnedah (high nutrition). At Wards River (the low nutrition site), growth rates were linear for limited periods, with the rates changing significantly ($P<0.05$) between seasons. Within these periods, growth rates for individual animals were calculated by regressing liveweight against time. Figure 3 shows the mean growth rate from weaning to slaughter for the 1985 Devon steers in the two environments. At the high nutrition site, the mean growth rate from weaning to slaughter for the Devon steers was 0.78 kg/day. For the low nutrition site, the means for the four periods shown in Figure 3 were: 0.06, 0.52, -0.25 and 0.74 kg/day for the low weight gain, moderate gain, weight loss and high weight gain periods, respectively.

A repeated measures analysis was used to examine the effect of breedtype, weaning weight and weaning age on growth rate in the low nutrition environment. Specific contrasts between growth periods were used to study interactions between growth rate and the above effects.

Carcase data:

Hot carcase weight was analysed using univariate models which contained terms for breedtype and group. This model was run with and without adjustment for slaughter weight.

Kidney and channel fat from the three groups of steers was analysed using a univariate model. The final model contained terms for steer breedtype, group, hot carcase weight and breedtype *x* group interaction.

The eye muscle area and fat depths from left and right sides of the carcase were averaged prior to analysis. The final model for eye muscle area contained terms for breedtype, group, hot carcase weight and a hot carcase weight *x* group interaction.

Differences in subcutaneous fat depth i.e. measurements of fat depth at the nine sites over the carcase (see Figure 2), were analysed in a multivariate model, in which non-significant interactions ($P>0.05$) were deleted from the model. The final model contained terms for breedtype, group, hot carcase weight, and a hot carcase weight *x* group interaction. When the breedtype term was partitioned into three single degree of freedom contrasts, there was a significant straightbred effect for fat depth over the carcase. To identify the subset of sites which contributed to the significance of the straightbred effect, a canonical variate analysis was used.

8.2 Experimental Results

Slaughter weight of the steers was evaluated for the effects of heterosis, straightbred (direct additive) and maternal (additive maternal) differences. The effects of weaning weight and group (i.e. environment) on slaughter weight were also examined. Hot carcase weight, eye muscle area and fatness, measured as kidney and channel fat and subcutaneous fat depth, were studied for the effects of heterosis, straightbred and maternal differences; group differences were also evaluated for each trait.

8.2.1 Slaughter weight

The least squares analysis of variance of slaughter weight presented in Table 8.2 shows differences occurred between the breedtypes for slaughter weight. The level of heterosis for slaughter weight was significant, crossbred steers were 18.5 ± 6.7 kg ($P<0.01$) heavier than the straightbreds, which was 5.0 % heterosis for slaughter weight (Table 8.3).

No significant straightbred or maternal differences occurred for slaughter weight, although a trend existed for the Devon to be heavier than the Hereford and the Hereford *x* Devon reciprocal cross steers to be

Table 8.2: Least squares analysis of variance for weaning weight and slaughter weight (unadjusted (+) and adjusted (#) for weaning weight) of Devon, Hereford and reciprocal cross steers.

Independent variables	df	Mean squares		
		Weaning weight (kg)	Slaughter weight (kg) +	Slaughter weight (kg) #
Full model (df)		5167.5 (6)	10826.9 (6)	13595.7 (9)
Breedtype				
Heterosis	1	269.1	8862.9 **	5206.9 **
Straightbred	1	1515.7 *	3237.2	407.4
Maternal	1	1506.2 *	2429.6	14.5
Group	2	193.7	9202.2 ***	2628.9 *
Weaning age	1	23950.1 ***	34599.0 ***	43.7
Weaning weight	1	—	—	33918.0 ***
Group *x* weaning wt.	2	—	—	2453.7 *
Error (df)		377.7(103)	1149.1(103)	609.5(100)
R^2		44.4	35.4	66.8

* P<0.05, ** P<0.01, *** P<0.001

Table 8.3: Breedtype means, heterosis levels, straightbred and maternal differences (and standard errors) for weaning weight (kg), slaughter weight (kg) and slaughter weight adjusted for weaning weight (kg) for Devon, Hereford and reciprocal cross steers.

Trait	Breedtype (sire breed first) DD	DH	HD	HH	Heterosis (kg)	%	Straightbred difference (DD-HH)	Maternal difference (DH-HD)
Weaning weight	156.0 (3.6)	148.4 (3.5)	159.1 (4.2)	145.0 (4.2)	**3.2** (3.8)	**2.0**	**11.0** * (5.5)	**-10.7** * (5.4)
Slaughter weight	376.6 (6.2)	380.2 (6.2)	393.8 (7.3)	360.4 (7.3)	**18.5** ** (6.7)	**5.0**	**16.1** (9.6)	**-13.6** (10.8)
Slaughter weight (adjusted for weaning weight)	374.5 (4.7)	386.5 (4.6)	385.4 (5.4)	368.7 (5.4)	**14.4** ** (4.9)	**3.9**	**5.9** (7.2)	**1.1** (7.1)

* P<0.05, ** P<0.01

heavier than the Devon *x* Herefords (Table 8.3). There were significant group and weaning age effects on slaughter weight. Steers from Groups 1 and 2 were on average 33.1 kgs heavier at slaughter than the steers from Group 3. An increase in weaning age of one day, was associated with an increase in slaughter weight of 0.95 ± 0.17 kg. (Appendix 2).

The average slaughter weight was 377.8 ± 3.5 kgs, with the average age at slaughter being 496, 844, and 438 days for Groups 1, 2 and 3, respectively. Breedtype means, heterosis levels and straightbred and maternal differences for slaughter weight are presented in Table 8.3.

The least squares analysis (Table 8.2) shows that when slaughter weight was adjusted for weaning weight, heterosis remained significant ($P<0.01$). However heterosis was reduced from 18.5 to 14.4 kg (3.9 %). Straightbred and maternal differences for slaughter weight adjusted for weaning weight were not significant ($P>0.05$) (Table 8.3).

Weaning weight had a significant effect on adjusted slaughter weight; a 1 kg increase in weaning weight resulted in 1.04 ± 0.14 kg increase in slaughter weight (Appendix 2). A weaning weight *x* group interaction also had a significant effect on adjusted slaughter weight, although the biological basis for the interaction is unclear.

At weaning, the reciprocal crossbred calves on Devon dams were 10.7 kg ($P<0.05$) heavier than those on Hereford dams. Straightbred Devon calves were significantly heavier at weaning (11.0 kg) than the straightbred Herefords (Table 8.3). This maternal Devon advantage for weaning weight was maintained in absolute terms to slaughter, although the difference was not significant ($P>0.05$).

No significant breedtype *x* environment interaction occurred for slaughter weight. The straightbred Devons and Herefords did not differ in slaughter weight within the high or low nutrition groups. However they did perform differently during the four periods of growth in the low nutrition groups.

8.2.2 Growth rate within Environment B

The repeated measures analysis for growth rate during four periods of growth within the low nutrition environment (Environment B) is presented in Table 8.4. The results show that interactions for level of heterosis and of maternal effects for growth between the four periods were non-significant. However the straightbred effect for growth rate did change between the growth periods. The linear contrasts presented in Table 8.4 shows a trend for the straightbred effect for growth rate to interact between the 1st and 2nd growth periods with the 4th growth period. The combined effect was that the average growth rate of the straightbreds in periods 1 and 2 interacted significantly with growth rate in period 4 ($\chi^2=6.29$, on 1 d.f., $P<0.05$). All other contrasts were tested and found to be non-significant. Therefore the results show that during periods of slow to moderate gain, the Devon steers had the relative advantage in growth, although this was reversed during periods of high gain where the Herefords had the advantage. Genotype means for growth rate within each of the growth periods in the low nutrition environment are presented in Table 8.5.

Table 8.4: Chi-squares and specific contrasts for liveweight gain, (kg/day) during four growth periods in Environment B, of Devon, Hereford and reciprocal cross steers.

Independent variables		Chi-square (on df)	Probability (%)
Steer breedtype			
Heterosis	mean	3.17 (on 1)	7.5
Straightbred	mean	1.37 (on 1)	24.1
	contrast		
	P1 vs P4	4.96 (on 1)	2.6
	P2 vs P4	3.68 (on 1)	5.5
	(P1+P2)/2 vs P4	6.29 (on 1)	1.2 *
Maternal	mean	0.34 (on 1)	56.0
Weaning weight	mean	0.27 (on 1)	60.2
Weaning age	mean	0.01 (on 1)	92.4

* $P<0.05$

Contrasts	**P1 vs P4**	Low (P1) versus high gain (P4).
	P2 vs P4	Moderate gain (P2) versus high gain (P4).
	(P1+P2)/2 vs P4	The average of low and moderate gain (P1+P2) versus high gain (P4).

Table 8.5: Liveweight gain (kg/day), heterosis levels, and straightbred and maternal differences (and standard errors) for four growth periods, of Devon, Hereford and reciprocal cross steers grown out in a low nutrition environment.

Growth period	Breedtype (sire breed first) DD	DH	HD	HH	Heterosis (kg/day)	Straightbred difference	Maternal difference
1. Low gain	0.07 (0.03)	0.09 (0.03)	0.06 (0.03)	0.01 (0.03)	**0.03** (0.03)	# **0.06** (0.05)	**0.04** (0.05)
2. Mod. gain	0.51 (0.04)	0.55 (0.04)	0.51 0.04)	0.43 (0.04)	**0.05** (0.04)	**0.08** (0.06)	**0.05** (0.06)
3. Weight loss	-0.24 (0.04)	-0.29 (0.04)	-0.21 (0.04)	-0.26 (0.04)	**0.00** (0.04)	**0.02** (0.05)	**-0.08** (0.05)
4. High gain	0.74 (0.03)	0.81 (0.03)	0.77 (0.03)	0.79 (0.03)	**0.02** (0.03)	**-0.05** (0.04)	**0.04** (0.04)

Contrasts: see Table 8.4

8.2.3 Carcase studies

The results of the least squares analysis of variance for hot weight, kidney and channel fat and eye muscle area are summarised in Table 8.6. Significant heterosis occurred ($P<0.01$) for hot carcase weight, the crossbred carcases being 13.6±4.2 kgs (7.4 %) heavier than the straightbreds. Differences between the two straightbreds and between the reciprocal crosses were not significant.

When slaughter weight was included as a covariate it accounted for an additional 75 % of the variation in hot carcase weight and the estimate of heterosis for hot carcase weight was reduced ($P>0.05$, Table 8.6). A 1 kg increase in slaughter weight resulted in a 0.54 kg increase in hot carcase weight. Significant differences occurred for dressing percentage between groups with steers from Group 1 dressing heavier than Groups 2 and 3. Predicted means for hot carcase weight are presented in Table 8.7.

The results for the analysis of variance for eye muscle area and for kidney and channel fat are presented in Table 8.6. No heterosis, straightbred or maternal differences existed for eye muscle area. The average eye muscle area was 56.2±0.8 cm^2, adjusted for hot carcase weight.

Table 8.6 shows that no significant heterosis occurred for kidney and channel fat, however the crossbreds tended to have more fat at the same hot carcase weight. The straightbred effect was significant; Devon carcases had 0.62±0.25 kgs more fat than the straightbred; Herefords. The maternal (additive) effect was not significant. A significant difference

Table 8.6: Least squares analysis of variance for hot carcase weight (kg), kidney and channel fat (kg) and eye muscle area (cm^2) of Devon, Hereford and reciprocal cross carcases.

Factor	df	Mean squares			
		Hot carcase weight	Hot carcase weight +	K and C fat	Eye muscle area
Full model(df)		2570.75 (5)	9748.82 (6)	12.03 (12)	256.07 (8)
Breedtype					
Heterosis	1	4814.47 **	40.81	0.53	3.63
Straightbred	1	1563.80	99.95	4.48 *	13.42
Maternal	1	568.65	3.06	0.01	39.08
Group	2	3093.03	760.11 ***	50.68 ***	491.35 ***
Slaughter weight	1	—	45639.18 ***	—	—
Hot carcase weight	1	—	—	33.49 ***	812.34 ***
Hot carcase wt. *x* group	2	—	—	—	480.11 ***
Breedtype x group	6	—	—	1.76 *	—
Error (df)		467.78 (104)	3009.97 (103)	0.72 (97)	32.59(101)
R^2		20.9	95.1	67.4	38.4

* P<0.05, ** P<0.01, *** P<0.001

\+ adjusted for slaughter weight

occurred between groups for weight of kidney and channel fat. Steers from the low nutrition environment had on average 2.17 kgs less kidney and channel fat, at the same hot carcase weight, than the two groups from high nutrition.

Least square means for eye muscle area and kidney and channel fat are presented in Table 8.7. The average weight of kidney and channel fat, adjusted for hot carcase weight was 2.83 ± 0.09 kg.

The analysis of variance of fat depth at the nine subcutaneous sites showed no significant heterosis or maternal effects. However a significant straightbred effect occurred and the standardised elements from the canonical variate analysis were used to identify the subset of variables which contributed to the significance of the straightbred term. The standardised elements presented in Table 8.8 showed five sites as contributing most to the straightbred effect. In an attempt to further separate out the important variables, these five sites were included in a subsequent analysis (Table 8.8), although the magnitude and ranking of the standarised elements changed little. The analysis shows the signs of the standardised elements differed with three out of the five being positive the others negative, indicating an interaction between breed and fat site. From the least squares means in Table 8.8 the Devon carcases were fatter at the topside, 12/13th rib and 5/6th rib (site 1) sites compared to the Herefords which were relatively fatter at the silverside and rump.

Table 8.7: Breedtype means, heterosis levels, straightbred and maternal differences (and SE) for hot carcase weight (kg) and hot carcase weight (kg), adjusted for slaughter weight and kidney and channel fat weight (kg) and eye muscle area (cm^2), adjusted for hot carcase weight for Devon, Hereford and reciprocal cross carcases.

Trait	Breedtype (sire breed first) DD	DH	HD	HH	Heterosis units	%	Straightbred difference	Maternal difference
Hot carcase weight	189.3 (3.9)	194.1 (3.9)	200.7 (4.7)	178.3 (4.6)	**13.6** ** (4.2)	**7.4**	**11.1** (6.04)	**-6.6** (6.0)
Hot carcase weight (adj. slaughter weight)+	190.2 (1.0)	193.2 (1.0)	192.7 (1.2)	193.1 (1.2)	**1.3** (1.1)	**0.7**	**-2.9** (1.55)	**0.5** (1.5)
Kidney and channel fat#	3.07 (0.16)	2.93 (0.19)	2.90 (0.23)	2.44 (0.22)	**0.16** (0.19)	**5.8**	**0.62** * (0.25)	**0.03** (0.27)
Eye muscle area#	55.9 (1.2)	56.9 (1.1)	55.2 (1.4)	57.0 (1.4)	**-0.4** (1.2)	**-0.7**	**-1.0** (1.6)	**1.8** (1.6)

* P<0.05 ** P<0.01

\# adjusted to a hot weight of 193 kg

+adjusted to a slaughter weight of 380 kg

Table 8.8: Chi-squares, standardised elements of the canonical variate, least square means and univariate F ratios for the effect of breed (straightbred Hereford vs. Devon) on fat depth at several sites over the carcase.

	Standardized elements of the canonical variate (RSD) for the DEVON and HEREFORD breeds			Least square means (SE) (mm)		
	Complete set of dependent variables	Reduced set of dependent variables	Univariate F ratios			
χ^2 (on df)	19.25 (on 9) P=0.023	19.45 (on 5) P=0.0016	(1,93)			
Fat sites				Devon	Hereford	D-H
topside	0.408	0.439	3.12	1.80 (0.15)	1.41 (0.17)	**+0.39**
silverside	-0.386	-0.386	0.17	1.43 (0.17)	1.53 (0.20)	**-0.10**
round	-0.019	—	0.09			
rump	-0.526	-0.497	0.04	8.02 (0.34)	8.12 (0.39)	**-0.10**
sirloin	0.120	—	3.17			
12/13th rib	0.501	0.528	7.49 **	4.35 (0.26)	3.28 (0.30)	**+1.07**
8/9th rib	-0.040	—	0.85			
5/6th rib (1)	0.699	0.723	9.43 **	5.81 (0.30)	4.44 (0.35)	**+1.37**
5/6th rib (2)	0.050	—	0.57			

** $P<0.01$

8.3 Discussion

8.3.1 Steer growth and slaughter weight:

Heterosis for slaughter weight was 5.0 % (18.5 kgs). This is in agreement with the mean of 4 % (range 1 to 8 %) for post-yearling weight (beyond 400 days) for British beef breed crosses, summarized by Long (1980).

When slaughter weight was adjusted for weaning weight, to remove preweaning direct and maternal growth differences, heterosis was 14.4 kg (3.9 %). Hence, the crossbreds exhibited significant heterosis for postweaning growth. Warwick (1968) summarised a number of experiments involving first cross calves of British breeds and reported estimates of heterosis for postweaning gain ranging from 2.4 to 6.5 %. A review by Long (1980) reported heterotic effects for postweaning gain ranging between 2 and 11 % with a mean of 6 %. However the estimates varied with sex and management regimes and generally decreased with increasing age hence, the range in the estimates.

Slaughter weights of the straightbreds were not significantly different, however the Devons tended to be heavier than the Herefords. However much of this advantage was removed when adjusting for differences in weaning weight.

There were no differences in postweaning growth between the Devon-Hereford reciprocal crossbreds, indicating that additive maternal influences were minor. This is in agreement with results of Lasley et al. (1973); however, Long (1980) reported reciprocal differences in postweaning gain ranging between 0-11 % with a mean of 5 %.

It is of note that the maternal Devon advantage for weaning weight was maintained in absolute terms to slaughter weight, a positive carry-over of this preweaning maternal environment. At weaning, the reciprocal crossbred calves on Devon dams were heavier than those on Hereford dams. Straightbred Devon calves were heavier at weaning than the straightbred Herefords. Gyles et al. (1986) concluded that these differences were largely due to milk production. Many researchers have shown that the expression of heterosis for preweaning growth is influenced by the maternal environment, particularly dam milk production (Long 1980, Damon et al. 1961 and Smith et al. 1976a).

Lerner (1954) suggested that crossbred animals are expected to be less influenced by environmental effects than their purebred parental lines. This is in agreement with an extensive review of the expression of heterosis in which Barlow (1981) concluded that heterosis for most traits appears to be greater in sub-optimal environments, with the notable exception of heterosis for growth, which in both plant and animal species was enhanced by favourable nutrition. However, in this study there was no significant heterosis *x* environment interaction for slaughter weight, indicating the relative performance of the crossbreds was not influenced by the two environments used in this study.

Whilst the straightbred Devon and Hereford steers did not differ in weight at slaughter within the high and low nutrition environments, they did perform differently during periods of slow and faster growth in the low nutrition environment. During periods of slow to moderate gain the Devons had the relative advantage in growth, although this was reversed during the period of rapid gain, where the Herefords had the advantage. The interaction between growth periods was cancelled at slaughter with no difference between the Devon and the Hereford in slaughter weight.

The straightbred interaction for growth between periods may have been confounded with breed differences in the shape of the growth curves, that is, differences between the breeds for stage of maturity. If breed differences existed for maturing rate then this may have contributed to the interaction in this study. However an analysis of growth in Group 1 steers (high nutrition) failed to show any significant interaction between the straightbreds' growth rate over the seven bimonthly weighing periods, suggesting that under high nutrition there was little difference in the shape of the growth curves. The relative advantage of the Devons during the periods of slow gain supports the industry view that Devons have an ability to perform relatively better under harsh conditions.

8.3.2 Carcase traits

The heterosis for hot carcase weight (7.4 %) reflects the heavier slaughter weight of the crossbreds at the same age and a slight increase in dressing percentage of 1.2 %. Similar results were reported by Johnson et al. (1986), viz. heterosis for slaughter weight of 8.4 %, hot carcase weight of 10.4 % and dressing percent of 1.9 % in straightbred Angus, Hereford and reciprocal cross steers. A review by Long (1980) reported heterosis for dressing percentage as low, ranging between 0 and 1 %.

Differences between the carcase weights of the straightbreds and of the reciprocal crosses were not significant and primarily reflect the lack of difference in slaughter weight. This also suggests no significant differences in dressing percentage.

No heterosis or maternal differences occurred for eye muscle area when adjusted to a constant hot carcase weight. Similar results have been reported by Gregory et al. (1966b), Koch et al. (1976), Gregory et al. (1978c), Marshall et al. (1987), Alenda et al. (1980b) and Johnson et al. (1986) where significant heterotic or maternal effects were removed (or significantly reduced) by adjusting the data sets to a constant hot carcase weight. However, reports by Gaines et al. (1967) and Long and Gregory (1975b) showed significant heterosis (2 to 3.5 %) after adjustment for hot weight, but the estimates still show the magnitude to be relatively small.

In this present study no direct additive differences between the Devon and Hereford breeds were apparent for eye muscle area, although several other reports have shown differences between other breeds of up to 26 % (Alenda et al. 1980b). These other studies commonly involve comparisons between the large European and the British breeds. Studies between British breeds have not shown significant differences in eye muscle area (Alenda et al. 1980b, Gregory et al. 1966b).

The lack of significant heterosis or maternal differences for kidney and channel fat is in agreement with results of Hedrick et al. (1975), Marshall et al. (1987), Gregory et al. (1978c). Long and Gregory (1975b) reported significant heterosis (3.8 %) for kidney fat weight, although this was no longer significant when adjusted to a constant hot carcase weight.

Additive differences between the breeds were identified for the weight of fat in the internal body depots, with straightbred Devon steers having significantly more kidney and channel fat than Herefords, when adjusted for hot carcase weight. Results from sire evaluation studies found that Devon sired carcases had more kidney, heart and pelvic fat than Angus and Hereford sired carcases (Young et al. 1978b). Additive breed differences for kidney, pelvic and heart fat have been reported in several other studies (Hedrick et al. 1975, Adams et al. 1977, Gregory et al. 1978c) and a general finding is that dairy breeds deposit more of their fat in the abdominal cavity compared to beef breeds, which deposit more of theirs subcutaneously (Truscott et al. 1983).

The average estimate of heterosis for carcase fatness, as reviewed by Long (1980), was 5 %. The experiments reviewed commonly used fat depth at the 12/13th rib as the sole measure of carcase fatness. However, this present study showed no significant heterosis for carcase fatness when this was measured at 9 sites over the carcase.

Differences existed between the Devon and the Hereford in the depth of subcutaneous fat. Five sites were identified as contributing to this difference. Devon carcases were fatter than the straightbred Hereford at the topside, 12/13th rib and 5/6 rib (site 1) and the Hereford was fatter at the silverside and rump sites. Other workers have also reported additive differences in carcase fatness with estimates of up to 55 % having been observed (Long 1980). However, carcase fatness can be highly variable between environments and comparisons between studies are difficult. Gregory et al. (1978c) reported Herefords to be intermediate in fatness to Brown Swiss and Angus. Several reports have shown the additive effect on carcase fatness increases with an increase of British breeding content (Damon et al. 1960, Klosterman et al. 1968, Adams et al. 1977, Alenda et al. 1980b). Although several reports exist in the literature describing breed differences in the partitioning of fat between the major depots few studies have examined breed differences in the distribution of fat within a depot. This present study indicates that such differences may exist between the Devon and Hereford breeds. Truscott et al. (1983) also reported differences between Friesian and Hereford steers in the distribution of fat within the subcutaneous depot.

8.4 Conclusions

Heterosis for postweaning growth rate was 3.9 % and for slaughter weight 5.0 %. These estimates were within the range of reports between *Bos taurus* crosses. No significant differences existed between the straightbreds, or between the reciprocal crosses for slaughter weight. However within the low nutrition environment during periods of slow and fast growth, the Devons and the Herefords performed differently. The two environments significantly affected the growth rate of the steers, however heterosis for slaughter weight was of the same magnitude in both environments.

The carcase results from this study are consistent with the conclusions of Gregory et al. (1978c) who reported that there was not a major change in carcase composition associated with the heavier weights of carcases from crossbred steers. When carcase traits were adjusted to a constant carcase weight, heterosis effects and reciprocal differences were generally not important. Hence heterosis was being expressed in carcase traits through an increase in carcase weight. Breed additive effects were important on carcase traits due to the additive effects of genes, independent of breed effects on growth rate and weight. The Devon carcases had more kidney and channel fat at a constant hot carcase weight and an additive difference occurred in the partitioning of fat within the subcutaneous depot.

CHAPTER 9

Postweaning growth and maternal performance of Devon, Hereford and reciprocal cross heifers

Additive and non-additive differences in birth weight and preweaning gain of Red Angus sired calves from Devon, Hereford and reciprocal cross heifers were examined. The impact of milk production on calf weight, milk yield and composition were measured at four stages during lactation with parallel studies on suckling and grazing behaviour, using a sample of the Devon, Hereford and reciprocal cross heifers.

9.1 Materials and Methods

The overall design of the trial has been described in Section 7.2 and is represented diagrammatically in Figure 1.

9.1.1 Animals and management

A total of 112 heifers from the 1985 drop were all weaned at the same time with the average age being six months (150 kgs). Post-weaning, all heifers were managed as a single herd and grown out on high quality pasture at Gunnedah (Environment A). Bimonthly weights were taken from weaning to joining. At an average age of 15.5 months the four breedtypes were equally divided into three single sire mating groups. The heifers were divided based on breedtype and distributed across a prejoining weight to create groups of similar average weight. Each group was joined to terminal sires (three Red Angus bulls) for a nine week period, after which they were again managed as a single herd.

Calving occurred in February and March 1987. The number of heifers that calved in each breedtype was 16 DD, 19 DH, 16 HD and 17 HH. This low calving rate was explained by two factors. Firstly, Leptospirosis was diagnosed in the herd and possibly caused at least 13 detected abortions. Secondly, one of the Red Angus bulls sired only 18 calves (49 % calving rate) and later, via a serving capacity test, was diagnosed to have a spiral deviation of the penis.

During the calving period, heifers were inspected three times daily and those experiencing difficulties were yarded and assisted. Within 12 hours of birth all calves were individually identified, weighed and body dimensions measured. Identification was by an ear tag and ear tattoo and body measurements comprised chest girth, body length and cannon bone length.

The number of live calves per breedtype was 13 DD, 18 DH, 15 HD and 14 HH. Post-birth weights were recorded approximately monthly and male calves were castrated in May (average age three months). All calves were weaned in November with the average age being nine months.

Milk production was measured in a sub-sample of 40 heifers from the project. The sampling criteria for the heifers included was based on their calving date and breedtype. The number sampled from each breedtype was 10 straightbred Devon, 11 Devon *x* Hereford, 9 Hereford *x* Devon and 10 straightbred Hereford heifers. Milk yield and milk composition data was collected at four stages during lactation. The average calf age at each of these four collections was 5, 12, 22 and 37 weeks, with the 40 calves ranging in age from 12 to 48 days at the first collection. At each of the collections individual calf weights, heifer weights and heifer body fat scores were recorded.

Suckling and grazing behaviour studies were conducted on the same 40 heifers and their calves as used in the milking experiments. Three studies were performed at 12, 22 and 37 weeks lactation prior to the 2nd, 3rd and 4th milk collections, respectively. A study was planned to coincide with the first milking experiment (at 5 weeks); however, poor weather conditions prevented this study from occurring.

9.1.2 Experimental techniques

9.1.2.1 Body weight

Calf birth weights were measured within 12 hours of birth. Weights were recorded to the nearest 0.1 kg. All subsequent calf and heifer weights (unfasted) were measured to the nearest 1.0 kg using electronic cattle scales which were repeatedly checked for accuracy.

9.1.2.2 External body fat scoring (condition scoring)

The technique used to manually estimate fat cover on the heifers was the same as that described in Section 8.1.3.2.

9.1.2.3 Body shape

At birth, calf chest girth (body circumference immediately posterior to the forelimbs), body length (distance from the spinous process of the first thoracic vertebra to the midpoint between the tuber coxae) and cannon bone length (distance from the centre of the carpus to the distal end of the metacarpus bones) were measured. At weaning, calf hip height (height at the midline in a line from the tuber coxae), chest girth and body length (as above) were measured. All measurements were recorded to the nearest centimeter.

9.1.2.4 Milking experiments

Milk yield was measured by the technique which utilises oxytocin and teat cannulation (Butson et al. 1980).

The same experimental procedure and the same 40 heifers were used at the four collection experiments. The heifers were separated from their calves overnight and allowed to suckle at dawn, then separated again (0640 hours), to establish a reference point. They were then reyarded at 1100, 1045, 1030, 1100 hours, respectively at each of the four experiments. The heifers were milked in a random order and the time and order of milking recorded.

The extraction of milk involved the cannulation of each teat with a 38 mm stainless steel cannular (a modified 14 gauge hypodermic needle) and an injection of 20IU (2mls) of oxytocin-S, a synthetic oxytocin, in the coccygeal vein (main tail vein). When milk letdown occurred (approximately 60 seconds after injection) the milk was collected in a container via a funnel and plastic tube. The time lapse between injection and completion of milk letdown ranged from 3 to 10 minutes. The time taken to milk the 40 heifers was approximately 6, 6, 6 and 4.5 hours for each collection, respectively.

The milk collected was immediately weighed (to 0.01 kg) and a sample taken and stored at $4^{0}C$ for subsequent milk composition analyses. Milk samples were analysed for butterfat percentage using procedures described by Shipe (1972) and for protein using the technique described by Grappin et al. (1980).

9.1.2.5 Behaviour studies

Three behaviour studies were performed. Prior to each of the observation periods, large identification numbers were painted on both sides of the heifers (and the calves in the third study) using an aluminium based paint. The heifers and their calves were placed in a six hectare paddock with adequate feed and water for a day prior to recording behaviour.

Observations began at first light and terminated at dusk. The duration of the three studies was approximately 12, 11 and 14 hours for May, July and November, respectively. Each study involved two people continuously observing the 40 heifers and their calves with the aid of binoculars from stationary vehicles located in the paddock (2-way radios were used to communicate between the vehicles).

The duration of a suckling bout for each calf was recorded to the nearest minute (a suckling bout was defined as a period of suckling that lasted longer than one minute). Suckling times were then summed over the period of observation to give total suckling time (minutes/daytime). The number of suckling bouts (defined as the number of successful sucklings) were recorded and summed to give total number of suckling bouts for the observation period. In studies 1 and 2 the total grazing time of each heifer was recorded based on 15 minute observations of the herd. In the third study individual calf grazing time was recorded to the nearest minute.

9.1.3 Data analysis

All data were analysed by least squares procedures. Main effects, covariates and all first order interactions were included in the initial models and non-significant ($P>0.05$) interactions were sequentially removed to produce the final models. All variables were tested using the residual term. A description of the variables included in the final model for each trait is given below.

The breedtype term in all the analyses was constrained to give 3 single degree of freedom contrasts, viz.

- Heterosis, calculated as the crossbred mean minus the straightbred mean i.e. [(DH+HD)-(DD+HH)]/2
- Straightbred effect, the differences between the straightbred means i.e. DD-HH; and
- Maternal effect, the difference between the reciprocal cross means i.e. DH-HD#.

This estimate may also contain reciprocal differences generated by any sex linkage for the traits, but this will assumed to be negligible.

9.1.3.1 Heifer postweaning growth

Postweaning gain of the heifers to joining and joining weight were analysed in univariate models. Firstly, joining weight was analysed in a model which contained terms for breedtype, age at weaning, and breedtype *x* weaning age interaction. Secondly, since the heifers showed a linear pattern of growth, and the same model was used to analyse postweaning gain (linear regression of five individual weights over time) with the exception that weaning weight was included as a covariate. Least square means for both joining weight and postweaning gain were generated.

9.1.3.2 Calf weights and shape

Birth weights of the calves from the four female breedtypes were analysed in a univariate model. The final model contained terms for breedtype of dam, sire and calf sex.

Body shape at birth, which included chest girth, body length and cannon bone length was analysed using a multivariate analysis. The final model contained terms for breedtype of dam, sire and sex of calf, with birth weight included as a covariate.

Body shape at weaning, which included chest girth, body length and hip height, was also analysed by fitting a multivariate model. This contained terms for breedtype of dam, sire and sex of calf, with weaning weight and age included as covariates in the model.

Preweaning weight gain (PWG) from birth to weaning was calculated by subtracting birth weight from weaning weight. A least-squares model was fitted to the PWG records, and included terms for dam breedtype, calf sex, calf age within dam breedtype and sex, sire and sire *x* breedtype of dam interaction. As female calves were born earlier, particularly in the DH group, calf age was adjusted within dam breedtype and sex. The sires were fitted as a fixed effect in all the models.

Maternal heterosis for each trait was estimated as the difference between the mean performance of the calves from the crossbred dams and that of the calves from the straightbred dams.

9.1.3.3 Milking experiments

Milking data from the four experiments was transformed by the following computations prior to analyses being performed.

1. Actual milk yield (kg) = weight of milk collected (kg)
2. Separation interval (min) = time of milk collection (min) minus time of calf separation (min)
3. Adjusted milk yield = actual milk yield (kg) adjusted at each collection to a common separation interval of 433 minutes *.
4. 24 hour milk yield (kg/day) = adjusted milk yield (kg) X (1440/433)
5. Body fat score change = linear regression of the 4 fat scores over time (5 to 37 weeks)

6. Initial fat score = fat score 1 (at 5 weeks lactation)
7. Average heifer weight (kg) = (wt1 + wt2 + wt3 + wt4)/4, where wts1 to 4 are the individual heifer liveweights at each of the four milking experiments.
8. Average heifer fat score = (fs1 + fs2 + f3 + fs4)/4, where fs1 to 4 are the individual heifer body fat scores at each of the four milking experiments.

* 433 minutes was the average separation interval for the four collections. Individual adjusted milk yield was calculated at each of the collections by regressing actual milk yield against the separation interval. These regression equations for each of the collections were then multiplied by the average separation interval of 433 minutes to give a grand mean. Individual residual milk yields were then added or subtracted to give the adjusted milk yield for each heifer at each collection.

Milk yield and milk composition data from the four experiments were analysed as repeated measures in multiple regression models. The independent variable of primary interest was breedtype of dam. Correlations between milkings were calculated to examine the repeatability of the milking technique.

Milk yield:

Adjusted 24 hour milk yield was used as the dependent variable in all the analyses. Initial models contained fixed effects (heifer breedtype, calf sire, sex and age) and covariates (initial fat score and fat score change) and all first order interactions. Two final models for milk yield were derived; one adjusted for only the fixed effects and the other containing body fat measures (initial fat score and fat score change) as covariates. Adjusted least square means and their standard errors were generated for milk yield for both models.

The persistence of milk yield was estimated by analysing final adjusted milk yield (at 37 weeks) in a model which included terms for dam breedtype, sire, calf sex and age and initial milk yield (at 5 weeks).

Calf weaning weight and milk yield:

The weaning weights of the calves from the 40 heifers used in the milking experiments were analysed using a univariate model which contained terms for breedtype of dam, birth weight, sire, calf age and sex. The model was fitted with and without average daily milk yield as a covariate. Maternal heterosis for weaning weight was calculated as the difference between the average of the crossbreds' calves, minus the average of the straightbreds' calves.

Milk composition:

Butterfat percentage:

The initial analysis for butterfat percentage for each experiment was fitted in 4 univariate models which contained terms for dam breedtype, actual milk yield, separation time and heifer fat score at each of the four experiments, respectively. These initial analyses showed that separation time and actual milk yields had significant effects on butterfat percentage at each milking. Therefore to adjust for separation time in a multivariate analysis, actual milk yield at each milking was adjusted to a mean separation time of the four milkings to give an average adjusted milk yield which was included in the models. The final model for butterfat percentage contained terms for dam breedtype, average fat score and average adjusted milk yield.

Protein percentage:

The initial analysis for protein percentage for each experiment was fitted in 4 univariate models which contained terms for dam breedtype, actual milk yield, separation time and heifer weight at each of the four experiments respectively. The regression coefficients for separation time and actual yield on protein percentage were not consistent across the four experiments and therefore the multivariate analysis of percentage protein included terms for breedtype, average heifer weight and average actual yield.

9.1.3.4 Behaviour studies:

All the suckling data was analysed as repeated measures in multivariate models. Predicted least square means were generated for each trait.

Total Suckling Time (TST):

TST was analysed using a model which contained terms for breedtype of dam, sire, sex and age of calf. The model was fitted with and without adjustment for average adjusted milk yield.

Number of Suckling Bouts (NSB):

The NSB was analysed using the same independent variables as for the TST analysis (see above).

Cow and calf grazing times:

The final models for cow grazing time and number of grazing periods at the two studies contained terms for breedtype, calf age and sex. Average milk yield was included as a covariate. Calf grazing data was only recorded in the third study. Calf grazing time and number of grazing periods were analysed by separate univariate models which contained terms for breedtype, sire, sex and age.

9.2 Experimental Results

The experimental results from this stage of the trial present estimates of heterosis, additive direct and additive maternal differences for several traits related to heifer performance. Estimates of maternal heterosis, straightbred and additive maternal differences as measures of their calves' performance were evaluated for several growth traits.

9.2.1 Postweaning growth

Postweaning gain of the heifers over the nine month period and average joining weight at an average age of 15.5 months were 0.54 ± 0.01 kg/day and 292 ± 2.5 kg, respectively. Results from the analysis of variance are presented in Table 9.1. Heterosis for postweaning weight gain was significant with the crossbred heifers growing 0.04 ± 0.1 kg/day (7.3 %) faster than the straightbreds. Heterosis for joining weight interacted

Table 9.1: Least squares analysis of variance for joining weight (kg) and postweaning gain (kg/day) of Devon, Hereford and reciprocal cross heifers.

Independent variable	Degrees of freedom	Mean squares	
		Joining weight (kg)	Postweaning gain (kg/day)
Full model (df)		9483.2 (7)	0.016 (8)
Heterosis	1	1626.6	0.033 **
Straightbred	1	4300.8 **	0.031 **
Maternal	1	4343.8 **	0.030 **
Weaning age	1	38946.2 ***	0.024 **
Weaning weight	1	—	0.010
Heterosis x weaning age	1	2691.2 *	—
Straightbred x weaning age	1	3528.0 *	0.028 *
Maternal x weaning age	1	4410.8 **	0.030 **
Error (df)		544.3 (90)	0.004 (90)
R^2		57.5	23.8

** P<0.01, *** P<0.001

significantly with weaning age and the estimates of heterosis for joining weight ranged from 9.7 kg (at weaning age of 160 days) to 29.5 kg (at 200 days), but were only significant at the latter weaning age.

The analysis of variance in Table 9.1 shows that the straightbred and maternal effects for postweaning weight gain and joining weight interacted significantly with weaning age. All the calves were ewanined on a common day hence differences in weaning age was the result of variation in birth dates. Predicted means, heterosis levels, maternal and straightbred differences are presented in Table 9.2. Crossbred heifers from Hereford dams, weaned at 160 days of age, were 22.5 kgs heavier at joining than those from Devon dams. However, when weaned at 200 days of age, crossbred heifers from Devon dams were 15.6 kgs heavier than those from Herefords. A similar interaction occurred for postweaning gain of the crossbreds, with heifers from Hereford dams, weaned at 160 days of age, growing (0.07 kg/day) faster postweaning than those from Devon dams, and at a weaning age of 200 days, heifers from Devon dams growing (0.04 kg/day) faster postweaning than those from Herefords. Hence, this preweaning impact of heifer growth depending on breed of dam was carried over to postweaning growth.

Straightbred Devon heifers were 25.1 kgs heavier at joining than Herefords when weaned at 160 days, whereas the Herefords were 5.0 kgs heavier at joining than the Devons when the average weaning age was 200 days. The effect of this breedtype *x* weaning age interaction on postweaning gain was that at the 160 day weaning age straightbred

Table 9.2: Breedtype means, heterosis levels, straightbred and maternal differences (standard errors) postweaning gain (kg/day) and predicted means for joining weight (kg) and postweaning gain at two different weaning ages in Devon, Hereford and reciprocal cross heifers.

	weaning age	Heifer breedtype DD	DH	HD	HH	Heterosis DH+HD/2-HH+DD/2 kg	%	Straightbred difference	Maternal difference
Postweaning gain		0.53	0.57	0.55	0.51	**0.04**	**7.3**	—	—
		(0.01)	(0.02)	(0.01)	(0.01)	(0.01)			
Joining weight	160	282.4	290.8	268.3	257.4	**9.7**	**3.7**	**25.1**	**22.5**
		(4.9)	(7.5)	(7.6)	(5.8)	(6.5)		(5.4)	(7.5)
	200	295.2	319.4	335.0	300.0	**29.5**	**10.1**	**-5.0**	**-15.6**
		(7.7)	(6.7)	(6.1)	(6.5)	(6.8)		(7.1)	(6.4)
Postweaning gain	160	0.55	0.55	0.49	0.49	—		**0.06**	**0.07**
		(0.01)	(0.02)	(0.02)	(0.02)			(0.02)	(0.02)
	200	0.55	0.54	0.0.58	0.57	—		**-0.02**	**-0.04**
		(0.02)	(0.02)	(0.02)	(0.02)			(0.02)	(0.02)

Devon heifers grew (0.06 kg/day) faster but at 200 days weaning age the straightbred Herefords grew 0.02 kgs/day faster.

9.2.2 Birth traits for progeny of crossbred and straightbred dams

9.2.2.1 Birth weight

The average birth weight was 30.2 ± 1.1 kgs. No significant maternal heterosis, straightbred or maternal differences occurred for birth weight (Table 9.3). However, the estimate of 2.4 % maternal heterosis for birth weight is within the range reported in Table 3.2. Male calves were 1.64 ± 1.04 kgs heavier than females, but this difference was not significant (Appendix 3). Breedtype means are presented in Table 9.4. The model used only accounted for a very small part (R^2=10 %) of the total variation in birth weight.

A total of 14 heifers required assistance at calving, however the low number of animals and non-normal nature of this trait meant that analysis for calving difficulty was not warranted.

9.2.2.2 Calf body shape at birth

Results presented in Appendix 4 show only small differences between the body dimensions of the calves from the four dam breedtypes. The estimates of maternal heterosis, straightbred, direct maternal differences and sex of calf effects were not significant. Birth weight had a significant effect on body shape, a 1 kg increase in birth weight was associated with an increase of 0.4 ± 0.1 cm, 0.7 ± 0.1 cm and $0.1 \pm 4.0 \times 10^{-2}$ cm for chest girth, body length and cannon bone length, respectively.

Table 9.3: Least squares analysis of variance for for birth weight (kg) of Red Angus sired calves from Devon, Hereford and reciprocal cross heifers.

Independent variables	df	Mean squares Birth weight (kg)
Full model	6	14.51
Dam breedtype		
Maternal heterosis	1	7.31
Straightbred	1	0.51
Maternal	1	0.05
Calf sex	1	37.88
Sire	2	13.16
Error	53	15.32

Table 9.4: Dam breedtype means, maternal heterosis, straightbred and reciprocal cross differences (standard error) for birth weight (kg) of Red Angus sired calves from Devon, Hereford and reciprocal cross heifers.

Trait	Heifer breedtype				Maternal heterosis		Straightbred differences	Maternal differences
	DD	DH	HD	HH	kg	%	DD-HH	DH-HD
Birth weight	29.8 (1.2)	30.6 (1.0)	30.6 (1.0)	30.0 (1.1)	**0.7** (1.0)	**2.4**	**-0.3** (1.5)	**0.1** (1.4)

9.2.3 Calf weaning traits

9.2.3.1 Preweaning weight gain (PWG)

The least squares analysis of variance for preweaning weight gain is summarised in Table 9.5. It shows a significant sire *x* breedtype of dam interaction occurred for PWG. Least square means for preweaning weight gain (PWG) for all the calves from the four heifer breedtypes and the three Red Angus sires are presented in Table 9.6. Sire 1 weaned heavier calves from Devon and Hereford *x* Devon heifers than from the straightbred Hereford heifers. Sire 2 calves from the straightbred heifers were not significantly different, although calves from the Devon *x* Hereford heifers were heavier than from the straightbred Devon heifers. Sire 3 calves from the four heifer breedtypes were not significantly different for preweaning gain, however the number of calves per dam breedtype were low for that sire.

The existence of the sire *x* breed of dam interaction prevented estimation of the overall breedtype effects, for PWG. However, estimates from each sire showed maternal heterosis for PWG of 12.5 kgs (6.4 %) and 21.5 kg (10.9 %) for sires 1 and 2, respectively. An estimate from sire 3 was not calculated due to the low number of progeny, especially for the Devon dam subclass.

9.2.3.2 Body dimensions at weaning

Dam breedtype had no significant effect on calf body shape at weaning, adjusted for weight and the estimates of differences between the breedtypes presented in Table 9.7 are very small. Calf sex had a significant effect on body shape with male calves being 1.8 ± 0.5 cm

Table 9.5: Least squares analysis of variance for preweaning gain (kg) of Red Angus sired calves from Devon, Hereford and reciprocal cross heifers.

Independent variables	df	Mean squares Preweaning gain(kg)
Full model	20	1254.78
Dam breedtype	3	238.04
Calf sex	1	816.60
Sire	2	142.24
Weaning age within dam breedtype and sex		
MDD	1	186.12
FDD	1	1149.38
MDH	1	2225.11 *
FDH	1	2908.79 *
MHD	1	83.40
FHD	1	1960.79
MHH	1	837.10
FHH	1	3218.53 *
Sire x breedtype of dam	6	1201.75 *
Error	39	480.21
R^2		57.3

* $P<0.05$
M=male F=female

Table 9.6: Predicted means for preweaning weight gain (kg) (standard error) and numbers of calves for each Red Angus sire from Devon, Hereford and reciprocal cross heifers.

Heifer breedtype	Calf numbers			Preweaning weight gain		
	Sire 1	Sire 2	Sire 3	Sire 1	Sire 2	Sire 3
DD	4	8	1	222 ^{a} (14)	190 ^{b} (12)	207 ^{a} (27)
DH	4	10	4	193 ^{ab} (13)	225 ^{a} (9)	209 ^{a} (12)
HD	7	5	3	223 ^{a} (11)	212 ^{ab} (12)	208 ^{a} (15)
HH	3	7	4	169 ^{b} (15)	204 ^{ab} (13)	196 ^{a} (14)

a b: Means in the same column without a common superscript differ (P<0.05).

longer and 1.6±0.7 higher than females with no significant difference in chest girth. Both weaning weight and weaning age had significant effects on body shape. A 1 kg increase in weaning weight resulted in an increase of $0.2\pm2\times10^{-2}$, $0.1\pm1\times10^{-2}$ and $0.1\pm01\times10^{-2}$ cm for chest girth, body length and height, respectively. A 1 day increase in weaning age resulted in an $0.1\pm2\times10^{-2}$, $0.1\pm2\times10^{-2}$ cm increase in chest girth and body length with no change in body height.

9.2.4 Milk Production and Composition

9.2.4.1 Milk yield

The analysis of variance for average daily milk yield is presented in Table 9.8. Estimates of average daily yield at the 5, 12, 22 and 37 weeks lactation were 5.17±0.32, 4.44±0.22, 3.87±0.26 and 2.52±0.18 kg/day. Significant heterosis occurred for milk yield with the crossbreds producing 1.33±0.63 (29 %), 1.30±0.43 (34 %), 0.96±0.50 (28 %), and 0.80±0.35 (37 %) kg/day more milk than the average of the two straightbreds at the four stages of lactation (Table 9.8 and 9.9). These estimates show the substantial heterosis for milk yield from the Devon-Hereford reciprocal crosses. No significant differences existed between the straightbreds, nor were any maternal additive effects detected for milk yield, although a trend existed for the HD heifers to have a higher yield than the DH heifers at each of the four experiments.

When initial fat score at the 5 week milking and fat score change over the four experiments were added to the model as covariates, both had a significant effect on milk yield. Initial fat score was negatively associated with milk yield; a 1 score increase in fat score at 5 weeks

Table 9.7: Least squares deviations and regression coefficients (standard errors) for calf body shape (chest girth, body length and height) of Red Angus sired calves from Devon, Hereford and reciprocal cross heifers at weaning.

		Least squares deviations and regression coefficients (standard error)				
Factor	Level	Chest Girth (cm)	Body length (cm)	Body height (cm)	Chi-square (on df)	Probability (%)
Intercept		85.0(5.4)	35.6(4.7)	78.9(4.3)	107.27 (on 8)	0.00
Dam breedtype						
	Maternal heterosis	-1.7(1.5)	-0.1(1.3)	0.6(1.2)	0.19 (on 1)	66.38
	Straightbred	3.0(2.5)	-1.0(2.2)	-1.5(1.0)	0.01 (on 1)	90.73
	Maternal	-0.2(1.7)	-1.0(1.5)	-1.5(1.3)	0.81 (on 1)	36.78
Calf sex	M	-0.1(0.4)	0.9(0.4)	0.8(0.3)	4.66 (on 1)	3.09
	F	0.1(0.5)	-0.9(0.1)	-0.8(0.4)		
Sire	1	-0.2(0.6)	-1.2(0.5)	1.1(0.5)	1.51 (on 2)	47.05
	2	1.1(0.6)	0.5(0.5)	-0.4(0.4)		
	3	-0.8(0.7)	0.7(0.6)	0.8(0.6)		
Weaning weight		0.2(0.0)	0.1(0.0)	0.1(0.0)	72.66 (on 1)	0.00
Weaning age		0.1(0.0)	0.1(0.0)	-0.0(0.0)	9.05 (on 1)	0.26

Table 9.8: Chi-squares for the analysis of milk production (kg/day) from straightbred Devon, Hereford and reciprocal cross heifers at four stages of lactation.

Factor	Level	Chi-square (on df)	Probability (%)
Intercept		9.914 (on 7)	19.35
Dam breedtype	Heterosis	6.154 (on 1)	1.31
	Straightbred	0.017 (on 1)	89.77
	Maternal	1.415 (on 1)	23.43
Calf sex		1.314 (on 1)	25.16
Sire of calf		0.851 (on 2)	65.36
Calf age		0.010 (on 1)	92.01

Table 9.9: Dam breedtype means, heterosis levels, straightbred and reciprocal cross differences for milk production (kg/day) (standard errors) from straightbred Devon and Hereford heifers and their reciprocal crosses at four stages of lactation.

Stage of lactation (weeks)	Daily milk yield Breedtype				Heterosis DH+HD/2-HH+DD/2		Straightbred difference	Maternal difference
	DD	DH	HD	HH	kg/day	%		
5	4.82 (0.67)	5.59 (0.60)	6.05 (0.67)	4.19 (0.63)	**1.33** (0.63)	**29**	**0.65** (0.93)	**-0.47** (0.90)
12	3.72 (0.47)	4.62 (0.40)	5.55 (0.43)	3.86 (0.43)	**1.30** (0.43)	**34**	**-0.13** (0.63)	**-0.93** (0.60)
22	3.43 (0.53)	3.82 (0.47)	4.89 (0.53)	3.36 (0.50)	**0.96** (0.50)	**28**	**0.07** (0.74)	**-1.06** (0.70)
37	2.00 (0.37)	2.73 (0.33)	3.09 (0.37)	2.26 (0.33)	**0.80** (0.35)	**37**	**-0.27** (0.51)	**-0.37** (0.49)

resulted in a decrease in milk yield of 1.64$\pm$0.78, 1.04$\pm$0.53, 1.89$\pm$0.58 and 1.25$\pm$0.43 kgs/day at each of the four milkings, respectively. Similarly fat score change was negatively associated with milk yield. A unit (0.001 units/day) increase in fat score over the lactation period (224 days) resulted in a decrease in milk yield of 0.41$\pm$0.14, 0.29$\pm$0.09, 0.31$\pm$0.10 and 0.16$\pm$0.08 at the four milkings, respectively (Appendix 5).

9.4.2.2 Persistence of lactation

No significant breedtype differences occurred for persistence of lactation as measured by the slope of the lactation curve, adjusted for calf sex, age, sire and initial milk yield (Table 9.10). Initial milk yield (at 5 weeks) was associated with final yield (at 37 weeks). A 1 kg increase in initial milk yield resulted in an increase of 1.27$\pm$0.24 kg at final yield, at 37 weeks (Appendix 6).

9.4.2.3 Correlations between milkings

Correlations between average adjusted milk yield at the four experiments are contained in Table 9.11. The correlations between successive milkings were all higher than 0.7, indicating a high degree of repeatability of the milking technique.

Table 9.11: Correlations between average adjusted milk yield at the four experiments.

	1	2	3	4
1	1.00	0.80	0.70	0.70
2		1.00	0.71	0.69
3			1.00	0.73
4				1.00

Table 9.10: Least squares analysis of variance for persistence of lactation in Devon, Hereford and reciprocal cross heifers.

Independent variables	df	Mean squares Milk Yield 4 (kg)
Full model	8	0.29
Dam breedtype		
Heterosis	1	0.06
Straightbred	1	0.10
Maternal	1	0.01
Calf sex	1	0.03
Calf age	1	0.04
Sire	2	0.07
Milk Yield 1	1	1.16 ***
Error	31	0.06
R^2		58.2

*** P<0.001

9.4.2.4 Effect of milk yield on weaning weight

Least squares analyses for the effect of milk yield on weaning weight are presented in Table 9.12. The result show calves from the crossbred heifers were 14.4 kgs (P=0.062) or 6.5 % heavier than those from straightbreds, with no differences between either of the straightbreds or between the reciprocal crossbreds (Table 9.13). When average daily milk yield was included in the model as a covariate the difference in weaning weight of calves from the four heifer breedtypes was not significant. The addition of average daily milk yield accounted for a further 43 % of the variation in weaning weight (R^2 increased from 40 to 83%). Least square means for weaning weight and weaning weight adjusted for milk yield for the 40 calves used in the lactation studies are presented in Table 9.13. A 1 kg increase in average daily milk yield was associated with an increase in weaning weight of 15.2$\pm$1.7 kgs (P<0.001, Appendix 7).

9.4.2.5 Milk composition

Butterfat percentage:

The results of butterfat percentage from preliminary univariate analyses of each of the 4 experiments are presented in Table 9.14. The regression coefficients from these analyses showed that separation time had a significant positive effect on butterfat percentage in 3 of the 4 experiments and there was also a positive trend in actual milk yield affecting butterfat percentage at all milkings. To adjust for the effects of separation time in a multivariate analysis, actual milk yield at each milking was adjusted to a mean separation time of the four milkings.

Table 9.12: Least squares analysis of variance for weaning weight (kg), (adjusted (+) and unadjusted (#) for dam milk yield), of Red Angus sired calves from Devon, Hereford and reciprocal cross heifers.

Independent Variables	df	Mean squares	
		Weaning weight # (kg)	Weaning weight + (kg)
Full model(df)		1334.21(8)	2484.22(9)
Dam breedtype			
Maternal heterosis	1	1960.21	15.16
Straightbred	1	47.84	3.92
Maternal	1	28.17	204.44
Calf sex	1	28.17	437.49
Birth weight	1	5264.90 **	2217.01 ***
Sire	2	305.28	309.51
Calf age	1	870.22	1111.77 *
Daily milk yield		—	11684.28 ***
Error(df)		524.69(31)	152.70(30)
R^2		40	83

* P<0.05, ** P<0.01, *** P<0.001

Table 9.13: Breedtype means, maternal heterosis, straightbred and reciprocal cross differences (standard error) for weaning weight (kgs) of Red Angus sired calves (adjusted and unadjusted for daily milk production) from Devon, Hereford and reciprocal cross heifers

Trait	Dam breedtype (sire breed first)				Maternal Heterosis DH+HD/2-HH+DD/2		Straightbred difference	Maternal difference
	DD	DH	HD	HH	kg	%		
Weaning weight	225.4 (8.1)	236.2 (6.9)	240.1 (7.8)	222.0 (7.5)	**14.4** (7.5)	**6.5**	**-3.3** (11.1)	**3.9** (10.4)
Weaning weight (adjusted for daily milk yield)	231.9 (4.41)	233.3 (3.76)	226.7 (4.47)	230.7 (4.17)	**-1.4** (4.41)	**-0.3**	**1.0** (6.0)	**6.6** (5.7)

Table 9.14: Least square deviations and regression coefficients of percentage butterfat at the four experiments (separate univariate analyses) from Devon, Hereford and reciprocal cross heifers.

		Least square deviations and regression coefficients (SE)			
		Butterfat %			
Factor	Level	1	2	3	4
Intercept		5.58(1.96)	7.26(1.80)	5.54(1.86)	10.17(2.47)
Dam Breed	DD	0.29(0.37)	0.13(0.45)	-0.05(0.35)	0.18(0.36)
	DH	-0.30(0.39)	0.26(0.40)	0.24(0.35)	0.07(0.36)
	HD	-0.27(0.36)	-0.26(0.40)	-0.88(0.37)	-0.33(0.34)
	HH	0.28(0.37)	-0.13(0.38)	0.69(0.33)	0.08(0.31)
Actual milk yield		0.70(0.36)	1.14(0.62)	0.68(0.46)	1.49(0.70) *
Separation time		-0.00(0.00) *	-0.01(0.00) *	-0.00(0.00)	-0.01(0.00) *
Fat score		1.29(0.53) *	1.07(0.62)	0.88(0.46)	0.05(0.38)

* $P<0.05$

Table 9.15 presents the analysis of variance for butterfat percentage. Heterosis, straightbred and maternal differences for butterfat percentage were small and non-significant. There was a significant effect of adjusted milk yield and body fat score on butterfat percentage. A 1 kg increase in average adjusted milk yield resulted in an increase of 1.41 ± 0.67, 1.56 ± 0.72, 0.69 ± 0.65 and 1.36 ± 0.62 butterfat percentage at the four experiments, respectively. A 1 score increase in average fat score resulted in an increase of 1.60 ± 0.65, 1.31 ± 0.70, 0.89 ± 0.64, and 0.68 ± 0.61 butterfat percentage. Breedtype means, heterosis, straightbred and maternal differences for butterfat percentage are presented in Table 9.16. The average butterfat percentage at experiments 1, 2, 3 and 4 were 5.49 ± 0.20 %, 5.88 ± 0.21 %, 5.47 ± 0.20 % and 5.13 ± 0.19 %, respectively.

To further investigate the effect of average adjusted milk yield on butterfat percentage, records that were greater than two standard deviations from the mean were excluded from the analyses. The result of removing the records (identified in the univariate analyses) from the multivariate analysis was to render the influence of average adjusted milk yield on butterfat percentage not significant, and the positive trends in the regression coefficients were removed (Appendix 8).

Protein Percentage:

The univariate analyses showed that separation time and actual yield did not significantly influence protein percentage at each of the experiments (Appendix 9). Therefore protein percentages from each

Table 9.15: Chi-squares for the analysis of variance of butterfat percentage from Devon, Hereford and reciprocal cross heifers at four stages of lactation.

Factor	Level	Chi-square (on df)	Probability (%)
Full model		12.83 (on 5)	2.51
Dam breedtype	Heterosis	2.52 (on 1)	11.23
	Straightbred	0.02 (on 1)	88.60
	Maternal	0.73 (on 1)	39.19
Average body fat score		6.31 (on 1)	1.20
Average adjusted milk yield		7.39 (on 1)	0.66

Table 9.16: Breedtype means, heterosis level, straightbred and reciprocal cross differences (standard error) for butterfat percentage from Devon, Hereford and reciprocal cross heifers at four stages of lactation.

Stage of lactation (weeks)	Butterfat % Heifer breedtype				Heterosis DH+HD/2-HH+DD/2		Straightbred difference	Maternal difference
	DD	DH	HD	HH	Units	%		
5	5.94 (0.47)	5.06 (0.46)	5.29 (0.45)	5.66 (0.41)	**-0.62** (0.51)	**-10.7**	**0.28** (0.60)	**-0.23** (0.64)
12	6.09 (0.50)	5.93 (0.49)	5.53 (0.48)	5.97 (0.44)	**-0.30** (0.54)	**-5.0**	**0.12** (0.65)	**0.41** (0.69)
22	5.57 (0.46)	5.60 (0.45)	4.57 (0.44)	6.15 (0.40)	**-0.78** (0.49)	**-13.3**	**-0.58** (0.59)	**1.02** (0.62)
37	5.33 (0.44)	5.03 (0.43)	4.79 (0.42)	5.37 (0.39)	**-0.44** (0.47)	**-8.2**	**-0.04** (0.56)	**0.24** (0.60)

milking were analysed in a multivariate model which contained terms for breedtype, average actual milk yield and average heifer weight.

Table 9.17 presents the analysis of variance for protein percentage. Estimates of heterosis and maternal differences were small and non-significant. A significant straightbred effect occurred for protein percentage with the Devons producing 0.19±0.14 %, 0.15±0.12 %, 0.26±0.17 % and 0.36±0.18 % more milk protein than the Herefords. Heavier cows also tended to have a higher milk protein percentage, although the effect was not significant. Breedtype means, heterosis, straightbred and maternal differences for protein percentage are presented in Table 9.18. The average protein percentage at each stage of lactation was 3.10±0.05, 3.02±0.04, 3.76±0.06 and 3.83±0.06, respectively.

9.2.5 Behaviour Studies

9.2.5.1 Total Suckling Time (TST)

The overall average TST was 20.7±1.2, 17.3±1.1 and 17.7±1.0 min/daytime for the 2nd, 3rd, and 4th milkings, respectively. There was a significant ($P<0.05$) heterotic effect on TST. Crossbred cows suckled their calves for 4.5±2.3, 1.1±2.2 and 4.4±2.0 min/daytime longer than straightbred cows at each of the three studies, respectively (Table 9.19 and Appendix 10). However, the significance of this effect was reduced ($P=0.053$) when TST was adjusted for average milk yield at the three experiments (Appendix 11). No significant differences existed between the total suckling time of calves from the crossbred dams or between the straightbred dams.

Table 9.17: Chi-squares for analysis of variance of protein percentage from Devon, Hereford and reciprocal cross heifers at four stages of lactation.

Factor	Level	Chi-square (on df)	Probability (%)
Full model		6.68 (on 5)	24.57
Dam breedtype	Heterosis	0.10 (on 1)	75.33
	Straightbred	4.38 (on 1)	3.65
	Maternal	0.19 (on 1)	66.15
Average actual milk yield		0.51 (on 1)	47.75
Average heifer weight		3.18 (on 1)	7.44

Table 9.18: Breedtype means, heterosis level, straightbred and reciprocal cross differences (standard error) for protein percentage from Devon, Hereford and reciprocal cross heifers at four stages of lactation.

Stage of lactation (weeks)	Milk protein % Breed / cross				Heterosis DH+HD/2-HH+DD/2		Straightbred difference	Maternal difference
	DD	DH	HD	HH	Units	%		
5	3.17 (0.11)	3.14 (0.09)	3.12 (0.10)	2.98 (0.10)	**0.05** (0.11)	**1.7**	**0.19** (0.14)	**0.02** (0.14)
12	3.11 (0.09)	2.96 (0.08)	3.06 (0.09)	2.96 (0.08)	**-0.03** (0.10)	**-0.9**	**0.15** (0.12)	**-0.10** (0.12)
22	3.93 (0.13)	3.73 (0.11)	3.71 (0.12)	3.67 (0.11)	**-0.08** (0.13)	**-2.1**	**0.26** (0.17)	**0.02** (0.16)
37	4.04 (0.14)	3.74 (0.12)	3.87 (0.13)	3.68 (0.12)	**-0.06** (0.14)	**-1.5**	**0.36** (0.18)	**-0.13** (0.17)

Table 9.19: Breedtype means, heterosis levels, straightbred and reciprocal cross differences for total suckling time (minutes/daytime) (standard error) of Devon, Hereford and reciprocal cross heifers suckling Red Angus sired calves at three stages during lactation.

Stage of lactation (weeks)	Total suckling time (min/daytime) Breed / cross				Heterosis DH+HD/2-HH+DD/2		Straightbred difference	Crossbred difference
	DD	DH	HD	HH	Units	%		
12	20.9 (2.5)	22.4 (2.3)	23.6 (2.4)	16.0 (2.3)	**4.5** (2.3)	**24.4**	**6.0** (3.4)	**-1.2** (3.3)
22	18.6 (2.32)	15.5 (2.11)	20.2 (2.25)	14.9 (2.16)	**1.1** (2.2)	**6.7**	**3.7** (3.1)	**-4.7** (3.1)
37	15.9 (2.13)	19.0 (1.93)	20.9 (2.07)	15.0 (1.98)	**4.4** (2.0)	**28.7**	**0.9** (3.1)	**-1.8** (2.8)

No cross suckling bouts were observed in any of the three studies. Breedtype means, heterosis, straightbred and maternal differences for total suckling time per period of daytime observation are presented in Table 9.19. The table shows the longer total suckling time of the calves from the crossbred cows compared to the straightbreds. A trend between the straightbreds existed with calves on Devon dams suckling for a greater time compared to the Herefords, although not significantly. Maternal differences were not significant with no trend existing between the calves from the reciprocal cross dams.

9.2.5.2 Number of Suckling Bouts (NBS)

Heterosis estimates for number of suckling bouts per daytime observation were positive but not significant. The difference between the reciprocal cross heifers for number of sucking bouts of their calves showed a trend existed with the calves on HD heifers had a greater number of suckling bouts than calves on DH heifers, although not significantly. A significant straightbred effect occurred, Devon dams suckling their calves for 0.88 ± 0.44, 0.47 ± 0.35 and 0.50 ± 0.34 bouts/daytime more than Hereford dams, at each of the three stages of lactation (Table 9.20 and Appendix 12). This effect remained significant ($P<0.01$) after adjusting for differences in milk yield (Appendix 11). Breedtype means, heterosis, straightbred and maternal differences for number of suckling bouts are presented in Table 9.20. The overall average NSB was 2.25 ± 0.13 bouts/daytime observation.

Table 9.20: Breedtype means, heterosis levels, straightbred and reciprocal cross differences (standard error) for suckling bouts (number/daytime observation) of Devon, Hereford and reciprocal cross heifers suckling Red Angus sired calves at three stages during lactation.

Stage of lactation (weeks)	Number of suckling bouts Dam breedtype				Heterosis DH+HD/2-HH+DD/2		Straightbred difference	Crossbred difference
	DD	DH	HD	HH	Units	%		
12	2.82 (0.32)	2.64 (0.29)	2.73 (0.31)	1.94 (0.30)	**0.30** (0.30)	**12.6**	**0.88** (0.44)	**-0.09** (0.42)
22	2.16 (0.26)	1.71 (0.23)	2.40 (0.25)	1.70 (0.24)	**0.12** (0.24)	**6.2**	**0.47** (0.35)	**-0.68** (0.34)
37	2.35 (0.25)	2.20 (0.23)	2.55 (0.24)	1.85 (0.23)	**0.27** (0.23)	**12.9**	**0.50** (0.34)	**-0.35** (0.33)

9.2.5.3 Calf grazing

The average calf grazing time during the daylight (measured at 37 weeks lactation) was 349±9.0 min (5 hours 48 min.) with an average of 6.9±0.3 grazing periods. No significant calf breedtype differences occurred for total grazing time, or for the number of grazing periods. Calf sex, age and sire had no significant effect on grazing time, or the number of grazing periods. Least square means for calf grazing time and number of grazing periods per daylight observation at 37 weeks are presented in Table 9.21. The results presented show no consistent trends with differences between the breedtypes been small for each trait.

9.2.5.4 Cow grazing

The average cow grazing time during the daylight hours, measured at 12 and 22 weeks lactation, was 537±7 min (8 hours 57 min.) and 591± 7 min (9 hours 50 min.) with an average of 4.6±0.2 and 3.7±0.1 grazing periods, respectively. No significant heterosis, straightbred or maternal differences occurred for either trait and no apparent trends were observed. Calf sex, age and sire had no significant effects on grazing time or the number of grazing periods. Average milk yield significantly affected the number of grazing periods at 22 weeks. Least square means for total grazing time and number of grazing periods per daylight observation at 12 and 22 weeks are presented in Table 9.22.

Table 9.21: Breedtype means, maternal heterosis, straightbred and maternal differences (standard error) for calf grazing time (min/daylight observation) and number of grazing periods of Red Angus sired calves from Devon, Hereford and reciprocal cross heifers at 37 weeks lactation.

Trait	Heifer breedtype				Maternal Heterosis DH+HD/2-HH+DD/2		Straightbred difference	Maternal difference
	DD	DH	HD	HH	units	%		
Total grazing time	358 (19)	352 (17)	339 (18)	346 (17)	**-7** (17)	**-2.0**	**11** (25)	**13** (24)
Number of grazing periods	6.7 (0.7)	6.3 (0.6)	7.6 (0.7)	6.9 (0.6)	**0.2** (0.6)	**2.9**	**-0.2** (0.9)	**-1.2** (0.9)

Table 9.22: Breedtype means, heterosis level, straightbred and maternal differences (standard error) for grazing time (min/daylight observation) and number of grazing periods per day of Devon, Hereford and reciprocal cross heifers at two stages of lactation.

	Stage of lactation (weeks)	Heifer breedtype DD	DH	HD	HH	Heterosis DH+HD/2-HH+DD/2 units	%	Straightbred difference	Maternal difference
Grazing time	12	546 (14)	534 (14)	555 (15)	514 (14)	**14** (14)	**2.7**	**33** (20)	**-21** (20)
	22	596 (13.)	582 (13)	593 (14)	593 (13)	**-7** (13)	**-1.1**	**2.6** (19)	**-11** (19)
Number of grazing periods	12	4.4 (0.4)	4.6 (0.4)	4.7 (0.5)	4.6 (0.4)	**0.1** (0.5)	**2.9**	**-0.2** (0.3)	**-0.1** (0.3)
	22	3.9 (0.2)	3.6 (0.2)	3.5 (0.2)	3.9 (0.2)	**-0.3** (0.2)	**-7.8**	**0.0** (0.1)	**0.2** (0.1)

9.3 Discussion

The direct genetic performance of the heifers and their indirect performance as dams was assessed. Firstly the four heifer breedtypes were examined for heterotic, additive direct and maternal differences for growth and production traits. Secondly the four female breedtypes were examined for maternal heterosis, straightbred effects and direct maternal performance.

9.3.1 Heifer Growth

Heterosis for postweaning gain and joining weight are within the range of estimates of heterosis for post-yearling weights (see Table 3.1). The importance of this result to a beef breeding system would depend on the relationship between body weight and age at puberty and any independent effects of heterosis on age at puberty. Puberty in beef heifers is influenced by level of nutrition, breed, sire, growth rate and heterosis (Wiltbank et al. 1966, Reynolds et al. 1963 and Wiltbank et al. 1969). Wiltbank et al. (1969) reported an interaction between age and weight at puberty on different levels of nutrition in Hereford, Angus and the crosses between the two breeds. On high nutrition 10.4 % heterosis occurred for weight at puberty, but no heterosis for age at puberty (average age 381 days). However, on low nutrition, heterosis for weight at puberty was 5.5 % and -25.8 % for age at puberty (crossbreds 424 days, straightbreds 572 days). Hence, there appears to be a minimum age at which puberty occurs irrespective of weight, but after this critical age heterosis may function to decrease the age at puberty.

The effect of weaning age on postweaning performance of the reciprocal crossbred heifers indicates differences in the preweaning maternal environment. The early weaning of crossbred calves from Hereford dams resulted in a higher postweaning gain and heavier joining weight when compared with early weaned crossbreds from Devon dams. Whereas, the crossbreds from Devons, weaned at an older age, grew faster and were heavier than those from Herefords. These differences between the reciprocal crosses may indicate differences in compensatory gain as a result of differences in both milk yield and the persistency of lactation of the Devon and Hereford base cows. Significant interactions also occurred between the two straightbreds for joining weight and postweaning gain, but here maternal effects and sire breed effects are confounded.

9.3.2 Birth traits of Red Angus sired calves

When the four dam groups were mated to Red Angus bulls there was no dam breedtype effects on birth weight. The lack of significance of and low maternal heterosis estimate for birth weight is consistent with results in the literature (McDonald and Turner, 1972, Gaines et al. 1966, Olson et al. 1985 and Alenda et al. 1980a). This suggests that the *in utero* environment provided by a crossbred dam differs little from that provided by the straightbred dam.

No difference occurred for birth weight of the calves from the two straightbreds. This indicates that the Devon and Hereford were similar in combining ability (i.e. additive and/or non-additive) with the Red Angus for birth weight. The lack of a significant difference between the two reciprocal crossbred dams for birth weight of their calves indicates that genetic differences for grand-maternal effects were small. Cundiff et al. (1974b) found no differences for birth weight between reciprocal crosses of Hereford/Angus, Shorthorn/Hereford and Angus/Shorthorn. Similar results have been reported by Bailey and Moore (1980). Turner (1969) reported a significant difference between the birth weight of calves from Angus/Hereford reciprocal crosses, but no differences were observed in the reciprocal crosses between Angus/Brangus/Brahman and Hereford/Brangus/Brahman breeds.

Although not significant, male calves were 1.64 ± 1.04 kgs heavier than females at birth. This is within the range of results from studies involving British beef crosses (Bellows et al. 1971, Rollins et al. 1969, Long and Gregory 1974 and Cundiff et al. 1974b).

Calf body shape at birth showed no difference between the breedtypes and sexes after adjustment for birth weight and removing sire differences. Birth weight significantly increased body dimensions. The association of birth shape and weight with dystocia was summarized by Meijering (1984) who concluded that the part of variance in dystocia rate associated with calf dimensions was well accounted for by birth weight alone.

9.3.3 Calf weaning traits

The ranking of the three Red Angus sires for preweaning weight gain of their progeny differed between the four heifer breedtypes. Although numbers in each sire-dam breedtype sub-class were very low, this interaction suggests that the performance of the calves may vary with sire-dam genotypic combination. Benyshek (1979) postulated that the significant Limousin sire by breed of dam interaction he observed for weaning weight may have arisen from a genotype *x* genotype interaction as a result of differences in allelic or non-allelic interactions when individuals from genetically different populations were combined. In addition the interaction could have involved a genotype *x* maternal environment interaction with the different dam breeds providing different maternal environments.

The difference in the performance of calves from the straightbred dams by Sire 1 suggests there are genetic differences for PWG between the Devons and Herefords. These may be additive or non-additive gene action. As the calves from the straightbred dams by Sire 2 showed no significant difference, the non-additive interpretation is favoured. Further evidence to support this theory is the preweaning growth of Devons and Herefords in Phase 1 of the trial which showed no significant differences for weaning weight between the breeds. When the performance of the crossbred dams is considered it also suggests that Sire 1 and 2 were performing differently with respect to dam breedtype. The overall effect may be related to a sire *x* grandmaternal breedtype interaction. Sire 1 produced heavier calves from Devon granddams compared to the straightbred Hereford (HH), whereas Sire 2 tended to produce heavier calves from Hereford granddams compared to the straightbred Devon (DD).

This small study demonstrated the existence of a significant sire *x* breedtype of dam interaction for preweaning weight gain. The biological basis for the interaction is unclear. However, the interaction suggests the effect is due to non-additive gene action. Further work is required to quantify the magnitude of this interaction across a greater number of sires and dams and to investigate the benefits of testing sires prior to their use in a crossbreeding program.

9.3.4 Milk Production

Estimates of daily milk yield in beef cattle are limited. This lack of knowledge is probably due to the difficulties associated with the direct measurement of milk production in beef cattle. The results from this study are within the range of reported milk yields in British beef breeds and their crosses (Melton et al. 1967, Gleddie and Berg 1968, Rutledge et al. 1971, Cundiff et al. 1974b, Boggs et al. 1980 and Butson and Berg 1984a,b).

Very few experiments exist that have been designed to estimate heterosis for milk yield in beef cattle. The estimate of 1.1 kg/day (32 %) heterosis for average daily milk yield from this study was in the range of limited published results (Chapter 3, Table 3.4) but tended to the high end of the range. No significant differences occurred between the reciprocal crossbreds for milk yield. Two studies have reported differences between the reciprocal crosses for milk yield (Notter et al. 1978b and Cundiff et al. 1974b). This effect has been postulated to be due to the maternal granddams providing a favourable maternal environment which subsequently reduces milk yield in the next generation (Koch 1972).

However in this trial the heifers were weaned at an early age (6 months) and therefore effects due to differences in maternal environments should have been small.

Calf sex had no significant influence on milk yield. This is in agreement with much of the literature (Jeffery et al. 1971a, Gleddie and Berg 1968, Chenette and Frahm 1981, Reynolds et al. 1978 and Wilson et al. 1971, Williams et al. 1979). However, Melton et al. (1967) found that cows nursing male calves produced significantly more milk than those with females, with this effect declining through the lactation. Others have reported dams nursing female calves were found to produced more milk than those with males (Rutledge et al. 1971, Zimmerman et al. 1982, Robison et al. 1978).

In this study milk yield was significantly reduced by increasing body fat score or condition during lactation. Similar result were reported by Jeffery et al. (1971a), Wilson et al. (1971) and Boggs et al. (1980) where weight gain or weight to height ratios were used as measures of increasing condition. Garnsworthy and Gardner (1985) reported that pre-calving condition score did not affect milk yield because leaner cows increased food intake and fatter cows tended to deplete labile fat reserves (i.e. decreased weight and condition score), thus indicating that milk yield is maintained at the expense of body weight (Hohenboken et al. 1973). However the result was different in this study. Heifers that were higher in fat score early in lactation (at 5 weeks) produced significantly less milk at all four milkings. Two possible explanations exist; (1) fat deposition early in lactation reduces overall milk production and (2) low producing heifers became fatter as their lactation progressed.

Several other biological factors have been reported to affect milk yield. Dam age has been shown to influence yield (Reynolds et al. 1978, Butson and Berg 1984b, Gaskins and Anderson 1980, Williams et al. 1979). However, in the present experiment all heifers used were the same age.

The stimulus of crossbred calves has also been shown to increase milk yield. Rutledge et al. (1971) reported a 16 % increase in milk yield from cows suckling crossbred calves compared to those with straightbreds. Gyles (1987) reported a trend for straightbred dams nursing crossbred calves to produce more milk per day than dams nursing straightbred calves, with similar results being reported by Reynolds et al. (1978) and Nicol (1976). Neidhardt et al. (1979) showed that milk production and calf weight mutually influenced each other. The stimulation of higher milk production by fast growing calves (expressing heterosis) results from higher suckling frequency (Drewry et al. 1959, Nicol 1976) and more complete emptying of the udder (Jeffery et al. 1971b). In this present study all calves were crossbreds with those on the straightbred Devon and Hereford cows being two breed cross and on the crossbred cows three breed cross. As all calves were sired by a third breed, based on the degree of heterozygosity, all calves would be expected to be exhibiting 100 % heterosis and therefore the effect of calf breedtype on milk yield should have been similar for each heifer breedtype. However, as different crosses of calves were involved i.e. two and three breed crosses, differences in absolute levels of heterosis may have existed.

The persistence of lactation is an important component of total production. No genotypic differences were detected in this study for persistence of lactation as measured by the slope of the lactation curves. Gaskins and Anderson (1980) found that lower producing cows declined linearly but the decline was convex for cows with higher production. This suggests that the milk production of the cows in this study may not have been high enough to result in differences in persistence. Cundiff et al. (1974b) found crossbred cows to be more persistent in milk production with heterosis increasing from 7.5 % at 6 weeks to 38 % at 29 weeks. Further, Clutter and Nielsen (1987) reported higher producing cows to be slightly more persistent in maintaining that level as lactation progressed. However, Notter et al. (1978b) found that heterosis for milk yield declined as the lactation progressed and that increased persistence was inversely proportional to average milk yield. These last mentioned findings are in conflict with results from the present study, where the higher producing cows early in lactation were also the higher producers later in lactation.

The difference in the weaning weight of calves from the crossbred and straightbred heifers was largely explained by differences in daily milk yield. This suggests that the four breedtypes of calves were genetically similar for direct preweaning growth, but the calves from the crossbred dams were heavier due to heterosis for milk yield in their dams.

A 1 kg increase in average daily milk yield resulted in an increase in weaning weight at 260 days of 15.2 kgs. A very similar result was reported by Bishop et al. (1975) with an increase in milk production of 1kg per day throughout a 10 month lactation increasing weaning weight by 16 kgs. However the present result is higher than an estimate by Boggs et al. (1980) who reported that each additional kilogram of milk per day added 7.2 kgs of 205 day adjusted weaning weight. Wilson et al. (1971) found that the mean daily milk yield per kilogram calf daily gain was 10.1 kilograms in Angus-Holstein cows. Nicol (1976) found that for each additional litre of milk in a 135 day lactation, calf weight increased by 7.6 kg. On average these results represent a conversion ratio of kg milk to kg calf weight of 12.5:1 (Neville 1962), 18:1 (Nicol 1976), 19:1 (Bishop et al. 1975), 28:1 (Boggs et al. 1980),. Clutter and Nielsen (1987) reported conversion ratios ranging between 19-31:1. In the present study the conversion ratio was 17:1. Obviously the results are expected to vary with the energy content of the milk.

In the present study 43 % of the variation in weaning weight was accounted for by differences in average daily milk yield. This was within the range of 40-50 % reported by Jeffery and Berg (1971). Neville (1962) reported that 66 % of the variation in weaning weight was due to milk consumption and Rutledge et al. (1971) estimated that approximately 60 % of the variance in weaning weight was due to the independent effects of milk yield.

9.3.5 Milk composition

Milk composition is highly variable with substantial differences existing between breeds. This makes comparisons between breeds and experiments difficult. The average estimate of 5.5 % for butterfat percentage from this experiment is within the range of reports for Herefords (Daley et al. 1986, Butson and Berg 1984a,b, Gleddie and Berg 1968, Melton et al. 1967) and Hereford cross cows (Cundiff et al. 1974b, Chenette and Frahm 1981). An estimate of butterfat percentage for the Devon breed was reported by Gyles (1987) as 6.1 %. In the same study Herefords had a butterfat percentage of 5.9 %.

No heterosis was observed for butterfat percentage and this is in agreement with Cundiff et al. (1974b) and Daley et al. (1986). Robison et al. (1981) found no significant heterosis for butterfat percentage and suggests this is expected due to the high heritability of the trait.

Higher body fat scores resulted in increased butterfat percentages. No literature was found to support this finding, but Garnsworthy and Gardner (1985) reported that milk composition did not differ significantly with different body fat scores. Dairy research has shown that the secondary source of nutrients necessary for the synthesis of milk fat are obtained from the mobilization of fat from the body reserves, especially in early lactation (Holmes and Wilson 1984). To establish the relationship between body fat score and butterfat percentage a blood assay to determine the levels of mobilized fats, primarily the long chain fatty acids, would have been required.

The butterfat percentage increased with increasing milk yield. This result is not generally supported by beef, or more extensively, dairy data (Butson and Berg 1984a, Schwulst et al. 1966 and Gleddie and Berg 1968, Holmes and Wilson 1984). In general butterfat percentage has been found to increase with declining milk yield and therefore usually increases as lactation progresses.

In this study the significant effect of actual milk yield on butterfat percentage may have been due to six measurements being greater than two standard deviations from the mean. These results may have been due to problems with the techniques of collection, or the composition analysis. The second postulate was eliminated because duplicate samples taken at each experiment were within ± 0.1 % of the actual. Further inspection of the data revealed that a majority (4 out of 6) of the measurements removed, (greater than two standard deviations from the mean) were from cows milked very early in the duration of the experiment. Whittlestone (1964) found that with dairy cows injected with oxytocin following normal milking, an additional quantity of milk will be obtained that is extremely rich in fat. Therefore, in the present study the extreme values of the records removed (up to 11% of butterfat percentage), may indicate residual butterfat being extracted using oxytocin from a few early milked cows. Chenette and Frahm (1981) reported that more milk was produced in the first 6 hours of separation than later hours and that butterfat, protein and total solids were higher in this early-produced milk.

These findings suggest that the milking procedure which uses a single milking may not be suitable to obtain an accurate estimate of milk composition, especially of butterfat percentage. The problem could be avoided by using oxytocin to completely empty the udder of milk and fat prior to the commencement of the experiment. However this would add substantially to the work load.

In general differences between beef breeds for protein percentage are small (Butson and Berg 1984b). The average milk protein percentage from this study (3.4 %) was similar to estimates reported in the literature from Hereford and Hereford cross cows (Gleddie and Berg 1968, Schwulst et al. 1966, Butson and Berg 1984a and Chenette and Frahm 1981) and was not affected by separation time and stage of lactation. Heterosis for protein percentage was not significant. Daley et al. (1986) reported a similar result.

Straightbred Devon heifers had a significantly higher protein percentage than straightbred Herefords. The only work to support this result was Gyles (1987) who found that the Devon base cows, used to generate the heifers used in this experiment, had higher milk protein percentage than the base Herefords in mid-lactation.

The similar composition of the milk from crossbreds and straightbreds suggests that the higher weaning weight of the calves from the crossbred dams had to be achieved through a higher daily consumption of milk by these calves or a higher absolute heterosis for efficiency of milk use in the three-breed versus the two-breed cross calf.

9.3.6 Behaviour traits

Very few studies have been carried out on the behaviour of beef cows and calves; even less work has been done relating behaviour to milk yield and calf growth from crossbred versus straightbred cows. Walker (1962) suggested that a knowledge of calf suckling behaviour would be relevant to understanding calf gain and maternal ability of the dam.

Total suckling times from this study are similar to those reported by Ewbank (1969). However the results are less than those reported by Rienhardt and Rienhardt (1981), Hutchison et al. (1962), Sommerville and Lowman (1979), Cartwright and Carpenter (1961), Neindre and Petit (1976) and Odde et al. (1985). Probable reasons for these differences in total suckling time may be due to differences in the duration of the studies, recording techniques, milk yields of the breeds involved or other breed differences influencing suckling time and the stage of lactation when the studies were performed.

Calves on the crossbred heifers suckled for a longer time per daylight observation than calves on the straightbreds. This difference was removed when the data were adjusted for differences in milk yield. Hence total suckling time was positively associated with milk yield; although even following adjustment, a trend remained for calves on the crossbred cows to suckle for a longer time per day. Drewry et al. (1959) reported a similar result where, at 6 months lactation, heavier milking cows spent more time suckling their calves. However in early lactation lower producing cows suckled their calves longer. This same negative relationship between milk production and suckling time was reported by

Williams et al. (1977), Nicol and Sharafeldin (1975), Day et al. (1987) and Koots and Crow (1983). Drewry et al. (1959) suggested that in early lactation calves on lower producing cows need to suckle longer to obtain the same quantity of milk as calves on higher producing cows. In late lactation the appetite of the calves generally exceeds milk supply, and therefore calves on low producing cows suckled for a shorter time.

The number of suckling bouts or frequency of suckling in this study were slightly less than those reported in the literature. These differences may be due to differences in the length of the observation periods, or to breed differences. Straightbred Devon dams suckled their calves more frequently and for a shorter time than Herefords, even after adjustment for milk yield. This may indicate dam breedtype differences in milk letdown or differences in the suckling ability (i.e. milk withdrawal ability) of the calves. Some studies have shown no effect of milk yield on suckling frequency (Neindre and Petit 1976) whereas other reports have found decreased suckling frequency with increasing stages of lactation, where milk yield is likely to be confounded with age of calf (Ewbank 1969, Sommerville and Lowman 1979, Williams et al. 1977).

No breedtype differences occurred for cow and calf grazing times or the number of grazing periods. The average grazing time of the cows was within the range of those reported by Stobbs and Minson (1983). However to deduce differences in food intake (I) based on grazing time (T) requires the added measurement of the number of bites per unit time (R) and the weight of each bite (S), where I=T x R x S (Chacon et al. 1976 as cited by Stobbs and Minson 1983). Hence the absence of differences in total grazing time in the present study may not necessarily suggest that differences in food intake did not occur. Further research is required to determine if differences in food intake are occurring between the dam breedtypes and what effect heterosis for milk production and mature weight is having on food intake.

Calf grazing time was approximately 60 % of adult grazing time. This in agreement with Nicol and Sharafeldin (1975), who also reported that grazing time of calves was depressed by 11.2 min for every additional litre of milk produced by the cow per day. No differences were observed in this study between the calf breedtypes, even though differences in milk yield existed between the dam breedtypes. Boggs et al. (1980), Le Du et al. (1976) and Ansotegui (1986) reported that calves increased forage intake in response to decreased milk production. However, as discussed, grazing time alone is not a direct measure of food intake.

9.4 Conclusions

Crossbred heifers grew faster postweaning (7.3 %) and were heavier than the straightbreds at joining. As dams the crossbreds produced more milk (32 %) of a similar composition, suckled their calves for longer per daylight observation (19 %) and weaned heavier calves (6.5 %) than the straightbreds.

The study showed a significant preweaning environment effect on the postweaning growth of the heifers to joining. The age at weaning and the breedtype of the dam significantly affected postweaning growth and subsequent joining weight of the heifers.

Differences between the performance of the reciprocal cross heifers and their calves were generally small and non-significant for the traits studied. The performance of the straightbred Devon and Hereford heifers was similar for most traits. However some important differences were observed. Although similar in daily milk yield, the Devon heifers had higher percentage milk protein than the Herefords. The Devon dams suckled their calves more frequently and for a shorter time than Hereford heifers which may indicate differences in milk letdown.

Male calves from the four heifer breedtypes tended to be heavier than females at birth and heavier calves had greater body dimensions. The results from the milking studies showed that fatter heifers produced less milk. The weaning weights of the calves from the four heifer breedtypes showed the existence of a sire *x* breed of dam interaction which affected the estimate of maternal heterosis for weaning weight.

CHAPTER 10 - General Discussion and Conclusions

This study of growth, carcase, behaviour and maternal performance has once again demonstrated the strength of the diallel design for breed and cross evaluation. The study has documented the additive and non-additive direct and maternal differences for the Devon and Hereford breeds under Australian production environments.

Non-additive direct effects, as exhibited by the Devon-Hereford reciprocal crosses, contributed to the crossbred steers being heavier than the straightbreds at weaning, growing faster postweaning and having carcases which were heavier than those of the straightbreds. However carcases did not differ in depth or eye muscle area at the same hot carcase weight. The Devon-Hereford reciprocal cross heifers grew faster postweaning and were heavier at joining than the straightbreds. These findings are in broad agreement with the literature involving British breed crosses (e.g. Long 1980 and sections 3.2, 8.3.1 and 8.3.2 herein). The expression of heterosis for growth was not affected by the environments used in this study, contrary to the review findings of Barlow (1981) (sections 4.3.1 and 8.2.1).

Non-additive maternal effects were studied in the progeny of the Devon-Hereford reciprocal cross heifers. The birth weights of calves from the crossbred heifers were similar to those from the straightbred heifers. Similar results have been reported in the literature (section 9.3.2). The preweaning gain of the calves from the crossbreds was greater than that of calves from the straightbreds. This difference can be accounted for primarily by the higher milk yield of the crossbred heifers. Few studies have actually measured milk yield of beef cows, but the results are in general agreement with the limited number of reports in the literature (Table 3.4 and section 9.3.4). Calves from the crossbred heifers obtained this extra milk by increasing their daily suckling time.

An interaction of sire with dam breedtypes for preweaning gain of their progeny has highlighted a potential problem for the estimation of heterosis where a third breed is used in the design. Further work is required to quantify the magnitude of this interaction using a larger sample of sires and dams. Such an interaction has rarely been examined, for experimental design or other reasons. However, a small number of studies have found it has the potential to distort (additive) sire evaluations (section 4.5.1).

Additive direct differences between the Devon and the Hereford breeds were small for slaughter weight, hot carcase weight and eye muscle area. However, Devon steer calves were heavier than the Herefords at weaning, but this advantage was not apparent at slaughter. Although there was no difference in hot carcase weight, the Devon and Hereford straightbreds did perform differently during periods of slow and faster growth in the low nutrition environment. Devon carcases were fatter than the Herefords, both in the amount of kidney and channel fat and in subcutaneous fat depth at a constant hot carcase weight. No reported studies have examined the growth and carcase traits of straightbred Devons and Herefords in the same experiment. However, Devon cross carcases were reported as having more internal fat than Angus and Hereford crosses (Young et al. 1978a,b and sections 6.4 and 8.3.2 herein).

An additive direct difference between the Devon and Hereford heifers was observed for postweaning growth to joining. This result would have been influenced by the significant breedtype by weaning age interaction (section 9.2.1). Straightbred Devons and Herefords did not differ in daily milk yield; however, the Devons had higher milk protein percentage than the Herefords (section 9.3.4). Differences between the progeny of the straightbred heifers for birth weight, body shape and weaning weight were small. Direct additive and non-additive effects could not be partitioned for design reasons. The sire *x* breed of dam interaction also affected the weaning weights of the calves from the straightbred heifers.

Additive maternal differences, measured as differences between the performance of the reciprocal crosses, were important for weaning weight, with steers from Devon dams being heavier than those from Herefords. Similar results were reported by Dillard et al (1980) and many researchers have shown preweaning growth is influenced by the maternal environment (section 8.3.1). Additive maternal effects for postweaning growth were not apparent. This is in agreement with Lasley et al (1973), but a review by Long (1980) reported additive maternal differences for postweaning gain (section 8.3.1). Carcase weight, kidney and channel fat and fat depth did not differ between the reciprocal crosses; which is in agreement with the conclusions of Gregory et al (1978c) (section 8.2.3 and 8.3.2).

The additive maternal influences for birth weight indicates that the genetic differences for grand-maternal effects were small. Similar results have been reported in the literature (section 9.3.2). Additive maternal differences for daily milk yield and composition were small. This is not surprising, as the reciprocal crosses generated from a diallel design are expected to be equal in terms of genetic components, except for an effect due to maternal granddams (Dickerson 1969). This maternal granddam effect can affect the subsequent maternal performance of the heifers as reflected in their calf's performance (Cundiff et al. 1974b, and sections 4.2.1 and 9.3.4 herein). The similar daily milk yield and composition was reflected in similar weaning weight of their progeny but once again the sire *x* breed of dam interaction affected these estimates.

In general this study has shown the advantages in growth and maternal traits that were achieved from heterosis generated from crossing the Devon and Hereford breeds. For most of the traits studied maternal additive differences were negligible. Additive differences between the Devon and Hereford straightbreds were generally small, however important differences did exist for the quality related traits of carcase kidney and channel fat, subcutaneous fat depth and milk protein percentage.

In summarising the findings, the genetic contribution of the Devon breed to a crossbreeding system should be considered. The results from the steer evaluations suggest that a simple two-breed cross involving the Devon breed can increase beef produced per animal. The tendency of the Devon to fatten at an earlier weight may be a very useful trait if crossed with a faster growing, later maturing breed. The increased milk production and subsequent weaning weight of calves from Devon cross heifers shows that Devon cross dams mated to a terminal sire to produce three-breed cross calves could be an appropriate system, although a comparative economic evaluation has not yet been undertaken. To do this evaluation properly comparative data on feed requirements and reproductive rate is necessary. The problem of obtaining Devon cross replacement heifers may necessitate combining the Devon in a simple two- or three-breed rotation unless the commercial producer was prepared to maintain the total terminal cross system.

Although the basic design used proved very effective in producing a wide range of information for this evaluation, undoubtedly more significant differences would have been obtained with greater diallel cell numbers. This would have allowed the study of the important reproductive traits where, because of the nature of their distribution, considerably greater numbers are required to detect even large genetic differences. Larger cell numbers would also have allowed the examination of the biological and economic relationships among all economic traits.

Nevertheless, the study, suggests that the future of the Devon breed in crossbreeding in Australia is primarily its contribution to the maternal component of crossbreeding i.e. as one of the breeds which is crossed to make a productive crossbred dam. To fully establish the place of the breed, further research would be necessary to investigate 1) the relative feed intake and reproductive performance of the Devon cross dam and 2) the performance of the crossbred dam under different environments. The performance of the Devon crossed with other breeds would provide additional information necessary for the design of optimum crossbreeding programs involving the Devon breed.