



Early reproductive traits in beef heifers differing in milk production
by Charles Allan Steffan

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

Montana State University

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Abstract:

Postweaning growth and early reproductive traits in heifers whose potential for milk production differed were studied at the Northern Agricultural Research Center near Havre during the years 1976 through 1979. Data were collected on 230 heifers raised on ≥ 3 -yr-old Hereford dams which comprised the following breed groups: Hereford (HH), Angus-Hereford (AH), 25% Simmental - 75% Hereford (1S3H) and Simmental-Hereford (SH). Least-squares analyses of variance procedures were used to compare pubertal traits and traits at first pregnancy and to identify relationships between these traits and various measures of growth. Mature size (weight and height) and measures of maturity were also analyzed. Finally, step forward-backward regression procedures were used to predict traits at puberty and first pregnancy and to determine the magnitude of the influence of important factors affecting these traits. The model included effects of breed group, year, age of dam and appropriate two-factor interactions. Ninety-one percent of the heifers reached puberty by the end of the breeding period. Crossbred heifers were younger, but not always heavier or taller at puberty than straight-bred Hereford heifers. Puberty age, weight and height for HH, AH, 1S3H and SH groups were 406.6, 371.0, 381.6 and 367.5 d; 300.8, 301.9, 304.8 and 312.8 kg; and 114.6, 114.2, 116.7 and 118.5 cm, respectively. Pregnancy rates were lower for Hereford heifers, 58.9 versus 90.0, 77.2 and 86.0% for AH, 1S3H and SH heifers, respectively. No differences among breeds were found for pregnancy date. Prediction equations accounted for 22 to 76% of the variation in early reproductive traits. Date of birth and average daily gain from birth to yearling were the only significant factors in the regression analysis for puberty age while puberty age had the greatest influence on pregnancy rate and pregnancy date. Crossbred heifers were generally heavier, taller and grew faster to various ages than did HH heifers. Maturity analysis indicated all breed groups reached puberty at a similar percentage of their mature size as measured by weight and height, but differences existed between groups at 1 yr of age.

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MONTANA STATE UNIVERSITY
Bozeman, Montana

July 1983

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of a thesis submitted by

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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To Mom and Dad

VITA

Charles Allan Steffan was born to Mr. and Mrs. Charley J. Steffan in Dickinson, North Dakota on October 21, 1959. He attended South Heart Public School and graduated from South Heart High School in May of 1977.

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ACKNOWLEDGEMENTS

I would like to express my appreciation to Dr. D. D. Kress for his positive direction and thoughtful guidance throughout my graduate program. To my graduate committee, Drs. A. C. Linton and P. J. Burfening and Dan Doornbos for their valuable advice and suggestions.

Thanks to Don Anderson, Dan Doornbos and the staff at the Northern Agricultural Research Center for their dedication to this research project and for their generous assistance in collecting the data.

A note of gratitude is extended to Dale Trowbridge for his help and patience in data analysis.

And to the staff and fellow graduate students for their support and friendship which made graduate school much more enjoyable.

Finally, special thanks to my parents, family, and friends for their immeasurable encouragement and for not disowning me while I was a Montanan.

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ABSTRACT

Postweaning growth and early reproductive traits in heifers whose potential for milk production differed were studied at the Northern Agricultural Research Center near Havre during the years 1976 through 1979. Data were collected on 230 heifers raised on ≥ 3 -yr-old Hereford dams which comprised the following breed groups: Hereford (HH), Angus-Hereford (AH), 25% Simmental - 75% Hereford (1S3H) and Simmental-Hereford (SH). Least-squares analyses of variance procedures were used to compare pubertal traits and traits at first pregnancy and to identify relationships between these traits and various measures of growth. Mature size (weight and height) and measures of maturity were also analyzed. Finally, step forward-backward regression procedures were used to predict traits at puberty and first pregnancy and to determine the magnitude of the influence of important factors affecting these traits. The model included effects of breed group, year, age of dam and appropriate two-factor interactions. Ninety-one percent of the heifers reached puberty by the end of the breeding period. Crossbred heifers were younger, but not always heavier or taller at puberty than straightbred Hereford heifers. Puberty age, weight and height for HH, AH, 1S3H and SH groups were 406.6, 371.0, 381.6 and 367.5 d; 300.8, 301.9, 304.8 and 312.8 kg; and 114.6, 114.2, 116.7 and 118.5 cm, respectively. Pregnancy rates were lower for Hereford heifers, 58.9 versus 90.0, 77.2 and 86.0% for AH, 1S3H and SH heifers, respectively. No differences among breeds were found for pregnancy date. Prediction equations accounted for 22 to 76% of the variation in early reproductive traits. Date of birth and average daily gain from birth to yearling were the only significant factors in the regression analysis for puberty age while puberty age had the greatest influence on pregnancy rate and pregnancy date. Crossbred heifers were generally heavier, taller and grew faster to various ages than did HH heifers. Maturity analysis indicated all breed groups reached puberty at a similar percentage of their mature size as measured by weight and height, but differences existed between groups at 1 yr of age.

INTRODUCTION

The production cycle of the beef cow is composed of key physiological events, each one being critical to efficient beef production. With gestation consuming approximately three-fourths of the production cycle, early conception in heifers could foreseeably allow for a longer initial postpartum period where involution, estrus and subsequent pregnancy could occur. Puberty initiates this sequence of events, but little is known concerning the nature of the relationships which exist between puberty and other reproductive traits. Lesmeister et al. (1973) documented evidence that heifers which were capable of conceiving early in the breeding season continued to calve early in the calving season and had greater lifetime efficiency if first calving occurred by 2 yrs of age. If this is the goal to be realized, early puberty could facilitate the breeding of virgin heifers earlier in the breeding season. Restricted breeding periods and the use of synchronizing agents appear to have potential in achieving earlier conception but are dependent on the occurrence of a fertile estrus prior to the start of the breeding period. Therefore, broadening the knowledge of pubertal information for various types of beef heifers should assist breeders in using these management systems to more efficiently produce red meat.

The objectives of this study were to compare pubertal traits in breed groups of beef heifers whose milk production potential differed

and to identify relationships between these traits and reproductive traits at first pregnancy. And secondly, to develop regression models to determine the accuracy at which pubertal and reproductive traits could be predicted and to identify the influence of various measures of growth on these traits.

REVIEW OF LITERATURE

Breed Effects on Puberty Age

Within the past decade, scientists have attempted to define, characterize and predict puberty through mating systems within and among various breeds of cattle. Sumption et al. (1970) reviewed age at puberty in straightbred cattle of domestic and European origin and classified them according to skeletal size. Cundiff (1981) similarly reviewed breed characterization studies and classified sire breed of heifers according to biological type (table 1). Joubert (1963) was among the first to cite strong evidence for breed of sire effects on puberty age. Since then, sire breed differences have universally been demonstrated, the most extreme being between sires of *bos indicus* and *bos taurus* species (Reynolds et al., 1963; Young et al., 1978; Gregory et al., 1979; Stewart et al., 1980; Dow et al., 1982). Gregory et al. (1979) noted that *bos indicus* cattle achieved first estrus later than late maturing *bos taurus* breeds of low milk production but projected that a favorable environment could possibly enhance the onset of first estrus in *bos indicus* heifers to an acceptable age. Cundiff (1981) suggested these differences could have arisen from differences in selection pressure between these two species for the age at which puberty is reached.

Heifers sired by larger framed, later maturing breeds were generally older at puberty (Laster et al., 1976; Laster et al., 1979;

TABLE 1. PUBERTY AGE FOR BREEDS AND BREED TYPES OF HEIFERS

Sumption et al. (1970)			Cundiff (1981)					
Breed	Age	S	Sire breed	Age	G	L	M	N
Highland	2	S	Jersey-X	1	1	1	5	117
Red Poll	2	S	Hereford-Angus-X	3	2	2	2	322
Galloway	2	M	Red Poll-X	2	3	3	3	95
American Angus	1	M	South Devon-X	2	3	3	3	120
Beef Shorthorn	2	M	Tarentaise-X	2	3	3	3	85
Milking Shorthorn	2	M	Pinzgauer-X	2	3	3	3	114
Murray Grey	2	M	Sahiwal-X	5	2	3	3	87
American Hereford	4	M	Brahman-X	5	4	3	3	103
Devon	3	M	Brown Swiss-X	2	4	4	4	126
South Devon	3	L	Gelbvieh-X	2	4	4	4	81
Amer. Brown Swiss	3	L	Simmental-X	3	5	4	4	157
Holstein-Friesian	3	L	Maine-Anjou-X	3	5	4	3	89
Limousin	3	L	Limousin-X	4	3	5	1	161
Maine-Anjou	3	L	Charolais-X	4	5	5	1	132
Simmental	3	L	Chianina-X	4	5	5	1	92
Charolais	4	L						

Heading letters indicate S = mature size, small, medium and large, G = growth rate and mature size, L = lean to fat ratio, M = milk production. Ratings = 1 indicates the lowest, most desirable for puberty age, and 5 would indicate the highest or oldest puberty age. For G, L and M, 5 indicates the highest rank, while 1 indicates the lowest rank. Since these studies are independent, rankings are relative within each study only. N = number of heifers. Number of heifers were not available for Sumption et al. (1970).

Baker, 1981; Grass et al., 1982). However, Mason (1971) noted that all the differences in puberty could not be accounted for by mature size or growth rate of the sire breed. Heifers sired by breeds selected for milk production or beef and milk production were younger at puberty (Gregory et al., 1978; Laster et al., 1979; Stewart et al., 1980). Cundiff (1980) and Gregory et al. (1982) projected the favorable influence of milk production on puberty age could cancel and possibly override the negative influence of the increased skeletal size of some breeds. Ferrel (1982) noted some of these differences may be related to the direct maternal effects, phenotypically expressed through higher rates of preweaning growth in heifers from dams of higher milk production. Therefore, strong evidence exists that selection in the development of cattle as distinct breeds has had an effect on age at puberty. Pubertal traits and pregnancy for various breeds and breedtypes of cattle are given in table 2.

The weighted average for Hereford heifers from these studies was 421.3 d which was older than the estimation of 371.2 d for Angus-Hereford and reciprocal crosses or the 357.1 d estimate for Simmental sired (F_1) heifers. No citations in the literature could be found for 25% Simmental-75% Hereford crosses, but Young et al. (1978) found heifers from 50% Simmental-50% Angus or Hereford dams mated to Hereford, Angus, Devon, Brahman or Holstein sires reached puberty at 380 ± 7.4 d.

Sire differences within a breed for puberty age have been reported (Wiltbank et al., 1966; Laster et al., 1976; Burfening et al., 1979). Dam breed has been documented to significantly affect puberty age and is generally consistent with sire breed rankings for puberty age (Laster et

TABLE 2. PUBERTAL TRAITS AND PREGNANCY FOR VARIOUS BREEDTYPES OF HEIFERS

STRAIGHTBREDS						
Angus (A)						
First Author	Year	N	Puberty		Pregnancy Rate	Comments
			Age	Weight		
Baker	1981	N/A	413			
Christian	1957	9	353	239		
Ferrel	1982	76	410	309	93	LMH
Gregory	1978	52	365	276	87	
Laster	1972	24	373	274		
Laster	1976	64	366	255	82	
Pleasants	1975	40	394	194		
Reynolds	1963	N/A	433	244		
Stewart	1980	7	303	230		Penned
		21	385	225		Pastured
Wiltbank	1966	29	396	233		Lo
	1966	23	337	251		Hi
Wiltbank	1969	12	483	257		Lo
	1969	12	374	305		Hi
Weighted mean		369	382.6	260.8	87.7	
Blond D' Aquitaine (BDA)						
Baker	1981	N/A	443			
Brahman (B)						
Stewart	1980	21	479	299		Pastured
	1980	6	382	275		Penned
Reynolds	1963	N/A	816	321		
Weighted mean		27	457.4	293.7		
Brown Swiss (BS)						
Ferrel	1982	47	317	305	102	
Gregory	1978	18	324	297	82	
Weighted mean		65	318.9	302.8	96.5	
Charolais (C)						
Ferrel	1982	36	388	355	91	LMH

TABLE 2. PUBERTAL TRAITS AND PREGNANCY FOR VARIOUS BREEDTYPES OF HEIFERS (CONTINUED)

Friesian (F)						
First Author	Year	N	Puberty		Pregnancy Rate	Comments
			Age	Weight		
DesJardins	1968	24	207			
Dufour	1974	34	323	262		
Hawk	1953	67	397			
Menge	1960	184	345			
Morgan	1981	48	298	294		
Stewart	1980	26	361	223		Pastured
	1980	7	288	242		Penned
Morrow	1968	53	296			
Weighted mean		443	332.8	265.3		
Hereford (H)						
Arije	1971	298	436	251		
Burfening	1979	190	385	296		
Christian	1957	16	378	289		
Ferrel	1982	84	429	302	86	LMH
Gregory	1978	38	397	273	89	
Laster	1972	27	390	269		
Laster	1976	62	415	274	78	
Morgan	1981	38	464	290		
Stewart	1980	48	454	235		Pastured
	1980	7	300	197		Penned
Wiltbank	1966	26	457	269		Lo
	1966	26	413	306		Hi
Wiltbank	1969	8	660	279		Lo
	1969	8	387	294		Hi
Weighted mean		876	421.3	272.7	83.9	
Jersey (J)						
Stewart	1980	11	387	167		Pastured
	1980	6	331	164		Penned
Weighted mean		17	367.2	165.9		
Red Poll (RP)						
Ferrel	1982	61	355	270	102	LMH
Gregory	1978	22	346	277	77	
Weighted mean		83	352.6	271.9	95.4	

TABLE 2. PUBERTAL TRAITS AND PREGNANCY FOR VARIOUS BREEDTYPES OF HEIFERS (CONTINUED)

Shorthorn (SH)						
First Author	Year	N	Puberty		Pregnancy Rate	Comments
			Age	Weight		
Christian	1957	10	383	252		
Wiltbank	1966	30	413	226		Lo
	1966	25	318	243		Hi
Weighted mean		65	371.9	236.5		
Simmental (S)						
Ferrel	1982	91	348	328	92	LMH
F ₁ CROSS HEIFERS						
Angus (A)						
Gregory	1978	62	309	306	80	ABS
Gregory	1978	50	362	294	84	ARP
Wiltbank	1966	14	366	244		ASH
	1966	13	290	247		ASH
Young	1978	41	383	258	95	(A or H)X,NM
Young	1978	60	388	275	85	(A or H)X,AI
Also see ANGUS-HEREFORD						
Weighted mean		139	332.0	287.9	81.8	

TABLE 2. PUBERTAL TRAITS AND PREGNANCY FOR VARIOUS BREEDTYPES OF HEIFERS (CONTINUED)

Angus-Hereford (AH), Hereford-Angus (HA)						
First Author	Year	N	Puberty		Pregnancy Rate	Comments
			Age	Weight		
Baker	1981	N/A	392			
Gregory	1978	38	383	286	94	AH
	1978	52	361	284	75	HA
Gregory	1979	31	331	296	76	AH
	1979	70	371	296	90	HA
Laster	1972	23	371	280		AH
	1972	23	351	278		HA
Laster	1976	132	371	266	93	AH, HA
Short	1971	89	411	248		AH, HA, LMH
Stewart	1980	17	416	249		AH, HA, Pastured
	1980	6	312	250		AH, HA, Penned
Wiltbank	1966	12	407	261		AH, Lo
	1966	12	338	282		AH, Hi
	1966	21	388	243		HA, Lo
	1966	16	383	291		HA, Hi
Wiltbank	1969	10	416	270		AH, Lo
	1969	9	384	331		AH, Hi
	1969	7	402	238		HA, Lo
	1969	8	378	329		HA, Hi
Weighted mean		576	371.2	273.5	87.7	
Brahman (B)						
Gregory	1979	61	394	343	89	BA
Gregory	1979	42	402	332	97	BH
Morgan	1981	47	397	306		BF
Morgan	1981	34	568	336		BH
Reynolds	1963	N/A	460	303		
Stewart	1980	See ANGUS				AB, BA
Stewart	1980	20	404	277		BF, FB, Pastured
	1980	6	360	302		BF, FB, Penned
Stewart	1980	31	425	272		BH, HB, Pastured
	1980	6	343	276		BH, HB, Penned
Stewart	1980	23	395	229		BJ, JB, Pastured
	1980	6	400	325		BJ, JB, Penned
Young	1978	46	426	308	85	BX
Weighted mean		230	428.2	325.4	90.0	

TABLE 2. PUBERTAL TRAITS AND PREGNANCY FOR VARIOUS BREEDTYPES OF HEIFERS (CONTINUED)

Brown Swiss (BS)						
First Author	Year	N	Puberty		Pregnancy Rate	Comments
			Age	Weight		
Laster	1979	126	349	281	92	BSA,BSH
Gregory	1978	62	336	287	90	BSA
	1978	67	361	278	95	BSH
	1978	18	337	289	81	BSRP
Weighted mean		273	348.2	282.2	91.6	
Charolais (C)						
Baker	1981	N/A	430			CA,CH
Laster	1972	16	371	339		CA
Laster	1972	35	365	306		CH
Laster	1976	132	398	303	81	CA,CH
Morgan	1981	37	309	313		CF
Morgan	1981	45	470	326		CH
Swierstra	1977	30	344	306		CA
Swierstra	1977	22	360	336		CH
Swierstra	1977	46	321	319		CSH
Weighted mean		363	377.0	313.0	81.0	
Chianina (CH)						
Laster	1979	92	401	319	85	CHA,CHH
Devon (D)						
Young	1978	67	384	275	91	DX
Friesian (F)						
Baker	1981	N/A	353			FA,FH
Morgan	1981	33	347	263		FH
Pleasants	1975	177	328	223		FF,FA,FFJ
Stewart	1980	21	385	221		FJ,JF,Pastured
	1980	6	311	220		FJ,JF,Penned
Stewart	1980	28	375	233		FH,HF,Pastured
	1980	5	303	247		FH,HF,Penned
Stewart	1980	See	ANGUS			FA,AF
Stewart	1980	See	BRAHMAN			FB,BF
Young	1978	50	370	284	97	FX
Weighted mean		260	338.5	239.8		

TABLE 2. PUBERTAL TRAITS AND PREGNANCY FOR VARIOUS BREEDTYPES OF HEIFERS (CONTINUED)

Hereford (H)						
First Author	Year	N	Puberty		Pregnancy Rate	Comments
			Age	Weight		
Gregory	1978	21	365	293	80	HRP
Gregory	1978	13	334	302	90	HBS
Morgan	1981	41	277	285		HF
Stewart	1980	See	ANGUS-HEREFORD			AH,HA
Stewart	1980	See	BRAHMAN			HB,BH
Stewart	1980	See	FRIESIAN			HF,FH
Stewart	1980	40	398	209		HJ,JH,Pastured
	1980	6	299	217		HJ,JH,Penned
Wiltbank	1966	13	379	230		HSH,Lo
	1966	18	283	232		HSH,Hi
Young	1978	See	ANGUS			(H or A)X,AI,NM
Also see HEREFORD-ANGUS						
Weighted mean		106	315.0	272.9	83.8	
Gelbvieh (G)						
Laster	1979	81	343	286	93	GA,GH
Jersey (J)						
Baker	1980	N/A	340			JA,JH
Laster	1972	16	325	219		JA
Laster	1972	29	319	237		JH
Laster	1976	117	322	219	86	JA,JH
Stewart	1980	See	ANGUS			JA,AJ
Stewart	1980	See	BRAHMAN			BJ,JB
Stewart	1980	See	FRIESIAN			FJ,JF
Stewart	1980	See	HEREFORD			HJ,JH
Weighted mean		162	321.7	222.2		
Limousin (L)						
Baker	1981	N/A	436			LA,LH
Laster	1972	25	358	273		LA
Laster	1972	33	359	287		LH
Laster	1976	161	398	292		LA,LH
Swierstra	1977	85	352	289		LA
Swierstra	1977	73	353	297		LH
Swierstra	1977	97	342	313		LSH
Weighted mean		474	366.5	295.2		

TABLE 2. PUBERTAL TRAITS AND PREGNANCY FOR VARIOUS BREEDTYPES OF HEIFERS (CONTINUED)

Maine Anjou (M)						
First Author	Year	N	Puberty		Pregnancy Rate	Comments
			Age	Weight		
Baker	1980	N/A	404			MA,MH
Laster	1979	89	374	307		MA,MH
Pinzgauer (P)						
Gregory	1979	69	287	288	89	PA
Gregory	1979	45	319	294	100	PH
Weighted mean		114	299.6	290.4	93.3	
Red Poll (RP)						
Gregory	1978	50	351	268	83	RPA
Gregory	1978	8	320	295	69	RPBS
Gregory	1978	43	364	266	85	RPH
Laster	1979	95	354	265	84	RP,RPH
Weighted mean		196	354.0	267.2	83.4	
Sahiwal (SA)						
Gregory	1979	55	376	306	98	SAA
Gregory	1979	32	390	304	97	SAH
Weighted mean		87	381.1	305.3	97.6	
Shorthorn (SH)						
Wiltbank	1966	17	413	226		SHA,Lo
	1966	18	316	276		SHA,Hi
Wiltbank	1966	20	384	247		SHH,Lo
	1966	18	314	254		SHH,Hi
Weighted mean		73	356.7	251.0		
Simmental (S)						
Baker	1981	N/A	414			SA,SH
Laster	1972	22	360	290		SA
Laster	1972	28	369	301		SH
Laster	1976	157	372	286	86	SA,SH
Swierstra	1977	34	344	288		SA
Swierstra	1977	30	331	289		SH
Swierstra	1977	54	329	314		SSH
Weighted mean		325	357.1	292.7	86.0	

TABLE 2. PUBERTAL TRAITS AND PREGNANCY FOR VARIOUS BREEDTYPES OF HEIFERS (CONTINUED)

South Devon (SD)						
First Author	Year	N	Puberty		Pregnancy Rate	Comments
			Age	Weight		
Baker	1981	N/A	402			SDA,SDH
Laster	1972	18	358	288		SDA
Laster	1972	18	371	284		SDH
Laster	1976	120	364	274	85	SDA,SDH
Weighted mean		156	364.1	276.8	85.0	
Tarentaise (T)						
Gregory	1979	52	301	292	84	TA
Gregory	1979	33	335	300	97	TH
Weighted mean		85	314.2	295.1	89.0	
Sire Breed of Dam of F ₂ Cross Heifers						
Young	1978	44	403	293	93	CA,CH
Young	1978	41	405	275	88	A and H
Young	1978	45	369	269	102	JA,JH
Young	1978	47	404	285	69	LA,LH
Young	1978	49	380	287	97	SA,SH
Young	1978	38	378	272	92	SDA,SDH

Comments column indicates wintering level, breedtypes and in some studies whether heifers resulted from natural mating (NM) or AI.

Wintering levels within an experiment were lo or hi and in some cases a pooled estimate of heifers under lo, med, and hi wintering levels (LMH) are presented. Pastured indicates a low wintering level and penned indicates heifers were wintered in a dry lot, a high wintering level.

Breed types of F₁ cross heifers are given by sire breed code first and dam breed code second, F₂ cross heifers have the sire breed of dam indicated in the comments column and were mated to A, B, D, F and H bulls. X indicates heifers were from various crossbred dams, specifically dams sired by C, J, L, S, and SD bulls from A or H cows. Means were weighted by the number of heifers in each study.

al., 1972, 1976, 1979; Swierstra et al., 1977; Gregory et al., 1978; Morgan, 1981). Young et al. (1978) found sire breed of dam to affect puberty age in three breed cross heifers.

Because of the availability of Hereford and Angus seedstock for experimental use, differences between these dam breeds have been well documented. Laster et al. (1972, 1976, 1979) reported heifers from Angus dams were 22, 26 and 35 d younger, respectively, at puberty than were their contemporaries out of Hereford dams. Laster et al. (1979) found the difference for puberty age between these two breeds was greater than the difference between their respective reciprocal crosses and indicated that a portion of the differences between these two dam breeds could have resulted from the transmitted effects of the Angus breed in addition to any maternal advantage. Gregory et al. (1978) in a similar study with different sire types found maternal differences but did not report a transmitted advantage for Angus dams. Milk production differences in favor of the Angus dams have been reported (Melton et al., 1967; Gleddie and Berg, 1968; Cundiff et al., 1974; Kress and Anderson, 1974; Notter et al., 1978).

Swierstra et al. (1977) noted that heifers from Angus and Hereford dams did not differ in puberty age, but both groups were 16 to 22 d older than Shorthorn dams ($P < .01$). Morgan (1981) pointed out distinct differences between heifers of Friesian dams and Hereford dams and suggested a high maternal ability of the dams could facilitate earlier breeding of virgin heifers. Dow et al. (1982) also noted differences of the Red Poll over the Hereford breed. Laster et al. (1976) postulated that breed crosses with a genetic makeup to reach puberty earlier had a

greater opportunity to express this trait with higher milk production from their dams prior to weaning. Young et al. (1978) reported higher maternal ability (milk) of the dam could decrease puberty age and Laster et al. (1979) reported a breed group mean correlation between puberty age and milk production of $-.88$ ($P < .01$) when these traits were analyzed as averages of several breed groups.

The maternal effect is further substantiated by cow age. Laster et al. (1979) found heifers from 5-yr-old dams were 13 ± 2 d younger at puberty than heifers from 4-yr-old cows. Gregory et al. (1978) found a similar advantage of 12 d between dams of 4 and 5 yr of age. Laster et al. (1976) documented puberty age estimates of 387, 368, 353 and 357 d for heifers of 2-, 3-, 4- and ≥ 5 -yr-old dams, respectively. Younger cows have been associated with lower levels of milk production (Melton et al., 1967; Jeffrey et al., 1971; Williams, 1977; Notter et al. 1978; Doornbos et al., 1982).

Within Hereford cattle, Burfening et al. (1979) showed line of dam affected age at first estrus when birth date was held constant and noted the magnitude of the influence of the line of dam was greater than that for line of sire.

Moderate heritabilities have been documented for puberty age, of $.36 \pm .30$ (Arije and Wiltbank, 1971), $.67 \pm .24$ (Smith et al., 1976), $.41 \pm .17$ (Laster et al., 1979), $.41$ (Lunstra, 1982) and $.48 \pm .18$ (King et al., 1983). This information coupled with sire within breed effects and those of line of dam on puberty age would suggest that puberty age in beef heifers could be hastened by capitalizing on the genetic variation for this trait within a breed through selection. However,

since age at puberty is a sex-limited trait, selection for early ages at puberty is somewhat impeded because of the difficulty to measure a sire's genetic worth for this trait at a young age. However, recent research has noted relatively high correlations between puberty age and scrotal circumference between half-sib progeny, $r = -.71$ (Brinks et al., 1978), $r = -.98$ (Lunstra, 1982), and $r = -1.07$ (King et al., 1983). With heritability estimates for scrotal circumference similar to those for puberty age, .52 (Lunstra, 1982) and $.26 \pm .23$ (King et al., 1983), selection for sires with larger scrotal circumference could enhance improvement for puberty age in beef heifers.

Heterosis for Puberty Age

Smith et al. (1976) indicated that alteration of growth patterns could increase the efficiency of a beef production system by increasing early growth and efficiency to a greater degree than subsequent mature size. Several studies have shown that heterosis can accelerate the maturing process by decreasing puberty age and have documented the existence of non-additive genetic variation for this trait (Kaltenbach et al., 1962; Reynolds et al., 1963; Wiltbank et al., 1966, 1969; Short and Bellows, 1971; Laster et al., 1972, 1976; Pleasants et al., 1975; Nelsen et al., 1982). Wiltbank et al. (1966) suggested that the heterosic effect was due to effects of a breed rather than the effect of sires within a breed. The level of heterosis is expected to be greatest in the progeny of two parents of diverse type and genetic background (Falconer, 1981). Reynolds et al. (1963) demonstrated such a

relationship and showed dramatic heterosis in first cross heifers of *bos taurus* and *bos indicus* breeding.

Laster et al. (1976) reported a 19.5 d decrease in puberty age in Angus-Hereford and Hereford-Angus crosses compared to straightbred Hereford and Angus heifers and noted that a larger percentage of the crossbreds (6 to 20%) reached puberty at various ages from 300 to 510 d. Laster et al. (1972) found the crossbred and straightbred difference in a similar study to be 20 ± 11 d for the same breeds and crosses and noted $17.0 \pm 7.1\%$ more of the crossbred heifers reached puberty by 15 mo of age. A study by Gregory et al. (1978) found the heterosis estimate for age at puberty only approached significance ($P < .10$) and was -9.4 d. Swierstra et al. (1977) noted a nonsignificant breed of sire by breed of dam interaction when three British dam breeds (Angus, Hereford and Shorthorn) were mated to three European breeds (Charolais, Simmental and Limousin).

Under two management systems heterosis estimates were consistently lower under a high feeding level when compared to a low level of feed (Wiltbank et al., 1966 and 1969). They found heterosis levels were 41 versus 35 and 148 versus 0 respectively for low versus high feeding levels when straightbred heifers were compared to crossbred heifers. Stewart et al. (1980) fed heifers in a drylot and grazed another group on pasture and found crossbred heifers were 15 d ($P < .05$) younger when raised on pasture but 11 d ($P < .05$) older when fed in a drylot when compared to straightbreds. It would appear from these reports that the heterosis estimate can be influenced by feeding level.

Wiltbank et al. (1966) noted significant heterosis was present under both feeding levels after puberty age had been adjusted for average daily gain. This indicated that heterosis for postweaning growth rate and heterosis for puberty age were independent. Wiltbank et al. (1969) found similar independence of puberty age and preweaning growth rate under the low level of feed. Gregory et al. (1978) noted independent heterosis estimates for puberty age and puberty weight. Kaltenbach and Wiltbank (1962) found a 58 d heterosis advantage for crossbred heifers versus straightbred heifers but noted that 38 of these days could be accounted for by differences in growth rate. These results would give support to those of Wiltbank et al. (1966 and 1969) and Short and Bellows (1971) who proposed that something other than weight was involved in the onset of puberty. This was based on evidence that heifers could reach puberty at significantly different weights under two feeding regimes. Secondly, crossbred heifers were significantly heavier at puberty than straightbreds even though they achieved first estrus at the same time on a high feeding level. Finally, regressions of puberty age on growth could not explain all the variation in this trait. Arije and Wiltbank (1974) could explain 35 to 67% of the variation in puberty age through various prediction equations.

Efficient utilization of feed may have potentially important implications in explaining these differences. Unfortunately, research has been unable to address this question largely because of the difficulty encountered with its measurement.

Burfening et al. (1979) noted a nonsignificant 11 d advantage in puberty age for crossline heifers versus linebred heifers of the

Hereford breed. Hawk et al. (1953) and Menge et al. (1960) found system of mating in dairy cattle to significantly affect puberty age through its affect on growth rate. In the earlier study the difference between outbred heifers from inbred dams and inbred heifers from outbred dams approached significance ($P=.08$, 383 vs 412 d) while Menge found significant differences between similarly mated groups (318 versus 370 d, respectively). Menge reasoned that heterosis was being expressed in the outcrossed heifers while inbreeding depression was occurring in the inbred group. In both studies the effect of system of mating on puberty age was acting wholly through its effect on 6 mo weight.

Environmental Effects on Puberty Age

Environmental conditions can influence when first estrus is attained (Joubert, 1963; Joandet and Cartwright, 1970). Dale et al. (1959) reported differences between breeds for age at puberty when confined to constant environmental temperatures. Roy et al. (1980) found Holstein heifers born during periods of increasing day length reached puberty at earlier ages than those born during decreasing periods of daylight and noted phase of the moon influenced the time of estrus. Greer (unpublished data) in a similar study could not find relationships relating to lunar phase.

In beef cattle some advantage is apparent for heifers born in the spring over those born in the winter (Menge et al., 1960; Grass et al., 1980). It is conceivable that early growth in winter born calves would be reduced and could cause a delay in puberty.

Growth Relationships with Puberty Age

Among calves born in the spring, Arije and Wiltbank (1971) and Swierstra et al. (1977) found significant relationships indicating heifers born later in the calving season were younger at puberty ($r = -.24$ and $-.37$, respectively). Swierstra et al. (1977) explained the difference due to the older calves being affected to a greater degree by the availability of forage and milk supply prior to weaning. It would appear that placement of the calving season or reducing the length of the calving period could be effective in maximizing growth and minimizing the variation in puberty age due to date of birth. Wiltbank et al. (1971) attributed the delay due to a lower rate of growth which deterred the onset of first estrus until heifers were turned out to pasture and sufficient forage was available so they could acquire the necessary weight to reach puberty. Wiltbank et al. (1974) found the opposite relationship ($r = .20$, $P < .01$) and concluded the higher winter growth rate in this study accounted for the difference in puberty age (.33 kg/d versus .18 kg/d).

Swierstra et al. (1977) found heifers with larger birth weights were older at puberty ($r = .41$, $P < .01$). Laster et al. (1979) also documented a positive breed group mean correlation ($r = .66$, $P < .01$) between birth weight and puberty age. Larger birth weights have been generally associated with breeds which mature at larger weights (Smith et al., 1976; Anderson et al., 1978) and would justify findings previously cited in this review that some larger, later maturing breeds were older at puberty.

The rate of preweaning growth appears to be vitally important to the occurrence of initial estrus. Menge et al. (1960), through the use of standard partial regression coefficients, noted growth to 6 mo was 3.7 times more important in its effect on puberty age than was growth from 6 to 12 mo of age. Pleasants et al. (1975) realized this importance and further proposed that "acute checks to growth, particularly before weaning, may be more important to the attainment of puberty than the absolute level of feed intake as measured by growth or weight." This theory is supported by Hawk et al. (1953) who studied puberty in scouring heifers and found puberty age was increased through a decreased rate of growth to 6 mo.

When puberty age was regressed on preweaning rate of growth, Swierstra et al. (1977) noted puberty age was decreased 6.3 d/.1kg gain per d. Wiltbank et al. (1966) found a stronger relationship, -18.7 d/.1kg gain per d and Menge et al. (1960) found growth to 6 mo was moderately correlated ($r=-.56$) with puberty age. However, Wiltbank et al. (1969) noticed that regressions on growth at preweaning, postweaning or at 1 yr of age were only important for straightbred heifers on a low level of feed.

Smith et al. (1976) noted heifers which were heavier at any age except puberty, tended to reach puberty sooner. They also observed that heifers younger at puberty grew more rapidly prior to weaning and throughout their second summer but had slower rates of growth postweaning and at ages past 550 d. It is conceivable that calves which were raised on dam breeds of lower maternal ability would show compensatory gains following weaning and growth during this period may

be equally important to their attainment of puberty. Lamond (1970) noted body weight gains of the heifer prior to the onset of first estrus were influenced by previous weight gains of the heifer. Dufour et al. (1975) reported preweaning growth rate had less influence than weight gains after weaning until puberty. Wiltbank et al. (1966) noted a significant correlation between puberty age and postweaning gains until heifers were pastured ($r=-.50$).

Laster et al. (1972) found heifers which reached puberty by 15 mo of age were significantly heavier than those which did not reach puberty by that age. Short and Bellows (1971), in a study with three feeding levels, reported body weight on May 7 to be associated with puberty age ($r=-.55$). When puberty age was regressed on this weight, effects of feeding level and breed were no longer important. They did notice that high feeding levels tended to accelerate somatic growth as measured by weight faster than physiological growth as measured by puberty age. Ferrel (1982) reported findings among straightbred cattle that various breeds respond differently to low, medium and high levels of feed as reflected by the percentage of heifers reaching puberty by 240 to 520 d of age. In that study, Simmental heifers responded greater at high levels of feed, while Angus and Charolais had a greater response at medium levels. Red Poll and Brown Swiss were more efficient at a medium level of feed, and Hereford heifers showed little variation in percent reaching puberty regardless of feeding level.

Moseley et al. (1981) found level of feed did not change puberty age and reasoned that the occurrence of first estrus was limited by age in heavy heifers and by weight in light heifers. Nelsen et al. (1982)

noted results that supported an hypothesis made by Frisch (1974) that a minimum weight for height was required to reach puberty but also noted that age could be a limiting factor. Bellows et al. (1965) found weight gains prior to the breeding period were four times more important to the attainment of puberty than were weight gains made during the winter.

Older heifers at puberty are usually heavier as shown by various residual correlations between age and weight of .57 (Arije and Wiltbank, 1971), .32 (Laster et al., 1972), .32 (Smith et al., 1976), and .24 (Swierstra et al., 1977). The genetic relationship for age and weight at puberty was .36 (Arije and Wiltbank, 1971, $.67 \pm .24$ (Smith et al., 1976c) and .25 Burfening et al. 1979).

Considering the negative relationships reviewed for growth traits prior to puberty and puberty age and the association between age and weight at puberty, heifers older at puberty would tend to be heavier at puberty but would have achieved that weight at a slower rate.

Smith et al. (1976b), in a study of maturity traits of Hereford, Angus and Shorthorn cattle, found heifers which matured at heavier weights tended to grow longer and be smaller at earlier ages and physiological stages such as puberty relative to their mature weight.

Puberty Age and Reproductive Traits

The associations that exist between puberty age and reproductive traits such as pregnancy rate, date of first calving and milk production have not been extensively researched and could have considerable merit. Some researchers have noted favorable relationships between puberty age and pregnancy traits. Laster et al. (1979) found a nonsignificant

association between age at first estrus and pregnancy rate of $-.42$ ($P < .05$) when comparing these traits as averages of several breed groups. Ferrel (1982) reported a similar relationship for straightbred heifers but no correlation was cited. Izard and Vandenberg (1982) found heifers which reach puberty before the start of the breeding period had no advantage in pregnancy rate over those which had not reached puberty. However, they maintained that this lack of advantage could have been due to the relatively long (90 d) breeding period.

Hawk et al. (1953), working with dairy cattle, found a significant correlation between puberty age and breeding efficiency measured as a percentage of days after breeding started until pregnancy occurred, $r = -.33$ ($P < .05$). However, when efficiency was adjusted to correctly account for heifers which had not reached puberty prior to the breeding period, the correlation was no longer significant. This led the author to believe that the length of time a heifer had been cycling prior to the breeding period had no effect on her ability to conceive earlier in the breeding period. Although differences were not significant, he found heifers which had their first cycle at an earlier age required less services than heifers which were older at puberty (2.00 versus 2.26).

Laster et al. (1979) reported heifers which were younger at puberty tended to calve a higher percentage of their offspring during the first 25 d of the calving season ($r = -.75$, $P < .05$).

Menge et al. (1960) developed path coefficients for milk production and noted puberty age did not have an effect on milk production for the

first 90 d of the lactation period but did have a significant effect on the butterfat percentage in the milk.

Findings thus far in this area of postpubertal reproduction indicate that puberty age may not have a significant influence on whether pregnancy occurs, if heifers reach puberty before the end of the breeding season. It appears that a stronger relationship may exist between the age at pregnancy and age at puberty. However, a study by Aman et al. (1981) of age at first conception, although no relationships for puberty age were cited, found that growth traits and age at first conception had relatively low associations.

Weight at Puberty

Weight to any given chronological age is a function of initial weight, rate of growth and time. Weight at a stage of maturity is dependent more so on the time it takes to achieve that stage of development. Brody (1945), in reference to growth curves, defined puberty to exist at a point of inflection where the increasing rate of growth had stopped but the declining rate of growth had yet to begin. He reasoned it was this point where gains were most rapid and probably most economical. Consequently, weight at puberty can be an important indicator of the extent of development or the rate of growth through a particular time period that is necessary for certain breeds to exhibit puberty. Laster et al. (1979) found breed group associations between puberty age and weight with percentage of fat trim at a constant weight in steer contemporaries of $-.70$ and $-.90$, respectively. This finding in relation to Brody's inference on growth patterns would suggest that

identifying factors which affect puberty weight may not only be important in understanding why age at first estrus might be hastened or impeded but might also reflect differences between breeds for declining efficiency in the production of lean versus fat at a specific stage of maturity.

Yearly environmental effects have been known to affect weight at puberty (Laster et al. 1976; Gregory et al., 1978; Morgan, 1981; Dow et al., 1981). Effects of year/sire breed and year/breed group on puberty weight have also been demonstrated (Arije and Wiltbank, 1974; and Gregory et al., 1979; respectively). Arije and Wiltbank (1971), Swierstra et al. (1977), Young et al. (1978) and Burfening et al. (1979) showed nonsignificant effects of year. Arije and Wiltbank (1966) found year affects which they proposed were due to different feeding levels across years. Other effects of management have been shown, with higher feeding levels tending to increase weight at puberty (Bellows et al., 1965; Wiltbank et al., 1966 and 1969; Moseley et al., 1982). Short and Bellows (1971) reported feeding levels had a greater affect on puberty weight than on puberty age. Dufour et al. (1974) noted puberty weight was significantly influenced by feeding regimen during the early stage of growth only. However, Stewart et al. (1980) found no difference in heifers' weight at puberty under two nutritional levels.

Breed Effects on Puberty Weight

Larger, later maturing breed types generally sire heifers which reach puberty at heavier weights than smaller, earlier maturing types (Swierstra et al., 1977; Young et al., 1978; Laster et al., 1979;

Morgan, 1981). Puberty weight in larger scaled, later maturing breeds was heavier to a greater extent because of these heifers being heavier at birth and other chronological points more so than because age at puberty was older. However, heavier weights of the *bos indicus* breeds at puberty were more of a reflection of their older age at puberty rather than their respective size at a given age (Young et al., 1978; Gregory et al., 1979; Morgan, 1981). Laster et al. (1976) and Burfening et al. (1979) noted sires within a breed affected weight at first estrus. Arije and Wiltbank (1971) noted variation within breeds and found sires had a greater effect on puberty weight than they did on puberty age. They also found an estimated heritability for puberty weight of $1.09 \pm .27$. This is higher than that reported by Laster et al. (1979) of $.40 \pm .17$ and was believed to be caused by random effects and a low effective number of progeny per sire ($n=8$).

Weighted means from the literature for puberty weights of Hereford heifers were slightly lower than Angus-Hereford and Hereford-Angus crosses (272.7 kg versus 273.5 kg) but both were lower than that reported for Simmental sired heifers (292.7 kg). Young et al. (1978) reported puberty weight for heifers of 50% Simmental, 50% Angus or Hereford dams sired by Hereford, Angus, Brahman, Devon or Holstein bulls to be 387 ± 5.3 kg (table 2).

Swierstra et al. (1977) found breed of dam significantly affected weight. The average weight of heifers from Angus dams was 294 kg compared to 307 and 313 kg at puberty for Hereford and Shorthorn dams, respectively. Gregory et al. (1979) noted breed of dam (Hereford and Angus) did not affect puberty, but in a study with the same dam breeds

Laster et al. (1976) found heifers from Angus dams were 9 kg lighter ($P < .01$). Gregory et al. (1978) noted a maternal effect of 22 to 24 kg for puberty weight in favor of heifers from Brown Swiss and Red Poll dams compared to Angus and Hereford dams. Pleasants et al. (1965) found breed of dam differences between Angus and Friesian cows on puberty weight approached significance ($P < .01$). Burfening et al. (1978) noted line of dam had significant influence on puberty weight in Hereford heifers. Milk production differences for dam line have been demonstrated (Abadia and Brinks, 1972).

Dam age appears to have a similar, favorable affect on weight at puberty as it does for age at puberty. Laster et al. (1976) noted weights at puberty of 258, 267, 269, and 276 kg for heifers from dams 2 to 5 yr old, respectively. This is consistent with milk production estimates for these dams and would indicate that puberty weight was affected maternally through the preweaning growth rate. Morgan (1981) agreed and noted that high maternal influence increased weight at puberty by increasing preweaning growth. Laster et al. (1972) found no maternal effect on puberty weight, while Young et al. (1978) found both positive and negative maternal effects on puberty weight.

The effects of heterosis have been shown to contribute to weight at puberty but are not as large as estimates for puberty age in some studies (Laster et al., 1972 and 1976). Gregory et al. (1978) reported a 2.4% estimate for heterosis ($P < .05$), while Gregory et al. (1966) found a -9.8% estimate at low levels of feed ($P < .01$) but no advantage was evident at a high regime. Stewart et al. (1980) in a diallel mating found combining abilities for puberty weight were not significantly

different even though large deviations were present but did find significant heterosis for weight and height. Burfening et al. (1978) noted a nonsignificant 14 kg difference between crossline and linebred heifers, favoring crossline heifers.

Growth Relationship with Puberty Weight

Some studies have noted heifers born earlier in the year were lighter at puberty (Arije and Wiltbank, 1971; Swierstra et al., 1977). In addition to this, Swierstra et al. (1977) noted heifers with heavier birth weights tended to be heavier at weaning and also at puberty. Wiltbank et al. (1974) found no association between birth weight and puberty weight but noted heifers which grew faster to weaning tended to weigh more at puberty. Other studies also demonstrate this positive relationship (Plasse et al., 1968; Arije and Wiltbank, 1971). Laster et al. (1972) noted the differences in weight at puberty for various breed crosses were similar to differences in their weight at weaning, while a similar study (Laster et al., 1976) found weight at puberty coincided with the ranking for birth weight and weight at 400 d. A more recent study (Laster et al., 1979) found no association for rankings between growth and weight at puberty.

Puberty Weight and Reproductive Traits

Aman et al. (1981) found weight at various ages to be negatively correlated with age at conception. Although some of the correlations were significant, most were relative low ($r < -.23$). Other studies have cited the importance of a minimum weight at breeding to pregnancy rate

(Carter and Cox, 1973; Ellis, 1974), but the extent of the influence of puberty weight on subsequent fertility in heifers remains unidentified.

Puberty Height

A paucity of information is available for puberty height. Stewart et al. (1980) studied height at puberty in a diallel mating of Hereford, Angus, Brahman, Red Poll and Holstein breeds and found the breed affects for height were most consistent of any pubertal trait regardless of management or sex group. Crossbreds were taller than straightbreds, which was determined to be due to heterosis. Relationships with growth and other pubertal traits were not reported.

MATERIALS AND METHODS

Experimental Design

This research project was conducted at the Northern Agricultural Research Center, located 11 miles southwest of Havre, Montana. Two hundred and eighty-eight heifers born in the years 1976 through 1979 were used in this study. These heifers were progeny of Hereford, Angus, half Simmental - half Hereford (F_1) and Simmental sires bred to high quality, straightbred, commercial polled and horned Hereford cows that were managed alike. Another group of 58 three-quarter Simmental - one quarter Hereford heifers were purchased from nine Montana breeders. These heifers resulted from mating half Hereford - half Simmental dams to Simmental sires. Heifers were selected to be the average of their contemporaries and had to be sired by the same bulls which produced the half Simmental - half Hereford heifer breed group. In addition, half Simmental - half Hereford sires used in this study were also sons of these same Simmental sires and performance tested dams. Consequently all heifer groups involving Simmental breeding were descendants (daughters or granddaughters) of this group of purebred Simmental sires. Approximately 20 three-quarter Simmental, one-quarter Hereford heifers were purchased per year as they approached 1 yr of age. Since it is highly probable that some of these females exhibited puberty prior to their arrival at the station where initial estrus was being observed, their use in this experiment as contemporaries will be limited. Unless

cited otherwise, the group of 230 heifers raised at the station will make up the experimental group.

Dams of the heifers were randomly assigned to sires on a within age of dam basis each year. Consequently, the variation in maternal influence was minimized by having one dam type and by the randomization of dam age across breed groups. The range in age of these dams was 3 to 11 yr. Young cows were brought into the experiment each year (except 1979) to provide a 3-yr-old subclass. However, for purposes of data analyses the dam ages were reclassified into 3-, 4- and ≥ 5 -yr-old age categories.

In order to have progeny representative of each breed type, a large number of sires were used (nine or ten per breed type) resulting in a small number of progeny per sire. Hereford, Angus and Simmental semen were used from A.I. studs. Both polled and horned Hereford sires were used, but no distinction between these two breed types was made in the analyses. Lawlor (1980) observed nonsignificant differences for polled and horned Hereford progeny for birth and preweaning traits.

Table 3 gives the number of heifers per breed group by year. Angus-Hereford cross heifers were not produced the first year of the study nor were any Simmental cross females produced or purchased the last year of the study. However, confounding of the breed types and year was minimized and analyses made possible since straightbred Herefords were produced every year of the study.

Birth traits, calf viability, preweaning and weaning traits, postweaning and carcass information on steers, dam's weight and condition have been previously discussed and reported by Lawlor (1980).

TABLE 3. DESIGN AND NUMBER OF HEIFERS

Year	Breed Type ^a					Total
	HH	AH	1S3H	SH	3S1H	
1976	18	0	22	17	20	77
1977	18	20	23	16	19	96
1978	14	16	17	15	19	78
1979	19	15	0	0	0	34
Total	69	51	62	48	58	288

^a Where HH = straightbred Hereford, AH = half Angus, half Hereford, 1S3H = quarter Simmental, three-quarters Hereford, SH = half Simmental, half Hereford, 3S1H = three-quarters Simmental, quarter Hereford.

As calves, these heifers were raised on their dams and pastured throughout the summer until approximately October 1 of each year when they were weaned at an average age of 187 ± 1.1 d and an average weight of 193.5 ± 1.5 kg. Calves born in 1976 and 1977 were pastured on a lease at the Fort Belknap Reservation, 40 miles south of Harlem, Montana. In 1978 and 1979, calves were pastured on the Webster Thackery lease, a privately owned ranch located approximately 18 miles south of Havre on the northeast end of the Bear Paw Mountains. The summer grazing season began the first week in May at the research center. Approximately June 1, cow-calf pairs were put on the lease and remained there until summer grazing ended the first week in October when all calves were weaned.

Health and Veterinary Care

All calves were vaccinated for blackleg and malignant edema at branding in late April or early May with a booster given at weaning. At weaning calves were also vaccinated intranasally for the prevention of IBR (Infectious Bovine Rhinotracheitis) and PI₃ (parainfluenza₃). A grubicide was also administered. In November, just prior to going on winter feed test, heifers received a leptospirosis vaccination and were vaccinated for Brucellosis two weeks later. Beginning in 1978, heifers also received a BVD (Bovine Virus Diarrhea) vaccination. In March, heifers were number branded on the left hip to aid in identification. Near April 10, each heifer received their first vibriosis (Bovine Vibrio Fetus Bacterin) vaccination with a subsequent booster around mid-May just prior to the breeding period.

Management of Heifers

At weaning calves were weighed, measured for body height and given a condition score. Condition scores ranged numerically from one to nine with one being thin or poor body condition and nine being fat or heavy body condition. After weaning, they were placed in a drylot for a short period of time (less than one week) where they had access to third cutting alfalfa and water. They were then put on hay fields to graze the regrowth. In later October or early November (November 8, 1976; November 13, 1977; November 7, 1978; October 28, 1979) heifers were brought back to the drylot for a warm-up period prior to the feed test. The 140 d winter feeding period began approximately November 20 of each year when initial weights were taken. Weights were recorded every 28 d

during the feed test. Heifers were group fed 9.0 kg (20#) corn silage, .9 kg (2#) concentrate and second cutting alfalfa ad libitum per day. Actual consumption by year, nutrients fed and actual gain on feed are given in table 4. Climatic conditions during the winter feeding period are given in table 5. Heifers finished the 140 d winter feeding period approximately April 10 of every year. At that time, final weight, condition score, body height and pelvic width and height (measured with a Rice pelvimeter) were recorded. Heifers continued on the same ration in the drylot until the beginning of the pasture season.

TABLE 4. ACTUAL CONSUMPTION OF NUTRIENTS AND GAIN DURING THE WINTER FEEDING PERIOD FOR YEARS 1976 THROUGH 1979

Year	Consumed Ration (kg/day)			(Pro) ^a	140 d Average daily gain
	Silage	Grain	Hay		
1976 ^b	7.70	.70	2.2	(18.0)	.57 ± .08
1977 ^c	8.39	1.43	2.7	(17.2)	.65 ± .01
1978 ^d	11.18	1.09	4.8	(17.5)	.77 ± .02
1979 ^d	7.27	.86	2.5	(16.9)	.85 ± .02

^a Percent protein in hay

^b Oat-wheat grain mixture

^c Barley fed the first 56 days at 4.4 kg/day, speltz fed for 56 days at 6.6 kg/day, and barley fed for the last 28 days at 4.4 kg/day.

^d Barley

TABLE 5. AVERAGE TEMPERATURE AND PRECIPITATION DURING THE WINTER FEEDING PERIOD (NOVEMBER TO APRIL)

Year	Temperature (°C)	Precipitation (cm)
1976	-0.22	2.28
1977	-6.00	2.45
1978	-6.70	2.10
1979	-1.17	1.18

^a Figures based on conversions from Annual Reports of Progress 1976 to 1979.

Epididymized bulls with chinball markers were used to aid in the detection of estrus from the beginning of the winter feeding period when the heifers were an average age of 232 ± 1.1 d and weighed 209.9 ± 1.7 kg until the end of the breeding season. In the process of epididymizing these bulls, a local anesthetic was given in the lower portion of the scrotum. An incision was made in this area which proceeded through the tunica dartos and the mesorchium until the tail of the epididymis was exposed. The epididymis was then dissected, severing the vas deferens, with the subsequent healing and formation of scar tissue causing the interruption of sperm passage. The incision was not stitched such that fluid drainage could occur.

Heifers were checked visually twice daily and were considered to be in estrus when marked by a detecting bull or when observed standing for other heifers. Date of puberty was defined as the date of first estrus confirmed by a second estrus within 45 d, except for the last 45 d of

the breeding period when age at puberty was defined as the first incidence of estrus. This was done to ensure that heifers were cycling. Heifers which did not reach puberty before the end of the breeding period were assigned a puberty date 10 d (one half an estrus cycle) after the end of the breeding season. This was done to account for heifers not reaching puberty across breedtypes. Height at puberty was interpolated from heights taken at weaning, at the end of the feeding period and at the following weaning when heifers were approximately 18 mo of age. Weight at puberty was interpolated from weights which bracketed the puberty date. Breeding began May 23, May 15, May 22 and May 27 for heifers born in the years 1976 through 1979, and respective breeding period lengths were 47, 47, 60 and 56 days. The length of the artificial insemination period was extended for 1978 born heifers because a large number of noncycling heifers still existed by the end of the originally scheduled breeding period.

Heifers born in 1976 were artificially inseminated after estrus occurred naturally. However, those born in 1977, 1978 and 1979 were used in synchronization trials during their first breeding period. Heifers were divided at random within breed groups into two treatments. The first was an untreated group (control) which were bred approximately 12 h after estrus. The second group was injected with PGF2 on the morning of the first breeding date. Those responding to the treatment within 7 d were bred 12 h after estrus. Heifers which failed to respond to the treatment were given a second injection of PGF2 a week after the first injection (subtreatment group) and breeding was continued 12 h after estrus for the remainder of the breeding season.

After the breeding season, heifers continued on pasture until the beginning of October when weight, body height and condition score were again recorded. All height measurements taken in 1976 and 1977 were recorded level to the withers. In 1978, both a withers and hip height measurement were taken. In 1979 only hip height measurements were recorded. Conversions from withers height to hip height were made by adding the average difference between the two measurements taken in 1978 to the withers height. Mature cow heights, recorded at 30 mo, were taken at the withers and were converted in the same manner using the average difference between wither and hip heights taken from data recorded by Williams (1977) for mature cows. Conversion factors at weaning, yearling and maturity were 6.04, 7.4 and 5.65 cm respectively.

During the fall weaning heifers were also tested for pregnancy by rectal palpation. The date of pregnancy was defined as the last date at which a heifer had been serviced during the breeding season for heifers which had conceived to a service.

Breeding efficiency, a measure of the reproductive ability of all heifers (n=230), was coded in the following way:

<u>Number of services</u>	<u>Pregnant</u>	<u>Code</u>
0	no	0
3	no	1
2	no	2
1	no	3
4	yes	4
3	yes	5
2	yes	6
1	yes	7

Statistical Analysis

The least squares fixed model procedure outlined by Harvey (1975) was used to determine effects of breed, year, and age of dam for all dependent variables. The BMDP stepwise regression procedure (Dixon and Jennrich, 1981) was used to develop predictive models and to account for variation in pubertal traits. The model used as a foundation for both procedures was as follows:

$$Y_{ijkl} = u + b_i + c_j + d_k + (\text{significant interactions}) + e_{ijkl}.$$

Where Y = the dependent variable of the lth calf from the kth age of dam in the jth year of the ith breed group.

u = overall mean

b_i = the effect of the ith breed group

c_j = the effect of the jth year

d_k = the effect of the kth age of dam

e_{ijkl} = random error

All three way interactions were assumed to be nonsignificant. All main effects were considered fixed. Random error was assumed to be normally and independently distributed with a mean of zero and a variance equal to σ_E^2 .

The BMDP regression procedure was a stepwise forward-backward method. The main effects and interactions were forced into the regression equation with other independent variables being added to the equations based on their ability to explain variation in the dependent variable in conjunction with those variables already in the model. If at any time a variable already in the model should lose its influence

because of the addition of other significant variables to the model, it would fall out of the equation.

Traits Studied

Traits studied in this experiment were as follows:

- 1) Birth traits - date of birth and birth weight.
- 2) Preweaning and weaning traits - preweaning average daily gain, 180 d adjusted weight, 180 d adjusted hip height, condition score, weight-height ratio, weight per day of age, actual weaning weight and actual weaning height.
- 3) Postweaning traits - prefeeding average daily gain, average daily gain on 140 d gain test, 365 d adjusted weight, 365 d adjusted hip height, average daily gain from birth to yearling, yearling weight per day of age, yearling condition score, yearling weight-height ratio, pelvic width, pelvic height, pelvic area, postfeeding average daily gain, actual yearling weight and actual yearling height.
- 4) Puberty traits - age, weight, height, weight per day of age, height per day of age, weight-height ratio, the percentage of heifers reaching puberty by 10 to 16 mo (via monthly intervals), and percentage of heifers reaching puberty by 227 to 386 kg (via 22 kg classes).
- 5) Post yearling traits - prebreeding weight, 18 mo pregnancy test, breeding efficiency, number of services per pregnancy, pregnancy date, 18 mo hip height, 30 mo weight, 30 mo hip height, and 36 mo weight.
- 6) Maturity traits - percent mature weight at puberty using 30 mo and 36 mo weights as a mature weight measurement, percent mature height at

puberty using the 30 mo height as a mature height, percent mature weight and height as a yearling using the same respective mature measurements.

Before maturity analyses were run, a test was made to determine the effect of a suckling calf or the state of gestation on the mature weight of the cow. The weight at 30 mo was taken about the first week in October when calves were weaned. Coding the presence of a suckling calf prior to this weight as one and the absence of a suckling calf as zero and running this difference as a main effect revealed 30 mo weights were significantly heavier (53.7 kg) for cows which did not have a calf at side. Consequently, cows which did not wean a calf at 30 mo were removed from the data set to obtain a more accurate estimate of this weight. After edits, 176 head remained for the analysis involving 30 mo maturity traits.

A similar procedure was followed to test the effect of gestation (as determined by rectal palpation at 30 mo) on mature weights recorded at 36 mo. Open cows were significantly heavier (34.6 kg) than gestating cows and were removed from the data set, leaving 175 head for analyses of 36 mo maturity traits.

The effect of a suckling calf prior to 30 mo of age had no effect on either 30 mo height or 36 mo weight. Seven head had been culled from the herd for various reasons, which left 223 cows for analysis for 30 mo height and respective maturity traits.

In order to estimate the relationships between maturity traits through residual correlations, cows with missing maturity data were deleted from these 3 data sets, after which 136 head remained.

Weight-height ratios at weaning and yearling were calculated from unadjusted measurements with the weight-height ratio at puberty calculated from weight and height measurements based on their interpolation for puberty age. Height adjusted to a constant age was made by regressing weaning height, yearling height and 18 mo height on each individual's birth date. The regression values were significant only for weaning and yearling heights. The quadratic regressions of each respective height were not significant. Further analyses revealed skeletal growth to weaning and yearling did not differ between breeds, years or dam ages. Thus the overall regressions were used to adjust heights to 180 d and 365 d of age. The overall regressions for 180 d, 365 d and 18 mo heights were $-.090 \pm .020$, $.057 \pm .022$ and $-.031 \pm .022$ cm/d.

Adjusted weight measurements (180 and 365 d) accounted for age according to that individual's linear rate of growth.

RESULTS AND DISCUSSION

Pubertal Traits

Two hundred and nine of 230 heifers (91%) reached puberty by the end of the breeding period. Thirteen HH heifers, six 1S3H heifers, one AH heifer and one SH heifer did not reach puberty and were assigned a puberty date (table 6). All heifers born in 1976 reached puberty while

TABLE 6. NUMBER OF HEIFERS NOT REACHING PUBERTY BY BREED GROUP AND YEAR

Year	Breed Group				Total
	HH	AH	1S3H	SH	
1976	0	-	0	0	0
1977	3	0	2	0	5
1978	6	1	4	1	12
1979	4	0	-	-	4
Total	13	1	6	1	21

more heifers born in 1978 did not reach puberty. Pregnancy records at 30 mo indicated that at least 18 of the 21 heifers reached puberty after the breeding season, but 3 heifers, 2 HH and 1 AH heifer, failed to attain pregnancy after a second breeding season and were culled from the herd. The 10 d adjustment for nonpubertal heifers therefore should constitute a more accurate representation of the ability of these

heifers to reach puberty than if they were deleted from the data. Of the three-quarter Simmental, one-quarter Hereford heifers, four failed to attain puberty by the end of the breeding period. The distribution across years for these nonpubertal heifers was 1, 1 and 2 for 1977, 1977 and 1978, respectively.

Breed and year were generally significant sources of variation for pubertal traits (table 7). Straightbred Hereford heifers were 25.0, 35.6 and 39.1 d older ($P < .01$) at puberty than 1S3H, AH and SH heifers, respectively (table 8). Breed group rankings for puberty age in this study agreed with Laster et al. (1972) who found respective ages at puberty for SH, AH and HH heifers were 369 ± 10 , 371 ± 11 and 390 ± 13 d. Contrasts between these breed groups, however, were not reported. Puberty age for HH heifers in this study were older than HH heifers studied by Burfening et al. (1979), Gregory et al. (1978) and Laster et al. (1972), but younger than HH heifers in studies by Arije and Wiltbank (1971), Laster et al. (1976) and Morgan (1980). Weighted means for puberty age from the literature were 421.3, 371.2 and 357.1 d for HH, AH and SH groups, respectively (table 2). Although no reports for 1S3H heifers could be found in the literature, the 381.6 d estimate made in this study was close to the 378 d estimate made by Young et al. (1978) for 25% Simmental-cross heifers even though the origin of influence of the Simmental breed was through the maternal grandsire rather than the paternal grandsire as it was in this study.

Breed was not a significant source of variation ($P < .07$) for puberty weight although linear contrasts showed a significant difference between HH and SH heifers in favor of SH heifers. Pubertal weights reported by

TABLE 7. ANALYSES OF VARIANCE FOR PUBERTAL TRAITS (N=230)

Source	df	Mean squares					
		Age (d ²)	Weight (kg ²)	Height (cm ²)	Weight/day (kg/d) ²	Height/day (cm/d) ²	Weight/height (kg/cm) ²
Breed (B)	3	18045**	1361 [†]	174.7**	.1021**	.0142**	.0103
Year (Y)	3	15856**	2762**	64.5**	.0521**	.0068**	.0883
Age of dam	2	803	380	6.4	.0176 [†]	.0008	.0295
B x Y	6			29.1*			
Residual	221 ^a	1410	877	12.8	.0066	.0007	.0441

[†] P<.07

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

^a Degrees of freedom for residual were 215 for height.

TABLE 8. BREED GROUP MEANS AND STANDARD ERRORS FOR PUBERTAL TRAITS AND BREED GROUP CONTRASTS (N=230)

Breed group	Age (d)	Weight (kg)	Height (cm)
μ	381.71 $\pm$ 3.4	305.07 $\pm$ 2.67	116.00 $\pm$.32
HH	406.63 $\pm$ 4.9 ^a	300.77 $\pm$ 3.84 ^a	114.62 $\pm$.46 ^a
AH	371.05 $\pm$ 5.9 ^b	301.92 $\pm$ 4.67 ^{ab}	114.16 $\pm$.57 ^a
1S3H	381.63 $\pm$ 5.5 ^b	304.81 $\pm$ 4.37 ^{ab}	116.71 $\pm$.53 ^b
SH	367.51 $\pm$ 6.2 ^b	312.78 $\pm$ 4.91 ^b	118.50 $\pm$.60 ^c
Contrast	Mean difference and standard error		
SH versus 1S3H	-14.12 $\pm$ 7.2 [†]	7.97 $\pm$ 5.70	1.80 $\pm$.69**
SH versus AH	-3.54 $\pm$ 8.1	10.87 $\pm$ 6.38	4.34 $\pm$.77**
SH versus HH	-39.12 $\pm$ 7.4**	12.02 $\pm$ 5.84*	3.88 $\pm$.71**
1S3H versus AH	10.59 $\pm$ 7.7	2.89 $\pm$ 6.05	2.55 $\pm$.74**
1S3H versus HH	-25.00 $\pm$ 6.9**	4.05 $\pm$ 5.46	2.09 $\pm$.66**
AH versus HH	-35.59 $\pm$ 7.1**	1.15 $\pm$ 5.62	-0.46 $\pm$.68

a, b, c Means in the same column with no common superscript letters differ (P<.05).

[†] P<.06, * P<.05, ** P<.01, differ according to the t distribution (Snedecor and Cochran. 1981).

Laster et al. (1972) were 300 ± 9 , 280 ± 9 and 269 ± 11 kg for SH, AH and HH heifers respectively. Weights of heifers at puberty in this study were generally heavier than for heifers of the same breed type in other studies (table 2). Weighted means for pubertal weight from the literature were 272.7, 273.5 and 292.7 kg for HH, AH or HA, and SH breed groups respectively. Several reasons can be given for this difference: (1) the nutritional level was higher in this study than several other comparable studies (Laster et al., 1972; Arije and Wiltbank, 1971), (2) puberty age in this study was older than in studies with similar nutrition levels (Swierstra et al., 1977; Gregory et al., 1979; Bufening et al., 1979) and (3) weights and gains at other constant ages were higher for these heifers (Young et al., 1978).

The significant breed by year interaction for puberty height was largely due to Simmental-cross heifers born in 1978 having larger puberty heights than Simmental-cross heifers born in other years while AH heifers born in 1978 had shorter puberty heights than AH heifers born in other years. Mean puberty age was delayed in 1978 for Simmental-cross heifers to a greater degree than in AH heifers (393 ± 10 , 403 ± 9 and 381 ± 9 d for SH, 1S3H and AH heifers respectively) and the difference in puberty height may have been due to these heifers' older puberty age allowing for more skeletal growth to occur before puberty was reached. Puberty height was greatest for SH heifers ($P < .01$) with 1S3H heifers intermediate and taller ($P < .01$) than AH or HH heifers which did not differ. In studies involving two feeding levels, Stewart et al. (1980) reported shorter pubertal heights for AH heifers while Grass et al. (1982) reported shorter estimates for HH heifers but found a taller

height for Simmental heifers on a lower feeding level and a shorter height on a higher level of feed.

An analysis of only heifers reaching puberty before the end of the breeding season ($n=209$) showed the effects of year and breed were still significant (table 9). As expected, variation within and across breed groups had decreased but significant contrasts between heifer breed groups for age, weight and height still remained. The only exception was an additional important contrast between SH and 1S3H heifers for puberty weight (table 10).

Since SH heifers were heavier, taller and younger at puberty it would be expected that respective growth rates to this physiological stage would also be greater. Table 11 shows SH heifers had faster ($P<.05$) rates of skeletal and somatic growth to puberty than AH or 1S3H heifers with all three groups gaining weight and height faster ($P<.01$) than HH heifers. The weight to height ratio between all breed groups at puberty did not differ ($P<.80$), which would indicate that within these groups of heifers the distribution of the ratios of body weight to body height were similar. Frisch (1974) hypothesized that a minimum weight for height was required for puberty. Nelson et al. (1982a) agreed and further postulated a minimum age was also required. Even though puberty height differences were evident among breed types in this study, the lack of differences between the weight-height ratios indicate weights at puberty were proportionate to these heights such that differences due to breed were not important. In addition, year effects which were significant for both puberty weight and height were not significant for the weight to height ratio.

TABLE 9. ANALYSES OF VARIANCE FOR PUBERTAL TRAITS FOR HEIFERS WHICH REACHED PUBERTY (N=209)

Source	df	Age (d) ² Mean squares	df	Weight (kg) ² Mean squares	df	Height (cm) ² Mean squares
Breed (B)	3	6391.3**	3	2131.5*	3	161.60**
Year (Y)	3	3727.6**	3	3146.9**	3	47.35**
Age of dam	2	1346.2	2	341.7	2	10.52
B x Y					6	26.32*
Residual	221	915.5	221	791.0	215	11.68

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

TABLE 10. BREED GROUP MEANS AND STANDARD ERRORS OF PUBERTAL TRAITS AND BREED GROUP CONTRASTS FOR HEIFERS WHICH REACHED PUBERTY (N=209)

Breed group	Age (d)	Weight (kg)	Height (cm)
μ	375.07 $\pm$ 2.84	302.80 $\pm$ 2.64	115.82 $\pm$.32
HH	391.54 $\pm$ 4.33 ^a	296.78 $\pm$ 4.02 ^a	114.31 $\pm$.50 ^a
AH	371.97 $\pm$ 4.88 ^b	301.49 $\pm$ 4.54 ^{ab}	114.22 $\pm$.56 ^a
1S3H	371.64 $\pm$ 4.72 ^b	300.42 $\pm$ 4.38 ^a	116.34 $\pm$.54 ^b
SH	365.14 $\pm$ 5.11 ^b	312.51 $\pm$ 4.75 ^b	118.43 $\pm$.58 ^c
Contrast	Mean difference and standard error		
SH versus 1S3H	-6.50 $\pm$ 6.0	12.09 $\pm$ 5.58*	2.09 $\pm$.69**
SH versus AH	-6.83 $\pm$ 6.63	11.02 $\pm$ 6.15	4.21 $\pm$.75**
SH versus HH	-26.41 $\pm$ 6.27**	15.72 $\pm$ 5.83**	4.12 $\pm$.72**
1S3H versus AH	-.33 $\pm$ 6.44	-1.07 $\pm$ 5.98	2.12 $\pm$.74**
1S3H versus HH	-19.91 $\pm$ 5.99**	3.64 $\pm$ 5.57	2.03 $\pm$.71**
AH versus HH	-19.57 $\pm$ 6.13**	4.71 $\pm$ 5.70	-.09 $\pm$.71

a, b, c Means in the same column with no common superscript differ (P<.05).

* P<.05, ** P<.01, differ according to the t distribution (Snedecor and Cochran. 1981).

TABLE 11. BREED GROUP MEANS AND STANDARD ERRORS FOR PUBERTAL TRAITS AND BREED GROUP CONTRASTS (N=230)

Breed group	Weight/day (kg/d)	Height/day (cm/d)	Weight/height (kg/cm)
μ	.80 $\pm$.007	.307 $\pm$.002	2.63 $\pm$.019
HH	.74 $\pm$.011 ^a	.285 $\pm$.003 ^a	2.62 $\pm$.027 ^a
AH	.81 $\pm$.013 ^b	.309 $\pm$.004 ^b	2.64 $\pm$.033 ^a
1S3H	.80 $\pm$.012 ^b	.308 $\pm$.004 ^b	2.61 $\pm$.031 ^a
SH	.85 $\pm$.014 ^c	.325 $\pm$.004 ^c	2.63 $\pm$.035 ^a

Contrast	Mean difference and standard error		
SH versus 1S3H	.046 $\pm$.016**	.017 $\pm$.005**	.026 $\pm$.040
SH versus AH	.036 $\pm$.018*	.016 $\pm$.005**	-.005 $\pm$.045
SH versus HH	.104 $\pm$.016**	.039 $\pm$.005**	.015 $\pm$.041
1S3H versus AH	-.010 $\pm$.017	-.001 $\pm$.005	.031 $\pm$.043
1S3H versus HH	.058 $\pm$.015**	.022 $\pm$.005**	-.011 $\pm$.039
AH versus HH	.068 $\pm$.015**	.023 $\pm$.005**	.020 $\pm$.040

a, b, c Means within columns without a common superscript letter differ (P<.05).

* P<.05, ** P<.01, differ according to the t distribution (Snedecor and Cochran. 1981)

All pubertal traits had moderate to high correlations with puberty age (table 12). As age at puberty increased, weight and height also

TABLE 12. RESIDUAL CORRELATIONS BETWEEN PUBERTAL TRAITS ^a

Trait	Coded trait				
	2	3	4	5	6
(1) Puberty age	.54	.44	-.42	-.92	.48
(2) Puberty weight		.67	.48	-.33	.95
(3) Puberty height			.22	-.11	.42
(4) Puberty weight/day of age				.59	.50
(5) Puberty height/day of age					-.36
(6) Puberty weight/height ratio					

^a Correlations greater than .14 were significantly different from zero ($P < .05$), $r > .18$, ($P < .01$).

tended to increase. The .54 correlation between puberty age and weight was intermediate to correlations of .57, .32, .32 and .24 reported by other researchers (Arije and Wiltbank, 1971; Laster et al., 1972; Smith et al., 1976; Swierstra et al., 1977; respectively). No correlation between height at puberty and age at puberty could be found in the literature. The relationships with puberty weight/day and puberty height/day and puberty age suggest that faster growth to puberty tended to be associated with younger puberty ages. Since puberty age is a denominator in both of these growth traits, the strength of these associations could be questioned. However, when puberty date was the dependent variable, the associations between these traits were still

important and did not change dramatically (-.47 vs -.42, for puberty weight/day and -.87 vs -.92, for puberty height/day, for puberty date and age respectively). Taller heifers tended to be heavier at puberty. Regression analysis of puberty weight on height indicated that puberty weight increased $5.4 \pm .46$ kg/cm ($P < .01$). The linear regression coefficients between breed groups were not significantly different. The quadratic regression of puberty weight on height approached significance ($P < .06$). The .42 correlation between the weight to height ratio at puberty and puberty height indicated taller heifers also had higher weight to height ratios. Arithmetically one would expect increasing the puberty height would cause a decrease in this ratio. However, the relative increase in weight (as indicated by the linear regression) was substantial enough for the positive correlation to be significant. Considering this relationship it seems reasonable that higher weight to height ratios tended to be associated to a greater degree with heifers of older puberty ages, since positive correlations existed between puberty age and puberty weights and heights at puberty.

Percent Reaching Puberty by Age and Weight

Fewer ($P < .01$) HH heifers reached puberty by 12, 13, 14 and 15 mo of age than all other breed groups (table 13). At 14 mo of age, a higher ($P < .01$) percentage of AH heifers reached puberty than 1S3H heifers, otherwise differences for AH, 1S3H and SH groups were nonsignificant from 11 to 16 mo. Higher lifetime efficiency has been documented for heifers which calve earlier in the calving season and for heifers calving at 2 yr of age vs 3 yr (Lesmeister et al., 1973). In either

TABLE 13. BREED GROUP MEANS AND STANDARD ERRORS FOR PERCENTAGE OF HEIFERS REACHING PUBERTY BY SPECIFIED AGES

Breed Group	Age (mo)					
	11	12	13	14	15	16
μ	6.9 $\pm$ 2.5	36.0 $\pm$ 4.0	76.5 $\pm$ 3.6	85.5 $\pm$ 3.0	89.2 $\pm$ 2.6	99.3 $\pm$ 1.1
HH	2.1 $\pm$ 3.6 ^a	19.1 $\pm$ 5.9 ^a	53.1 $\pm$ 5.2 ^a	64.0 $\pm$ 4.3 ^a	76.4 $\pm$ 3.7 ^a	95.0 $\pm$ 1.6 ^a
AH	4.2 $\pm$ 4.4 ^a	37.6 $\pm$ 7.2 ^b	91.5 $\pm$ 6.4 ^b	99.4 $\pm$ 5.3 ^b	98.4 $\pm$ 4.5 ^b	98.8 $\pm$ 2.0 ^{ab}
IS3H	7.0 $\pm$ 4.1 ^a	38.6 $\pm$ 6.7 ^b	75.4 $\pm$ 6.0 ^b	84.6 $\pm$ 4.9 ^c	89.9 $\pm$ 4.2 ^b	101.5 $\pm$ 1.8 ^b
SH	14.2 $\pm$ 4.7 ^b	48.6 $\pm$ 7.5 ^b	85.9 $\pm$ 6.7 ^b	93.8 $\pm$ 5.5 ^{bc}	93.2 $\pm$ 4.8 ^b	101.7 $\pm$ 2.1 ^b

a, b, c Means within a column with different subscript letters differ (P<.05).

case a high percentage of females reaching puberty by 15 months or sooner would be desirable. Most crossbred heifers had met this condition, however, only 76.4% of HH heifers had reached puberty by 15 mo. This estimate is lower than that reported by Anderson et al. (1979) for HH heifers at 15 mo of age (94%). Gregory et al. (1979) and Laster et al. (1976) reported similar percentages for AH or HA and SH heifers at various ages as reported here.

Identifying the weight at which puberty is reached can be useful in management of replacement heifers of various breed types such that cost efficient gains to this projected weight can be made while ensuring a high percentage of cycling heifers. When heifers were categorized by the weight class when puberty occurred, significantly fewer SH heifers had reached puberty by 295 or 318 kg than either HH or 1S3H groups (table 14.) No differences in F_1 crosses were found at any weight division. Approximately 90% of the heifers had reached first estrus by a weight of 340 kg. Findings by Gregory et al. (1979) and Laster et al. (1976) noted similar responses for AH and HA heifers, although Simmental-cross heifers in the later study had 90% reaching puberty by 340 kg.

Pregnancy and Reproductive Traits

The analysis of variance for first pregnancy traits are given in table 15. Breed group differences for pregnancy rate and breeding efficiency were mainly due to a lower ($P < .01$) percentage of HH heifers which had become pregnant and was consequently reflected in a lower breeding efficiency (table 16). When only heifers which reached puberty were analyzed, differences between breed groups for pregnancy rate and

TABLE 14. BREED GROUP MEANS FOR PERCENTAGE OF HEIFERS REACHING PUBERTY BY SPECIFIED WEIGHTS

Breed Group	Weight (kg)					
	250	273	295	318	340	364
μ	3.1 ± 1.5	14.4 ± 3.1	41.6 ± 4.4	62.9 ± 4.2	86.9 ± 2.7	95.7 ± 1.5
HH	9.1 ± 2.1^a	15.1 ± 4.4^a	43.7 ± 6.3^{ab}	68.4 ± 6.0^a	91.6 ± 3.9^a	98.6 ± 2.2^a
AH	2.4 ± 3.5^{ab}	16.3 ± 5.4^a	46.8 ± 7.7^{ab}	67.8 ± 7.4^{ab}	87.6 ± 4.8^a	97.8 ± 2.7^{ab}
1S3H	-0.5 ± 2.3^b	12.6 ± 5.0^a	49.8 ± 7.2^a	66.8 ± 6.9^a	85.8 ± 4.5^a	92.1 ± 2.5^b
SH	1.2 ± 2.8^b	13.5 ± 5.7^a	26.1 ± 8.0^b	48.8 ± 7.7^b	82.8 ± 5.0^a	94.2 ± 2.8^{ab}

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a, b Means within a column having no superscript letter in common differ ($P < .05$).

TABLE 15. ANALYSES OF VARIANCE FOR TRAITS AT PREGNANCY

Source	df	First pregnancy rate (%) ²	df	Breeding efficiency ^a	df	Pregnancy date (d) ²	df	Number of services ^b
		Mean squares		Mean squares		Mean squares		Mean squares
Breed	3	1.11**	3	42.50**	3	32.47	3	.015
Year	3	.47*	3	9.25	3	1664.34**	3	.811 [†]
Age of dam	2	.08	2	2.22	2	789.92*	2	.526
Residual	221	.17	221	6.12	164	228.27	164	.358

^a Coded relative to number of services and pregnancy status (0 to 7)²

^b Number of services/pregnancy (1 to 3)²

[†] P<.10

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

TABLE 16. BREED GROUP MEANS AND STANDARD ERRORS FOR PREGNANCY AND REPRODUCTIVE TRAITS

Breed group	n	First pregnancy rate (%)	Breeding efficiency ^a	n	Pregnancy date	Number of services
μ	230	78.1 ± 3.7	5.37 ± .22	173	159.1 ± 1.6	1.41 ± .06
HH	69	58.9 ± 5.3 ^a	4.22 ± .32 ^a	41	160.2 ± 2.6 ^a	1.40 ± .10 ^a
AH	51	90.0 ± 6.5 ^b	6.19 ± .39 ^b	48	158.9 ± 2.5 ^a	1.40 ± .10 ^a
1S3H	62	77.2 ± 6.1 ^b	5.26 ± .37 ^b	45	157.9 ± 2.6 ^a	1.41 ± .10 ^a
SH	48	86.0 ± 6.8 ^b	5.79 ± .41 ^b	39	159.2 ± 2.8 ^a	1.44 ± .11 ^a

a, b Means within column having no superscript letter in common differ (P<.05).

breeding efficiency were no longer present (appendix table 43). Pregnancy rate for only pubertal heifers (n=209) was 75.1 ± 5.0 , 88.5 ± 5.6 , 87.8 ± 5.5 and 89.0 ± 5.9 for HH, AH, 1S3H and SH breed groups respectively. Respective breeding efficiencies were $5.59 \pm .38$, $5.98 \pm .31$, $5.98 \pm .30$ and $5.98 \pm .33$. Weighted means for pregnancy rate from the literature for HH, AH or HA, 25% Simmental-cross and SH or SA crosses were 83.9 (n=184), 87.7 (n=323), 97.0 (n=49) and 86.0 percent (n=157) respectively.

An analysis was undertaken to determine if the age (mo) or the weight at which heifers attained puberty had an effect on subsequent pregnancy rate. An initial run with all heifers (n=230) indicated a downward trend in pregnancy rates as puberty age increased (figure 1). However, since heifers which had not reached puberty before the end of the breeding period could not become pregnant, a second analysis was run to test the influence of puberty age on pregnancy rate for only pubertal heifers (n=209). Figure 2 indicates no advantage in pregnancy rates of heifers which had reached puberty early over heifers which reached puberty at a later age. Results from a study by Izard and Vandenberg (1982) for a 90 d breeding period reported no difference in pregnancy rate for heifers which had reached puberty before the start of the breeding period or after the start of the breeding period.

A breakdown of pregnancy rates by the weight class a heifer had achieved puberty was similar for the data set considering all heifers or the one in which all heifers reached puberty (figures 3 and 4). Higher pregnancy rates were generally noted when heifers reached puberty within a range from 273 to 364 kg. However, some caution is advised since the

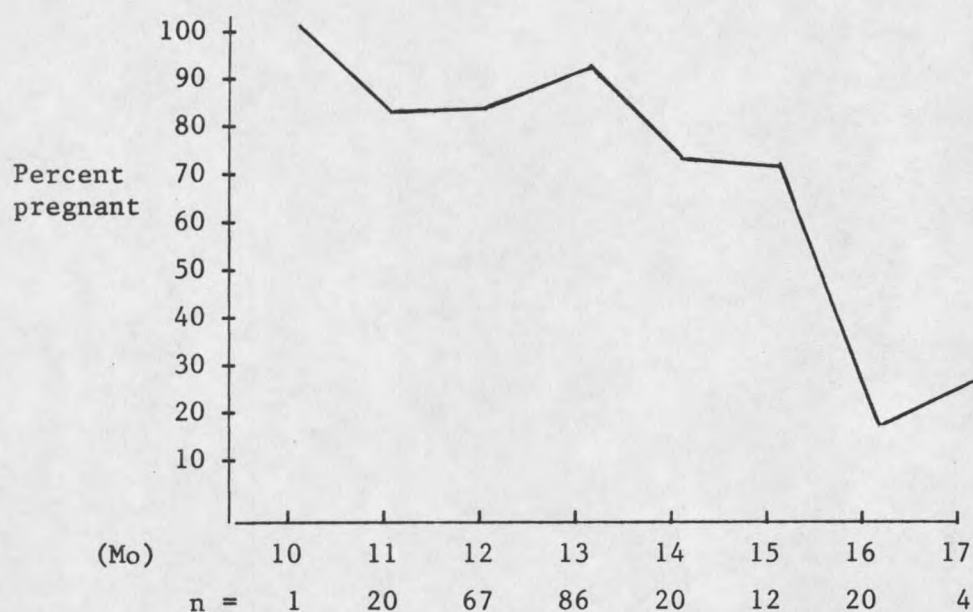


FIGURE 1. PERCENT PREGNANT BY MONTH REACHING PUBERTY (N=230)

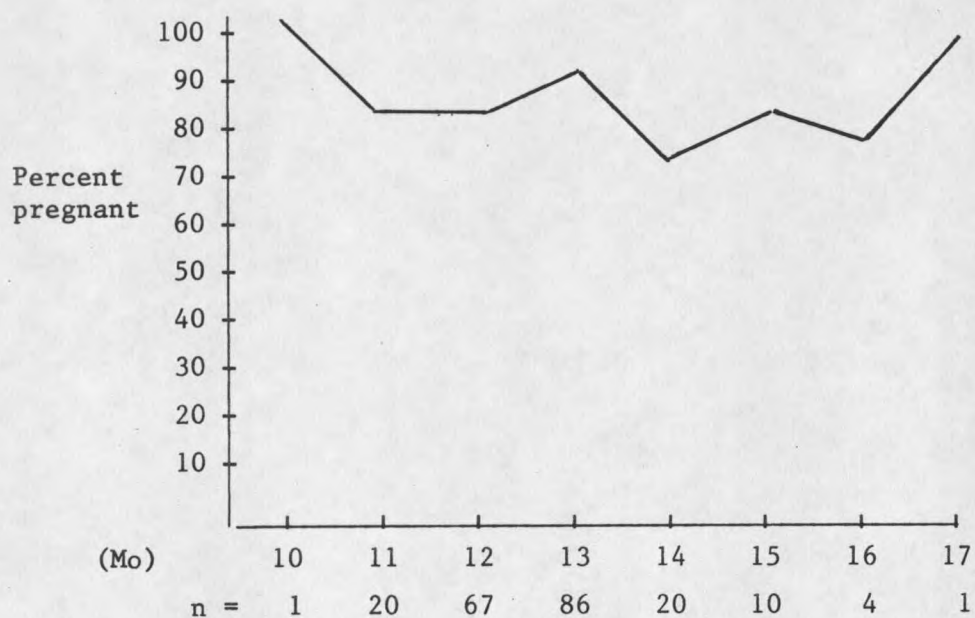


FIGURE 2. PERCENT PREGNANT BY MONTH REACHING PUBERTY (N=209)

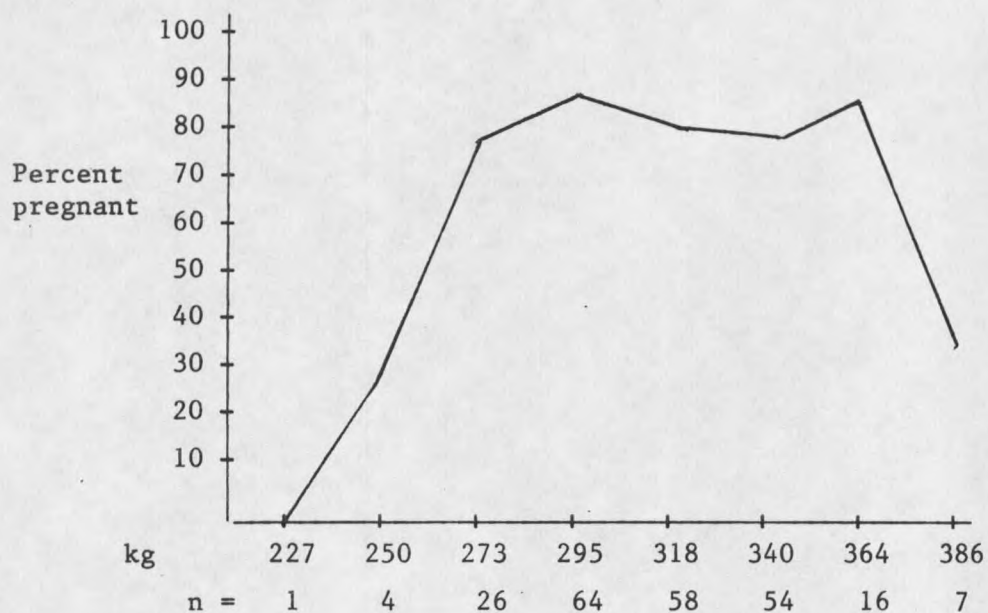


FIGURE 3. PERCENT PREGNANT BY WEIGHT REACHING PUBERTY (N=230)

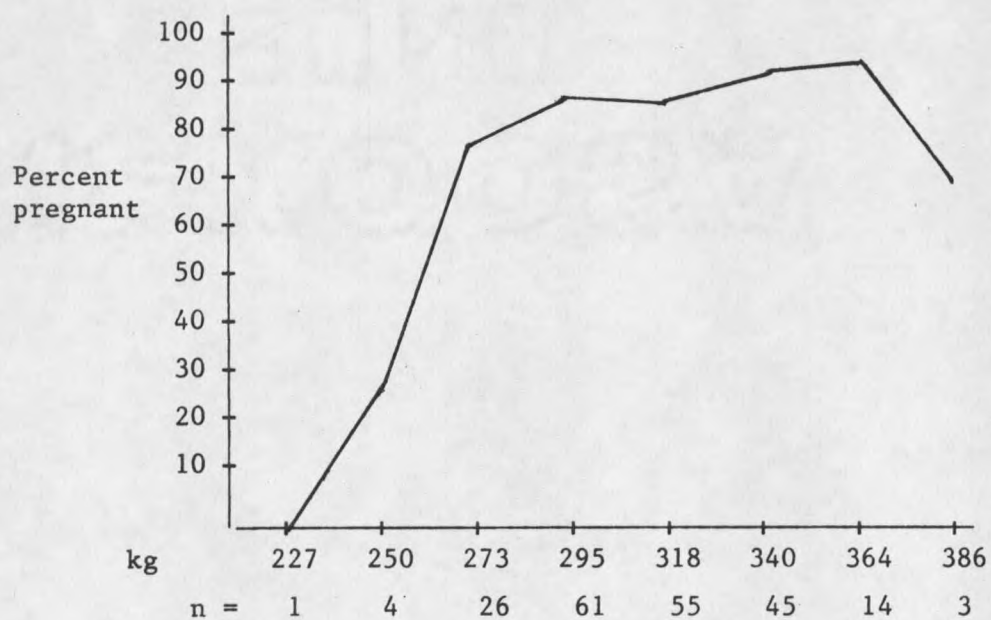


FIGURE 4. PERCENT PREGNANT BY WEIGHT REACHING PUBERTY (N=209)

number of heifers in weight classes outside of this range are small and may not accurately reflect pregnancy rates for heifers of these weights at puberty.

Only heifers which were pregnant were used in the analysis of pregnancy date and number of services/pregnancy. No breed differences for either trait were found. The year effect showed heifers born in 1977 had a pregnancy date 12.5, 12.2 and 10.8 d earlier than heifers born in the respective years 1976, 1978 and 1979. However, the breeding period in 1977 started 8, 7 and 15 d sooner than did breeding seasons in the same respective years.

Heifers from younger dams became pregnant later in the breeding season than heifers from dams of older ages. Means and standard errors for heifers of 3-, 4- and ≥ 5 -yr-old dams were 165.5 ± 3.4 , 155.2 ± 2.7 and 156.4 ± 1.4 d respectively. The later date of pregnancy for heifers of 3-yr-old dams did not appear to be due to age of dam effects on birth date since they were nonsignificant. However, even though age of dam differences were not present for puberty ages, the mean age for heifers of 3-, 4- and ≥ 5 -yr-old dams was 381.1 ± 6.6 , 373.5 ± 5.4 and 369.6 ± 2.8 d, respectively, and may have delayed the attainment of pregnancy.

The residual correlations for pubertal traits and traits at first pregnancy are given in table 17. Heifers which were younger at puberty tended to have higher first pregnancy rates and of those that became pregnant, heifers with earlier puberty ages tended to have an earlier day of pregnancy.

As previously demonstrated by the breakdown of pregnancy rates and percent reaching puberty by month, the residual correlation between

TABLE 17. RESIDUAL CORRELATIONS BETWEEN TRAITS AT PREGNANCY AND PUBERTAL TRAITS

Trait	Puberty					
	Age	Weight	Height	Weight/day	Height/day	Weight/ height
Pregnancy rate ^a	-.40	-.09	-.07	.31	.39	-.07
Breeding efficiency ^a	-.42	-.11	-.10	.28	.38	-.09
Pregnancy date ^b	.23	.13	.16	-.05	-.13	.10
Number of services ^b	-.02	.01	.10	.04	.08	-.02

^a Correlations with this trait greater than .14 are significant ($P < .05$) and greater than .18, ($P < .01$).

^b Correlations with this trait greater than .16 are significant ($P < .05$) and greater than .21, ($P < .01$).

puberty age and pregnancy rate was no longer important when nonpubertal heifers were deleted from the data ($r=-.05$). Laster et al. (1979) found a nonsignificant breed group correlation of $-.42$ between puberty age and pregnancy rate and a significant association between puberty age and percentage calving during the first 25 d of the calving season ($r=-.75$) when these traits were considered as averages of various breed groups. A higher association between puberty weight and percent calving the first 25 d of the calving season ($r=-.69$, $P<.05$) was also found in that study than what is reflected here by the correlation between puberty weight and pregnancy date ($r=.13$). Most of the remaining correlations were not significant. However, growth rates (height and weight) to puberty had favorable associations with pregnancy rate and breeding efficiency. Clanton et al. (1982) presented conflicting evidence suggesting that time of growth and the rate of growth from weaning to breeding had no effect on conception date. Growth measurements at puberty were, however, not reported.

The correlation between pregnancy date and number of services was as expected, high ($-.71$, $P<.01$). The age at which puberty occurred had no influence on the number of services required to reach pregnancy. Hawk (1954) in dairy cattle also reported nonsignificant differences in the number of services between a group of heifers reaching puberty at an early age and those reaching puberty at older ages.

Early Growth Traits

Early growth traits of these heifers and their steer contemporaries were reported by Lawlor (1980). Analyses of variance and least-squares

means for early growth traits of heifers unique to this study are presented in appendix tables 44 through 47. Most of the relationships of early growth traits and pubertal traits were low, while many of the correlations of early growth traits with reproductive traits were nonsignificant (table 18). Heifers born later in the calving season tended to be younger at puberty. A similar but higher association was found by Swierstra et al. (1977) and Arije and Wiltbank (1971). Respective correlations for these two studies were $-.37$ and $-.24$. The source of explanation for these correlations was due to a lack of available forage and milk supply in the first study while a delay in puberty for older heifers due to a low feeding regimen was the cause in the study by Arije and Wiltbank (1971). The significance of this correlation to this study is not apparent but may be related to limited forage availability during the calving period, since cows and calves were not turned out to grass until the first week in May, and may also be due to the limited milk supply later in the fall, which would affect calves born earlier in the year to a greater extent than later born calves. Milk production estimates made at the same location have been found to be lowest from 140 to 160 d in the lactation period for straightbred Hereford cows (Casebolt et al., 1983). The average weaning age of calves in this study was 187 ± 1 d.

Larger birth weights have been generally associated with later maturing breeds and older ages at puberty (Laster et al., 1979; Cundiff, 1981). Swierstra et al. (1977) found the association between puberty age and birth weight at $.41$. But the relationship found in this study was low and negative. SH heifers had the highest birth weights and

TABLE 18. RESIDUAL CORRELATIONS FOR EARLY GROWTH TRAITS AND TRAITS AT PUBERTY AND PREGNANCY

Trait	Puberty ^a			Pregnancy			
	Age	Weight	Height	Rate ^a	Breeding efficiency ^a	Date ^b	Number of services ^b
Birth date	-.16	-.23	-.15	-.16	-.15	-.01	-.08
Birth weight	-.08	.32	.28	.02	.00	.01	.02
180 d weight	-.27	.41	.30	.09	.11	-.05	.02
180 d height	-.23	.42	.56	.08	.13	.06	.15
Preweaning ADG	-.26	.35	.26	.10	.11	-.06	.02
Weaning weight/height	-.15	.45	.25	.14	.16	-.08	.01
Weaning condition score	-.13	.26	.10	.15	.16	-.00	.06

^a Correlations greater than .14 are significantly different from zero ($P < .05$), $r > .18$, ($P < .01$).

^b Correlations greater than .16 are significantly different from zero ($P < .05$), $r > .21$, ($P < .01$).

earliest puberty ages and could be a contributing factor to this negative relationship. This lack of an association supports a proposal by Mason (1971) that all of the differences in puberty age could not be accounted for by differences in mature size, in this case reflected by higher birth weights. The relationships between puberty age and weaning traits, although significant, did not take on the magnitude of similar associations reported by Menge et al. (1960), Swierstra et al. (1977) and Wiltbank et al. (1966). Most correlations of early growth traits had higher relationships for puberty weight and height than they did for puberty age. Swierstra et al. (1977) noted that higher birth weights were related to higher weaning weights which in turn were related to heavier weights at puberty. The correlation between 180 d weight and birth weight in this study was .41 and in conjunction with the relationship between 180 d weight and puberty weight ($r=.42$), supports this relationship.

Younger heifers and higher condition scores at weaning had a positive influence on pregnancy rate and breeding efficiency but in both the correlations were small. Early growth traits appear to have a greater association with traits at puberty than those at first pregnancy.

Postweaning Growth and Yearling Traits

In feeding phases prior to and following the 140 d gain test, breed and year were significant sources of variation for average daily gain (table 19). Because of the short periods of time encompassed by these two periods, weight gains made during the 140 d gain would be expected

TABLE 19. ANALYSES OF VARIANCE FOR POSTWEANING GROWTH RATE (ADG) AND PREBREEDING WEIGHT

Source	df	Mean squares			
		Prefeeding phase (kg/d) ²	140d test (kg/d) ²	Postfeeding phase (kg/d) ²	Prebreeding weight (kg ²)
Breed (B)	3	.044*	.120**	.185**	12168.1**
Year (Y)	3	1.035**	.270**	4.306**	8141.3**
Age of dam (A)	2	.002	.023 [†]	.008	234.8
Y x A	5		.019 ^{††}		3033.2**
Residual	221 ^a	.016	.009	.043	738.9

[†] P<.08, ^{††} P<.06

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

^a Residual degrees of freedom for 140 d test and prebreeding weight were 216.

to be a more accurate estimate of potential growth during the post-weaning period. Forty-four of 77 heifers born in 1977 lost weight during the postfeeding phase and this helps explain the large mean square value for the effect of year.

Age of dam and the year by age of dam interaction approached significance for the 140 d test while the interaction of year by age of dam was highly significant for prebreeding weight. In the prefeeding phase, F_1 heifers gained at a faster rate ($P < .05$) than either HH or 1S3H heifers (table 20). SH heifers had the highest ($P < .01$) gain/day during the 140 d gain test with AH and 1S3H heifers intermediate and higher than test gains made by HH heifers. Because of the diversity in levels of nutrition and lengths of postweaning periods, accurate comparisons of growth rate to other studies during this period are difficult. However, in studies involving Simmental crosses, Laster et al. (1972) found weight gains between HH, AH and SH heifers were .41, .51 and .51 kg/d over a feeding period extending from weaning to breeding. In a 200 d test, Laster et al. (1976) found AH and HA heifers gained .488 kg/d compared to .524 kg/d for Simmental-sired calves.

While heifers from younger dams gained at slower rates during the preweaning period, heifers from 3-yr-old dams appeared to make compensatory gains during the 140 d gain test. The average gain/day for heifers from 3-, 4- and ≥ 5 -yr-old dams was .716, .690 and .671 kg/d. This compensatory affect was especially evident in heifers of 3-yr-old dams born in 1978 when compared to 3-yr-old dams' progeny born in 1977 who showed no compensatory weight gains over 4- and ≥ 5 -yr-old dams' progeny born in the same year. Also, as was the case for weaning

TABLE 20. BREED GROUP MEANS AND STANDARD ERRORS FOR POSTWEANING GROWTH RATE (ADG) AND PREBREEDING WEIGHT

Breed group	Prefeeding phase (kg/d)	140d test (kg/d)	Postfeeding phase (kg/d)	Prebreeding weight (kg)
μ	.310 $\pm$.011	.692 $\pm$.009	.383 $\pm$.019	320.8 $\pm$ 2.67
HH	.289 $\pm$.016 ^{ab}	.636 $\pm$.013 ^a	.326 $\pm$.027 ^a	301.4 $\pm$ 3.70 ^a
AH	.336 $\pm$.020 ^b	.702 $\pm$.015 ^b	.332 $\pm$.033 ^a	326.28 $\pm$ 4.45 ^{bc}
LS3H	.281 $\pm$.019 ^a	.681 $\pm$.014 ^b	.418 $\pm$.031 ^b	319.0 $\pm$ 4.16 ^b
SH	.332 $\pm$.021 ^b	.750 $\pm$.016 ^c	.454 $\pm$.035 ^b	336.7 $\pm$ 4.64 ^c

a, b, c Means within a column with different superscript letters differ (P<.05).

traits, heifers from 4-yr-old dams born in 1979 continued to grow faster during the postweaning period.

During the postfeeding period, Simmental-cross heifers gained faster ($P<.01$) than either HH or AH heifers. Hereford heifers had the lightest weight at prebreeding ($P<.01$) with 1S3H heifers lighter ($P<.01$) than either AH or SH groups which did not differ. The compensatory gains made by heifers from 3-yr-old dams born in 1978 was reflected in heavier prebreeding weights for these heifers.

Breed, year and age of dam effects were significant for most weight related traits at 1 yr of age (table 21). The age of dam by year interaction for these traits was similar to that found for weaning traits where 1979-born heifers from 4-yr-old dams had noticeably higher weights. The differential effect of 3-yr-old dams' progeny born in 1978 was also present. Breed and year were the only significant sources of variation for linear measurements made at 1 yr of age (table 21). As yearlings, SH heifers were heavier and taller than all other breed groups ($P<.01$). AH and 1S3H heifers were similar in weight and heavier than HH heifers while 1S3H heifers were taller ($P<.01$) than either AH or HH groups (table 22). The weight to height ratios and condition scores for AH and HH heifers at yearling were consistent, showing AH heifers had a significantly greater proportion of weight to height and were visually evaluated to have a greater condition score. Long et al. (1979) noted weight was a slower maturing character than height and as weight approaches height in degree of maturity, weight to height ratios increase. He also suggested condition scores increase with age, and considering the difference between AH and HH heifers for weight to

TABLE 21. ANALYSIS OF VARIANCE FOR YEARLING TRAITS

Source	df	Mean squares			
		365 d weight (kg ²)	Weight/height (kg/cm) ²	Condition score (1-9) ²	Average daily gain (kg/d) ²
Breed	3	10429.85**	.355**	5.895**	.066**
Year (Y)	3	4695.42**	.195**	12.154**	.037**
Age of dam (A)	2	474.72	.013	.622	.002
Y x A	5	2255.62**	.157**	2.363**	.017**
Residual	216	593.05	.038	.663	.004

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

TABLE 21 (CONTINUED). ANALYSES OF VARIANCE FOR YEARLING TRAITS

Source	df	Mean squares			
		365d height(cm ²)	Pelvic height(cm ²)	Pelvic width(cm ²)	Pelvic area(cm ²) ²
Breed	3	311.22**	2.16 [†]	7.43**	2346.36**
Year	3	69.93**	21.10**	2.44**	4025.63**
Age of dam	2	10.52	1.50	.69	510.68
Residual	221	11.31	.921	.63	309.01

[†] P<.10

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

TABLE 22. BREED GROUP MEANS AND STANDARD ERRORS FOR YEARLING TRAITS

Breed group	365 d Weight (kg)	Weight/height (kg/cm)	Condition Score (1-9)	Average daily gain (kg/d)
μ	300.04 ± 2.39	2.63 ± .02	6.30 ± .08	.719 ± .006
HH	282.97 ± 3.30 ^a	2.53 ± .03 ^a	5.97 ± .11 ^a	.674 ± .008 ^a
AH	302.68 ± 3.99 ^b	2.71 ± .03 ^b	6.77 ± .13 ^b	.733 ± .010 ^{bc}
1S3H	297.76 ± 3.72 ^b	2.59 ± .03 ^a	6.25 ± .12 ^a	.712 ± .009 ^b
SH	316.76 ± 4.16 ^c	2.67 ± .03 ^a	6.22 ± .14 ^a	.755 ± .011 ^c

a, b, c Means within columns with different superscript letters differ (P<.05).

TABLE 22 (CONTINUED). BREED GROUP MEANS AND STANDARD ERRORS FOR YEARLING TRAITS

Breed group	365d height(cm)	Pelvic height(cm)	Pelvic width(cm)	Pelvic area(cm ²)
μ	113.75 ± .30	13.21 ± .09	10.45 ± .07	138.64 ± 1.59
HH	111.24 ± .44 ^a	13.11 ± .14 ^a	10.00 ± .10 ^a	131.57 ± 2.28 ^a
AH	112.31 ± .53 ^a	13.17 ± .15 ^{ab}	10.30 ± .13 ^{ab}	136.04 ± 2.78 ^{ab}
1S3H	114.40 ± .50 ^b	13.06 ± .14 ^a	10.60 ± .12 ^{bc}	138.93 ± 2.60 ^b
SH	117.06 ± .56 ^c	13.50 ± .16 ^b	10.90 ± .13 ^c	148.02 ± 2.91 ^c

a, b, c Means within a column with no superscript letter in common differ (P<.05).

height ratios and condition score at yearling, coupled with the younger pubertal age of AH heifers, it appears AH heifers were maturing at a faster rate than HH heifers.

Weight at a constant condition in cattle has been reported by Brody (1945) to vary with the 4.3 to 4.6 power of height. Considering this relationship, Long et al. (1979) suggested that comparison of weight to height ratios were not qualified across large ranges in height. Upon this recommendation, weight to height ratio comparisons between breed groups based on a similar height could be made only between AH and HH groups.

Pelvic height and width were smallest for HH heifers and largest for SH heifers. When pelvic area was computed, SH heifers had larger pelvic areas than all other groups. 1S3H heifers had a greater pelvic volume than HH heifers but no differences were noticed between AH and 1S3H groups or AH and HH groups. Laster (1974) measured pelvic size in yearling heifers and found SH heifers had larger pelvic openings than AH heifers, while both of these breed groups were greater than HH heifers.

The higher weights and heights for crossbred heifers compared to HH heifers at 1 yr and the greater gains made through the postweaning period are likely to be partly due to heterosis. Even though no estimate could be obtained from this data, heterosis for height and to a greater extent weight has been reported and discussed by many researchers (Cundiff, 1970; Pahnish et al., 1971; Lasley et al, 1973; Laster et al., 1976 and 1979; Gregory et al., 1978; Long et al., 1979).

The relationship of postweaning and yearling traits with traits at puberty and first pregnancy are given in table 23. As noted with growth

TABLE 23. RESIDUAL CORRELATIONS OF POSTWEANING AND YEARLING TRAITS WITH PUBERTAL AND PREGNANCY TRAITS

Trait	Puberty ^a			1st Pregnancy			
	Age	Weight	Height	Rate ^a	Breeding efficiency ^a	Date ^b	Number of services ^b
Prefeeding ADG	.10	.20	.09	-.10	.17	-.08	-.12
140d ADG	-.14	.40	.24	.22	.14	-.02	.01
Post feeding ADG	.15	.16	.05	.18	-.04	.16	.07
Prebreeding weight	-.16	.63	.43	.25	.25	-.01	.04
365 d weight	-.29	.56	.38	.23	.24	-.07	-.01
365 d height	-.12	.35	.80	.15	.13	.06	.10
Yearling ADG	-.28	.55	.36	.25	.26	-.08	.00
Yearling weight/ height	-.21	.55	.15	.24	.27	-.09	-.02
Yearling condition score	-.15	.38	.12	.05	.04	-.06	.00
Yearling pelvic area	-.07	.32	.35	.14	.16	.05	.10

^a Correlations greater than .14 are significantly different from zero ($P < .05$), $r > .18$, ($P < .01$).

^b Correlations greater than .16 are significantly different from zero ($P < .05$), $r > .21$, ($P < .01$).

traits at weaning, most associations of postweaning growth and traits measured as a yearling were lower for puberty age than for puberty weight or height. Traits characterizing faster weight gains or heavier weights at a constant age tended to be related to earlier ages at puberty. These correlations, however, were not as high as those previously reported by Wiltbank et al. (1966), Short and Bellows (1971) and Laster et al. (1972).

Heavier weight to height ratios at 1 yr were associated with earlier puberty ages ($r = -.21$). A similar relationship existed for the weaning weight to height ratio and puberty age ($-.15$). However, the weight to height ratio at puberty was positively correlated with puberty age ($r = .48$). These findings are supported by Long et al. (1979), who noted different interpretations for weight/height relationships at a chronological age constant and a physiological age constant. Higher weight/height values at yearling and weaning reflected earlier physiological maturity while higher weight to height ratios at puberty were inclined to reflect heifers reaching physiological maturity later.

Postweaning traits and those measured at 1 yr had higher associations with pregnancy rate than those measured at weaning. Prebreeding weight, 365 d weight, yearling average daily gain and the weight to height ratio at yearling all had similar positive associations with pregnancy rate. Postfeeding average daily gain was the only correlation which approached having a significant interpretation when relationships with pregnancy date were considered. The associations between pelvic area and these traits suggest that pelvic size is more highly related to growth traits than reproductive traits. Varner et al. (1977) noted

pelvic areas and cannon bone lengths were greater for heavy heifers than light heifers at weaning and when measured on May 5.

Maturity Traits

Mature weight and height analyses were included in this study to gain a better understanding of maturing rates at puberty and 365 d. Analyses of variance for mature weights and heights are given in table 24. Breed approached significance as a main effect for 30 mo weight and was highly significant for 30 mo height. The near significance of age of dam effects for 36 mo weight were due to lighter weights of cows born to 3-yr-old dams. Year of birth effects were always important but varied with the trait. For 30 mo weight, weights of cows born in 1976 were heavier than cows born in other years, while cows born in 1978 were taller at 30 mo and heavier at 36 mo. The mean difference of 50.7 kg between mature weights taken at 30 and 36 mo indicates weights of mature cows at different points in the production cycle exhibit substantial variation (table 25). Brody (1945) demonstrated that height measurements were affected to a lesser degree by nutrition than weight, Fitzhugh and Taylor (1971) reported height was affected less by the environment than weight, and Long et al. (1979) noted height was a faster maturing character than weight. Therefore, it seems possible that weights measured at maturity in this study may have been younger than what may be desired and that 30 mo height may be a more accurate reflection of mature size in these cows.

The only significant difference between breed groups for weight at 30 mo was between SH and HH cows. However, height differences at 30 mo

TABLE 24. ANALYSES OF VARIANCE FOR MATURE WEIGHTS AND HEIGHT

Source	df	Mean squares				df	30 month height (cm ²)
		30 month weight (kg ²)	df	36 month weight (kg ²)			
Breed	3	3410.78 [†]	3	2174.42	3	198.53**	
Year	3	29671.69**	3	9847.98**	3	120.55**	
Age of dam	2	1472.92	2	4289.12 [†]	2	10.25	
Residual	167	1437.45	166	1774.44	214	13.77	

[†] P<.10

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

TABLE 25. BREED GROUP MEANS AND STANDARD ERRORS FOR MATURE WEIGHT AND HEIGHT

Breed group	Trait					
	n	30 month weight (kg)	n	36 month weight (kg)	n	30 month height (cm)
μ	176	434.52 ± 3.98	175	485.19 ± 4.32	223	126.52 ± .34
HH	46	424.75 ± 6.11 ^a	52	478.00 ± 6.55 ^a	67	124.79 ± .49 ^a
AH	49	437.0 ± 6.35 ^{ab}	42	478.47 ± 7.39 ^a	51	125.00 ± .59 ^a
LS3H	42	429.86 ± 6.85 ^{ab}	48	489.61 ± 6.99 ^a	60	126.88 ± .56 ^b
SH	39	445.85 ± 6.99 ^b	33	494.67 ± 8.31 ^a	45	129.41 ± .63 ^c

a, b, c Means within a column with different superscript letters are different (P<.05).

were similar to breed contrasts for these heifers at 180 d, 365 d and puberty. Estimates of asymptotic weights made by Nelson et al. (1982) were intermediate to 30 and 36 mo weights reported here for HH cows and heavier than both 30 and 36 mo weights for AH and reciprocal cross cows. Smith et al. (1976b) reported weights for HH and AH cows at 3-1/3 yr of 434 kg and 425 kg respectively.

At puberty, there were no breed differences among these heifers for the proportion of their mature weight or height (tables 26 and 27). If the weight to height ratio is a measure of the degree of maturity (Long et al., 1979), the lack of breed differences for percent mature weight and height at puberty is supported by the lack of breed differences for the weight to height ratio at puberty. Smith et al. (1976b) reported degree of mature weight at puberty for HH heifers of 56.4% and 53.4% for AH heifers. Nelson et al. (1982) reported maturing rate at puberty for AH cattle was 52.2% for weight and 84.8% for height.

Year and interactions with year were sources which had significantly affected these traits. All breed groups of heifers born in 1978 had lower percentages of mature height except SH heifers. Puberty age for this breed-year class was relatively greater than other subclasses and may have allowed for additional skeletal growth to occur before the onset of puberty. The year by breed interaction for percent mature weight followed a similar trend and was compounded by greater pubertal weight gains/day for SH heifers than other heifer groups born in that year.

Large differences between age of dam by year subclasses existed (58.3 to 77.2%). The small number of heifers within these divisions

TABLE 26. ANALYSES OF VARIANCE FOR MATURITY TRAITS AT PUBERTY

Mean squares						
Source	df	Mature weight ^a (%) ²		Mature weight ^b (%) ²		Mature height (%) ²
Breed (B)	3	58.29	3	3.04	3	3.18
Year (Y)	3	796.61**	3	306.16**	3	85.01**
Age of dam (A)	2	17.16	2	27.54	2	1.04
B x Y	6	89.80*			6	16.30**
Y x A	5	101.28*				
Residual	156	38.83	166	39.60	208	5.27

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

^a Mature weight recorded at 30 mo.^b Mature weight recorded at 36 mo.

TABLE 27. BREED GROUP MEANS AND STANDARD ERRORS FOR MATURITY TRAITS AT PUBERTY

Breed group	Pubertal					
	n	Mature weight ^a (%)	n	Mature weight ^b (%)	n	Mature height (%)
μ	176	70.72 ± .72	175	62.59 ± .64	223	91.74 ± .21
HH	46	71.87 ± 1.09	52	62.68 ± .98	67	91.76 ± .30
AH	49	69.44 ± 1.11	42	62.98 ± 1.10	51	91.39 ± .37
1S3H	42	71.63 ± 1.20	48	62.42 ± 1.04	60	92.03 ± .35
SH	39	69.94 ± 1.20	33	62.26 ± 1.24	45	91.79 ± .39

^a Mature weight recorded at 30 mo.

^b Mature weight recorded at 36 mo.

($n \leq 7$ for 6 of 11 subclasses) consequently overshadow whatever importance this interaction might have. Several rank changes between dam ages and years occurred but no discernible trend could be established.

Among the variables measuring percentage of mature size attained at 365 d, breed differences were only evident for the proportion of mature height (table 28). Year was a significant source of variation for percent mature weight at 30 mo and for percent mature height. Heifers born in 1976 from 4-yr-old dams had gained a substantially lower portion of their mature height by 1 yr than did 4-yr-old dams born in 1979 when compared to other ages of dam classes.

The percent mature height recorded at 365 d was lower for HH heifers than Simmental-cross heifers with AH heifers not differing from any of the groups. Even though differences between groups for percent mature weight at 30 mo were nonsignificant, the rankings of breed groups were the same (table 29). Fitzhugh and Taylor (1971) reported the degree of maturity of an animal had as many values as traits that can be measured at a particular stage. Consequently, the noncompliance of degrees of maturity as measured by weight and height at 365 d might be expected.

The data suggest that even though Simmental-cross heifers matured at a larger height and at 30 mo, a larger weight, very little difference existed in maturing rate as measured by 365 d weight as a percentage of mature weight. And when measured in units of height, maturing rate proceeded at a faster rate for Simmental-cross heifers over HH heifers.

Breed group means for percent of 36 mo weight at 365 d were characterized by rather large standard errors. The reason for this was

TABLE 28. ANALYSES OF VARIANCE FOR MATURITY TRAITS AT ONE YEAR

365 d						
Source	df	Mature weight ^a	df	Mature weight ^b	df	Mature height
		(%) Mean squares		(%) Mean squares		(%) Mean squares
Breed (B)	3	28.96	3	349.44	3	18.17*
Year (Y)	3	697.58**	3	32.94	3	180.57**
Age of dam (A)	2	27.66	2	1116.42	2	.42
Y x A	5	146.22**				
Residual	162	31.61	166	804.12	214	5.83

^a Mature weight recorded at 30 mo.

^b Mature weight recorded at 36 mo.

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

TABLE 29. BREED GROUP MEANS FOR MATURITY TRAITS AT ONE YEAR

Breed group	365 d					
	n	Mature weight ^a (%)	n	Mature weight ^b (%)	n	Mature height (%)
μ	176	70.00 ± .64	175	55.60 ± 2.91	223	89.97 ± .22
HH	46	69.07 ± .95 ^c	52	53.29 ± 4.4 ^c	67	89.18 ± .32 ^c
AH	49	69.34 ± .98 ^c	42	54.47 ± 5.0 ^c	51	89.88 ± .38 ^{cd}
1S3H	42	70.76 ± 1.05 ^c	48	59.88 ± 4.7 ^c	60	90.26 ± .36 ^d
SH	39	70.84 ± 1.07 ^c	33	54.75 ± 5.6 ^c	45	90.57 ± .41 ^d

^a Mature weight recorded at 30 mo.

^b Mature weight recorded at 36 mo.

^{c, d} Means within a column with different superscript letters are different (P<.05).

not apparent. The residual correlation between mature weights at 30 and 36 mo was .77, and the relationship between percentage of 30 and 36 mo weight at puberty was .78. Otherwise, correlations of comparative traits measured at an age or maturity constant were low (table 30).

Correlations between maturity traits and traits at puberty and first pregnancy are given in table 31. When the percentage of 30 mo weight at 365 d was higher, heifers tended to have earlier puberty ages. The same measure at 36 mo, however, was positive and nonsignificant. Increased measures of percent mature weight at puberty were usually related with older age at puberty. Percent mature height at puberty had a positive correlation with puberty age, while percent mature height at 365 d had a negative sign ($P < .05$). A faster maturing rate at 365 d may be more indicative of early maturity than measures of percent maturity measured at puberty. Long et al. (1979) suggested different interpretations for weight-height ratios at a chronological age constant versus a physiological age constant. Similar application appears to apply to measures of percent maturity measured at different age constants (chronological and physiological).

Initial pregnancy rates were usually lower for cows which matured at larger weights. Since cows in this project were culled after two failures to become pregnant, some heifers which were open as yearlings and consequently did not raise a calf as a two-yr-old would be expected to have heavier mature weights. This condition applies to only 36 mo weights since edits were made for nonpregnant yearlings in the 30 mo analyses. In this study, 36 mo weights of cows that were open as

TABLE 30. RESIDUAL CORRELATIONS AMONG MATURITY TRAITS (N=136) ^a

Trait	Coded trait							
	2	3	4	5	6	7	8	9
(1) 30 month weight	-.58	-.43	.77	-.05	-.16	.17	-.12	-.09
(2) % mature weight - 365 d ^b		.61	-.35	.14	.37	.06	.22	.16
(3) % mature weight - puberty ^b			-.20	.21	.78	.02	.08	.15
(4) 36 month weight				-.02	-.37	.20	-.07	-.04
(5) % mature weight - 365 d ^c					.18	-.01	-.02	-.01
(6) % mature weight - puberty ^c						-.00	.03	.09
(7) 30 month height							.87	.88
(8) % mature height - 365 d								.98
(9) % mature height - puberty								

^a Correlations greater than .18 were significantly different from zero ($P < .05$), $r > .23$, ($P < .01$).

^b Mature weight recorded at 30 mo.

^c Mature weight recorded at 36 mo.

TABLE 31. RESIDUAL CORRELATIONS FOR MATURITY TRAITS AND TRAITS AT PUBERTY AND PREGNANCY

Trait ^a	Puberty			1st Pregnancy	
	Age	Weight	Height	Rate (%)	Breeding efficiency
30 month weight	.13	.52	.37	-.25	-.23
% mature weight - yearling ^b	-.27	.08	.00	.25	.22
% mature weight - puberty ^b	.45	.49	.30	.25	.20
36 month weight	.28	.42	.35	-.44	-.42
% mature weight - yearling ^c	.09	.06	.08	.10	.12
% mature weight - puberty ^c	.24	.57	.28	.35	.29
30 month height	.07	.16	.28	.09	.08
% mature height - yearling	-.08	-.03	.13	.32	.31
% mature height - puberty	.14	.10	.23	.22	.21

^a Correlations with mature weight traits greater than .16 are significantly different from zero ($P < .05$), $r > .21$, ($P < .01$), mature height traits with correlations greater than .14 ($P < .05$) and $r > .18$, ($P < .01$).

^b Mature weight recorded at 30 mo.

^c Mature weight recorded at 36 mo.

heifers were 506.1 ± 21.3 kg compared to cows which were pregnant as yearlings whose 36 mo weight was 466.0 ± 6.9 kg.

The positive correlation between percent mature (36 mo) weight at puberty and pregnancy rate or breeding efficiency could also be affected by open yearlings maturing at larger weights and consequently decreasing the percent mature weight.

Prediction of Pubertal Traits

The prediction of pubertal traits can serve several useful purposes. First, the nature and strength of relationships between pubertal traits and traits important to puberty can be identified. The regression derived from the prediction could then assist breeders in designing management systems in making adjustments to ensure that the onset of first estrus is attained by a desired age or a minimum weight or height.

In developing initial prediction equations, only traits from birth to 1 yr of age were used as covariates such that the final regression equation would constitute one of a truly predictive nature. A second analysis utilized all traits in an attempt to account for the maximum proportion of the variation in puberty traits.

The regression analysis using data up to 1 yr of age for the prediction of puberty age identified average daily gain from birth to 1 yr and date of birth as significant factors affecting puberty age (table 32). In an initial analysis, 365 d weight was entered into the equation first and was later removed when average daily gain from birth to 1 yr entered the equation. The two traits were highly correlated ($r=-.98$).

TABLE 32. REGRESSION ANALYSIS FOR PREDICTION OF PUBERTAL AGE (PA)

Covariate	Regression coefficient	Standard partial regression coefficient	R ²
Main effects ^a			.25
1. ADG, birth to 1 yr	-40.028 ± 7.356**	-.332	.07
2. Birth date	-.626 ± .191**	-.187	.03
Total			.35

Prediction equation: $\hat{PA} = 381.2 \text{ d} - .626 \text{ d/d (Birth date - 92.6 d)}$
 $-40.03 \text{ d/kg/d (ADG, Birth to 1 yr - .709 kg/d)}$

Standard error of estimate: 35.1 d

ANALYSIS OF VARIANCE:

Source	df	Mean squares	F
Regression	10	14518.91**	11.79
Residual	219	1231.23	

** P<.01

^a Breed, year and age of dam

Faster gains to 1 yr decreased puberty age 4.0 d for each additional .1 kg of gain above the average of the contemporaries. Heifers born earlier in the calving period had puberty ages .63 d older for every day earlier than average that they were born.

Higher regression values were found by Arije and Wiltbank (1971) and Swierstra et al. (1977) when puberty age was regressed on preweaning growth and by Arije and Wiltbank (1974) when puberty age was regressed on growth rate from weaning to grass. Both positive and negative regressions of puberty age on birth date for different breeds and breed crosses of heifers were found by Arije and Wiltbank (1974) but none were significant.

The standard partial regression coefficients indicate the relative strength of each variable in explaining the variation in puberty age.

The standard error of the estimate for puberty age was 35.1 d and the regression equation accounted for 35% of the variation in this trait. These results indicated that other unidentified variables accounted for variation in puberty age. Studies which have previously predicted puberty age (Arije and Wiltbank, 1974; Pleasants et al., 1975) accounted for approximately 30 to 67% of the variation in puberty age.

Some studies have suggested the effect of growth rate on age at puberty was through breed effects or system of mating effects on growth rate (Hawk et al., 1953; Menge et al., 1960; Kaltenbach and Wiltbank, 1962). However, when puberty age was regressed on growth rate to 1 yr, breed type was still important. This agrees with Wiltbank et al. (1966) in suggesting that there was an effect on puberty age due to breed type independent of growth rate. The importance of the regression of puberty

age on average daily gain to 1 yr points out the importance of high levels of growth throughout the pre- and postweaning periods and disagrees with previous work which found growth rate during one of these periods had more importance than the other (Menge et al., 1960; Bellows et al., 1965; Pleasants et al., 1975).

Approximately 43% of the variation in puberty weight was accounted for by the main effects in conjunction with the actual yearling weight and birth weight (table 33). Above average weights at approximately 1 yr and at birth would increase puberty weight .61 kg/kg and .85 kg/kg respectively. The comparative difference between the standard partial regression coefficients and the R^2 values for actual yearling weight and birth weight reflects the moderate association between these two traits ($r = -.38$, $P < .01$). Correlations between pubertal traits and actual measurements such as yearling weight are cited in appendix table 12. Breed group means and analysis of variance for actual measurements are given in appendix tables 88 through 51. Correlations between all traits used in the regression analyses are given in appendix table 52.

Ellis (1974) noted the importance of weight at breeding to percent calving and thus would support the possible use of this regression in projecting a minimum target weight that would be desired for a heifer at the beginning of the breeding season.

Various regressions developed for puberty weight by Arije and Wiltbank (1974) accounted for 24 to 54% of the variation, while Pleasants et al. (1975) found 40 to 80% of the variation could be explained.

Height at puberty had a higher level of predictability with traits in this study (table 34). Actual yearling height, average daily gain to

TABLE 33. REGRESSION ANALYSIS FOR PREDICTION OF PUBERTAL WEIGHT (PW)

Covariate	Regression coefficient	Standard partial regression coefficient	R ²
Main effects ^a			.06
1. Final weight	.610 ± .060**	.625	.35
2. Birth weight	.854 ± .370**	.138	.01
Total			.43

Prediction equation: $\hat{PW} = 304.6 \text{ kg} + .610 \text{ kg/kg (Final weight - 302.7 kg)} + .854 \text{ kg/kg (Birth weight - 37.9 kg)}$

Standard error of estimate: 23.5 kg

ANALYSIS OF VARIANCE:

Source	df	Mean squares	F
Regression	10	42658.78**	16.32
Residual	219	2614.42	

** P<.01

^a Breed, year and age of dam

TABLE 34. REGRESSION ANALYSIS FOR PREDICTION OF PUBERAL HEIGHT (PH)

Covariate	Regression coefficient	Standard partial regression coefficient	R ²
Main effects ^a			.17
1. Actual yearling height	.934 ± .045**	.972	.57
2. Yearling ADG	7.389 ± 2.062**	-.667	.01
3. 365 d weight	.071 ± .025**	.518	.01
Total			.76

Prediction equation: $\hat{PH} = 115.69 \text{ cm} + .934 \text{ cm/cm (Act. yearling height - 115.8 cm)} + 7.389 \text{ (Yearling ADG - .71 kg/d)} + .071 \text{ cm/kg (365d weight - 297.06 kg)}$

Standard error of estimate: 1.98 cm

ANALYSIS OF VARIANCE:

Source	df	Mean squares	F
Regression	11	240.475**	61.46
Residual	218	3.913	

** P<.01

^a Breed, year and age of dam

1 yr, 365 d weight and the main effects accounted for 75.6% of the variation in puberty height.

Respective increases for above average yearling weight, average daily gain to 1 yr and 365 d weight caused puberty height to increase .93, .94 and .07 cm. The standard partial regression coefficients were highest for yearling height, then ADG to 1 yr and 365 d weight. The residual correlations between these traits were high (.56 for yearling height and ADG to 1 yr, .54 for yearling height and 365 d weight, and .98 between ADG to 1 yr and 365 d weight). The negative regression of puberty height on ADG to 1 yr does not reflect the positive correlation between the two traits. However, since increased ADG to 1 yr was important in decreasing puberty age and earlier ages at puberty were correlated with shorter puberty heights, the decrease in puberty height due to early puberty ages seems to be a reasonable explanation for the sign of that regression.

Since weight and height relationships to productivity have recently become of interest, regressions were developed for puberty age on puberty weight and height and yearling weight and height to determine the effect of these traits on puberty age when one of these variables was held constant.

The increases seen in puberty age were $.56 \pm .10$ d/kg of puberty weight and $1.53 \pm .78$ d/cm of puberty height. The respective standard partial regression coefficients were .395 and .141 for puberty weight and puberty height. The regression value for height was larger in magnitude, but the standard regression values indicate weight had more impact on the age at puberty.

In the analysis of 365 d weight and height, respective changes in puberty age due to 365 d weight and 365 d height were $.52 \pm .12$ d/kg and $.79 \pm .87$ d/cm. Although the regression was positive, significance levels and the standard error indicate the regression value for 365 d height was not significantly different from zero.

These data support previous findings in this study that increases in puberty age were associated with increases in puberty weight and height. The favorable regression between 365 d weight and puberty age corresponded to the significant correlation with puberty age ($r=.29$). Similarly the lack of importance in the regression between puberty age and 365 d height was supported by their nonsignificant correlation ($r=-.12$).

When puberty age was regressed on all traits, 97.2% of the variation in puberty age was explained. The significant sources and their regression coefficients are given in table 35. The order these covariates entered into the equation was as follows: puberty height/d, puberty height, 365 d height and pelvic width. Allowing linear measurements at puberty into the equation and others previously allowed into prediction equations could account for a large portion of the variance associated with puberty age such that the standard error of the estimate was 7.4 d.

Puberty height/day and puberty height had the most influence on puberty age as measured by the standard partial regression coefficients and were regressing puberty age in a counteractive manner. The association between puberty age and puberty height/day was very high ($r=-.92$). A 1 cm increase in 365 d height and pelvic width caused respective

TABLE 35. SOURCES OF VARIATION FOR PUBERTAL AGE ^a

Covariate	Mean	Regression coefficient ^b	Standard partial regression coefficient	R ²
Main effects				.2488
1. Pubertal height/day (kg/d)	.307 ± .031	-1124.1 ± .45.7	-.809	.6345
2. Pubertal height (cm)	115.7 ± 3.9	5.23 ± .49	.48	.0871
3. 365 d height (cm)	113.5 ± 4.0	-1.94 ± .58	-.181	.0013
4. Pelvic width (cm)	10.47 ± .86	-1.67 ± .70	-.034	.0007
Total				.9724

^a $\mu = 381.2 \pm 42.6$ d^b Significant at $P < .01$.

decreases in puberty age of 1.9 and 1.7 d. The importance of height measurements in explaining variation in puberty age had not been previously reported in the literature. Since puberty height/day and puberty age share a common value, a regression was run without puberty height/d to test the strength of the remaining covariates as they explained puberty age. Puberty weight entered the equation first followed by yearling weight/day, puberty height, actual yearling height, birth date and actual weaning height (table 36). Puberty height and yearling height had the highest standard partial regression coefficients and also were opposite in sign. Puberty weights above average increased puberty age while yearling weight/day values greater than average acted to decrease age at puberty. Birth date and actual weaning hip height also had negative regressions, but the magnitude of their influence on puberty age was smaller than the other traits. The standard error of the estimate was 10.4 d, and 94.4% of the variation in puberty was accounted for. The standard partial regressions again pointed to the importance of height measurements in explaining variation in puberty age.

Six important sources of variation were found for puberty weight and all regressions were positive (table 37). The standard regression coefficients found puberty age had the strongest association with puberty weight followed by the yearling weight to height ratio, puberty height, birth date, prebreeding weight and yearling condition score. Every additional 1 d increase in puberty age increased puberty weight .49 kg, while a 1 cm increase in height accounted for a 2.2 kg increase in puberty weight. The influence of birth date, prebreeding weight and

TABLE 36. SOURCES OF VARIATION FOR PUBERTAL AGE WITHOUT PUBERTAL HEIGHT/DAY ^a

Covariate	Mean	Regression coefficient ^b	Standard partial regression coefficient	R ²
Main effects				.2488
1. Pubertal weight	304.6 ± 30.0	.59 ± .06 d/kg	.416	.2200
2. Yearling weight/day	.811 ± .078	-49.23 ± 4.90 d/kg/d	-.436	.4214
3. Pubertal height	115.7 ± 3.9	10.29 ± .74 d/cm	.945	.0069
4. Actual yearling height	113.5 ± 4.0	-8.43 ± .71 d/cm	-.806	.0361
5. Birth date	92.6 ± 12.7	-.51 ± .08 d/d	-.151	.0074
6. Actual weaning height	104.1 ± 3.7	-2.99 ± .80 d/kg	-.117	.0036
Total				.9442

^a $\mu = 381.2 \pm 42.6$ d.^b Significant at $P < .01$.

TABLE 37. SOURCES OF VARIATION FOR PUBERTAL WEIGHT ^a

Covariate	Mean	Regression coefficient ^b	Standard partial regression coefficient	R ²
Main effects				.0606
1. Pubertal height	115.7 ± 3.9	2.22 ± .25 kg/cm	.289	.4197
2. Yearling weight/height ratio	2.61 ± .22	81.41 ± 8.11 kg/kg/cm	.589	.2052
3. Pubertal age	381.2 ± 42.6	.49 ± .02 kg/d	.689	.1983
4. Birth date	92.6 ± 12.7	.43 ± .06 kg/d	.182	.0234
5. Prebreeding weight	317.0 ± 32.6	.15 ± .06 kg/kg	.165	.0031
6. Yearling condition score	6.24 ± 1.00	2.34 ± .95 kg/grade ^c	.078	.0024
Total				.9127

^a μ = 304.6 ± 30.0 kg.^b Significant at P<.01.^c Grades ranged from 1-9.

yearling condition score were relatively smaller than other significant covariates; however, the yearling weight/height ratio had the second highest standard partial regression and caused 8.1 kg increases in puberty weight for every .1 kg increase in the weight to height ratio.

The actual yearling height explained the greatest amount of variation in puberty height and had the highest standard partial regression coefficient (table 38). Puberty age was second in its influence, causing increases of .046 cm/d in puberty height as puberty age increased. Lesser, but significant portions of the variance were explained by birth date, actual weaning height, puberty weight and yearling condition score.

These regressions may help explain the nature of relationships between pubertal traits when other traits are allowed to exhibit their influence. From the analyses, puberty weight and height appear to be more dependent on puberty age than puberty age is dependent on weight or height at puberty. Several factors justify the greater independence of puberty age. Puberty age had the highest standard regression coefficient for puberty weight and the second highest standard partial regression for puberty height. The highest standard regression was for the actual yearling height whose association with puberty height was high ($r=.83$). In both analyses of puberty age, measures of puberty height were of greatest influence but were counteracted by height adjusted to 365 d and the actual yearling height whose influence was approximately as great but in an opposite direction.

TABLE 38. SOURCES OF VARIATION FOR PUBERTAL HEIGHT ^a

Covariate	Mean	Regression coefficient ^b	Standard partial regression coefficient	R ²
Main effects				.1648
1. Actual yearling height	113.5 ± 4.0	.838 ± .020 cm/cm	.872	.5690
2. Pubertal age	381.2 ± 42.6	.046 ± .022 cm/d	.504	.2102
3. Birth date	92.6 ± 12.7	.053 ± .004 cm/d	.171	.0213
4. Actual weaning height	104.1 ± 3.7	.087 ± .024 cm/cm	.082	.0035
5. Pubertal weight	304.6 ± 30.0	.011 ± .002 cm/kg	.092	.0014
6. Yearling condition score	6.24 ± 1.00	-.208 ± .070 cm/grade	-.053	.0012
Total				.9714

^a $\mu = 115.7 \pm 3.9$ cm.^b Significant at $P < .01$.

Prediction of Pregnancy Rate and Pregnancy Date

Since all traits available for the regression of pregnancy rate and pregnancy date were those measured prior to their occurrence, predictive equations were also those accounting for variation in these traits. Three traits had significant influence on pregnancy rate (table 39). Early ages at puberty accounted for a .46% increase in pregnancy rates for every day earlier puberty had occurred. Increases in date of birth and faster growth during the 140 d gain test increased pregnancy rates .725%/d and 6.6%/.1 kg/d respectively. The ranking of these traits for the order which they entered the equation, standard partial regression coefficients and R^2 values were similar. The total R^2 accounted for (33%) was reflected in the low accuracy at which pregnancy rate could be predicted (standard error of the estimate = 36.3%).

Only puberty age had significant influence on when pregnancy had occurred (table 40). The regression of pregnancy date on puberty age indicated every additional day older a heifer was at puberty would delay the date of pregnancy .12 d.

Only 21.8% of the variation in pregnancy date was explained, 17.4% by the main effects. Despite the lower percentage of variation explained for pregnancy date versus pregnancy rate, the standard error of the estimate observed for pregnancy date was proportionately smaller than that observed for pregnancy rate.

The prediction equations found for pregnancy rate and date reflect the low associations found between traits in this study and these measures of reproductive performance. Other factors obviously are affecting these traits. Conception rates have been shown to be affected

TABLE 39. REGRESSION ANALYSIS FOR PREDICTION OF PREGNANCY RATE (PR)

Covariate	Regression coefficient	Standard partial regression coefficient	R ²
Main effects ^a			.1246
1. Puberty age	-.455 ± .066**	-.448	.1406
2. Birth date	.725 ± .200**	-.213	.0445
3. ADG, 140 d	66,159 ± 26.03**	.188	.0207
Total			.3303

Prediction equation: $\hat{PR} = 75.22\% - .455 \%/d \text{ (Puberty age - 381.22 d)}$
 $+ .725\%/d \text{ (Birth date - 92.59 d)} + 66.159 \%/kg/d$
 $\text{(ADG, 140 d - .660 kg/d).}$

Standard error of estimate: 36.29%

ANALYSIS OF VARIANCE:

Source	df	Mean squares	F
Regression	11	128.746**	9.78
Residual	218	13.171	

** P<.01

^a Breed, year and age of dam

TABLE 40. REGRESSION ANALYSIS FOR PREDICTION OF PREGNANCY DATE (PD)

Covariate	Regression coefficient	Standard partial regression coefficient	R ²
Main effects ^a			.1742
1. Puberty age	.118 ± .039**	.232	.0437
Total			.2180

Prediction equation: $\hat{PD} = 156.156d + .118d/d$ (Puberty age - 381.22d)

Standard error of estimate: 14.748

ANALYSIS OF VARIANCE:

Source	df	Mean squares	F
Regression	9	1097.880**	5.05
Residual	163	217.508	

** P<.01

^a Breed, year and age of dam

by liveweight at the start of the breeding period (Cunningham et al., 1981; Ellis, 1974; Carter and Cox, 1973). However, weights of heifers in this study at breeding were much higher than these studies and were above the weight range where weight was critical to the time or rate of conception. Lunstra et al. (1983) studied factors affecting pregnancy rates in beef cows and heifers, but significant influences found in that study were not affecting or were not pertinent to heifers.

SUMMARY

Puberty, first pregnancy and growth traits from birth to puberty were studied for 230 heifers comprised of straightbred Hereford (HH), Angus-Hereford (AH), 25% Simmental-75% Hereford (1S3H) and Simmental-Hereford (SH) breed groups. Heifers were born to 3-yr-old and older Hereford dams in the years 1976 to 1979 at the Northern Agricultural Experiment Station near Havre. Least-squares analysis of variance and step forward-backward regression procedures were used to compare breed groups and characterize relationships among traits at puberty, first pregnancy and growth traits of beef heifers who differed in milk production. The model used in both procedures included breed group, year, age of dam and appropriate two-factor interactions. Prediction of pubertal traits and traits at first pregnancy were made as well as an analysis of maturing rate as measured by weight and height.

Straightbred Hereford heifers had older puberty ages, slower rates of growth to puberty, a smaller percentage of heifers reaching puberty by 15 mo and were always lighter or shorter at puberty when compared to crossbred groups. Respective puberty ages were 406.6, 371.0, 381.6 and 367.5 d for HH, AH, 1S3H and SH heifers. This ranking for puberty age agreed very closely to daily milk production estimates made on a sample of these heifers (Casebolt et al., 1983) in regard to breed group rankings and the relative differences between various breed groups. Daily milk production measured over a lactation period for these heifers

as mature cows were $8.7 \pm .54$, $11.6 \pm .56$, $10.2 \pm .52$ and $12.5 \pm .56$ kg for HH, AH, 1S3H and SH groups respectively. HH heifers also had the lowest pregnancy rates, while other contrasts between crossbred groups and contrasts for date of pregnancy were nonsignificant. An analysis of only heifers reaching puberty by the end of the breeding period found breed differences for pregnancy rate no longer existed, but significant breed group contrasts for other measures of reproductive traits were still important.

Rankings of groups for growth traits found SH heifers were usually heavier at any age and grew faster during the postweaning period in comparison to other groups. AH and 1S3H groups were similar in most respects and HH heifers were usually lighter. Height comparisons made at any age found SH groups tallest, with 1S3H heifers taller than either AH or HH groups, which did not differ. Simmental-cross heifers were taller at maturity but not necessarily heavier. No differences between breed groups were evident for maturing rate at puberty, but Simmental-cross heifers reached a higher percentage of their mature height at 365 d than HH heifers, while no differences were noted for maturing rate as measured by weight.

Prediction equations for pubertal traits and traits at first pregnancy accounted for 22 to 76% of the variation associated with these traits. Only the prediction equation for puberty height appeared it could be made with high accuracy. Relationships (correlations and regressions) of growth traits and puberty age showed most traits measuring growth rate or weight or height traits adjusted to a constant age decreased puberty age and took on a greater magnitude than actual

measurements. Correlations between puberty age and traits measured by weight were greater than traits measured by height, but standard partial regression coefficients of these covariates indicated height measured traits had greater influence on puberty age than weight measured traits. Most weight or height traits measured at puberty and subsequent to puberty had positive and usually moderate correlations with puberty age. Most associations with traits at first pregnancy were low or non-significant.

The effect of heterosis was suggested to be present for many traits in this study, as F_1 heifers generally showed the greatest values believed partially due to heterosis with the expected reduction of heterosis by one-half seen in 1S3H heifers. However, the true extent of its effects could not be documented.

Although the results reported here are a small segment of information that is available and which is likely to become available in the near future, information concerning early reproductive traits and the extent of their relationships with other production traits should assist producers in designing management systems and guide future research in discovering ways to produce red meat more efficiently.

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APPENDIX

APPENDIX TABLE 41. ANALYSIS OF VARIANCE FOR PREGNANCY TRAITS OF HEIFERS NOT REACHING PUBERTY (N=209)

Source	df	Mean squares	
		Rate (%) ²	Breeding efficiency (0-7) ²
Breed	3	.226	1.936
Year	3	1.187**	32.137**
Age of dam	2	.037	1.507
Residual	200	.123	3.716

** P<.01

APPENDIX TABLE 42. ANALYSIS OF VARIANCE FOR PERCENT REACHING PUBERTY BY MONTH

Source	df	Mean Squares					
		12	df	13	14	15	16
Breed (B)	3	.827*	3	1.674**	1.408**	.510**	.052**
Year (Y)	3	1.324*	3	.505*	.557**	.671**	.086**
Age of dam	2	.072	2	.065	.123	.026	.009
B x Y	6	.529**					.055**
Residual	215	.203	221	.163	.111	.082	.015

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

APPENDIX TABLE 43. ANALYSIS OF VARIANCE FOR PERCENT REACHING PUBERTY BY WEIGHT

Source	df	Mean squares				
		273 kg	295 kg	318 kg	340 kg	364 kg
Breed	3	.0125	.5591	.4231	.0703	.0483
Year	3	.2068	.5885	.7007*	.1456	.0536
Age of dam	2	.1292	.1487	.0186	.0520	.0326
Residual	221	.1167	.2345	.2177	.0909	.0290

P<.07

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

APPENDIX TABLE 44. ANALYSIS OF VARIANCE FOR BIRTH TRAITS

Source	df	Mean squares	
		Birth date(d ²)	Birth weight(kg ²)
Breed	3	454.30*	160.67**
Year	3	118.79	35.25
Age of dam	2	25.25	63.08*
Residual	221	154.86	20.13

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

APPENDIX TABLE 45. BREED GROUP MEANS FOR BIRTH TRAITS

Breed group	Birth date(d)	Birth weight(kg)
μ	92.8 ± 1.1	37.4 ± .40
HH	92.7 ± 1.6 ^{ab}	36.6 ± .58 ^a
AH	88.6 ± 2.0 ^a	35.6 ± .71 ^a
1S3H	93.4 ± 1.8 ^{ab}	37.3 ± .66 ^a
SH	96.5 ± 2.1 ^b	40.1 ± .75 ^b

a, b Means within a column with no superscript letters in common differ (P<.05).

APPENDIX TABLE 46. ANALYSES OF VARIANCE FOR TRAITS AT WEANING

Source	df	180 d weight (kg ²) M.S.	df	Prewaning average daily gain (kg/d) ² M.S.	df	180d Height (cm ²) M.S.	df	Weight/ height (kg/cm) ² M.S.	df	Condition score (1-9) ² M.S.
Breed (B)	3	2634.5**	3	.060**	3	202.5**	3	.134**	3	3.33*
Year (Y)	3	1091.9**	3	.028*	3	31.0*	3	.245**	3	10.14**
Age of dam (A)	2	1763.9**	2	.038*	2	15.9	2	.208**	2	9.29**
B x A									5	2.81*
Y x A	5	937.0*	5	.027*					6	2.84**
Residual	216	342.8	216	.009*	221	8.9	221	.028	210	.73

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

M.S. = Mean squares

APPENDIX TABLE 47. BREED GROUP MEANS AND STANDARD ERRORS FOR TRAITS AT WEANING

Breed group	180 d weight(kg)	Prewaning average daily gain(kg)	180 d height(cm)	Weight/height (kg/cm)	Condition score (1-9)
μ	189.5 ± 1.8	.845 ± .009	100.1 ± .27	1.82 ± .02	5.84 ± .09
HH	180.4 ± 2.5 ^a	.799 ± .013 ^a	99.7 ± .44 ^a	1.76 ± .02 ^a	5.94 ± .13 ^a
AH	189.7 ± 3.0 ^{bc}	.857 ± .016 ^b	98.3 ± .47 ^a	1.88 ± .03 ^b	5.40 ± .21 ^b
IS3H	190.2 ± 2.8 ^b	.850 ± .015 ^b	100.7 ± .44 ^b	1.82 ± .02 ^{ab}	6.20 ± .14 ^a
SH	197.5 ± 3.2 ^c	.875 ± .016 ^b	102.9 ± .50 ^c	1.83 ± .03 ^{ab}	5.83 ± .17 ^{ab}

a, b, c Means within column with no superscript letter in common differ significantly (P<.05).

APPENDIX TABLE 48. ANALYSIS OF VARIANCE FOR UNADJUSTED TRAITS AT WEANING

Source	df	Actual weaning weight (kg) Mean squares	df	Actual weaning height (cm) Mean squares	df	Weaning weight/day (kg/d) Mean squares
Breed	3	2348.45**	3	156.36**	3	.086**
Year (Y)	3	1292.02*	3	39.01*	3	.033*
Age of dam (A)	2	1851.56*	2	21.59	2	.054**
Y x A	5	1002.24*			5	.029*
Residual	216	441.31	221	11.19	216	.011

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

APPENDIX TABLE 49. ANALYSIS OF VARIANCE FOR UNADJUSTED YEARLING TRAITS AND 18 MONTH HEIGHT

Source	df	Actual yearling weight (kg) Mean squares	df	Actual yearling height (cm) Mean squares	df	Yearling weight/day (kg/d) Mean squares	df	18 month height (cm) Mean squares
Breed	3	9872.39**	3	279.77**	3	.077**	3	376.00**
Year (Y)	3	5305.81**	3	80.76**	3	.035**	3	143.49**
Age of dam (A)	2	332.33	3	11.44	2	.003	2	10.00
Y x A	5	2797.35**			5	.017		
Residual	216	718.18	221	12.55	216	.004	221	11.51

** P<.01

APPENDIX TABLE 50. BREED GROUP MEANS AND STANDARD ERRORS FOR UNADJUSTED TRAITS AT WEANING

Breed group	Actual weaning weight (kg)	Actual weaning height (cm)	Weaning weight/d (kg/d)
μ	191.68 $\pm$ 2.06	104.13 $\pm$.30	1.05 $\pm$.010
HH	182.63 $\pm$ 2.86 ^a	102.51 $\pm$.43 ^a	1.00 $\pm$.014 ^a
AH	196.09 $\pm$ 3.44 ^b	102.84 $\pm$.53 ^a	1.05 $\pm$.017 ^b
1S3H	191.87 $\pm$ 3.21 ^b	104.63 $\pm$.49 ^b	1.06 $\pm$.016 ^b
SH	196.14 $\pm$ 3.58 ^b	106.52 $\pm$.56 ^c	1.10 $\pm$.018 ^c

a, b, c Means within a column with different superscript letters differ (P<.05).

APPENDIX TABLE 51. BREED GROUP MEANS AND STANDARD ERRORS FOR UNADJUSTED YEARLING TRAITS AND 18 MONTH HEIGHT

Breed group	Actual yearling weight (kg)	Actual yearling height (cm)	Yearling weight/d (kg/d)	18 month height (cm)
μ	305.11 $\pm$ 2.63	116.00 $\pm$.32	.819 $\pm$.007	122.64 $\pm$.31
HH	287.88 $\pm$ 3.65 ^a	113.45 $\pm$.46 ^a	.772 $\pm$.009 ^a	119.97 $\pm$.44 ^a
AH	311.89 $\pm$ 4.39 ^b	114.90 $\pm$.56 ^b	.827 $\pm$.010 ^b	121.32 $\pm$.54 ^b
1S3H	302.18 $\pm$ 4.10 ^b	116.61 $\pm$.52 ^c	.813 $\pm$.101 ^b	122.78 $\pm$.50 ^c
SH	318.49 $\pm$ 4.58 ^c	119.04 $\pm$.59 ^d	.864 $\pm$.011 ^c	126.49 $\pm$.56 ^d

a, b, c, d Means within columns with different superscript letters differ (P<.05).

APPENDIX TABLE 52. RESIDUAL CORRELATIONS FOR UNADJUSTED TRAITS AND TRAITS AT PUBERTY AND PREGNANCY

Trait	Puberty ^a			1st Pregnancy			
	Age	Weight	Height	Rate ^a	Breeding efficiency ^a	Date ^b	Number of services ^b
Actual weaning weight	-.16	.49	.35	.15	.15	.01	.02
Actual weaning height	-.13	.41	.59	.20	.14	.07	.18
Weaning weight/day	-.28	.37	.27	.07	.08	-.07	.01
Actual yearling weight	-.20	.60	.41	.26	.27	-.06	.03
Actual yearling height	-.07	.42	.83	.20	.19	.07	.12
Yearling weight/day	-.29	.59	.38	.23	.24	-.07	-.01
18 month height	.01	.47	.69	.07	.08	.10	.08

^a Correlations greater than .14 are significantly different from zero ($P < .05$), $r > .18$, ($P < .01$).

^b Correlations greater than .16 are significantly different from zero ($P < .05$), $r > .21$, ($P < .01$).

APPENDIX TABLE 53. YEARLY MEANS AND STANDARD ERRORS

Trait	Year			
	1976	1977	1978	1979
Puberty age (d)	363.0 ± 7.7	375.0 ± 4.6	402.5 ± 5.3	386.3 ± 7.7
Puberty weight (kg)	295.3 ± 4.4	303.8 ± 3.6	303.8 ± 4.2	317.5 ± 6.1
Puberty height (cm)	114.8 ± .5	115.2 ± .4	116.2 ± .5	117.9 ± .7
Puberty weight/day (kg/d)	.809 ± .011	.815 ± .009	.756 ± .011	.824 ± .016
Puberty height/day (cm/d)	.317 ± .004	.310 ± .003	.292 ± .004	.308 ± .005
Puberty weight/height (kg/cm)	2.57 ± .03	2.63 ± .03	2.61 ± .03	2.69 ± .04
% by 12 mo	49.8 ± 6.7	48.1 ± 5.7	18.5 ± 6.5	29.5 ± 9.5
% by 13 mo	85.9 ± 5.9	78.7 ± 5.0	63.6 ± 5.7	77.8 ± 8.3
% by 14 mo	98.0 ± 4.9	86.2 ± 4.0	73.6 ± 4.7	84.0 ± 6.8
% by 15 mo	102.0 ± 4.2	92.5 ± 3.5	75.8 ± 4.0	86.5 ± 5.9
% by 16 mo	100.0 ± 1.8	100.5 ± 1.6	93.75 ± 1.8	102.9 ± 2.6
% by 250 kg	21.5 ± 5.0	19.2 ± 4.2	11.7 ± 4.8	5.2 ± 7.0
% by 273 kg	55.6 ± 7.1	40.1 ± 5.9	46.1 ± 6.8	24.4 ± 9.9
% by 295 kg	76.6 ± 6.9	67.5 ± 5.7	66.1 ± 6.5	41.5 ± 9.6
% by 318 kg	92.2 ± 4.4	90.7 ± 3.7	87.5 ± 4.2	77.3 ± 6.2
% by 340 kg	99.8 ± 2.5	95.3 ± 2.1	92.2 ± 2.4	95.3 ± 3.5
% by 364 kg	100.6 ± .9	98.9 ± .8	100.4 ± .9	100.0 ± 1.4
1st pregnancy rate (%)	64.6 ± 6.0	78.6 ± 5.0	76.0 ± .06	93.1 ± 8.5
Breeding efficiency (1-7)	5.00 ± .36	5.46 ± .30	4.97 ± .35	6.05 ± .51
Pregnancy date (d)	162.6 ± 2.8	153.2 ± 2.1	162.4 ± 2.5	161.0 ± 3.4
Number of services (1-3)	1.52 ± .11	1.22 ± .08	1.46 ± .10	1.46 ± .13
Birth date (d)	95.0 ± 1.8	92.1 ± 1.5	93.1 ± 1.7	91.0 ± 2.6
Birth weight (kg)	38.60 ± .66	37.56 ± .55	36.84 ± .63	36.56 ± .92
Preweaning ADG (kg/d)	.857 ± .016	.850 ± .013	.800 ± .017	.874 ± .025
180 d weight (kg)	192.9 ± 3.1	190.8 ± 2.6	180.7 ± 3.2	193.4 ± 4.9
180 d height (cm)	99.7 ± .4	99.2 ± .4	100.3 ± .4	101.2 ± .6
Weaning condition score (1-9)	6.30 ± .15	6.28 ± .12	5.48 ± .16	5.29 ± .23

APPENDIX TABLE 53. YEARLY MEANS AND STANDARD ERRORS (CONTINUED)

Trait	Year			
	1976	1977	1978	1979
Actual weaning weight (kg)	194.1 ± 3.5	194.7 ± 2.9	182.2 ± 3.7	195.8 ± 5.5
Actual weaning height (cm)	103.4 ± .5	103.3 ± .4	104.3 ± .5	105.5 ± .7
Weaning weight/height (kg/cm)	1.89 ± .02	1.87 ± .02	1.76 ± .03	1.80 ± .03
Weaning weight/d (kg/d)	1.07 ± .02	1.06 ± .01	1.00 ± .02	1.07 ± .03
Prefeeding ADG (kg/d)	.483 ± .021	.340 ± .017	.180 ± .021	.261 ± .033
140 d ADG (kg/d)	.571 ± .016	.655 ± .013	.704 ± .016	.840 ± .025
365 d weight (kg)	294.7 ± 4.0	301.2 ± 3.4	284.2 ± 4.3	320.1 ± 6.4
365 d height (cm)	113.6 ± .5	114.0 ± .4	112.2 ± .5	115.2 ± .7
ADG - birth to yearling (kg/d)	.700 ± .010	.722 ± .009	.677 ± .011	.776 ± .016
Yearling condition score	7.06 ± .14	6.15 ± .11	5.64 ± .14	6.36 ± .21
Actual yearling weight (kg)	298.6 ± 4.4	307.4 ± 3.7	288.5 ± 4.7	325.8 ± 7.0
Actual yearling height (cm)	155.7 ± .5	166.3 ± .4	114.4 ± .5	117.7 ± .7
Yearling weight/height (kg/cm)	2.59 ± .03	2.63 ± .03	2.53 ± .03	2.76 ± .05
Yearling weight/d (kg/d)	.804 ± .011	.823 ± .009	.776 ± .012	.874 ± .017
Pelvic width (cm)	10.00 ± .10	10.66 ± .10	10.27 ± .11	10.25 ± .11
Pelvic height (cm)	13.23 ± .14	14.00 ± .12	12.71 ± .13	12.90 ± .20
Pelvic area (cm ²)	136.1 ± 2.6	149.6 ± 2.2	131.0 ± 2.5	137.8 ± 3.6
Postfeeding ADG (kg/d)	.530 ± .035	.006 ± .029	.452 ± .039	.518 ± .055
Prebreeding weight (kg)	318.5 ± 4.5	307.6 ± 3.8	307.5 ± 4.8	349.7 ± 7.1
18 mo height	121.2 ± .5	121.2 ± .4	124.2 ± .5	124.0 ± .5

APPENDIX TABLE 54. MEANS AND STANDARD ERRORS FOR AGE OF DAM CLASSES

Trait	Age of dam (yr)		
	3	4	≥5
Puberty age (d)	386.0 ± 7.3	381.2 ± 7.3	378.0 ± 3.1
Puberty weight (kg)	303.1 ± 5.7	304.4 ± 4.5	307.8 ± 2.5
Puberty height (cm)	116.4 ± .5	116.4 ± .6	116.1 ± .3
Puberty weight/day (kg/d)	.787 ± .016	.796 ± .012	.819 ± .007
Puberty height/day (cm/d)	.302 ± .005	.308 ± .004	.310 ± .002
Puberty weight/height	2.61 ± .040	2.62 ± .032	2.64 ± .017
% by 12 mo	32.9 ± 8.9	36.6 ± 7.0	40.0 ± 3.8
% by 13 mo	76.3 ± 7.8	73.6 ± 6.1	79.6 ± 3.3
% by 14 mo	88.7 ± 6.5	79.8 ± 5.1	87.9 ± 2.8
% by 15 mo	86.8 ± 5.5	89.5 ± 4.4	91.4 ± 2.4
% by 16 mo	101.1 ± 2.5	98.1 ± 1.9	98.7 ± 1.1
% by 250 kg	3.2 ± 1.2	-.1 ± 1.0	-.05 ± .1
% by 273 kg	21.2 ± 6.6	11.1 ± 5.2	10.8 ± 2.8
% by 295 kg	47.8 ± 9.4	40.2 ± 7.4	36.7 ± 4.0
% by 318 kg	60.7 ± 9.0	65.2 ± 7.1	62.9 ± 3.9
% by 340 kg	82.6 ± 5.8	89.0 ± 4.6	89.2 ± 2.5
% by 364 kg	93.3 ± 3.3	95.6 ± 2.6	98.1 ± 1.4
1st pregnancy rate (%)	81.4 ± 8.0	73.3 ± 6.3	79.5 ± 3.4
Breeding efficiency (1-7)	5.46 ± .48	5.14 ± .38	5.50 ± .21
Pregnancy date (d)	165.5 ± 3.4	155.0 ± 2.7	156.4 ± 1.4
Number of services (1-3)	1.58 ± .13	1.30 ± .11	1.36 ± .06
Birth date (d)	93.0 ± 2.4	93.3 ± 1.9	92.1 ± 1.0
Birth weight (kg)	36.38 ± .87	37.31 ± .68	38.48 ± .37
Prewaning ADG (kg/d)	.807 ± .019	.862 ± .017	.862 ± .008
180 d weight (kg)	181.7 ± 3.7	192.4 ± 3.3	194.3 ± 1.5
180 d height (cm)	99.5 ± .6	100.3 ± .5	100.6 ± .2
Weaning condition score (1-9)	5.34 ± .19	5.97 ± .16	6.22 ± .16

APPENDIX TABLE 54. MEANS AND STANDARD ERRORS FOR AGE OF DAM CLASSES
(CONTINUED)

Trait	Age of dam (yr)		
	3	4	≥5
Actual weaning weight (kg)	184.5 ± 4.2	193.2 ± 3.7	197.4 ± 1.7
Actual weaning height (cm)	103.4 ± .6	104.2 ± .5	104.7 ± .3
Weaning weight/height (kg/cm)	1.76 ± .03	1.83 ± .03	1.88 ± .01
Weaning weight/d (kg/d)	1.01 ± .02	1.07 ± .02	1.08 ± .01
Prefeeding ADG (kg/d)	.308 ± .024	.316 ± .109	.305 ± .010
140 d ADG (kg/d)	.716 ± .019	.690 ± .017	.671 ± .008
365 d weight (kg)	295.7 ± 4.9	303.4 ± 4.3	301.0 ± 2.0
365 d height (cm)	113.1 ± .7	114.2 ± .5	114.0 ± .3
ADG - birth to weaning (kg/d)	.710 ± .012	.727 ± .011	.718 ± .005
Yearling condition score (1-9)	6.24 ± .16	6.44 ± .14	6.23 ± .07
Actual yearling weight (kg)	301.5 ± 5.3	307.0 ± 4.7	306.8 ± 2.2
Actual yearling height (cm)	115.3 ± .7	116.4 ± .6	116.3 ± .3
Yearling weight/height (kg/cm)	2.60 ± .04	2.64 ± .03	2.64 ± .02
Yearling weight/day (kg/d)	.808 ± .013	.828 ± .011	.822 ± .006
Pelvic width (cm)	10.29 ± .15	10.53 ± .12	10.53 ± .07
Pelvic height (cm)	12.99 ± .19	13.38 ± .15	13.26 ± .08
Pelvic area (cm ²)	134.2 ± 3.4	141.6 ± 2.7	140.1 ± 1.5
Postfeeding ADG (kg/d)	.400 ± .040	.370 ± .031	.377 ± .017
Prebreeding weight (kg)	318.2 ± 5.4	321.5 ± 4.8	322.8 ± 2.3
18 mo height (cm)	122.2 ± .7	122.6 ± .6	123.1 ± .3

APPENDIX TABLE 55. RESIDUAL CORRELATIONS AMONG VARIOUS TRAITS OF HEIFERS DIFFERING IN MILK PRODUCTION POTENTIAL

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1) Birth date	.26	-.01	.06	.12	-.33	-.44	-.29	-.40	.19	-.08	-.01	.00	.06	-.12	-.17	-.38	-.26	-.36	-.01	-.29	-.20
2) Birth weight		.18	.41	.41	.05	.24	.25	.20	.43	.16	.29	.49	.34	.31	.26	.35	.25	.31	.49	.08	.08
3) Preweaning ADG			.97	.59	.62	.88	.55	.87	.95	-.04	.05	.70	.43	.72	.41	.65	.42	.61	.70	.29	.23
4) 180 d weight				.64	.59	.87	.57	.86	.99	.00	.12	.77	.48	.74	.45	.69	.45	.64	.77	.29	.24
5) 180 d height					.23	.53	.87	.33	.64	.10	.21	.61	.74	.57	.26	.53	.68	.35	.61	.33	.25
6) Weaning condition score						.71	.40	.73	.56	.00	-.03	.43	.14	.47	.39	.53	.23	.54	.44	.15	.24
7) Actual weaning weight							.66	.97	.79	.03	.13	.69	.41	.73	.50	.81	.53	.75	.70	.40	.31
8) Actual weaning height								.51	.50	.05	.28	.58	.66	.58	.23	.68	.76	.51	.58	.45	.33
9) Weaning weight/height									.79	-.01	.07	.63	.26	.67	.48	.74	.37	.74	.64	.33	.26
10) Weaning weight/day										-.01	.11	.76	.48	.71	.41	.62	.39	.58	.75	.25	.20
11) Prefeeding ADG											.16	.31	.15	.31	.34	.31	.16	.29	.31	.11	.06
12) 140 d ADG												.65	.33	.64	.28	.61	.32	.60	.65	.33	.15
13) 365 d weight													.56	.98	.56	.92	.54	.87	.98	.43	.30
14) 365 d height														.53	.22	.50	.95	.21	.57	.40	.24
15) ADG - birth to 1 year															.57	.95	.56	.90	.98	.46	.32
16) Yearling condition score																.59	.26	.60	.56	.27	.19
17) Actual yearling weight																	.60	.94	.93	.47	.33
18) Actual yearling height																		.31	.55	.48	.29
19) Yearling weight/height																			.88	.41	.30
20) Yearling weight/day																				.43	.30
21) Pelvic width																					.46
22) Pelvic height																					
23) Pelvic area																					
24) Postfeeding ADG																					
25) Prebreeding weight																					
26) Puberty age																					
27) Puberty weight																					
28) Puberty height																					
29) Puberty weight/day																					
30) Puberty height/day																					
31) Puberty weight/height																					
32) Percent by 12 mo																					
33) Percent by 13 mo																					
34) Percent by 14 mo																					
35) Percent by 15 mo																					
36) Percent by 16 mo																					
37) Percent by 273 kg																					
38) Percent by 295 kg																					
39) Percent by 318 kg																					
40) Percent by 340 kg																					
41) Percent by 364 kg																					
42) 18 mo height																					
43) 1st pregnancy rate																					
44) Breeding efficiency																					
45) Pregnancy date																					
46) No. services/pregnancy																					

^a Correlations greater than .14 are significantly different from zero ($P < .05$), $r > .18$, ($P < .01$).

^b Correlations greater than .16 are significantly different from zero ($P < .05$), $r > .21$, ($P < .01$).

APPENDIX TABLE 55. RESIDUAL CORRELATIONS AMONG VARIOUS TRAITS OF HEIFERS
DIFFERING IN MILK PRODUCTION POTENTIAL (CONTINUED)

23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45 ^b	46 ^b	
-.29	.14	-.34	-.16	-.23	-.15	-.09	.12	-.22	.28	.00	.02	-.05	.13	.18	.19	.16	.11	.03	-.16	-.16	-.15	-.01	.08	(1)
.10	.15	.38	-.08	.32	.28	.40	.19	.28	.04	.03	.03	.05	.04	-.13	-.32	-.29	-.20	-.13	.32	.02	.00	.01	.02	(2)
.28	-.09	.62	-.26	.35	.26	.65	.39	.34	.24	.21	.11	.14	.05	-.29	-.32	-.21	-.21	-.08	.34	.10	.11	-.06	.02	(3)
.28	-.05	.67	-.27	.41	.30	.71	.42	.38	.24	.21	.11	.15	.05	-.30	-.38	-.27	-.24	-.10	.39	.09	.11	-.05	.02	(4)
.34	-.09	.51	-.23	.42	.56	.56	.46	.17	.19	.15	.11	.12	.12	-.22	-.26	-.24	-.22	-.07	.66	.08	.13	.06	.15	(5)
.14	-.08	.51	-.13	.26	.10	.40	.18	.29	.03	.13	.12	.13	.07	-.17	-.22	-.14	-.11	.00	.15	.15	.16	.00	.06	(6)
.40	-.13	.77	-.16	.49	.35	.67	.31	.47	.07	.19	.09	.15	-.01	-.36	-.43	-.33	-.27	-.10	.03	.00	.00	.01	.02	(7)
.44	-.13	.62	-.13	.41	.59	.56	.37	.27	.03	.13	.09	.14	.05	-.29	-.33	-.31	-.27	-.08	.74	.20	.16	.07	.18	(8)
.32	-.11	.71	-.15	.45	.25	.62	.25	.47	.08	.18	.08	.14	-.03	-.32	-.41	-.29	-.21	-.08	.28	.14	.16	-.08	.01	(9)
.24	-.03	.50	-.28	.37	.27	.69	.43	.34	.27	.20	.11	.13	.07	-.26	-.36	-.24	-.19	-.08	.56	.23	.24	-.07	.01	(10)
.08	.03	.29	.10	.20	.09	.32	.14	.21	.20	.17	.22	.27	.09	.00	-.02	-.04	-.04	.02	.07	-.10	.17	-.08	-.12	(11)
.29	.02	.61	-.14	.40	.24	.52	.23	.39	.03	.11	.13	.21	.08	-.27	-.31	-.37	-.25	-.12	.44	.22	.14	-.02	.01	(12)
.49	-.01	.86	-.29	.56	.38	.87	.46	.53	.21	.23	.18	.25	.07	-.40	-.48	-.41	-.34	-.14	.55	.23	.24	-.07	-.01	(13)
.39	.04	.50	-.12	.35	.80	.47	.44	.11	.11	.04	.03	.09	.14	-.28	-.27	-.23	-.24	-.08	.71	.15	.13	.06	.10	(14)
.44	-.07	.93	-.28	.55	.36	.86	.45	.53	.19	.25	.18	.26	.06	-.41	-.46	-.40	-.34	-.12	.55	.25	.26	-.08	.00	(15)
.26	.04	.59	-.15	.38	.12	.58	.24	.41	.19	.17	.06	.14	.00	-.33	-.34	-.23	-.23	-.15	.22	.05	.04	-.06	.00	(16)
.46	-.07	.94	-.20	.60	.41	.83	.37	.58	.09	.22	.16	.25	.02	-.43	-.51	-.46	-.36	-.14	.58	.26	.27	-.06	.03	(17)
.46	.00	.60	-.07	.42	.83	.48	.39	.18	.02	.04	.02	.10	.09	-.32	-.32	-.27	-.27	-.09	.73	.19	.16	.07	.12	(18)
.39	-.10	.91	-.21	.55	.15	.79	.29	.62	.21	.24	.18	.25	.06	-.39	-.48	-.43	-.32	-.12	.39	.24	.27	-.09	-.02	(19)
.41	-.03	.91	-.29	.59	.38	.88	.48	.55	.09	.24	.18	.26	.07	-.40	-.48	-.42	-.34	-.13	.56	.23	.24	-.07	-.01	(20)
.86	.00	.47	-.09	.31	.35	.40	.21	.24	.00	.10	.09	.09	.04	-.32	-.29	-.19	-.16	-.02	.37	.17	.19	.08	.11	(21)
.84	-.06	.32	-.03	.24	.24	.25	.11	.20	-.01	.04	.02	.21	.04	-.30	-.23	-.10	-.20	-.09	.26	.03	.05	.04	.07	(22)
-.03	.46	-.07	.32	.35	.38	.19	.26	.00	.09	.06	.17	.00	-.37	-.18	-.22	-.06	-.01	.38	.14	.16	-.06	.00	(23)	
	.14	.15	.16	.05	.02	-.14	.18	.00	-.18	-.21	-.07	.00	-.09	-.15	-.18	-.08	-.10	.00	.18	-.04	.16	.07	(24)	
	-.16	.63	.43	.83	.34	.60	.06	.16	.10	.19	.03	-.43	-.54	-.49	-.37	-.17	.54	.25	.25	-.01	.04	(25)		
		.54	.44	-.42	-.92	.48	-.64	-.78	-.79	-.70	-.29	-.21	-.40	-.46	-.34	.31	.02	-.40	-.42	.23	-.02	(26)		
			.67	.48	-.33	.95	-.37	-.39	-.48	-.35	-.17	-.59	-.78	-.78	-.59	-.41	.46	-.09	-.11	.13	.01	(27)		
				.22	-.11	.42	-.29	-.36	-.37	-.30	-.37	-.39	-.51	-.51	-.46	-.31	.69	-.07	-.10	.16	.10	(28)		
					.59	.50	.30	.39	.25	.27	.08	-.38	-.41	-.33	-.25	-.10	.45	.31	.28	-.05	.04	(29)		
						-.36	.66	.70	.66	.57	.21	.08	.24	.31	.19	.20	.24	.39	.38	-.13	.08	(30)		
							-.34	-.33	-.43	-.30	-.18	-.58	-.76	-.75	-.53	-.37	.28	.07	-.09	.10	-.02	(31)		
								.39	.25	.16	.03	.11	.32	.31	.15	.09	-.03	.09	.06	-.01	-.08	(32)		
									.72	.55	.18	.17	.27	.28	.29	.21	-.05	.34	.34	-.15	-.03	(33)		
										.77	.26	.16	.32	.38	.39	.30	-.04	.40	.44	-.30	-.02	(34)		
											.35	.11	.22	.32	.24	.37	.06	.49	.54	-.38	-.04	(35)		
												.04	.13	.14	.09	.18	-.31	.14	.16	-.20	.08	(36)		
													.46	.26	.12	.07	-.38	-.08	-.03	-.21	.18	(37)		
														.58	.27	.17	-.36	.06	.08	-.04	-.05	(38)		
															.46	.26	-.30	.13	.16	-.11	.04	(39)		
																.54	-.21	.13	.15	-.08	.02	(40)		
																	-.06	.24	.24	-.12	-.05	(41)		
																		.07	.02	.10	.08	(42)		
																			.04	--	--	(43)		
																						-.71	-1.00	(44)
																							.71	(45)

APPENDIX TABLE 56. SIMPLE MEANS AND STANDARD ERRORS FOR VARIOUS TRAITS OF 3S1H HEIFERS

Trait	Mean	n ^a
Birth date (d)	74.0 ± 3.0	58
Birth weight (kg)	41.1 ± .66	58
Yearling condition score (1-9)	6.1 ± .17	59
Yearling wither height (cm)	114.8 ± .46	59
Yearling hip height (cm)	120.1 ± .78	20
Yearling pelvic height (cm)	14.14 ± .15	59
Yearling pelvic width (cm)	11.42 ± .10	59
Yearling weight (kg)	340.2 ± 6.7	39
Prebreeding weight (kg)	342.8 ± 7.7	20
Pregnancy rate (%)	66.1 ± 10.7	59
Number of services (1-3)	1.29 ± .15	59
18 mo weight (kg)	433.6 ± 5.3	59
18 mo height (cm)	123.6 ± .8	59
18 mo condition score (1-9)	6.36 ± .14	59
Adjusted 18 mo weight (kg)	420.8 ± 5.2	58
30 mo weight (kg)	445.6 ± 4.7	57
36 mo weight (kg)	495.9 ± 8.5	57

^a n indicates the number of heifers for which data was available or had been recorded.



N378
St326
cop.2

Steffan, C. A.
Early reproductive
traits in beef heifers
differing in milk
production

DATE	ISSUED TO

MAIN VOL.

N378
St 326
Cap 2