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

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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APPROVAL

of a thesis submitted by

Charles Allan Steffan

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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Signature Charles A. Steffan

Date August 5, 1983

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.

In the fall of 1977, he enrolled at North Dakota State University and graduated with a Bachelor of Science degree in Animal Science in May of 1981.

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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 citings 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

First Author	Year	N	Puberty Age	Puberty Weight	Pregnancy Rate	Comments
Angus (A)						
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)

First Author	Year	N	Puberty Age	Puberty Weight	Pregnancy Rate	Comments
			Friesian (F)			
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)

First Author	Year	N	Puberty Age	Puberty Weight	Pregnancy Rate	Comments
			Shorthorn (SH)			
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 Age	Puberty Weight	Pregnancy Rate	Comments
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)

First Author	Year	N	Puberty Age	Puberty Weight	Pregnancy Rate	Comments
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)

First Author	Year	N	Puberty Age	Puberty Weight	Pregnancy Rate	Comments
			Brown Swiss (BS)			
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 Age	Puberty Weight	Pregnancy Rate	Comments
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)

First Author	Year	N	Puberty Age	Puberty Weight	Pregnancy Rate	Comments
Laster	1979	81	343	286	93	GA,GH

Jersey (J)

First Author	Year	N	Puberty Age	Puberty Weight	Pregnancy Rate	Comments
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)

First Author	Year	N	Puberty Age	Puberty Weight	Pregnancy Rate	Comments
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)

First Author	Year	N	Puberty Age	Puberty Weight	Pregnancy Rate	Comments
			Maine Anjou (M)			
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)

First Author	Year	N	Puberty Age	Puberty Weight	Pregnancy Rate	Comments
			South Devon (SD)			
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 F_1 cross heifers are given by sire breed code first and dam breed code second, F_2 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 ± .30 (Arije and Wiltbank, 1971), .67 ± .24 (Smith et al., 1976), .41 ± .17 (Laster et al., 1979), .41 (Lunstra, 1982) and .48 ± .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 ± .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 ± 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 ± .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 Vandenbergh (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 affect 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 ± .27. This is higher than that reported by Laster et al. (1979) of .40 ± .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

	Breed Type [a]					
Year	HH	AH	1S3H	SH	3S1H	Total
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 PI_3 (parainfluenza$_3$). 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

	Consumed Ration (kg/day)				140 d
Year	Silage	Grain	Hay	(Pro)[a]	Average daily gain
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 trails 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:

Number of services	Pregnant	Code
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:

$Y_{ijkl} = u + b_i + c_j + d_k$ + (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^2_E.

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

	Breed Group				
Year	HH	AH	1S3H	SH	Total
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)

		Mean squares					
Source	df	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 ± 3.4	305.07 ± 2.67	116.00 ± .32
HH	406.63 ± 4.9 [a]	300.77 ± 3.84 [a]	114.62 ± .46 [a]
AH	371.05 ± 5.9 [b]	301.92 ± 4.67 [ab]	114.16 ± .57 [a]
1S3H	381.63 ± 5.5 [b]	304.81 ± 4.37 [ab]	116.71 ± .53 [b]
SH	367.51 ± 6.2 [b]	312.78 ± 4.91 [b]	118.50 ± .60 [c]
Contrast	**Mean difference and standard error**		
SH versus 1S3H	-14.12 ± 7.2†	7.97 ± 5.70	1.80 ± .69**
SH versus AH	-3.54 ± 8.1	10.87 ± 6.38	4.34 ± .77**
SH versus HH	-39.12 ± 7.4**	12.02 ± 5.84*	3.88 ± .71**
1S3H versus AH	10.59 ± 7.7	2.89 ± 6.05	2.55 ± .74**
1S3H versus HH	-25.00 ± 6.9**	4.05 ± 5.46	2.09 ± .66**
AH versus HH	-35.59 ± 7.1**	1.15 ± 5.62	-0.46 ± .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).