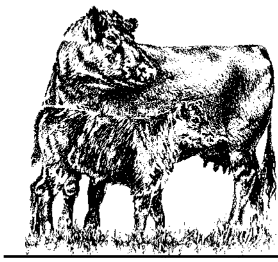

Genetics of Reproduction

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The reproductive efficiency of heifers, cows, and bulls is extremely important in determining net return to the cow-calf producer. Past research has shown that many of the measures of reproduction had low heritability and would respond slowly to selection. Several of these traits were gross measures made up of several component traits. These complex traits are affected greatly by environmental effects masking the expression of any underlying genetic differences among animals in their genetic potentials for efficient reproduction. Emphasis has been placed on improved management, nutrition, and the use of hybrid vigor resulting from crossing systems to improve reproductive efficiency.

Recent studies have looked at new measures or component parts of the more complex measures of reproductive efficiency. We may have some real breakthroughs in which selection can be used effectively to improve the genetic potential for improved reproduction. This publication reviews some of the more recent studies in this area although it is not a comprehensive review.

Reproductive Measures in Young Bulls

A breeding soundness exam (BSE) on yearling bulls at the completion of the performance test has been an integral part of data collection procedures at the San Juan Basin Research Center since the early 1950s. The early exams included the seminal traits of concentration, motility, percent live cells, percent primary abnormalities, percent secondary abnormalities, and percent normal sperm, along with physical soundness traits. Scrotal circumference (SC) was added to the list of measurements in 1969. The present BSE is that recommended by the Society of Theriogenology. The scoring system used for bulls 12 to 14 months of age is:

Classification	Very good	Good	Fair	Poor
Motility score	20	12	10	3
% motility	70%+	50-70%	30-50%	30%-
Abnormal sperm score	40	24	10	3
% abnormals	10%-	10-24%	24-35%	35%+
Scrotum circum. score	40	24	10	10
Scrotum circum. (cm)	34+	30-34	30-	30-
Total score	100	60	30	16

Seminal Traits

Estimates of heritability for several seminal traits along with estimates of genetic correlations among these traits are shown in Table 1. These estimates are from 534 linecross Hereford bulls produced at the Center from 1957 through 1970.

Heritability estimates for concentration, motility, primary abnormalities, and normal sperm ranged from 23 to 30 percent while the estimate for live cells was some-what lower at 17 percent. Heritability of secondary abnormalities is essentially zero. The genetic correlations of percent primary abnormalities with other seminal traits were fairly high negative values, indicating that as percent primaries increase, other seminal traits also tend to become poorer.

In a separate study on 291 bulls, repeatability estimates between first and second ejaculates for concentration, volume, and motility were .53, .54, and .63, respectively.

Scrotal Circumference

Scrotal circumference measurements were first taken at the Center in 1969. These measurements were taken every 28 days during a 140-day performance test on 132 bulls of primarily Hereford breeding. The SC averages by 20-day intervals from 240 through 400 days of age were:

Table 1. Heritability and genetic correlation estimates among seminal traits.[1]

	Heritability	Genetic correlations: Motility	Live cells	Primary abnormalities	Normal
	(%)	(%)	(%)	(%)	
Concentration	.28	.53	.26	-.67	.63
Motility (%)	.23		.44	-.93	.88
Live cells (%)	.17			-.37	.72
Primary abnormalities (%)	.30				-1.06
Normal sperm (%)	.24				
Secondary abnormalities (%)	-.05				

[1]From Abadia, Brinks, and Carroll, 1976.

Age (days)	SC (cm)
240	24.3
260	25.8
280	27.7
300	29.1
320	30.6
340	31.8
360	32.4
380	33.8
400	34.2

SC was highly correlated with both age (.78) and weight (.84), as one might expect. The SC measurement has been shown to be highly repeatable, comparing measurements on the same animal taken by the same person or by different people. These repeatability values have exceeded .90 in all cases (a perfect repeatability value is 1.0). Thus, the measurement is highly accurate if care is taken in obtaining it.

Scrotal circumference appears to be highly heritable (Table 2). In addition, measurements show breed differences as well as considerable variability among bulls within breeds (Table 3). The relatively high heritability coupled with large within-breed variation indicates that selection would be effective in increasing SC as well as changing traits that are genetically correlated with SC.

Research at Colorado indicates that SC is favorably related to semen quality traits. Brinks et al. (1978) found positive correlations of SC with percent motility (.25), percent normal sperm (.58), volume (.29), sperm concentration (.46), and total sperm output (.42). SC was negatively correlated with percent primary (-.51) and secondary (-.42) abnormalities.

Relationship of SC to Age at Puberty

Working at the Roman L. Hruska Meat Animal Research Center, Lunstra (1982) reported that SC was a more accurate predictor of when a bull reached puberty than either age or weight, regardless of breed or breed cross. Bulls reach puberty (50 x 10^6 sperm with a minimum of 10 percent motility) at an average of 27.9 cm in SC. Lunstra reported a correlation of .98 among breed means (8 breeds) for SC of bulls with age at puberty in heifers (Table 3).

Table 2. Heritability estimates for scrotal circumference in beef bulls.

Estimate	Age	Source
.26	yearling	King et al. 1983
.38	yearling	Latimer et al. 1982
.60	weaning	Latimer et al. 1982
.52	yearling	Lunstra 1982
.69	yearling (adj for wt)	Lunstra 1982
.68	yearling	Coulter 1979

Table 3. Breed comparisons: bull testicular size vs. heifer age at puberty.

Breed	Heifer age at puberty	Scrotal circumference of yearling bulls[1]: Average	Range
	(days)[2]	(inches)[3]	(inches)
Gelbvieh	341± 9(81)	13.7±0.2(22)	11.9-16.6
Brown Swiss	347± 8(126)	13.5± .2(19)	12.2-15.6
Red Poll	352± 8(95)	13.2± .2(20)	11.7-14.6
Angus	372± 12(24)	12.9± .2(79)	10.3-15.1
Simmental	372± 6(157)	12.9± .3(28)	10.3-15.4
Hereford	390± 13(27)	12.1± .2(55)	10.3-14.2
Charolais	398± 7(132)	12.0± .3(31)	10.0-14.8
Limousin	398± 6(161)	11.9± .2(20)	9.6-13.5
Average	368± 3(723)	12.7± .1(274)	

[1]Data adjusted to 365 days of age.
[2]Least-squares means ± standard error. Number of heifers measured is given in parentheses.
[3]Least-squares means ± standard error. Number of bulls measured is given in parentheses.

Table 4. Relationships of age at puberty in heifers with reproductive traits in yearling bulls.

Heifers	Bull traits: SC	% normal sperm	% primary abnorm.	% secondary abnorm.	Motility
Age at puberty[1,2]	-.71	-.37	.36	.09	.33
Age at puberty[2,3]	-.36	-.37	.36	.34	-.29
Age at puberty[1,4]	-1.07				

[1]Estimates of genetic correlations.
[2]Correlation between line of sire means.
[3]From Brinks et al. 1978.
[4]From King et al. 1983.

Table 4 shows research at Colorado and Montana that has been conducted on the genetic relationship of age at puberty in heifers with SC and seminal traits of young bulls.

The correlations among line of sire means of age at puberty in females with reproductive traits in young bulls are all favorable. The genetic correlations of age at puberty in heifers with reproductive measures in bulls are all favorable except for the relationship with motility. Thus, as age at puberty in heifers becomes earlier, SC and percent normal sperm in half sib bulls increase and percent abnormalities decrease. The genetic correlation estimates of SC with age at puberty in half sib heifers are high (-.71 and -1.07), indicating a strong relationship. In fact, the genetic correlation estimates coupled with Lunstra's data (Table 4) indicate that age of puberty and SC are essentially the same trait.

If one selects bulls with larger SC, what changes in SC and age at puberty (AP) are expected in the offspring? Assume the following values:

Heritability of SC	=	.5
Genetic correlation of SC with AP	=	-.9
Genetic standard deviation of SC	=	1.4 cm
Genetic standard deviation of AP	=	24 days
Selection differential for sires	=	1 cm
Selection differential for dam	=	0 cm

Then:

Response (R) in male offspring = heritability x selection differential:

$$R = .5 \quad \frac{1.0\text{ cm} + 0\text{ cm}}{2}$$

$$= .25$$

Correlated response in AP of female offspring = R x genetic regression:

$$CR = .25 \times -.9 \quad \frac{24}{1.4}$$

Thus, for each centimeter superiority of sires above the population mean, one would expect .25 cm increase in SC of male offspring and 3.86 days earlier in puberty of female offspring.

Reproductive Measures in Females

Age at Puberty

Age at puberty of heifers can be important in determining reproductive efficiency. Most heifers probably have the potential to reach puberty and breed satisfactorily at yearling age if provided adequate nutrition and management. However, the cost of doing so may vary greatly among breeds and among heifers within a breed. Heifers with the inherent ability to reach puberty at early age can probably reach puberty and breed at less cost than heifers with later inherent age at puberty.

Table 5. Heritability estimates for puberty traits in heifers.

Age	Weight	Height	Condition[1]	Source
.20	1.09			Arije 1969
.41	.40			Laster et al. 1979
.67	.30	.43	.26	Werre 1980
.48				King et al. 1983
.64	.44			Smith et al. 1976
.41				Lunstra 1982

[1]Condition at puberty was estimated as height divided by weight.

Heritability estimates for age at puberty in heifers are relatively high (Table 5). Observations on the distribution of AP by years (Colorado) indicate that large differences in genetic potential for AP are manifested in years with much stress. In other words, few heifers reach puberty during the climatic stress period, and then a high percentage reach puberty immediately after the stress period. Thus, the underlying genetic differences are masked by environmental stress in certain years, which leads to lower heritability estimates.

Relation of AP to Growth Traits

Estimates of the genetic, environmental, and phenotypic correlations of AP in heifers and various growth traits are listed in Table 6. These estimates are from Colorado data.

The correlations are interesting since the genetic correlations are either small or negative (favorable), whereas the environmental are either small or positive. The genetic correlations indicate that heifers with genes for rapid early growth reach puberty earlier. The environmental correlations indicate that heifers receiving better than average environment (within contemporary groups treated alike), and gaining more rapidly because of environment, tend to reach puberty later. The phenotypic correlations are intermediate. The standard errors of the genetic correlations in this study were high (.40 to .48). Seasonal climatic effects also may influence these

Table 6. Estimates of genetic, environmental, and phenotypic correlations.[1]

		Weight at puberty	Height at puberty	Condition at puberty	ADG to weaning	ADG, weaning to puberty
Age at	G	-.41	.04	-.58	-.31	-.44
puberty	E	.69	.30	.71	-.04	.37
	P	.43	.27	.41	-.13	.70

[1]From Werre 1980.

Table 7. Correlation of age at puberty with productivity traits.[1]

	1st Lactation[2]			2nd Lactation			3rd Lactation			4th Lactation		
	HCC	AWWR	MPPA	HCC	AWWR	MPPA	HCC	AWWR	MPPA	HCC	AWWR	MPPA
Age at puberty[3]	.03	.11	.07	.15	-.04	-.15	.05	.02	-.10	.01	.02	-.26
Age at puberty[4]	.54	-.65	-.62	.34	-.11	-.38	-.06	-.24	-.10	.47	-.11	-.25

[1]From Werre 1980.
[2]HCC = heat cycles of conception (1 = early, 3 = late); AWWR = adjusted 205 day weaning weight ratio; MPPA = most probable producing ability.
[3]Residual.
[4]Line of sire means.

correlations as extreme winter stress conditions seem to prevent estrus at the San Juan Basin Research Center.

Other studies have reported a positive genetic correlation between age and weight at puberty. Laster et al. (1979), Arije and Wiltbank (1971), and Smith et al. (1976) reported values of .52, .36, and .67, indicating that, genetically, heifers reaching puberty at later ages were also heavier, or vice versa.

A seasonal effect (photoperiod) may also contribute to the interpretation of the correlation. King et al. (1983) reported that although heifers born later in the calving season reached puberty at an earlier age, heifers born earlier in the calving season reached puberty at an earlier date the following year. The same phenomenon was observed in Colorado studies.

Relation of AP to Subsequent Productivity

Residual correlations and correlations among mean AP by line of breeding with reproductive and productivity traits, through four lactations, are shown in Table 7.

The residual correlations of AP with heat cycle of conception, adjusted weaning weight ration, and MPPA were all small and nonsignificant. Most tended to be favorable, however.

Correlations among line of sire means were much higher and more favorable, which may indicate that heifers from lines with early puberty also tended to conceive earlier each year through four lactations, except for the third lactation. Also, they weaned heavier calves and had high accumulative MPPA values, presumably through higher milk production.

This favorable relationship of earlier age at puberty with higher milk production and reproduction is also observed from correlations among breed means from other studies. Laster (1979) reported the following correlations among breed means: AP with percent calving the first 25 days, -.75; AP with pregnancy percent, -.42; AP with milk production, -.88 indicating that earlier age at puberty resulted in earlier and more pregnancies and greater milk production on a between-breed basis. Doornbos (1983) reported a residual correlation of -.40 between AP and percent pregnant.

Gestation Length and Relationships to Growth

Data on 1,783 calvings from the Red Angus, Angus, and Hereford herds of Pioneer Hi-Bred International, Inc., were used to study genetic relationships of gestation length and age at first calving with various growth traits. The genetic, environmental, and phenotypic correlations are listed in Table 8.

The heritability estimates for gestation length were .36 and .37 for male and female calves, and the estimate for age at first calving was .07. Gestation length was

Table 8. Genetic, environmental, and phenotypic correlations of gestation length and age at first calving with various growth traits.*

		Birth wt.	Pre-natal gain	Pre-weaning gain	Weaning wt	Gain Br-Yr	Gain Wa-Yr	Year-ling wt	Herit-ability
Gestation length									
Males	G	.25	-.19	-.25	-.22	-.20	-.33	-.18	.36
	E	.36	.09	.15	.21	.18	.29	.23	
	P	.32	.01	-.05	-.01	-.03	.02	.01	
Females	G	.22	-.18	-.20	-.18	-.35	-.41	-.32	.37
	E	.36	.06	.03	.13	.18	.19	.25	
	P	.31	-.01	-.09	-.04	-.09	-.03	-.05	
Age at first calving									
Females	G	-.17	-.06	-.21	-.22	-.16	.00	-.17	.07
	E	.38	.45	.03	.10	-.01	-.03	.05	
	P	.12	.23	-.03	.00	-.04	-.02	-.02	

*From Bourdon and Brinks 1982.

negatively correlated (favorable) with all growth traits except birth weight on a genetic basis indicating calves with greater growth potential to yearling ages tend to have shorter gestation lengths. The corresponding phenotypic correlations were near zero except for that between gestation length and birth weight.

Summary

Several seminal traits in yearling bulls are moderately heritable (17 to 30 percent). Scrotal circumference is easy to obtain, is highly repeatable, and highly heritable. It is favorably related to seminal characteristics and is a good indicator of age at puberty in bulls and related in females. The high estimated genetic correlation between scrotal circumference and age at puberty in females indicates that sires with above average SC should produce female progeny with earlier ages at puberty.

From a genetic standpoint, age at puberty in heifers is favorably related to growth to yearling ages. AP also appears to be favorably related to subsequent reproduction (heat cycle of conception) and cow productivity as measured by calf adjusted weaning weights through four lactations. Gestation lengths is moderately heritable with estimates of 36 and 37 percent. On a genetic basis, cattle growing faster to yearling ages tend to have shorter gestation lengths, but a near zero phenotypic relationship exists. From data from a restricted breeding season, age at first calving appears to have low heritability but is somewhat favorably related (genetically) to growth to yearling ages.

Reproductive traits, milk production, and growth to yearling ages appear to be favorably related genetically. Since most genetic improvement is made through sire selection, SC may be a key indicator trait for improving reproductive potential in both bulls and females. Future research is needed to clarify more of the genetic relationships between reproduction and production traits. Estimated breeding values for reproductive indexes for both bulls and females need to be developed.

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Fourth edition; December 2016 Reprint