Genetic parameters of linear type traits for beef cattle and their correlation with production of Simmental cows
by David Paul Kirschten

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Animal and Range Sciences
Montana State University

Abstract:
Data provided by ABS Global were used to estimate genetic parameters of linear type traits for Simmental females. Scores were collected by 36 evaluators from 1988 to 2000. Body traits evaluated were stature, body length, muscle, capacity, femininity, rear leg set, and feet and pasterns. Udder traits evaluated were udder attachment, udder depth and, teat size. Body condition score was also included. Scores were assigned based on a 50 point linear scale. Body condition was assigned based on a 9 point scale. The number of animals evaluated for body traits ranged from 14,317 to 14,322. The number of animals evaluated for udder traits ranged from 8,046 to 8,052. The number of animals evaluated for body condition score was 9,230. All traits were analyzed using an animal model and MTDFREML procedures to estimate genetic parameters. The statistical model for all traits included the additive direct genetic (animal) effect and the fixed effects of age of cow and contemporary group. Heritability estimates ranged from 0.12 to 0.60. Genetic and phenotypic correlations differed in magnitude and sign among traits. In general, parameter estimates were within the range of those previously reported in the literature. Results from the study established. that with selection it is possible to change type traits in Simmental cattle. Measures of production in Sinunental cattle were regressed on linear type traits. Measures of production considered in the study were: number of calves, calving interval, calf adjusted birth weight, calf average adjusted weaning weight, and total calf adjusted weaning weight. Results from this study established that there were significant ($P < .05$) relationships among the traits and many measures of production. The relationships differed in magnitude and sign among the traits and measures of production.

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APPROVAL

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David Paul Kirschten

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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Date 3/10/2001

This work is dedicated to my dad, James D. Kirschten.

I think he would appreciate this project.

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I have had opportunities to express my appreciation for people that have had an effect in my life several times over the years. At any time that I have had an opportunity to do so, I invariably and unintentionally left someone out. I do have a few people that I would like to take this opportunity to thank, however.

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To the rest of my friends, instructors, and colleagues: I hope that I have shown you how important you are to me and how much I appreciate your friendship, by treating you in such a manner that you know it.

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ABSTRACT

Data provided by ABS Global were used to estimate genetic parameters of linear type traits for Simmental females. Scores were collected by 36 evaluators from 1988 to 2000. Body traits evaluated were stature, body length, muscle, capacity, femininity, rear leg set, and feet and pasterns. Udder traits evaluated were udder attachment, udder depth and, teat size. Body condition score was also included. Scores were assigned based on a 50 point linear scale. Body condition was assigned based on a 9 point scale. The number of animals evaluated for body traits ranged from 14,317 to 14,322. The number of animals evaluated for udder traits ranged from 8,046 to 8,052. The number of animals evaluated for body condition score was 9,230. All traits were analyzed using an animal model and MTDFREML procedures to estimate genetic parameters. The statistical model for all traits included the additive direct genetic (animal) effect and the fixed effects of age of cow and contemporary group. Heritability estimates ranged from 0.12 to 0.60. Genetic and phenotypic correlations differed in magnitude and sign among traits. In general, parameter estimates were within the range of those previously reported in the literature. Results from the study established that with selection it is possible to change type traits in Simmental cattle. Measures of production in Simmental cattle were regressed on linear type traits. Measures of production considered in the study were: number of calves, calving interval, calf adjusted birth weight, calf average adjusted weaning weight, and total calf adjusted weaning weight. Results from this study established that there were significant ($P < .05$) relationships among the traits and many measures of production. The relationships differed in magnitude and sign among the traits and measures of production.

CHAPTER 1

INTRODUCTION

The question of whether type is related to production has been of interest to breeders for many generations. Since man has tried to improve his cattle, he has usually selected on the basis of subjective evaluation of their usefulness for different purposes by visual appraisal (Brown et al., 1953). The importance of desirable conformation was recognized early by dairy breeders on the Island of Jersey when the first score card or scale of points was made in 1834 (Copeland, 1938). Not only has conformation been important to dairy producers, beef producers have used visual appraisal as well. Robert Bakewell used visual assessment in the selection of breeding stock for his experiments (Miles, 1893).

In a USDA Audit (Table 1), producers ranked 10 factors that they used to determine desirability of purchased seedstock. The top ranking factor, structural soundness/appearance, was rated very or extremely important by 94.5% of producers who completed the survey. In contrast, factors generally considered scientifically proven to be of economic value such as weaning and yearling weights, birth weight, scrotal circumference, and Expected Progeny Differences (**EPD**), were ranked as very or extremely important by 64.1%, 59.7%, 57.2% and 44.2% of producers, respectively.

Table 1. Factors considered in purchasing or selecting a bull.

Factor	Rating Very or Extremely Important, %
Structural soundness/appearance	94.5
Breed	88.0
Temperament	86.3
Price	68.2
Weaning and Yearling Weights	64.1
Reputation of the Breeder	61.9
Birth Weight	59.7
Hip Height/Frame score	58.8
Scrotal circumference	57.2
EPD	44.2

Taylor and Field (1999) ranked the economically important traits in beef cattle as: 1) reproductive performance, (2) weaning weight, (3) yearling weight, (4) feed efficiency, (5) carcass merit, (6) longevity, (7) conformation, (8) freedom from genetic defects, (9) disposition, and (10) adaptability. There is a definite disparity between the traits that have been scientifically proven to be of economic importance and the traits for which producers are actually selecting.

There may be important relationships between conformation/linear type traits and economically important performance traits. In the same USDA Audit, producers ranked the reasons they replaced bulls in the following order: infertility, structural unsoundness or physical injury, size, quality of the calves sired, temperament, disease, too many daughters in the herd, and age (Coe, 1999).

In response to producers' questions about how the progeny of a particular bull looked or what bull to use to correct conformational problems, Keith G. Vander Velde of American Breeders Service (now ABS Global) presented a plan of action to the

International Stockmen's Educational Foundation in 1989. American Breeders Service decided to evaluate those traits about which most producers asked questions: udder attachment, udder depth, teat size, stature, femininity, capacity, body length, muscling, rear leg set, and feet and pasterns. Body Condition Score (**BCS**) was evaluated as well because earlier studies indicated that BCS was important in changing type scores. In May 1988, ABS launched the Beef Genetic Trait Summary (**GTS**) program (Pope, 1989). By May 2001, 53 trained evaluators had evaluated over 120,000 animals. There were approximately 80,000 Red and Black Angus, 21,000 Simmental and 20,000 other animals consisting of Hereford, Polled Hereford, Limousin, and Gelbvieh that had been evaluated (D. Frank, personal communication). It is important to note that ABS evaluators scored progeny of ABS bulls as well as progeny of bulls from other AI studs and progeny from natural service and clean-up bulls. Progeny of these bulls were evaluated, not the bulls themselves.

In July 1998, ABS Global and the American Simmental Association (ASA) forged a partnership to jointly fund a project to evaluate the Simmental GTS data. The objectives were to determine: a) heritability of the GTS traits, b) the correlations among the traits, and c) the economic importance of the traits as they relate to production measures.

A review of the literature revealed several significant findings (Chapter 2). The bulk of the literature concerning linear type evaluation is based on dairy cattle. Some European literature contains linear type evaluation for breeds that are used as beef breeds

in the United States but maintained under traditional dairy or dual-purpose status on their native continent. Upon review of these studies, the following characteristics were discovered: 1) generally, there was close agreement among dairy studies with regard to estimated genetic parameters, 2) there was agreement between studies with dairy breeds and studies with dual-purpose breeds on some but not all traits, and 3) a nearly identical statistical model was used to estimate genetic parameters in all studies.

CHAPTER 2

LITERATURE REVIEW

Introduction

This literature review is intended summarize the available published information concerning linear type evaluation. The first objective will be to define the ABS GTS Traits that will be evaluated in this study. Second, literature estimates of heritabilities and of genetic and phenotypic correlations among linear type traits will be summarized. Different breed associations and research institutions use dissimilar definitions for the same linear type trait, hence there will some literature reviewed that does not exactly describe the ABS GTS Traits.

ABS GTS Traits

Stature

Evaluation of progeny frame size, based on hip height. Higher score indicates taller size.

Body Length

Evaluation of progeny from withers to pins. High score indicates longer body length.

Muscling

Progeny evaluation combines width of rump and hindquarter, with secondary consideration given to forearm muscling. Higher score indicates more muscling.

Capacity

Progeny evaluation combines depth of fore rib along with spring of rib and width of chest floor as well as depth of flank. Higher score indicates greater capacity.

Femininity

Evaluation of daughters' angularity and their ability to carry condition without becoming coarse and masculine. Higher score indicates more femininity.

Rear Leg Set

Evaluation of progeny rear leg structure, with scores near 25 being ideal. Higher scores tend towards sickle-hocked: lower scores tend toward post-legged.

Feet and Pasterns

Evaluation of progeny length and strength of pastern and foot angle. Higher score indicates stronger pastern with more depth of heel.

Udder Attachment

Daughter evaluation combines fore udder attachment, rear udder height, rear udder width, and center support. Higher score indicates stronger attachment.

Udder Depth

Evaluation of daughters' udder depth from top of fore udder to udder floor. Higher score indicates higher, better supported udders.

Teat Size

Evaluation of daughters' teat size, including length and diameter. Higher score indicates smaller teat size.

Accuracy of Evaluation

Brown et al. (1953) evaluated a type scoring system for beef cattle, although not specifically the same traits as the Beef GTS traits. The traits evaluated were general appearance, fore quarters, body, head and neck, hindquarters, breed type, and over-all rating. They concluded that judges with a basic knowledge of desirable conformation of beef cattle gave similar ratings to a particular animal at a particular time. Ratings of the judges appeared to be in closer agreement on items of conformation for which they considered only a part of the animal.

Frey et al. (1972) concluded that classifiers were not a significant source of variation in total classification scores. However, significant interactions of classifiers with both cows and seasons indicated the classifiers were not consistent in their scoring.

Estimates of Heritability

Table 2 summarizes literature estimates of heritability for dairy and dual purpose linear type traits that were used in this study.

Table 2. Heritabilities of linear type traits.

GTS Trait	Representative Trait[1]	Author	Heritability
Stature	Stature	Foster et al. (1988)	0.36
		VanRaden et al. (1990)	0.37
		Harris et al. (1992)	0.53
		Short and Lawlor (1992)	0.40
		Holstein Association USA (2001)	0.42
	Height at Withers	Casanova (1993)	0.56
	Height at Hip	Casanova (1993)	0.55
	Size	Nielsen and Willham (1974)	0.37 - 0.58
Body Length	Body Length	Casanova (1993)	0.43
Muscle	Muscle	Koch et al. (1974)	0.24, 0.30
	Loin	Nielsen and Willham (1974)	0.25 - 0.30
	Rump		0.24 - 0.38
	Rear quarters		0.40 - 0.66
	Muscularity	Casanova (1993)	0.29
		Interbull (1996)	0.24 - 0.25
	Muscularity at Thighs	Larroque (2000)	0.29
	Muscularity at Withers		0.28
	Muscularity of Back		0.13
	Muscularity of Loin		0.21
	Muscularity at Rump		0.18
	Muscularity at Thigh		0.21
	Overall Muscle Score		0.19
Capacity	Capacity	Kliewer (1971)	0.43 - 0.70
		Van Doormaal and Burnside (1987)	0.21, 0.23
	Strength	Foster et al. (1988)	0.23
	Body Depth		0.30
	Strength	VanRaden et al. (1990)	0.26
	Body Depth		0.32
	Strength	Harris et al. (1992)	0.26
	Body Depth		0.31
	Strength	Short and Lawlor (1992)	0.26
	Body Depth		0.31
	Strength	Holstein Association USA (2001)	0.31
	Body Depth		0.37
	Body Width	Casanova (1993)	0.17
	Body Depth		0.21
Femininity	Dairy Form	Foster et al. (1988)	0.25
		VanRaden et al. (1990)	0.23
		Harris et al. (1992)	0.25
		Short and Lawlor (1992)	0.24
		Holstein Association USA (2001)	0.29
Rear Legs -Side View	Rear Legs - Side View	Foster et al. (1988)	0.17
		VanRaden et al. (1990)	0.16
		Harris et al. (1992)	0.12
		Short and Lawlor (1992)	0.15
		Ral et al. (1995)	0.12 - 0.35
		Holstein Association USA (2001)	0.21

Table 2. Continued

GTS Trait	Representative Trait[1]	Author	Heritability
Rear Legs -Side View	Feet and Legs		
	Angle of Hock	Casanova (1993)	0.18
Feet and Pasterns	Foot Angle	Foster et al. (1988)	0.09
		VanRaden et al. (1990)	0.10
		Harris et al. (1992)	0.09
		Short and Lawlor (1992)	0.14
		Ral et al. (1995)	0.08 - 0.53
		Holstein Association USA (2001)	0.15
	Feet and Legs	Nielsen and Willham (1974)	0.32 - 0.52
	Pastern Angle	Casanova (1993)	0.25
	Depth of Heel		0.18
	Heel Height	Ral et al. (1995)	0.07 - 0.34
	Toe Angle		0.14 - 0.41
Udder Attachment	Fore Udder Attachment	Foster et al. (1988)	0.18
		VanRaden et al. (1990)	0.18
		Harris et al. (1992)	0.12
		Short and Lawlor (1992)	0.22
		Holstein Association USA (2001)	0.29
	Rear Udder Height	Foster et al. (1988)	0.19
		VanRaden et al. (1990)	0.18
		Harris et al. (1992)	0.28
		Short and Lawlor (1992)	0.20
		Holstein Association USA (2001)	0.28
	Rear Udder Width	Foster et al. (1988)	0.15
		VanRaden et al. (1990)	0.16
		Harris et al. (1992)	0.21
		Short and Lawlor (1992)	0.18
		Holstein Association USA (2001)	0.23
	Rear Udder Attachment	Casanova (1993)	0.21
	Strength of Attachment		0.25
Udder Depth	Udder Depth	Foster et al. (1988)	0.24
		VanRaden et al. (1990)	0.25
		Harris et al. (1992)	0.26
		Short and Lawlor (1992)	0.28
		Holstein Association USA (2001)	0.28
	Fore Udder Depth	Casanova (1993)	0.34
	Rear Udder Depth		0.28
	Udder Capacity	DeNise et al. (1987)	0.12
	Udder Shape		0.15
Teat Size	Teat Length	Harris et al. (1992)	0.32
		Casanova (1993)	0.22
		Holstein Association USA (2001)	0.26
	Teat Shape	Casanova (1993)	0.40
Body Condition Score	Condition	Marlowe and Morrow (1985)	0.31

[1]A representative trait is one that approximates the ABS GTS traits while not being exactly the same

Stature

In a study of Angus classification scores on 149,147 animals, Nielsen and Willham (1974) divided animal evaluations into four age-sex groups: mature males, preliminary males, mature females, and preliminary females. Preliminary males and females were yearling animals that had not sired or given birth to progeny at the time of the evaluation. Accompanying the scores on each animal was a herd code designation, the herd code is a number dependent on three variables: classifier, day of classification and herd. If any one of the variables changed, the herd code changed. All scores in the study were assigned by official classifiers of the American Angus Association. Heritabilities were estimated using three different models: within herd and herd code, within herd and across codes, and across herds and herd codes. Because the estimate of heritability across herds and herd codes is most appropriate to this review, only the third model will be discussed. Heritability estimates were generated using Paternal Half-sib analyses and least squares procedures. Estimates of heritability for size were 0.49, 0.58, and 0.37 for mature females, preliminary males, and preliminary females, respectively. The simple average of the heritability estimates was 0.48. Foster et al. (1988) estimated the heritability of stature to be 0.36 based on 43,428 records from daughters of Holstein bulls at 21st Century Genetics. VanRaden et al. (1990) estimated the heritability of stature in Holsteins to be 0.37 based upon 1,241,310 records. In an evaluation of genetic parameters for Guernsey type traits based upon 12,996 records, Harris et al. (1992), estimated the heritability of stature to be 0.53. Short and Lawlor (1992) reported a heritability of 0.40 based on 128,601 registered Holsteins. In a study of 4,137 first

lactation Swiss Braunvieh, Casanova (1993) estimated heritabilities of 0.56 and 0.55 for height at withers and height at hips, respectively. The Holstein Association USA reported the heritability of stature to be 0.42 based upon Holsteins indexed with the Association (2001).

Body Length

Literature concerning visual appraisal of body length is very limited. Casanova (1993) estimated the heritability of body length to be 0.43 based upon 4,137 evaluations in Swiss Braunvieh.

Muscling

The Angus classification system evaluated by Nielsen and Willham (1974) considered muscle shape at three different locations: loin, rump, and an overall rear-quarters score. Loin muscling score was estimated to have heritabilities of 0.25, 0.30, and 0.24 for mature females, preliminary bulls, and preliminary females. Heritability of rump score was estimated to be 0.26, 0.38, and 0.24 for the three groups. Overall rear-quarters scores were estimated to have heritabilities of 0.43, 0.66, and 0.40 for mature females, preliminary males, and preliminary females, respectively. Koch et al. (1974) reported heritability estimates of 0.24 and 0.30 for a visual muscling score in Hereford bulls and heifers, respectively. Larroque (2000) estimated genetic parameters for muscling traits from records in 442,545 French Montbeliarde cattle. Muscularity at withers was estimated to have a heritability of 0.28, muscularity at thighs was estimated to have a

heritability of 0.30. Additionally, Larroque estimated the heritability of muscle scores from 209,665 Normande cattle. Estimates of heritability were 0.13, 0.21, 0.18, 0.21, and 0.19 for muscularity on the back, loin, rump, thigh, and an overall muscle score, respectively. Heritability of muscularity in Irish Holstein-Friesian cattle was estimated to be 0.25 (Interbull, 1996). In an Austrian study, the heritability of muscularity in the Fleckvieh, Braunvieh, Pinzgauer, Shwarzbunte and Grauvieh breeds was estimated to be 0.24 (Interbull, 1996). Casanova (1993) reported an estimate for heritability of 0.29 for muscularity in the Braunvieh breed.

Capacity

The dairy literature contains very few estimates for capacity. Van Doormaal and Burnside (1987) reported an estimate for capacity of 0.21 for grade Holsteins and 0.23 for registered Holsteins based on an evaluation of 175,693 Canadian Holsteins. In an earlier study by Kliewer (1971), capacity for Holsteins was estimated to have a heritability of from 0.43 to 0.70 depending on age, with older cows having higher heritabilities. Capacity as it relates to beef GTS, is simply a composite of the dairy traits strength and body depth. The Holstein Association (2000) estimated heritabilities of 0.31 and 0.37 for strength and body depth. Harris et al. (1992) reported heritabilities of 0.26 for strength and 0.31 for body depth. Foster et al. (1988) reported estimates of 0.23 for strength and 0.30 for body depth. VanRaden et al. (1990) reported estimates of 0.26 and 0.32 for strength and body depth, which is in close agreement with the estimates of 0.26 and 0.31 reported by Short and Lawlor 1992). In Europe, much visual assessment work has been done with dairy and dual-purpose breeds. These studies may hold some interest to beef

cattle producers since the European dual-purpose breeds studied are used as beef breeds in the USA. Casanova (1993) reported heritability estimates of 0.21 and 0.17 for body depth and body width, which are somewhat lower than most estimates found in the dairy literature.

Femininity

There is very little information available in the literature with regard to femininity. The trait that may be thought of as most comparable to femininity is dairy form. The Holstein Association (2001) reported heritability of dairy form to be 0.29. Foster et al. (1988), VanRaden et al. (1990) and Short and Lawlor (1992) all reported similar estimates of 0.25, 0.23, and 0.24 respectively. Harris et al. (1992) estimated the heritability of dairy form in Guernsey's to be 0.25.

Rear Leg Set

Neilsen and Willham (1974) reported heritabilities of 0.42, 0.52, and 0.36 for mature females, preliminary males, and preliminary females, when rear legs and feet were evaluated as one trait. The Holstein Association (2001) reported a heritability estimate of 0.21 for rear legs-side view. Harris et al. (1992) estimated the heritability of rear leg-side view to be 0.12 for Guernsey cattle. Short and Lawlor (1992), VanRaden et al. (1990), and Foster et al. (1988) reported very similar estimates of 0.15, 0.16, and 0.17, respectively. Ral et al. (1995) reviewed many papers concerning the genetic aspects of leg and hoof traits in cattle and reported estimates of heritability for rear legs set from 0.12 to 0.35. Casanova (1993) reported heritability of hock angle to be 0.18.

Feet and Pasterns

The Holstein Association (2001) estimated the heritability of foot angle to be 0.15. Harris et al. (1992) reported an estimate of 0.09 for the Guernsey breed. In Swiss Braunvieh, Casanova (1993) estimated the heritability of pastern angle to be 0.25 and depth of heel to be 0.18. Foster et al. (1988) and VanRaden et al. (1990) reported heritability of foot angle to be 0.09 and 0.10, respectively. Short and Lawlor (1992) reported an estimate of 0.14. Ral et al. (1995) summarized five papers concerning foot angle and the average heritability was 0.24 with a range from 0.08 to 0.53. They also summarized four papers concerning toe angle with estimates ranging from 0.14 to 0.4, with an average estimate of heritability of 0.25. Additionally, five papers concerning heel height were reviewed by Ral et al. (1995) with an average heritability estimate of 0.19 and range from 0.07 to 0.34.

Estimates of Heritability for Udder Traits

A review of beef literature for udder attachment, udder depth, and teat size revealed no reports of heritability. DeNise et al. (1987) reported heritability of udder capacity to be 0.12 based on 460 records of Hereford cows. DeNise et al. (1987) also reported heritability of udder shape to be 0.15 based on 362 records.

Udder Attachment

The Holstein Association (2001) reported heritabilities of 0.29, 0.28, and 0.23 for fore udder attachment, rear udder height, and rear udder width, respectively. Harris et al. (1992) reported heritabilities of 0.12, 0.28, and 0.21 for fore udder attachment, rear udder

height and rear udder width, respectively, in Guernsey cattle. Foster et al. (1988) reported estimates of 0.18, 0.19, and 0.15 for fore udder attachment, rear udder height and rear udder width, which is in close agreement with the estimates from VanRaden et al. (1990) and Short and Lawlor (1992) (Table 2). Casanova (1993) reported estimates of heritabilities in Swiss Braunvieh cattle to be 0.21 and 0.25 for fore udder attachment and strength of attachment, respectively.

Udder Depth

VanRaden et al. (1990) reported heritability of udder depth to be 0.25. Harris et al. (1992) estimated the heritability of udder depth to be 0.26 in Guernsey cattle. The Holstein Association (2001) reported the heritability of udder depth to be 0.28. Foster et al. (1988) and VanRaden et al. (1990) reported heritabilities of 0.24 and 0.25 for udder depth. Short and Lawlor (1992) estimated the heritability to be 0.28. Casanova (1993) estimated the heritability of fore udder depth to be 0.34 and rear udder depth to be 0.28.

Teat Size

The Holstein Association (2001) estimated the heritability of teat length to be 0.26. Harris et al. (1992) reported an estimate of 0.32 for teat length. Casanova (1993) estimated the heritability of teat length and teat shape to be 0.40 and 0.22, respectively.

Body Condition Score

Marlowe and Morrow (1985) estimated genetic parameters for weight, grade, and condition of 1,371 Angus cows and reported a heritability for condition of 0.31.

The Holstein Association (2001) estimated the heritability of teat length to be 0.26. Harris et al. (1992) reported an estimate of 0.32 for teat length. Casanova (1993) estimated the heritability of teat length and teat shape to be 0.40 and 0.22, respectively.

Body Condition Score

Marlowe and Morrow (1985) estimated genetic parameters for weight, grade, and condition of 1,371 Angus cows and reported a heritability for condition of 0.31.

Genetic and Phenotypic Correlations among Traits

Table 3 presents literature estimates of genetic and phenotypic correlations. The table is based upon averages of United States dairy literature and European dairy and dual-purpose literature. No estimates of correlations with regard to these traits in beef cattle were found in the literature. Many estimates were near zero, and phenotypic correlations were generally low. There were some genetic correlations that may be of interest to beef producers.

Table 3. Genetic and phenotypic correlations among linear type traits.

GTS Traits	Representative Traits[1]	Author	Genetic Correlation	Phenotypic Correlation
Stature and Body Length				
	Wither Height and Body Length	Casanova (1993)	0.79	0.57
	Height at Hip and Body Length	Vukasinovic et al. (1995)	0.92	0.69
Stature and Muscle		Casanova (1993)	-0.50	0.02
		Vukasinovic et al. (1995)	-0.30	0.09
Stature and Capacity				

Table 3. Continued

GTS Traits	Representative Traits[1]	Author	Genetic Correlation	Phenotypic Correlation
Stature and Femininity				
	Stature and Dairy Form	Foster et al. (1988)	0.27	0.20
		Klei et al. (1988)	0.20	
		VanRaden et al. (1990)	0.28	0.15
		Harris et al. (1992)	0.65	0.43
		Short and Lawlor (1992)	0.34	0.16
Stature and Rear Legs - Side View		Foster et al. (1988)	0.04	-0.05
		Klei et al. (1988)	-0.13	
		VanRaden et al. (1990)	-0.07	-0.05
		Harris et al. (1992)	-0.05	-0.02
		Short and Lawlor (1992)	0.02	-0.04
		Vukasinovic et al. (1995)	-0.25	-0.09
Stature and Feet and Pasterns				
	Stature and Foot Angle	Foster et al. (1988)	0.24	0.09
		Klei et al. (1988)	0.37	
		VanRaden et al. (1990)	0.37	0.14
		Harris et al. (1992)	0.29	-0.16
		Short and Lawlor (1992)	0.39	0.14
	Stature and Pasterns	Vukasinovic et al. (1995)	0.07	-0.08
Stature and Udder Attachment		Foster et al. (1988)	0.00	0.02
		Klei et al. (1988)	0.17	
		VanRaden et al. (1990)	0.30	0.12
		Harris et al. (1992)	0.01	-0.01
		Short and Lawlor (1992)	0.32	0.14
		Vukasinovic et al. (1995)	0.22	0.07
Stature and Udder Depth		Foster et al. (1988)	0.37	0.16
		Klei et al. (1988)	0.34	
		VanRaden et al. (1990)	0.32	0.12
		Harris et al. (1992)	-0.15	-0.08
		Short and Lawlor (1992)	0.32	0.15
Stature and Teat Size				
	Stature and Teat Form	Vukasinovic et al. (1995)	0.00	0.02
	Stature and Teat Length	Harris et al. (1992)	0.32	0.22
		Vukasinovic et al. (1995)	-0.15	-0.01
Body Length and Muscle		Casanova (1993)	-0.42	0.11
		Vukasinovic et al. (1995)	-0.55	0.19

Table 3. Continued

GTS Traits	Representative Traits[1]	Author	Genetic Correlation	Phenotypic Correlation
Body Length and Capacity				
	Body Length and Body Depth	Casanova (1993)	0.45	0.43
		Vukasinovic et al. (1995)	0.52	0.45
	Body Length and Body Width	Casanova (1993)	0.02	0.35
		Vukasinovic et al. (1995)	-0.36	0.33
Body Length and Rear Legs				
	Body Length and Hock Angle	Vukasinovic et al. (1995)	-0.40	-0.14
Body Length and Feet and Pasterns				
	Body Length and Pasterns	Vukasinovic et al. (1995)	0.15	0.09
Body Length and Udder Attachment		Vukasinovic et al. (1995)	-0.13	0.10
Body Length and Teat Size				
	Body Length and Teat Form	Vukasinovic et al. (1995)	0.00	0.04
	Body Length and Teat Length	Vukasinovic et al. (1995)	-0.15	0.01
Muscle and Capacity				
	Muscle and Body Depth	Casanova (1993)	-0.12	0.25
		Vukasinovic et al. (1995)	-0.55	0.33
	Muscle and Body Width	Casanova (1993)	0.65	0.54
		Vukasinovic et al. (1995)	-0.09	0.33
Muscle and Rear Legs				
	Muscle and Hock Angle	Vukasinovic et al. (1995)	-0.59	-0.15
	Muscle and Pasterns	Vukasinovic et al. (1995)	0.09	0.10
Muscle and Udder Attachment		Vukasinovic et al. (1995)	-0.33	0.08
Muscle and Teat Size				
	Muscle and Teat Form	Vukasinovic et al. (1995)	-0.35	-0.01
	Muscle and Teat Length	Vukasinovic et al. (1995)	-0.07	0.03

Table 3. Continued

GTS Traits	Representative Traits[1]	Author	Genetic Correlation	Phenotypic Correlation
Capacity and Femininity				
	Body Depth and Dairy Form	Foster et al. (1988)	0.20	0.17
		Klei et al. (1988)	0.31	
		VanRaden et al. (1990)	0.19	0.10
		Harris et al. (1992)	0.52	0.45
		Short and Lawlor (1992)	0.23	0.08
	Strength and Dairy Form	Foster et al. (1988)	-0.35	-0.15
		Klei et al. (1988)	0.38	
		VanRaden et al. (1990)	0.28	0.15
		Harris et al. (1992)	0.36	0.32
		Short and Lawlor (1992)	-0.10	-0.15
Capacity and Rear legs				
	Body Depth and Rear Legs	Foster et al. (1988)	-0.06	0.03
		Klei et al. (1988)	0.06	
		VanRaden et al. (1990)	-0.10	-0.06
		Harris et al. (1992)	-0.10	-0.06
		Short and Lawlor (1992)	-0.03	-0.05
Capacity and Rear legs				
	Strength and Rear Legs	Foster et al. (1988)	-0.33	-0.13
		Klei et al. (1988)	-0.17	
		VanRaden et al. (1990)	-0.19	-0.11
		Harris et al. (1992)	-0.07	-0.13
		Short and Lawlor (1992)	-0.13	-0.05
Capacity and Feet and Pasterns				
	Body Depth and Foot Angle	Foster et al. (1988)	0.09	0.04
		Klei et al. (1988)	0.26	
		VanRaden et al. (1990)	0.37	0.16
		Harris et al. (1992)	0.47	0.16
		Short and Lawlor (1992)	0.30	0.17
	Strength and Foot Angle	Foster et al. (1988)	0.39	0.13
		Klei et al. (1988)	0.53	
		VanRaden et al. (1990)	0.46	0.19
		Harris et al. (1992)	0.57	0.23
		Short and Lawlor (1992)	0.41	0.17

Table 3. Continued

GTS Traits	Representative Traits[1]	Author	Genetic Correlation	Phenotypic Correlation
Capacity and Udder Attachment				
	Body Depth and Udder Attachment	Foster et al. (1988)	-0.08	-0.01
		Klei et al. (1988)	0.28	
		VanRaden et al. (1990)	0.20	0.12
		Harris et al. (1992)	0.13	0.03
		Short and Lawlor (1992)	0.26	0.13
	Strength and Udder Attachment	Foster et al. (1988)	0.27	0.10
		Klei et al. (1988)	0.52	
		VanRaden et al. (1990)	0.25	0.15
		Harris et al. (1992)	0.03	0.08
		Short and Lawlor (1992)	0.29	0.16
Capacity and Udder Depth				
	Body Depth and Udder Depth	Foster et al. (1988)	-0.39	-0.20
		Klei et al. (1988)	0.05	
		VanRaden et al. (1990)	0.00	-0.04
		Harris et al. (1992)	-0.35	-0.25
		Short and Lawlor (1992)	0.05	-0.03
Capacity and Udder Depth				
	Strength and Udder Depth	Foster et al. (1988)	0.07	0.00
		Klei et al. (1988)	0.38	
		VanRaden et al. (1990)	0.06	0.00
		Harris et al. (1992)	-0.30	-0.16
		Short and Lawlor (1992)	0.09	0.01
Capacity and Teat Size				
	Body Depth and Teat Length	Harris et al. (1992)	0.35	0.18
	Strength and Teat Length	Harris et al. (1992)	0.53	0.20
Femininity and Rear Legs				
	Dairy Form and Rear Legs	Foster et al. (1988)	0.13	0.11
		Klei et al. (1988)	-0.12	
		VanRaden et al. (1990)	0.27	0.14
		Harris et al. (1992)	0.08	0.00
		Short and Lawlor (1992)	0.31	0.14

Table 3. Continued

GTS Traits	Representative Traits[1]	Author	Genetic Correlation	Phenotypic Correlation
Femininity and Feet and Pasterns				
	Dairy Form and Foot Angle	Foster et al. (1988)	0.09	0.13
		Klei et al. (1988)	0.42	
		VanRaden et al. (1990)	-0.10	-0.02
		Harris et al. (1992)	0.12	0.13
		Short and Lawlor (1992)	-0.15	-0.03
Femininity and Udder Attachment				
	Dairy Form and Udder Attachment	Foster et al. (1988)	-0.01	-0.03
		Klei et al. (1988)	0.17	
		VanRaden et al. (1990)	-0.06	0.03
		Harris et al. (1992)	-0.14	-0.07
		Short and Lawlor (1992)	0.00	0.02
Femininity and Udder Depth				
	Dairy Form and Udder Depth	Foster et al. (1988)	-0.09	-0.11
		Klei et al. (1988)	0.03	
		VanRaden et al. (1990)	-0.11	-0.06
		Harris et al. (1992)	-0.41	-0.29
		Short and Lawlor (1992)	-0.03	-0.06
Femininity and Teat Size				
	Dairy Form and Teat Size	Harris et al. (1992)	0.22	0.18
Rear Legs and Feet and Pasterns				
	Rear Legs and Foot Angle	Foster et al. (1988)	-0.36	-0.10
		Klei et al. (1988)	-0.29	
		VanRaden et al. (1990)	-0.43	-0.18
		Harris et al. (1992)	-0.37	-0.23
		Short and Lawlor (1992)	-0.43	-0.21
	Rear Legs and Pasterns	Casanova (1993)	-0.30	-0.16
	Hocks Angle and Pasterns	Vukasinovic et al. (1995)	-0.23	-0.33
Rear Legs and Udder Attachment		Foster et al. (1988)	-0.12	-0.03
		Klei et al. (1988)	-0.10	
		VanRaden et al. (1990)	-0.11	-0.05
		Harris et al. (1992)	-0.07	-0.07
		Short and Lawlor (1992)	-0.08	-0.05
		Vukasinovic et al. (1995)	-0.02	-0.14

Table 3. Continued

GTS Traits	Representative Traits[1]	Author	Genetic Correlation	Phenotypic Correlation
Rear Legs and Udder Depth		Foster et al. (1988)	-0.02	-0.04
		Klei et al. (1988)	-0.12	
		VanRaden et al. (1990)	-0.06	-0.03
		Harris et al. (1992)	-0.13	-0.03
		Short and Lawlor (1992)	-0.04	-0.02
Rear Legs and Teat Size				
	Rear Legs and Teat Length	Harris et al. (1992)	-0.40	-0.03
		Vukasinovic et al. (1995)	0.04	0.04
	Rear Legs and Teat Form	Vukasinovic et al. (1995)	0.05	0.03
Feet and Pasterns And Udder Attachment				
	Foot Angle and Udder Attachment	Foster et al. (1988)	0.11	0.12
		Klei et al. (1988)	0.25	
		VanRaden et al. (1990)	0.25	0.15
		Harris et al. (1992)	-0.04	-0.07
		Short and Lawlor (1992)	0.28	0.14
Feet and Pasterns And Udder Attachment				
	Pasterns and Udder Attachment	Vukasinovic et al. (1995)	0.06	0.12
Feet and Pasterns and Udder Depth				
	Foot Angle and Udder Depth	Foster et al. (1988)	0.09	0.06
		Klei et al. (1988)	0.38	
		VanRaden et al. (1990)	0.16	0.08
		Harris et al. (1992)	-0.20	-0.03
		Short and Lawlor (1992)	0.25	0.07
Feet and Pasterns and Teat Size				
	Foot Angle and Teat Length	Harris et al. (1992)	0.31	0.05
	Pasterns and Teat Size	Lawstuen et al. (1987)	-0.07	-0.01
	Pasterns and Teat Form	Vukasinovic et al. (1995)	0.02	0.04
	Pasterns and Teat Length	Vukasinovic et al. (1995)	0.25	0.04

Table 3. Continued

GTS Traits	Representative Traits[1]	Author	Genetic Correlation	Phenotypic Correlation
Udder Attachment and Udder Depth		Foster et al. (1988)	0.75	0.38
		Klei et al. (1988)	0.86	
		VanRaden et al. (1990)	0.78	0.42
		Harris et al. (1992)	0.54	0.41
		Short and Lawlor (1992)	0.79	0.43
Udder Attachment and Teat Size				
	Udder Attachment and Teat Form	Vukasinovic et al. (1995)	0.17	0.32
	Udder Attachment and Teat Length	Harris et al. (1992)	0.05	-0.01
		Vukasinovic et al. (1995)	0.16	0.31
Udder Depth and Teat Size				
	Udder Depth and Teat Length	Harris et al. (1992)	-0.35	-0.15

[1]A representative trait is one that approximates the ABS GTS traits while not being exactly the same

Stature and body length were highly correlated with each other, both genetically (0.70 to 0.92) and phenotypically (0.57 to 0.69) in reports by Casanova (1993) and Vukasinovic et al. (1995). Conversely, the same authors found moderate to high negative genetic correlations between stature and muscling (-0.50 and -0.30), indicating that selection for larger framed animals may result in a decrease in muscle score. The phenotypic correlation between stature and muscle score was positive but quite low (0.02 and 0.09). In general, stature was strongly correlated with body depth (0.47 to 0.82) and strength (0.12 to 0.73), indicating that larger framed animals would be deeper and wider bodied with more width of chest. Casanova (1993) however, found a small negative (-0.08) genetic correlation between stature and body width. This is interesting to note since most of the strong positive correlations were from dairy literature and Casanova's

study was with Braunvieh, which is maintained as a beef breed in the United States. The genetic correlations between stature and dairy form were moderate with the exception of the estimate from Harris et al. (1992) which was higher (0.65). The phenotypic correlation from the Harris study was much higher than the other papers as well. This could due to the fact that the other dairy papers reviewed were from the Holstein breed and the Harris paper was with the Guernsey breed. There was a low negative correlation between stature and rear legs set with one exception. Vukasinovic et al. (1995) studied Brown Swiss cattle showed and showed a moderate negative (-0.25) genetic correlation between stature and rear legs set. Moderate genetic correlations were found between stature and foot angle (0.24 to 0.39).

Body length was moderately to highly negatively genetically correlated with muscling (-0.42 to -0.55) (Casanova, 1993; Vukasinovic, 1995). This may be expected due to the strong correlation between stature and body length previously mentioned. The phenotypic correlations were of lower magnitude and positive (0.11 to 0.19). Body length was moderately to highly correlated with body depth both genetically (0.45 to 0.52) and phenotypically (0.43 to 0.45). Vukasinovic et al. (1995) also showed that there was a moderate negative (-0.36) correlation between body length and body width, indicating that selection for body length would result in narrower cattle. Vukasinovic et al. (1995) demonstrated a moderate negative correlation (-0.40) between body length and hock angle.

A negative genetic correlation (-0.12 and -0.55) between muscle and body depth was reported by Casanova (1993) and Vukasinovic et al. (1995). However, Casanova

showed a strong genetic correlation between muscle and body width (0.65) while Vukasinovic et al. (1995) showed a slight negative genetic correlation (-0.09). Vukasinovic et al. (1995) also showed a strong negative genetic correlation (-0.59) between muscle and hock angle.

Body depth and dairy form were lowly to moderately correlated both genetically (0.19 to 0.52) and phenotypically (0.08 to 0.45). The genetic and phenotypic correlations between strength and dairy form were in disagreement, with the genetic correlation ranging from -0.35 to 0.38 and the phenotypic correlation ranging from -0.15 to 0.32. Generally the genetic and phenotypic correlations between body depth and rear legs and strength and rear legs were negative and of low magnitude. The genetic correlation between body depth and foot angle and strength and foot angle were somewhat higher (0.09 to 0.47) and (0.39 to 0.57) respectively.

There is considerable variation in the genetic correlations between dairy form and rear legs (-0.12 to 0.31) and dairy form and foot angle (-0.15 to 0.42). The phenotypic correlations are of the same sign but of lower magnitude.

Every paper reviewed (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992) published moderate negative correlations between rear legs and foot angle (-0.29 to 0.43), rear legs and pasterns (-0.30) (Casanova, 1993) and hocks angle and pasterns (-0.23) (Vukasinovic et al., 1995). The phenotypic correlations ranged from -0.10 to -0.33. These papers all indicated that as rear legs become straighter, foot angle increases and pasterns become straighter.

Udder attachment was moderate to highly correlated with udder depth in all papers reviewed (0.54 to 0.86). The phenotypic correlations ranged from 0.38 to 0.43. Vukasinovic et al. (1995) reported genetic and phenotypic correlations between udder attachment and teat form to be 0.17 and 0.32, respectively. Genetic and phenotypic correlations between udder attachment and teat length were reported to be 0.05 and -0.01 by Harris et al. (1992) and 0.16 and 0.31 by Vukasinovic et al. (1995). A single estimate of the genetic (-0.35) and phenotypic (-0.15) correlations between udder depth and teat length was given by Harris et al. (1992).

Economic Importance of the Traits

The economic value of type traits in cattle is often seen in their effect on improvement of functional stability of cows (Solkner and Petschina, 1999). Frey et al. (1972) evaluated the relationship of cow type classification score with cow productivity for Angus cows. They evaluated an overall type score, not individual parts of the animal, and concluded that there was a slight negative association between type classification scores and cow productivity as measured by calf weaning weight. Fatter cows received higher classification scores but weaned lighter, lower scoring calves. Total type classification score was of little value in predicting future producing ability. Body condition score had the largest effect in changing type score. It should be noted that the study conducted by Frey et al. (1972) looked at an overall type score, not individual parts of the animal. From studies with Angus and Hereford cows, Marlowe et al. (1962) and Marlowe and Morrow (1985) concluded that differences in flesh condition was the major source of variation in grade (type) within all breeds and age groups.

Stewart and Martin (1981) concluded that total weight weaned, years in the herd and weight weaned per year tended to decrease with increasing mature size. Buttram and Willham (1989) concluded that smaller heifers were more efficient reproductively in terms of calving rate than larger heifers, with medium sized heifers being intermediate. They also suggested that the relationship may be accentuated under unfavorable conditions. Lopez de Torre et al. (1992) also suggested that larger cows may be less productive because they wean fewer calves than smaller cows. They did however, note that there tended to be a positive relationship between mature size and weaning weight.

Solkner and Petschina (1999) studied 5,360 Austrian Simmental cows and analyzed the effect of linear type traits on length of productive life measured in days. They concluded that size and muscularity did not have significant effects on longevity. However, muscularity on the front part of the body did have the effect of shortening productive life. Beef cattle are heavier muscled and certainly more so on the front part of the body than dairy cattle. They concluded, however, by stating that the effect of type traits on longevity must to be viewed with caution because in many instances it might not be the functional deficiencies, but instead voluntary culling by the farmer for type, that reduces the lifetime of cows. This may certainly be the case for the cattle that do not conform to dairy type since they may be heavy muscled on the front part of the body.

Conformation of udder, feet and legs, and overall type have high genetic correlations with longevity (Everett et al., 1976; Klassen et al., 1992; Short and Lawlor, 1992; Dekkers et al., 1994; Weigel et al., 1995). Woodward (1968) stated that cattle with hock angles greater than 150 degrees appear to be more predisposed to becoming

"stifled". Based upon his experience at Fort Keogh Research Station, Woodward also stated that cattle that are post-legged tend to have more serious problems than those with sickle hocked conditions.

Udder traits have been shown to be economically important in increasing milk yield and productive life in dairy cattle (Rogers and McDaniel, 1988; Rogers et al., 1989). Solkner and Petschina (1999) also found that udder traits had significant positive effects on length of productive life. DeNise et al. (1987) concluded that there was no relationship between udder capacity and weight at weaning. Doornbos et al. (1981) suggested that a positive relationship existed between milk production and calf growth from birth to weaning, but concluded that the relationship between milk production and udder size was generally low. These results indicate that udder depth may have no relationship to weaning weight of beef calves.

CHAPTER 3

MATERIALS AND METHODS

Description of Data

Records from 21,052 Simmental cattle evaluated over a period of 12 years from 1988 to 2000 were sent to Montana State University for evaluation. The records represented 1,940 yearling bulls, 6,270 yearling heifers, and 8,052 mature cows. Thirty six trained evaluators collected the data.

When Beef GTS originated, the scoring system was adapted from ABS' Dairy linear type appraisal system. The first evaluators were required to successfully complete the dairy evaluation training. For the first year of the program, both a diary evaluation trainer and a beef evaluator trainer taught the evaluators. Since the inception of the program only two different instructors have taught the beef GTS portion of the training. One person taught the first year and from the second year until present (2001) the second instructor has trained all the evaluators.

When scoring the animals, evaluators recorded scores for the ten linear type traits as well as body condition score. When animals were scored, date, ABS customer number of the herd, and evaluation group were recorded. An evaluation group number was assigned to each group of cattle in a different pen or pasture at the time of evaluation.

Evaluators recorded the herd identification (generally ear tag number) of the animal at the time of scoring. After scoring the animals, evaluators received as much of

the pedigree of each animal as possible from the owner of the animal at the time of evaluation.

Edits were performed on the dataset to delete records from animals that did not have sire, maternal grandsire, and dam registered with the American Simmental Association. Yearling bulls were dropped from the evaluation due to the low numbers of scores. A number of animals were excluded from the evaluation for having obvious errors in their registration numbers. Animals that had complete herd identification and pedigree information but that were missing an individual registration number were assigned pseudonumbers for the purpose of the evaluation. These instances occurred when a herd identification number was mistakenly entered as an individual registration number in the ABS database.

Table 4 shows the number of animals analyzed for each trait, along with descriptions of the data analyzed. The difference in the number of records between body traits and udder traits indicates the number of yearling females that were scored and have no records for the udder traits. The linear type traits were scored on a scale from 0 to 50 points. Body condition score was assigned on a scale from 1 to 9.

Table 4. Scores and distributions of Simmental data from the ABS Global dataset.

GTS Trait	Number	Range	Mean	Standard Deviation
Stature	14,322	3 - 50	30.66	5.79
Body length	14,321	2 - 50	30.65	4.53
Muscle	14,320	2 - 50	28.71	4.81
Capacity	14,320	3 - 50	29.65	5.03
Femininity	14,320	2 - 50	26.37	5.21
Rear legs	14,320	2 - 45	25.17	3.60
Feet and pasterns	14,317	5 - 50	25.90	3.87
Udder attachment	8,046	1 - 50	25.75	6.15
Udder depth	8,050	0 - 50	26.95	6.02
Teat size	8,052	2 - 50	26.32	6.45
Body condition score	9,230	1 - 9	6.00	0.668

Contemporary groups

To account for herd, evaluation group, year, and evaluator effects on scores, contemporary group was defined as animals with the following in common: 1) herd, 2) evaluation date, 3) evaluation group, and 4) evaluator. There were 517 contemporary groups for the body traits. There were 323 contemporary groups for the udder traits and 355 groups for body condition score. The number of sires represented in the final dataset was 1,630.

Table 5 presents a description of the production records obtained from ASA. These records were merged with the ABS dataset so that a study of how the GTS traits may affect production measures of Simmental cattle could be made. A noticeable difference between the ASA database and the ABS database described is Table 4 is that

in the ASA database, there are more females with calving records. This is explained by the fact that at the time that some of the females were evaluated (some as early as 1988), they had not calved, but when the database was received in 2001 from ASA, those females now had records in the ASA database.

Table 5. Production measures and distributions from the ASA database.

Production Measure	Number	Range	Mean	Standard Deviation
# of calves	11,817	0 to 16	3.610	3.0112
Calving interval, d	7,347	350 to 800	419	87.136
Calf adjusted birth weight, lb	9412	46 to 128	90.791	8.553
Calf adjusted weaning weight, lb	9663	333 to 979	619.381	66.674
Total adjusted weaning weight, lb	9663	333 to 11,850	2654.85	1759.03

Statistical analyses

Variance components were estimated using the animal model with MTDFREML procedures (Boldman et al., 1995). These procedures were used to obtain estimates of heritabilities of GTS traits and genetic and phenotypic correlations among the traits. The single-trait model for analyses of GTS traits included the additive direct genetic effect of animal and the fixed effects of age of cow and contemporary group.

In matrix notation, the single-trait model equation for analyses of GTS traits was:

$$\mathbf{y} = \mathbf{X}\beta + \mathbf{Z}\mathbf{u} + \mathbf{e}$$

where: $\mathbf{y}$ is the vector of GTS trait observations, β is the vector of unknown fixed effects (age of cow and contemporary group), and $\mathbf{u}$ is the vector of random direct genetic effects

with associated incidence matrices **X** and **Z**, respectively, and **e** is a vector of random residual effects. The mean vector is $\mathbf{E(y)} = \mathbf{X}\beta$ and

$$V \begin{pmatrix} \mathbf{u} \\ \mathbf{e} \end{pmatrix} = \begin{pmatrix} \mathbf{A}\sigma^2_u & 0 \\ 0 & \mathbf{I}\sigma^2_e \end{pmatrix}$$

where: **A** is the numerator relationship matrix among animals, **I** is the appropriate identity matrix, and σ^2_u and σ^2_e are variances due to direct genetic and residual effects, respectively.

The pedigree file from the ABS Database was used to compute the inverse of the numerator relationship matrix ($\mathbf{A}^{-1}$). The file contained 22,765 animal, sire, and dam identification numbers.

All runs were carried out to nine decimal places for the convergence algorithm. Three repetitions were run for each model to insure that a global maximum of the log likelihood function was found.

The GTS traits were adjusted to account for the fixed effects of cowage and contemporary groups. Partial regression coefficients (SAS, 1993) were computed to determine effect of the adjusted GTS traits on relevant measures of production supplied by the ASA.

CHAPTER 4

RESULTS AND DISCUSSION

Presentation of results from this study will be separated into three main sections: 1) heritabilities of ABS GTS traits, 2) genetic and phenotypic correlations among the traits, and 3) relationships of the GTS traits with production measures of Simmental cattle.

Heritabilities

The heritabilities of the GTS traits are presented in Table 6 on the diagonal in bold type. In most cases the estimated heritabilities are within the range previously reported in the literature.

The heritability of stature from the GTS dataset was estimated to be 0.60. This estimate was higher that the estimates reported from the dairy literature (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992; Holstein Association, 2001) which ranged from 0.36 to 0.43 (Table 2). However, the estimate was comparable to the Angus classification heritabilities of 0.37, 0.49, and 0.58 reported by Nielsen and Willham (1974). It was also in agreement with the estimates of 0.56 for height at withers and 0.55 for height at hips reported by Casanova (1993).

Body length was estimated to have a heritability of 0.39. This estimate is in close agreement with the only other estimate in the literature of 0.39 for Swiss Braunvieh reported by Casanova (1993).

Table 6. Heritabilities and genetic and phenotypic correlations among ABS GTS traits.[1,2]

	ST	BL	MU	CA	FE	RL	FP	UA	UD	TS	BCS
ST	**0.6**	0.6	0.07	0.06	0.13	-0.07	0.11	-0.01	0.08	-0.02	-0.05
BL	0.86	**0.39**	0.12	0.05	0.15	-0.04	0.09	0	0	0.01	-0.03
MU	0.01	0.01	**0.42**	0.56	-0.2	-0.01	0.02	0.03	-0.05	0.03	0.42
CA	-0.03	-0.12	0.66	**0.44**	-0.17	0.05	-0.06	0.07	-0.08	-0.02	0.4
FE	0.27	0.36	-0.34	-0.34	**0.32**	-0.003	0.02	0.09	0.09	0.11	-0.17
RL	-0.22	-0.27	0.06	0.13	-0.08	**0.12**	-0.43	-0.01	-0.02	0	-0.001
FP	0.38	0.36	-0.12	-0.32	0.03	-0.79	**0.13**	0.01	0.07	0.01	-0.01
UA	0	-0.01	0	-0.04	0.13	0.01	-0.09	**0.23**	0.48	0.32	-0.005
UD	0.24	0.14	0.01	-0.15	0.06	-0.28	0.2	0.58	**0.35**	0.4	-0.06
TS	-0.04	0.02	0.13	-0.01	0.15	-0.05	-0.03	0.51	0.57	**0.39**	-0.005
BCS	-0.19	-0.3	0.73	0.65	-0.43	0.04	-0.12	0.04	-0.07	0.01	**0.24**

[1] ST = Stature, BL = Body length, MU = Muscle, CA = Capacity, FE = Femininity, RL = Rear legs, FP = Feet and pasterns, UA = Udder attachment, UD = Udder Depth, TS = Teat Size, and BCS = Body condition score.

[2] Heritabilities are on the diagonal in bold, phenotypic correlations are above the diagonal, and genetic correlations are below the diagonal

The estimate of heritability for muscle from the ABS dataset was 0.42. The estimate is within the range of 0.40 to 0.66 for the Angus classification scores reported by Nielsen and Willham (1974). Other estimates were somewhat lower than that from the ABS dataset. Koch et al. (1974) reported estimates of 0.24 and 0.30 for Hereford heifers and bulls, respectively. The research for Normande cattle (Larroque, 2000) points to estimates ranging from 0.13 to 0.29 depending upon where on the animal the evaluation was completed.

Capacity was estimated to have a heritability of 0.44. The estimate is at the lower end of the estimates from Kliewer (1971), which ranged from 0.43 to 0.70 depending on the age of the cow when evaluated. Van Doormaal and Burnside (1987) reported estimates of heritability for Canadian Holsteins of 0.21 and 0.23, depending on whether the cows were grade or registered. The estimate of 0.44 for heritability of capacity is greater than the average of the heritabilities of strength and body depth reviewed in Table 3 in every case (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992; Holstein Association, 2001).

The estimate of heritability for femininity from the ABS dataset was 0.32. The most similar dairy trait is dairy form. The heritability estimates for dairy form were in a tight range from 0.23 to 0.29 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992; Holstein Association, 2001) and the present estimate for femininity is only slightly out of the range established for dairy form in the literature.

Heritability of rear leg set has been well reviewed and most estimates are within the range of from 0.12 to 0.21, with only a few papers reported values up to 0.35 (Foster

et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992; Holstein Association, 2001). Nielsen and Willham (1974) estimated heritabilities of a composite feet and legs trait to range from 0.32 to 0.52. The estimate of heritability for rear legs set from the ABS dataset was 0.12, which is at the low end of the range established in the dairy literature. The only notable exception being the Nielsen and Willham paper which dealt with beef cattle.

The estimate of heritability from the ABS dataset for feet and pasterns was 0.13. The estimates of heritability for foot angle from the dairy literature ranged from 0.09 to 0.15 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992; Ral et al.1995; Holstein Association, 2001), with the exception of one paper reviewed by Ral et al. (1995) which estimated the heritability to be 0.53. Casanova (1993) estimated pastern angle and heel height to have heritabilities of 0.25 and 0.18 respectively. Again, Ral et al. (1995) had the high estimate of 0.34 for heel height and 0.41 for toe angle. The estimate for Simmental cattle from the ABS dataset is in general agreement with the estimates of heritability for foot and leg traits published in the dairy literature.

The estimate of heritability for udder attachment from the ABS dataset was 0.23. The ABS udder attachment score is a composite score of the dairy evaluations for fore udder attachment, rear udder height, and rear udder width. The dairy literature reviewing udder scores (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992) estimated the heritability of fore udder attachment to range from 0.18 to 0.29. Estimates for rear udder height ranged from 0.18 to 0.28 and estimates for rear

udder width ranged from 0.15 to 0.23. Casanova (1993) estimated heritability for rear udder attachment and strength of attachment to be 0.21 and 0.25 respectively. The estimate from the ABS dataset is clearly within the range previously established in the dairy literature.

Udder depth has been reported to have a heritability of from 0.24 to 0.34 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992) (Table 3). DeNise et al. (1987) reported estimates of heritability for udder capacity and udder shape to be 0.12 and 0.15, respectively, in Hereford cows. The estimate of heritability from the ABS dataset for Simmental cows was 0.35, which is at the high end of the dairy estimates.

The estimate of heritability of teat size from the ABS dataset was 0.39. Teat length was shown to have heritabilities ranging from 0.22 to 0.32 (Harris et al., 1992; Casanova, 1993; Holstein Association, 2001) (Table 3). Casanova (1993) estimated teat length to have a heritability of 0.40. The estimate from the ABS dataset is slightly out of the range of that reported in the dairy literature, but is in close agreement with the estimate reported by Casanova.

Heritability of body condition score from the ABS dataset was estimated to be 0.24. This was somewhat lower than the previous estimate by Marlowe and Marrow (1985) of 0.31.

Genetic and Phenotypic Correlations

Genetic and phenotypic correlations among the traits are shown in Table 6. With few exceptions, the genetic and phenotypic correlations among the traits were of similar magnitude and the same sign. Generally, the results of the present study were consistent with literature that was reviewed in Table 3. Correlations will be discussed on a trait by trait basis.

A strong genetic (0.86) and phenotypic correlation (0.60) existed between stature and body length, indicating that taller cattle are longer bodied, and selection for increased height will result in longer cattle and vice versa. The results are in close agreement with the studies by Casanova (1993) and Vukasinovic et al. (1995). Casanova found a genetic correlation of 0.79 between wither height and body length, with a phenotypic correlation of 0.57. Vukasinovic et al. found an exceptionally high genetic correlation of 0.92 between height at hip and body length, with a phenotypic correlation of 0.69.

The genetic correlation between stature and muscle from the present study was 0.01. This is in strong contrast with the genetic correlations reported in Casanova's 1993 study (-0.50) that reported by Vukasinovic et al. (1995) (-0.30). The phenotypic correlations between stature and body length were 0.02 and 0.09 from Casanova and Vukasinovic et al., respectively. Those estimates were close to the phenotypic correlation found in the present study, which was 0.07.

The estimate of the genetic correlation between stature and capacity from the ABS dataset was -0.03. This is in contrast with the estimates for the comparable dairy

traits of body depth and strength or body depth and width reviewed. The literature estimates for the genetic correlations between stature and those traits ranged from 0.12 to 0.82 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992; Casanova, 1993; Vukasinovic et al., 1995). The phenotypic correlations from those studies ranged from 0.19 to 0.65 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992; Casanova, 1993; Vukasinovic et al., 1995), which are different than the phenotypic correlation from the ABS dataset, which was 0.06. The only comparable genetic correlation is from Casanova's paper concerning the genetic correlation between stature and body width. The genetic correlation from that paper was -0.08. The phenotypic correlation from that paper was 0.24, which is larger in magnitude than the ABS dataset estimate of 0.06. These results may indicate that either the dairy traits are evaluated differently than the ABS GTS traits or, possibly, that different genetic parameters may be present in beef versus dairy breeds.

There were low genetic correlations of 0.27, -0.22 and 0.38 between stature and femininity, rear leg set, and feet and pasterns, respectively. Normally, this would be of small importance. However, the genetic correlations between body length and femininity, rear leg set, and feet and pasterns were 0.36, -0.27, and 0.36, which are in relative agreement with the correlations between the traits and stature. The genetic correlations, although of low magnitude, indicate that as selection for increased stature is practiced, some of the increase will be due to increasing the hock angle, thus straightening the rear legs. Some of the increase in stature will also be the result of

increasing the strength of pasterns and depth of heel. The literature reviewed in Table 3 showed only one paper with a genetic correlation between stature and rear legs set as extreme as was shown with the ABS dataset. Vukasinovic et al. (1995) showed a -0.25 correlation between stature and rear legs set, the range of the other papers reviewed was from -0.13 to 0.04 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992) The phenotypic correlations between stature and rear legs reviewed ranged from -0.09 to -0.02 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992; Vukasinovic, 1995), which is in close agreement with the results of this study (-0.07). The papers reviewed concerning genetic correlations between stature and foot angle were generally in agreement with the results of the present study. The range of genetic correlations reviewed was from 0.24 to 0.39 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992), with the correlation from the present study estimated at 0.38. There were low magnitude positive and negative phenotypic correlations between stature and foot angle presented in Table 3 ranging from -0.16 to 0.14 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). The estimate from the present study was 0.11, which was within the range of that previously reported. Vukasinovic et al. (1995) also found genetic and phenotypic correlations between body length and hock angle of -0.40 and -0.14 which are of greater magnitude than the estimates of -0.27 and -0.04 for the present study. The genetic correlations between stature and dairy form reviewed in Table 3 were consistent with the estimated genetic correlation between stature and femininity (0.27) from the ABS dataset. With the

extremely high (0.65) estimate by Harris et al. (1992) removed, the remaining papers ranged from 0.20 to 0.34 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Short and Lawlor, 1992), which was comparable to the estimate from the present study.

The estimate of the genetic correlation between stature and udder attachment from the present study was 0.00. Previous estimates ranged from 0.00 to 0.32 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992; Vukasinovic et al., 1995). The phenotypic correlation was estimated to be 0.01, Which compared more favorably to the previous literature estimates of -0.01 to 0.14 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992; Vukasinovic et al., 1995).

Foster et al., (1988); Klei et al., (1988); VanRaden et al., (1990); Harris et al., (1992); and Short and Lawlor, (1992) estimated the genetic correlation between stature and udder depth to range from -0.15 to 0.37. It should be noted that Harris et al. produced the low estimate of -0.15, the other four estimates ranged from 0.32 to 0.37. The estimate from the ABS dataset was 0.24. Although not a high correlation, this moderate correlation was fairly consistent across authors, with no explanation of a possible reason why stature may be correlated to udder depth. The phenotypic correlation between stature and udder depth ranged from -0.08 to 0.16 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). With the lone negative estimate by Harris et al. removed, the three remaining phenotypic correlations ranged from 0.12 to 0.16, which was only slightly larger than the correlation of 0.08 from the ABS dataset.

Stature and teat size were estimated to have a genetic correlation of -0.04 from the ABS dataset, with a phenotypic correlation of -0.02. This was comparable to Vukasinovic et al. (1995), who estimated genetic and phenotypic correlations of 0.00 and 0.02, respectively between stature and teat size. Harris et al. (1992) and Vukasinovic et al.. (1995) published genetic correlations between stature and teat length of 0.32 and -0.15, respectively. The phenotypic correlations from Harris et al. and Vukasinovic et al. were 0.22 and -0.01, respectively. These results indicated that teat form may be a better representative trait of the ABS GTS trait teat size than was teat length.

The genetic correlation between body length and muscle score from the ABS dataset was 0.01. This is in sharp contrast to the genetic correlations of -0.42 and -0.55 reported by Casanova (1993) and Vukasinovic et al. (1995). However, the phenotypic correlation from Casanova (0.11) and Vukasinovic et al. (0.19) was in closer agreement with the estimate of 0.12 from the ABS dataset.

Casanova (1993) and Vukasinovic et al. (1995) estimated the genetic correlation between body length and body depth to be 0.45 and 0.52 respectively. The same authors estimated the genetic correlation between body length and body width to be 0.02 (Casanova, 1993) and -0.36 (Vukasinovic et al., 1995). These correlations were mostly of the opposite sign of the estimate of -0.12 from the ABS dataset. The phenotypic correlations between body length and body depth were given as 0.43 (Casanova, 1993), and 0.45 (Vukasinovic et al., 1995). The phenotypic correlations between body length and body width were 0.35 (Casanova, 1993), and 0.33 (Vukasinovic et al, 1995). While these phenotypic correlation were in agreement with each other, they were larger in

magnitude that the estimate of 0.05 from the ABS dataset. These results indicate that even though part of the GTS trait capacity was defined as depth and width of body, the traits may be perceived differently in dairy cattle as compared to beef cattle.

The correlation between body length and feet and pasterns from the ABS dataset was 0.36. Vukasinovic et al. (1995) reported a lower genetic correlation of 0.15. However, the estimate for the phenotypic correlation from Vukasinovic et al. and from the ABS dataset were both 0.09

The estimates of genetic and phenotypic correlations between body length and udder attachment were of low magnitude in both Vukasinovic et al. (1995) and the ABS dataset. The estimates from the ABS dataset were -0.01 and 0.00 for the genetic and phenotypic correlations, respectively. The results published by Vukasinovic were -0.13 and 0.10 for the genetic and phenotypic correlations. . .

The genetic and phenotypic correlations between body length and teat size from the ABS dataset were 0.02 and 0.00, respectively. The genetic and phenotypic correlations between body length and teat form were 0.00 and 0.04, respectively Vukasinovic et al. (1995). In the same paper, the authors published genetic (-0.15) and phenotypic (0.01) correlations between body length and teat length, which were also of low magnitude.

The genetic correlation between muscle and capacity from the ABS dataset was 0.66. Casanova (1993) and Vukasinovic et al. (1995) estimated genetic correlation between muscle and body depth to be -0.12 and -0.55, respectively. These results are in

strong disagreement with the results from the ABS dataset. The genetic correlations between muscle and body width were given as 0.65 (Casanova, 1993) and -0.09 (Vukasinovic et al., 1995). The phenotypic correlation from the ABS dataset was 0.56. The phenotypic correlations between muscle and body depth were given as 0.25 (Casanova, 1993) and 0.33 (Vukasinovic et al., 1995). The phenotypic correlations between muscle and body width were closer to the estimate from the ABS dataset. Casanova (1993) estimated the phenotypic correlation to be 0.54, while Vukasinovic et al. (1995) estimated the correlation at 0.33. Part of the difference in the results may have been due to the smaller number of animals evaluated in the Casanova (1993) and Vukasinovic et al. (1995) papers.

Only slight genetic (0.06) and phenotypic (-0.01) correlations were found between muscle and rear leg set. The genetic correlation found by Vukasinovic et al. (1995) was negative and of a much larger magnitude (-0.59). The phenotypic correlation from the same study was -0.15, which is more closely associated with the estimate from the ABS dataset.

The genetic correlation between muscle and feet and pasterns was -0.12 from the ABS dataset. Conversely, Vukasinovic (1995) found a positive, low magnitude (0.09) estimate between muscle and pasterns. The phenotypic correlation from the ABS dataset was 0.02. The estimate from Vukasinovic et al. (1995) was only slightly higher at 0.10.

The genetic and phenotypic correlations from the ABS dataset between muscle and udder attachment were 0.00 and 0.03, respectively. Vukasinovic et al. (1995) estimated the same correlation to be -0.33 and 0.08.

The genetic and phenotypic correlations between muscle and teat size were 0.13 and 0.03. Vukasinovic et al. (1995) found stronger but negative (-0.35) genetic correlation between muscle and teat form. They also found a slight negative (-0.07) genetic correlation between muscle and teat length. The phenotypic correlations were -0.01 between muscle and teat form, and 0.03 between muscle and teat length, which is in agreement with the results of this study.

The genetic correlation between capacity and femininity was moderate and negative (-0.34) in this study. Earlier work indicated a range of from 0.19 to 0.52 for the genetic correlation between the dairy traits body depth and dairy form (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). Strength and dairy form from the same studies had genetic correlations ranging from -0.35 to 0.38. The phenotypic correlation between capacity and femininity from the ABS dataset was -0.17. The phenotypic correlation between body depth and dairy form reviewed in the literature were from 0.08 to 0.45 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). The phenotypic correlations between strength and dairy form ranged from -0.15 to 0.32 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992).

The genetic correlation between capacity and rear leg set from the ABS dataset was 0.13. In nearly every case, the genetic correlation between body depth and rear legs from the dairy literature was negative. The estimates ranged from -0.10 to 0.06 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). The genetic correlations between strength and rear legs set ranged from

-0.33 to -0.07 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). Although most of the genetic correlations are of low magnitude, the consistency of the sign being opposite from the results of this study indicate that the traits may not be the same traits when comparing beef to dairy cattle. The phenotypic correlation between capacity and rear legs from the ABS dataset was -0.00. The phenotypic correlation between body depth and rear legs from the dairy literature ranged from -0.06 to 0.03 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). The phenotypic correlations between strength and rear legs ranged from -0.13 to -0.05 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992).

The genetic correlation between capacity and feet and pasterns was -0.32. The genetic correlations between body depth and foot angle ranged from 0.09 to 0.47 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). The genetic correlations between strength and foot angle ranged from 0.41 to 0.53 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). The phenotypic correlation between capacity and feet and pasterns was -0.06 for the ABS dataset. The phenotypic correlations between body depth and foot angle were from 0.04 to 0.17 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). The phenotypic correlations between strength and foot angle ranged from 0.13 to 0.23 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992).

The genetic correlation between capacity and udder attachment for the ABS dataset was -0.04. The genetic correlations between body depth and udder attachment ranged from -0.08 to 0.28 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). The genetic correlations between strength and udder attachment ranged from 0.03 to 0.52 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). The phenotypic correlations were in closer agreement with the estimate from the ABS dataset for the correlation between capacity and udder attachment of 0.07. The phenotypic correlation between body depth and udder attachment ranged from -0.01 to 0.13 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). The phenotypic correlations between strength and udder attachment ranged from 0.08 to 0.16.

The genetic correlation between capacity and udder depth from the ABS dataset was -0.15. The genetic correlations between body depth and udder depth ranged from -0.39 to 0.05 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). The genetic correlations between strength and udder depth ranged from -0.30 to 0.38 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). The phenotypic correlation between capacity and udder depth from the ABS dataset was -0.08. The phenotypic correlation between body depth and udder depth ranged from -0.25 to 0.03 . (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). These results are in agreement with the phenotypic correlation from the ABS dataset. The phenotypic

correlations between strength and udder depth were from -0.16 to 0.01 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992).

The genetic correlation between capacity and teat size from the ABS dataset was -0.01. The genetic correlation between body depth and teat length published by Harris (1992) was 0.35. The genetic correlation between strength and teat length by the same author was 0.53. Both of the correlations are greatly different from that found in the ABS dataset. The phenotypic correlation between capacity and teat size from the ABS dataset was -0.02. The phenotypic correlation between body depth and teat length was 0.18 (Harris, 1992). Harris (1992) also concluded the phenotypic correlation between strength and teat length was 0.20.

The genetic correlation between femininity and rear legs set was -0.08 from the ABS dataset. The dairy literature reviewed showed a correlation ranging from -0.12 to 0.31 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992) for the correlation between dairy form and rear legs set. The phenotypic correlation from the present study was -0.00. The phenotypic correlation between dairy form and rear legs set was from 0.00 to 0.14 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992).

The genetic correlation between femininity and feet and pasterns from the ABS dataset was 0.03. The genetic correlation between dairy form and foot angle ranged from -0.15 to 0.42 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). The phenotypic correlations for the same traits ranged from -0.03 to 0.13 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short

and Lawlor, 1992), compared to the phenotypic correlation between femininity and pasterns from this study, which was 0.02.

The genetic correlation between femininity and udder attachment was 0.13. The genetic correlations between dairy form and udder attachment ranged from -0.14 to 0.17 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). The phenotypic correlation between femininity and udder attachment was 0.09. The estimates from the dairy literature ranged from -0.07 to 0.03 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992).

The genetic correlation between femininity and udder depth was 0.06. The genetic correlations between dairy form and udder depth were from -0.41 to 0.03 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). The phenotypic correlation between femininity and udder depth was 0.09. The phenotypic correlations between dairy form and udder depth ranged from -0.29 to -.06. (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992).

The genetic and phenotypic correlations between femininity and teat size were 0.15 and 0.11 respectively. The genetic and phenotypic correlations between dairy form and teat size were 0.22 and 0.18, respectively (Harris, 1992).

There was a strong negative genetic correlation (-0.79) and a moderate negative (-0.43) phenotypic correlation between rear leg set and feet and pasterns. The results from previous studies range from -0.23 to -0.43 (Foster et al., 1988; Klei et al., 1988;

VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992) for the genetic correlation between rear leg set and feet and pasterns, which are lower in magnitude than the results from this study. The same was true of the phenotypic correlations. The correlations from earlier studies ranged from -0.10 to -0.33 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992), which are lower estimates than -0.43 that was found in this study. These results indicate that straighter legged animals tend to have stronger, straighter pasterns and a deeper heel. Selection for straighter legs will result in straighter pasterns and more depth of heel.

The genetic correlation between rear legs set and udder attachment was 0.01. The genetic correlations between the same traits from the reviewed literature (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992; Vukasinovic et al., 1995) ranged from -0.11 to -0.02. The phenotypic correlation from the ABS dataset was -0.01. The phenotypic correlations from the earlier work ranged from -0.14 to -0.03 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992, Vukasinovic et al., 1995).

The genetic correlation between rear legs and udder depth from the present study was -0.28. The genetic correlations from the previous studies were of the same sign and ranged from -0.13 to -0.02 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). The phenotypic correlation from the present study (-0.02) was within the range of the previous estimates of from -0.04 to -0.02 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992).

The genetic correlation between rear legs and teat length from the present study was 0.05. This compares favorably to the estimates from Vukasinovic et al. (1995) for the genetic correlation between rear legs and teat length (0.04) and the genetic correlation between ear legs and teat form (0.05). The estimates of the genetic correlation between rear legs and teat length by Harris et al. (1992) was -0.40, which was negative and much stronger than the correlations from the ABS dataset and those reported by Vukasinovic et al. (1995). The phenotypic correlation between rear legs and teat size from the ABS dataset was 0.00. The phenotypic correlations between rear legs and teat length by Harris et al (1992) and Vukasinovic et al (1995) were -0.03 and 0.04, respectively. The phenotypic correlation between rear legs and teat form was 0.03 (Vukasinovic et al., 1995).

The genetic correlation between feet and pasterns from this study was -0.09. The literature reviewed for this correlation reveals only one negative genetic correlation of -0.04 (Harris et al., 1992) between foot angle and udder attachment. The remaining papers reviewed (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Short and Lawlor, 1992) published the genetic correlation as ranging from 0.11 to 0.28. Vukasinovic et al. (1995) estimated the genetic correlation between pasterns and udder depth to be 0.06. The phenotypic correlation between feet and pasterns and udder attachment from the ABS dataset was 0.01. The phenotypic correlations between foot angle and udder attachment ranged from -0.07 to 0.15 (Foster et al., 1988; VanRaden et al., 1990; Harris et al., 1992; Short and Lawlor, 1992). The phenotypic correlation between pasterns and udder attachment from the Vukasinovic et al. (1995) study was 0.12.

The genetic correlation between feet and pasterns and udder depth from the ABS dataset was 0.20. This is in general agreement with the reviewed literature except from a negative estimate of -0.20 by Harris et al. (1992). The other paper ranged from 0.09 to 0.38 (Foster et al., 1988; Klei et al., 1988; VanRaden et al., 1990; Short and Lawlor, 1992) for the genetic correlation between foot angle and udder depth. The phenotypic correlation between feet and pasterns and udder depth from the present study was 0.07. This estimate is in agreement with the range of from 0.06 to 0.08 published by Foster et al. (1988); VanRaden et al. (1990); Short and Lawlor (1992). The estimate by Harris et al. (1992) was -0.03, however.

The genetic correlation between feet and pasterns and teat size from the present study was -0.03. Harris et al. (1992) reported a genetic correlation between foot angle and teat length of 0.31. Vukasinovic et al. (1995) estimated the genetic correlation between pasterns and teat form to be 0.02. They also estimated the genetic correlation between pasterns and teat length to be 0.25. Lawstuen et al. (1987) reported the genetic correlation between pasterns and teat size to be -0.07. The phenotypic correlation between feet and pasterns and teat size from the present study was 0.01. The phenotypic correlation between foot angle and teat length by Harris et al. (1992) was 0.05. Vukasinovic et al. (1992) estimated the phenotypic correlation between pasterns and teat form to be 0.04 and the phenotypic correlation between pasterns and teat length to also be 0.04. Lawstuen et al. (1987) estimated the phenotypic correlation between pasterns and teat size to be -0.01. The results published by Lawstuen et al. (1987) were in closer agreement with the results from this study than were the other papers (Harris et al., 1992

and Vukasinovic et al., 1995). This may be because Lawstuen et al. (1987) evaluated teat size as a composite trait of teat length and diameter, in the same way as ABS defines teat size.

There were moderate to strong genetic and phenotypic correlations among the udder traits as a group. With genetic correlations of 0.58 between udder attachment and udder depth, selection for either trait should result in an improvement in the other. This was compared to the range of from 0.54 to 0.86 reported in previous dairy literature. Genetic correlations of 0.51 and 0.57 between udder attachment and teat size and udder depth and teat size also indicate that selection for change in any one udder trait will result in a corresponding change in the other traits. The phenotypic correlation between udder attachment and udder depth was 0.48 for the present study. Previous estimates ranged from 0.38 to 0.43 (Table 3). Although lower in magnitude, the phenotypic correlations among the udder traits indicate that tight uddered cows tend to have better attached udders with smaller teats than cows with deeper udders do. The phenotypic correlation between udder attachment and udder depth was 0.48. The phenotypic correlation between udder attachment and teat size was 0.32, the correlation between udder depth and teat size was 0.40.

Effect of GTS Traits on Production

Table 7 presents partial regressions of measures of production in Simmental cows on the GTS traits. Some GTS traits were important to more of the production measures than others. These regressions are useful only for describing how measures of production

change as GTS traits change on a phenotypic basis, but are not useful to predict change in a production measure as selection for change in a GTS trait is practiced.

Table 7. Partial regression coefficients of Production Traits of Simmental Cows on GTS Traits.[1,2]

	# OF CALVES	CALVING INTERVAL	CALF ADJ BW	CALF AVE ADJ WW	TOTAL CALF ADJ WW
Stature	0.009	0.660	0.182**	0.855**	-1.534
Body length	-0.000	0.532	0.201**	0.976**	-0.073
Muscle	0.031**	0.257	0.080**	0.774**	16.565**
Capacity	0.035**	-0.636	0.046*	1.043**	20.524**
Femininity	-0.000	-0.187	0.022	0.276*	3.563
Rear legs	0.011	-0.582	-0.028	0.152	7.584
Feet and pasterns	-0.014*	0.980*	0.022	0.007	-2.725
Udder attachment	0.009*	0.043	-0.32	0.041	3.247
Udder depth	-0.004	0.175	-0.086**	-1.327	-8.453*
Teat size	0.008	0.517	-0.048	-0.245	3.563
Body condition score	0.150**	0.962	0.066	1.093	64.468*

[1] CALF ADJ BW = Progeny's adjusted birth weight, CALF AVE ADJ WW = progeny's average adjusted weaning weight, and TOTAL CALF ADJ WW = lifetime total adjusted weaning weight of progeny.

[2] ** = $p < 0.01$

* = $p < 0.05$

Stature and body length were important to more production traits than the other GTS traits. Stature and body length were important for the same measures of production. These results further verify the positive genetic correlation of 0.86 between stature and body length that was earlier established in this study. It is also noteworthy that the regressions for stature and the production traits are quite similar to the regressions for body length and the production traits. Muscle and capacity were important to fewer production traits than stature and body length. Muscle, capacity, and body condition score had strong positive genetic relationships as well (Table 6). These GTS traits were generally important to the same production measures in Table 7, although there were some differences. In the case of the relationship between calf adjusted birth weight and the GTS traits, muscle and capacity were important, but body condition score was not. Udder depth and teat size were important to more production traits than was udder attachment. Femininity, feet and pasterns, udder attachment, and rear legs set were important to the least number of traits.

GTS Traits Important to Number of Calves

Number of calves had a regression of 0.031 ($P < 0.01$) on muscle score. A similar regression (0.035) was noted for capacity ($P < 0.01$). The regression of number of calves on body condition score was 0.150 ($P < 0.01$). There was a negative regression of –0.014 when number of calves was regressed on feet and pasterns ($P < 0.05$). A regression of 0.009 ($P < 0.05$) was observed when number of calves was regressed on udder attachment. These results indicate that higher capacity, heavier muscled, fatter cows

tended to raise more calves. Stature and body length from this study were not significantly related to number of calves as was suggested by Stewart and Martin (1981), Buttram and Willham (1989), and Lopez de Torre et al. (1992).

GTS Traits important to Calving Interval

One trait was important to calving interval. The regression of calving interval on feet and legs was 0.004 ($P < 0.05$). This trait may not have a large biological effect. Note that while stature and body length were not significant at P levels < .05, these traits approached significance with P values of 0.053 and 0.059, respectively. In a commercial cattle operation, a cow that failed to breed would generally be culled. In reviewing Table 5, an average calving interval of 419 days is shown. The reason for this is not that Simmental seed stock producers do not cull the females that fail to become pregnant. Part of the reason for the large calving interval is that some producers only reported information to the association on calves that may have been above average or met certain other criteria set by the individual producer. The calving interval is certainly smaller that that shown in Table 5. Without further editing, calving interval may not be an appropriate measure of performance in this analysis.

GTS Traits Important to Calf Adjusted Birth Weight

Stature and body length had significant effects on calf adjusted birth weight. For every one unit increase in stature, the females' resulting calves increased in birth weight by .182 pounds ($P < 0.01$). The regression of calf adjusted birth weight on body length

was 0.201 ($P < 0.01$). Muscle and capacity were important to calf adjusted birth weight, but to a lessor extent than stature and body weight. Calf adjusted birth weight depended on muscle and capacity with regressions of 0.080 ($P < 0.01$) and 0.046 ($P < 0.05$), respectively. When calf adjusted birth weight was regressed on udder depth, a regression of –0.086 ($P < 0.01$) resulted.

GTS Traits Important to Calf Adjusted Weaning Weight

Calf average adjusted weaning weight was dependent ($p < .01$) on stature, body length, muscle, capacity, and femininity, indicating that as those traits increased, average calf weaning weight did also. The regression of calf adjusted weaning weight on stature was 0.855. The regression of body length was slightly higher at 0.976. These scores indicate that for every one unit increase in stature or body length average adjusted weaning weight increased by nearly one pound. Calf adjusted weaning weight depended on muscle and capacity with regressions of 0.774 and 1.043, respectively. Femininity had a lower regression of 0.276 ($P < 0.05$). These results are in agreement with the positive trend between mature cow size and weaning weight noted by Lopez de Torre et al. (1992), but disagree with Stewart and Martin (1981), who stated that as mature size increased, weight weaned per year tended to decrease in Angus and Shorthorn crossbred cows.

GTS Traits Important to Total Calf Adjusted Weaning Weight

Regressions of total calf adjusted weaning weight on muscle, capacity, and body condition score were significant for increasing total adjusted weaning weight. Over the course of a cows' life a one unit increase in muscle score increased total adjusted weaning weight by 16.565 pounds ($P < 0.01$). The same one unit increase in capacity score increased total adjusted weaning weight by 20.524 pounds ($P < 0.01$). An increase in one body condition score increased total weaning weight by 64.468 pounds ($P < 0.05$). However, as udder depth becomes more shallow, lifetime production to decreased by 8.453 lbs ($P < 0.05$) for every one unit change in score.

Muscle and capacity were important to number of calves, average adjusted weaning weight, and total calf adjusted weaning weight. Caution must be used in using muscle and capacity as a predictor of lifetime weaning weight since there may be some bias introduced by producers who select for increased muscle in their cattle or cull light muscled animals out of the herd.

Animals that maintained higher body condition produced more total adjusted weaning weight. The producer must carefully weigh the cost of increasing body condition score against the benefit. It may not be economically feasible to increase lifetime weaning weight by artificially increased body condition score with feed.

CHAPTER 5

CONCLUSIONS AND IMPLICATIONS

Heritabilities for the majority of the traits ranged from low to moderate indicating that selection for most of the GTS Traits would be effective. Stature was highly heritable, indicating that rapid change could be made with selection. Some of the GTS traits are highly correlated genetically suggesting that fewer traits could be scored per animal, and that selection for one trait would lead to change in another. Most notable were the genetic correlations between stature and body depth; muscle, capacity and body condition score; and the udder traits. Some genetic and phenotypic correlations existed among the traits that indicate that some caution may be necessary when applying selection to avoid undesirable change in a related trait.

The regressions of number of calves, calving interval, calf adjusted birth weight, average adjusted weaning weight, and total calf adjusted weaning weight on the GTS traits may be important to commercial beef producers. The GTS traits may be useful to producers seeking improvement in the production measures. Care must be practiced to avoid undesirable consequences of selecting for an extreme of any one trait, since these relationships may change at the extremes, and the consequences may increase under unfavorable production environments. Also, these relationships are phenotypic, and may not accurately reflect genetic relationships.

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