HERD OF ORIGIN EFFECTS ON PERFORMANCE OF STATION TESTED BEEF BULLS

BY

Shah Amal

A Thesis
submitted to
The Faculty of Graduate Studies
The University of Manitoba
in Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

1984

HERD OF ORIGIN EFFECTS ON PERFORMANCE OF STATION TESTED BEEF BULLS

BY

SHAH AMAL

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

ABSTRACT

Nine years (1976-1984) of performance data from the Manitoba Bull Testing Station, Douglas was used to investigate herd of origin effects on the 140 day growth performance of bulls. The total dataset comprised four breeds -Hereford, Charolais, Simmental and Angus with about 3500 observations. The basic mixed model included year and breed as fixed effects with herd and sires as random effects in a hierarchical classification. Herd, sire and error components of variance and covariance were estimated for weights and gains of the bulls maintained at different intervals of the test. Estimates of the herd intraclass correlation revealed that about 30% of the variation among bull weights at the start of the test was due to herd of origin effects. The herd intraclass correlation dropped gradually to about 17% at the 112 day weighing. This difference was still maintained at 140 days and was statistically significant ($P < 0.05$). In contrast only about 7% of the total variation for the 140 day gain on test was attributed to herds. A test of significance confirmed that herd of origin was not an important source of variation for gain on test. Heritability estimates for bull weights at different time intervals were high with an estimate of 0.51 for end of test weight. Heritability of the 140 day test gain was low (0.17). Heritabilities of 112 day test weights and gains were consistently higher than 140 day weights and gains.

Gain on test and end of test weight exhibit strong positive phenotypic, genetic and environmental correlations with each other. (0.65,0.53 and 0.72). Initial weight and gain on test however showed much lower phenotypic, genetic and environmental correlations (0.06,0.16,0.00). The zero environmental correlation indicated that gain on test was free from pretest environmental factors such as herd effects. In brief the considerable differences among bull weights due to herd of origin effects was significant and persisted throughout the testing period. The 140 day test gain was free from herd of origin effects but had a much lower heritability.

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Dr. G.H. Crow for his guidance and encouragement throughout the course of this study and preparation of the thesis. The author also gratefully acknowledges the encouragement and constructive criticism of his committee members, Dr. G.D. Phillips, Dr. R.J. Parker and Dr. K. Mount. Data provided by the Manitoba Department of Agriculture is gratefully acknowledged. Special thanks is extended to the Department of Animal Science for providing the opportunity and financial support for this study. Finally, this thesis is dedicated to my dear friend and wife, Indra for her encouragement, love and understanding.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX TABLES

INTRODUCTION

Performance testing at central locations involves the measurement of growth characters of beef bulls reared in different herds. The primary goal of central performance testing is the comparison of beef bulls from different herds under uniform environmental and managemental conditions. A major problem of central testing however is the influence of pretest environmental factors such as herd of origin effects on performance of beef bulls at central testing facilities. The literature suggests that pretest environment, particularly herd of origin effects, could contribute to variation at the start of the test and may be a significant and persistent source of variation throughout the testing period. Bias may thus be introduced in the genetic evaluation of bulls at central testing stations. This study was undertaken to examine herd of origin effects on the performance of beef bulls at a central location. Another objective of the research was to examine other genetic and environmental factors relating to the effectiveness of performance testing.

REVIEW OF LITERATURE

The aim of testing or selection programs in animal agriculture is to identify animals as parents of the next generation which are likely to contribute towards efficient production. Performance testing is one of the most common methods used to select beef bulls. Basically performance testing estimates the breeding value of a bull for one or more traits through the bull's own performance. It is based on the concept that traits under investigation can be measured on the tested animal and that they are heritable. In beef cattle performance has been recorded in many different ways and is influenced by such factors as breeding objectives, herd size, economic feasibility and market forces. Performance may be recorded in the breeder's herd but small herd sizes makes the evaluation of animals more difficult. In addition variations in feeding and management complicates the comparison of beef bulls reared in different herds. Some of these problems are supposed to have been overcome by performance testing bulls at central stations where they are subjected to uniform environmental and managemental conditions.

Performance testing of beef was originally developed in the U.S.A.(Baker,1967) and since then adopted in many countries. The major focus of Central Performance Testing is postweaning growth rate since its first published estimate of heritability was reported to be 97% by Knapp and Nordskog(1946). A considerable volume of research has been done since then. Most estimates of heritability of postweaning growth rate come from the North American Continent and the reported values average 0.50(Preston and Willis,1974). The high heritability and favourable genetic correlation with efficiency of feed use (Carter and Kincaid,1959a,b; Lickley et al.1960; Koch et al. 1963) has established postweaning rate of gain as one of the most important factors in the selection of beef bulls. However the correlation between estimated and actual breeding value could be very different due to unknown and uncontrollable environmental factors. The importance of environmental influences on evaluations based on postweaning growth has been stressed by many researchers. Various aspects of postweaning growth rate in relation to central performance testing have been reviewed across the world (Gregory,1965; Krausslich,1974; Sundgren,1973; Lewis and Allen,1974; Dalton and Morris,1978; Okantah et al.,1978; Okantah and Curran,1982). The literature suggests that the pretest environment, particularly herd of origin effects could contribute to variation at the start of the test at central performance testing stations. The herd effects may be significant and persistent throughout the testing period and may bias the genetic evaluation of beef bulls.

Performance Testing of Beef Bulls in North America

Selection of beef bulls was first based on visual conformation. It was realized that there was little relationship between conformation and most important economic traits like growth rate, carcass composition and reproductive soundness. Lush (1936) reported the relative importance of heredity in determining performance of economic traits in swine. This was followed by work in sheep(Terrill and Hazel,1943) and in dairy cattle(Lush and Straus,1942). The application of genetic principles to beef cattle breeding was still a neglected field. Knapp and Nordskog(1946) collected the performance data accumulated from 1938 to 1944 from the U.S. Range Livestock Experimental Station, Miles City, Montana. They studied the records of 171 steer calves from 23 sires and presented a pioneer report on the estimates of heritability in beef cattle. Heritability calculated by the intra-sire or half-sib correlation method was 81% for final feedlot weight and 99% for gain in feedlot. Heritability by sire-progeny regression was also estimated as 94% for final weight and 97% for gain. Knapp and Clark(1947) obtained 72% heritability for feedlot gain based on 422 steers sired by 52 bulls. Patterson et al.(1949) analysed the data of 827 steers which were the progeny of 113 sires and estimated the intra-sire correlation to be 0.26 . A futher revision of the estimates of their previous values were reported by Knapp and Clark(1951) as 65% by half-sib correlation and 77% by regression of offspring on sire for feedlot gain. Considerable research has been done since on the heritability of growth characters of beef bulls.(Tables 1,2,&3). Many researchers have refined their experimental techniques and with the availability of high speed computers have introduced sophisticated statistical models to correctly estimate breeding values. The present preferred value of heritability of gain is 0.50. Therefore postweaning growth rate with a high heritability estimate and a high genetic correlation with efficiency of feed use (Koch et al. 1963), established itself as the most important economic trait in the selection of beef bulls. In addition the beef cattle enterprise in North America is directly related to feedlot production (Gregory 1965). Most performance tests start soon after weaning and terminate after a fixed period of time. In Canada, the Record of Performance National Advisory Board (Anonymous,1984) recommended that test bulls should be within an age range of 160 and 250 days and before commencing the 140 day performance test there should be a minimum 28 day adjustment period. In the U.S.A., the Beef Improvement Federation (1970) recommended that test bulls should be allowed at least a 21 day adjustment before commencement of the test. They also suggested that the bulls be within 180 to 305 days of age at the start of the test. The duration of the test varies from place to place with a range of 140 to 240 days. Yearling weight is the commonly used criterion for ranking bulls although test gain is considered the most important economic character.

Table 1. Heritability estimates of postweaning gain in feedlot

Location	No.of Records	Days in Feedlot/ Perfor -mance Test	Breed	h	Literature cited
Nebraska	3097	112	H	.18	Koch et al.,1982
Nebraska	3097	140	H	.20	Koch et al.,1982
Nebraska	3097	196	H	.21	Koch et al.,1982
Nebraska	3097	168	H	.22	Koch et al.,1982
North Carolina	695	160	H	.23	Mavrogenis et al.,1978
Nebraska	3097	224	H	.24	Koch et al.,1982
Virginia	192	200	A,H.S	.38	Kincaid & Carter,1958
South Dakota	224	140	H	.39	Dearborn & Dinkel,1959
Ohio	832	140	H	.40	Swiger,1962
Nebraska	2409	112	V	.42	Koch et al.,1982
South Dakota	224	196	H	.43	Dearborn & Dinkel,1959
South Dakota	149	140	H	.45	Dinkel,1958
Montana	542	196	H	.46	Shelby et al.,1960
Arkansas	371	154	A,H	.46	Shelby et al.,1960
Montana	1101	170	A	.47	Nelsen & Kress,1979
Montana	616	254	H	.48	Shelby et al.,1963
Nebraska	2409	140	V	.49	Koch et al.,1982
Denmark	2217	152	V	.49	Jensen & Andersen,1984
Nebraska	2409	196	V	.50	Koch et al.,1982
South Dakota	149	168	H	.52	Dinkel,1958
Nebraska	741	168	H	.52	Swiger et al.,1982
South Dakota	473	270	H	.52	Wilson et al., 1963
Nebraska	2409	168	V	.52	Koch et al.,1982
Nebraska	733	168	A,H	.56	Swiger et al.,1963
Nebraska	351	168	H	.63	Swiger et al.,1963
Texas	56	224	H	.64	Fitzhugh et al.,1967
South Dakota	149	196	H	.65	Dinkel,1958
Montana	880	252	H	.65	Knapp & Clark,1950
Nebraska	1324	168	A,H,S	.65	Koch et al.,1963
Virginia	212	168	A,H.S	.66	Carter & Kincaid,1959
Montana	635	252	H	.68	Shelby et al.,1963
Montana	613	252	H	.70	Knapp & Clark,1951
New Mexico	499	168	H	.76	Blackwell et al.,1962
Arkansas	201	154	A,H,S	.93	Brown & Gacula,1964
Nebraska	351	168	A,H,S	1.31	Swiger et al.,1963

A=Angus, H=Hereford, S=Shorthorn, V=Various

Table 2. Heritability estimates of final weight after performance Testing in feedlot

Location	No. of Records	Breed	h	Literature cited
California	200	H	.16	Rollins et al.,1962
Arkansas	179	A,H.S	.21	Gacula & Brown,1963
California	200	H	.41	Rollins et al.,1962
South Dakota	224	H	.43	Dearborn & Dinkel,1959
Montana	1101	A	.43	Nelsen & Kress.,1979
South Dakota	473	H	.45	Wilson et al.,1963
Ohio	832	H	.47	Swiger et al.,1963
Denmark	2217	V	.54	Jensen & Andersen,1984
Montana	616	H	.55	Shelby et al.,1963
Montana	616	H	.64	Shelby et al.,1963
Montana	1379	H	.65	Nelsen & Kress,1979
New Mexico	499	H	.70	Blackwell et al.,1962
Nebraska	480	A,H,S	.72	Swiger et al.,1965
Colorado	417	H	.72	Lickley et al.,1960
Montana	542	H	.77	Shelby et al.,1960
Montana	177	H	.81	Knapp & Nordskog,1946
Montana	635	H	.84	Shelby et al.,1955
Arkansas	371	A,H	.85	Brown & Gacula,1964
South Dakota	679	H	.85	Busch & Dinkel,1967
Montana	880	H	.86	Knapp & Clark,1950
Texas	241	V	1.00	DuBose & Cartwright,1967

A=Angus, H=Hereford, S=Shorthorn, V=Various

Table 3. Heritability estimates of yearling weights from field records

Location	No. of REcords	Breed	h	Literature cited
Hawaii	1108	A	.06	Francoise et al.,1973
Sweden	239	CH	.29	Kalm et al.,1974
Canada	5420	A	.31	Kennedy & Henderson,1975
Sweden	437	CH CROSS	.32	Kalm et al.,1974
Canada	46,943	H	.39	Kennedy & Henderseon,1975
Canada	327	S	.47	Andersen et al.,1974
Sweden	440	H CROSS	.49	Kalm et al.,1974
Canada	14,745	H	.50	Kennedy & Henderson,1975
Sweden	341	H	.54	Kalm et al.,1974
Sweden	671	CH	.60	Kalm et al.,1974
Hawaii	780	H	.65	Francoise et al.,1973
Sweden	690	H CROSS	.69	Kalm et al.,1974
Sweden	376	CH CROSS	.72	Kalm et al.,1974
Sweden	309	H	.73	Kalm et al.,1974
Canada	16,913	A	.78	Kennedy & Henderson,1975

A=Angus, H=Hereford, S=Shorthorn, V=Various

Performance Testing in Other Parts of the World

Beef production outside North America is often based on purebred and crossbred dual purpose cattle. In Europe, where the dairy and beef industries are closely interrelated, Krausslich (1974) reported great differences in the techniques of performance and progeny testing between and within countries. In Britain, test stations were similar to those in North America. However researchers in Britain were of the opinion that test gain was considerably influenced by pretest management. They reorganized their performance recording system to reduce the mean age at the start of the test to 170 days (± 20) from 210 days (± 30). The duration of the test has been increased from 168 to 210 days in order that the test should terminate when the bulls are approximately 400 days of age. The whole test is considered as an adjustment period and bulls are ranked on final weight for age adjusted to 400 days. Weight for age is considered as the sum of birthweight, gain to weaning and test gain. Very little emphasis is placed on daily gain during the test (Lewis and Allen,1974). In France, bulls of beef breeds commence test at 200 - 250 days of age while bulls of dual purpose breeds start at 150 days of age. The bulls are tested over a period of 126 to 154 days. The final assessments are made on the bulls' test gains and weights at 270 days and 400 days of age respectively (Krausslich 1974). In Germany the start age has been successfully reduced to 50 days for dual purpose breeds. The tests are terminated at 365 to 420 days. Sires from beef breeds begin the test at 120 days of age and tests are terminated at either 365 or 420 days (Lewis and Allen,1974). The reduction in start of test age at central performance testing stations in Europe was aimed at reducing the pretest environmental influence on the ranking of beef bulls. The success of this reduction was mainly due to the dual-purpose structure of the cattle industry and artificial rearing of calves.

Central testing of beef breeds operates quite differently in New Zealand where bulls spend the test period grazing in groups. Dalton (1972) reported the mean age of bulls entering test as 280 days with a test duration of 280 days. Bulls are selected on age corrected final weight as well as a conformation assessment. Test gain as a selection criterion has been discarded following the work of Carter (1971,1973) and Baker et al.(1975), who reported very low heritabilities for test gain.

Herd of Origin Effects

Most reports in the literature on herd of origin effects are based on information collected on the performance of beef cattle in different herds and not performance of cattle brought together in central stations as such.(Table 4). Much research has been done on the preweaning performance of beef cattle as it is recognized as an important factor determining herd returns.

Table 4. Relative importance of herd effects - herd variance expressed as % of total variance (field data)

FINAL WEIGHT/YEARLING WEIGHT

AUTHORS	BREED	% HERD
Edward et al. (1966)	Various	53 %
Wilson et al. (1972)	Angus	28.6%
	Hereford	19.6%
Dinkel and Busch (1973)	Hereford	1 %
Cundiff et al. (1975)	Angus and Hereford	27 %
Kennedy and Henderson (1975)	Non-creep Hereford	31 %
	Non-creep Angus	38 %
	Creep Hereford	31 %
	Creep Angus	44 %

POSTWEANING GAIN

AUTHORS	BREED	% HERD
Wilson et al. (1972)	Hereford	47.9%
	Angus	18.4%
Kennedy & Henderson (1975)	Non-creep Hereford	28 %
	Non-creep Angus	37 %
	Creep Hereford	31 %
	Creep Angus	27 %

Cunningham and Henderson (1965) reported the estimates of environmental effects, variance components, heritabilities and correlations for weaning traits in a large population of commercial herds. Herds accounted for 18% of total variation in preweaning daily gains for Hereford records adjusted for sex, age of dam and year effects. Herd variation of 16% was recorded for the Angus population from a similar analysis. Everitt et al. (1969) noted large differences between herds of beef cattle in an analysis across farms in New Zealand. Their data included 500 steers and heifers of purebred Aberdeen Angus and Friesian, and crosses of Friesian x Jersey, Hereford x Jersey and Charolais x Jersey which were raised on beef and sheep farms. Differences between herds constituted the most important source of variation (54%) while breed, breed x farm and sex accounted for only 4.7,6.8 and 5.6% respectively. In support of their results the authors quoted the analysis of Edwards et al.(1966) involving 4000 dairy crossbreds across 283 farms and 5 sire breeds which showed that 53% of the variation in liveweight at 365 days was due to farm differences. Sellers et al.(1970) investigated the influence of sex of calf, year of birth, age of dam, herd management, season of birth and breed and their interactions on 205 day weight of beef cattle. Their data consisted of weaning records of 19,907 Angus and Hereford calves from 1570 herds registered with the Iowa Beef Improvement Association (IBIA) program from 1956 through 1957. Herd management was a highly significant source of variation

(P<0.005) for both bulls and heifers. Herd management accounted for 30.09% of the total variation for Angus and 20.36% for Hereford respectively. Wilson et al.(1972) analysed data obtained from a steer progeny test of Angus and Hereford sires each replicated in different herds of each breed within the same years. The primary aim of their study was to determine the influence of herd x sire interactions on live and carcass characters of beef cattle. The authors realised that the herd effects include both environmental and genetic factors which cannot be separated. Herd effects were found to be highly significant (P<.05 or P<.01) for all traits with the exception of some carcass characters. However none of the characters were significantly influenced by herd x sire interactions. The percent of variation due to herds within years was 60.3, 47.9 and 19.6 for weaning weight respectively, postweaning ADG and 365 day weight for Hereford and 36.4, 18.4 and 19.6 for Angus. The authors suggested that herd effects could be due to environmental factors such as general managemental pratices, including irrigation, pasture species, age at weaning and postweaning diet or genetic differences between cow herds.

Production, carcass composition and carcass quality data obtained from 679 Hereford steers raised to weaning on 18 farms in South Dakota were examined by Dinkel and Busch (1973). The data were collected over a period of 8 years from 1958 to 1965. Among the various analyses performed was a hierarchical analysis to evaluate the relative importance of year, herd and sire. They concluded that for growth traits the herd component was most important for weaning weight (27%), less pronounced for daily gain (11%), least significant for final weight (1%) and had absolutely no influence on carcass grade (0%). Schaeffer and Wilton (1974) studied 94,627 records of Angus and Hereford calves from Canadian Record of Performance data to evaluate herd, cow and error components of variance for preweaning average daily gains. Herd differences were noted to be an important influence on ADG. Age of dam by level of herd performance interaction, not previously reported in the literature was found to be highly significant. Record files of 61,688 Hereford and 23,333 Aberdeen Angus cattle obtained from the Canadian Federal-Provincial Record of Performance (ROP) for beef cattle program were examined by Kennedy and Henderson (1975a). Year, year-herd, sire within herd, year-sire within herd and error variance components were estimated for growth characteristics. This was one of the few beef cattle studies concerned with the estimation of variance components using field data reflecting a large number of commercial herds spread across a vast geographical area. Despite complications in the analysis by some confounding between herd and year-herd subclasses, differences in herd location and management constituted the most important source of variation affecting calf growth. Herds accounted for 25-44% of total variation for growth traits studied. Herd variances were relatively larger for postweaning growth than for preweaning growth. It was the opinion of the authors that this probably reflects wider herd differences in postweaning nutritional practices across large geographical regions. Field records of Angus and Hereford cattle registered with the Montana Beef Performance Association were analysed for pre and postweaning characters by Nelsen and Kress (1979). Herd effects were significant for all growth characters except postweaning ADG in Angus bulls. However herds were a significant source of variation only for postweaning ADG and final test weight for Angus heifers. Analysis of variance for the Hereford bulls showed that herds were a major source of variation for all growth characters.

Knowledge of genetic variation among herds has been reported in dairy populations. The widespread use of artificial insemination across dairy herds has made it possible to partition the genetic and environmental components of herd variance. About 10-25% of the phenotypic variation in milk and butter production among herds is reported to be heritable (Robertson and Rendel,1954; Robertson and McArthur,1955; Pirchner and Lush,1959; Bereskin and Freeman,1965; Wiener,1960; Mao et al.,1972). Such a study is usually not possible in the present beef systems where A.I. across herds is not popular. In addition in beef populations there are usually too few bulls per sire and too few bulls per herd. Furthermore there may be a variable breed representation within herds (Wilson et al. 1972; Krausslich,1974; Morris, 1981). The within and between herd sources of genetic variation in beef cattle was first reported by Cundiff et al.(1975). They studied the growth and carcass traits of calves of Hereford and Angus cows artificially inseminated by 95 sires of the same breed representing 36 herds. Their results indicate that about 21% of herd phenotypic variation for yearling weight is heritable. This between-herd heritability showed that a portion of the differences among herds was due to genetic differences.

Herd of origin effects could be due to environmental or genetic differences between herds. The non-genetic differences among herds are due to nutritional practices, general herd health and management, maternal effects and other unaccountable and unknown environmental factors. These factors contribute towards variation in start of test weight and may have a carry-over effect on gain or final weight on test. Herd differences of genetic origin originate from genetic differences between cow herds or genetic herd differences due to the sample of sires of the particular bulls being tested (Morris,1981).

Maternal Environment in Herd of Origin

The cow influences the phenotypic expression of its calf through its genetic contribution and the maternal environment it provides during the early part of the calf's life.

Maternal environment can be divided into two phases - the first phase is the intra-uterine period from conception to birth and the second phase is from birth to weaning.

Koch and Clark (1955) compared the theoretical composition of paternal and maternal half-sib correlations, dam-offspring and sire-offspring correlations to estimate the influence of maternal environment. They suggested that maternal environment from conception to birth and from birth to weaning had a large influence on birth weight, gain from birth to weaning and weaning score but a negligible influence on yearling gain and yearling score. The dam's age and size appear to be the most important maternal environmental effects on calf growth traits.

Many researchers have confirmed that calf birth weight increases with age of dam (Marlowe and Gains,1958; Marlowe et al.,1965; Schalles and Marlowe,1967; Brown and Galvez,1969; Francoise et al.,1973; Cartwright et al.,1974). The effects of age of dam on weaning weight of 19,907 of Angus and Hereford calves were reported to be highly significant (P<.005) by Sellers et al.(1970). A highly significant influence of age of dam on preweaning ADG and weaning weight was noted by Singh et al.(1970). Francoise et al.(1973) found significant differences in weaning weight per day of age due to dam's age. However there are conflicting reports on the effects of age of dam on postweaning growth characters. Smaller effects of age of dam were observed for 400 day weights than for 200 day weights (Koch and Clark,1955). Swiger et al.(1963,1965) noted that age of dam had no significant influence on postweaning gain or score. Schalles and Marlowe (1967) observed that dam's age contributed significantly to 365 day weight at one station but did not influence this growth trait at another testing location. Francoise et al.(1973) noted that age of dam was not a consistent influence on postweaning growth traits. Many reports have suggested that the inconsistent effects due to dam's age on postweaning growth characters may be attributed to factors such as culling, selection and management practices within herds. The majority of researchers tend to believe that age of dam does not influence postweaning growth significantly (Koch and Clark,1955; Brinks et al.,1962; Swiger et al.,1963,1965; Pabst et al.,1977).

There are a number of studies which have investigated the relationship of cattle size to beef production, especially feedlot performance (Willey et al.,1951; Stonaker et al.,1952a; Stonaker et al.,1952b; Grizzle and Kincaid,1954; Knox,1957; Morris and Wilton, 1976). Heavier cows have been observed to wean heavier calves (Gregory et al.,1950; Knox,1957; Clark et al.,1958; Neville,1962; Smith and Fitzhugh,1968; Urick et al.,1971). The influence of cow weight on postweaning performance of calves were investigated by Singh et al.(1970). It was observed that though weight of cow at parturition significantly influenced birth weight, it was not related to preweaning ADG or weaning weight. Differences in maternal environment of bulls from different herds may thus be present and form part of the herd to herd differences among bulls at the start of the test.

Preweaning Nutrition

Preweaning nutritional status is recognized as an important factor determining growth of calves. About 80% of the calf's mature skeletal size is attained by the time of weaning, however only 40% of its mature weight is realized by this time. Growth during this period of rapid skeletal development could be variably influenced by the dam's milk production and the availability of supplemental creep feeding thus masking the calf's own genetic potential for growth (Knapp and Black,1941). Preston and Ugarte (1972) reported that suckling calves grew faster than those reared artificially. This is supported by an earlier work of Everitt et al.(1968) who observed that suckling calves induced a greater amount of milk from their dams than hand milked cows.

Marlowe and Gaines (1958) have shown that creep-fed calves gained more rapidly than non-creep fed calves during the period of time from 150 to 240 days of age. Hammes et al.(1959) reported similar differences for rate of gain. Christian et al. (1965) studied identical and fraternal twin Hereford heifers purchased from different farms. The twins and their progeny were fed in the drylot from the time of purchase or birth until slaughter. They found that the amount of creep-feed consumed had a significant effect on weaning weight. Pabst et al.(1977) observed that the higher the level of nutrition (creep feeding and nurse cow) the higher were the 200 day weights as compared to calves just suckling their dams. Preweaning nutrition is therefore important in determining the growth of calves from birth to weaning.

Herd of Origin Effects on Postweaning Performance at Central Test Stations

There are not many reports in the literature on the effects of herd of origin on the ranking of beef bulls at central test stations. In central tests herd effects when present, form part of the start of test weight. Patterson et al.(1955) examined the effectiveness of phenotypic assessments at central performance stations. They summarized the results accumulated over 12 years of feedlot performance tests conducted at Balmorhea substation of the Texas Agricultural Experimental Station. Pretest management of bulls differed greatly from ranch to ranch with bulls receiving varying degrees of supplemental and creep feeding. It was observed that gains were little affected by initial weight. The authors were of the opinion that initial weight did not bias the ranking of beef bulls at test stations. Beginning from 1949 full scale evaluation for postweaning growth rate was conducted under a more standardized procedure at the

Texas station. Warwick and Cartwright (1955) analysed data collected from 1949 to 1953 at this center. Some variation among cattle entering the test in age, weight and condition were noted. It was concluded that initial weight was not an important source of variation in test gains since initial weight accounted for only 1% of variation in subsequent test gains. A study was conducted by Moore et al.(1961) to evaluate the effects of measurable environmental and genetic variables on rate of gain in beef bulls at the Colorado Agricultural Experimental Station. Initial weight was observed to have a significant effect on test gain. Schalles and Marlowe (1967) reported a non-significant influence of start of test weight on test gains. However they noted a significant start of test effect on final weight. Non-significant effects of start of test weight on test gains were also reported by Stuedemann et al.(1968). Similarly from a Canadian study Wilton et al.(1973) observed non-significant effects of start of test weight on gains. Data from 15 central test stations across Canada representing Angus, Charolais, Hereford, Limousin, Simmental and Shorthorn breeds were examined for the effects of initial age and weight on daily gain on test by Tong (1982). Heavier bull weights for a given age were significantly related to faster bull gains at central test stations. Concern was expressed however over the high environmental correlation between pretest and on-test ADG suggesting substantial compensatory growth due to pre-test environmental effects. Cain and Wilson (1983) indicated that start of test weight adjustments should be made for evaluations based on postweaning data. This conclusion resulted from an analysis of 8636 Angus, Charolais, Hereford and Simmental bull data collected from several central test stations across Canada and the U.S.A.

Morris (1981) examined the herd of origin effects at central test stations under pasture conditions in New Zealand. Data from 288 Angus bulls from 8 central stations were analysed for sources of variation in start and final weight. Bulls had a mean start of test age of 254 ± 20 days and the duration of the test was about 8 months. The effect of herd of origin on performance of station tested beef bulls was reported as being significant. It was concluded that herd effects which form part of the start of test weight were persistent during test performance and this could confuse the ranking of beef bulls at the end of the test.

Growth Rate and the Role of Compensatory Growth

Growth is a quantitative character controlled by the simultaneous action of numerous genes. The continuous nature of variation of growth characters makes it dependent on measurements for the purpose of evaluation. Measurements reflect phenotypic variation in the population. The phenotypic variation is caused by variation in genotype, environment and their interaction. Genetic influences form the basis of growth and development through activation and repression of structural and regulatory genes. These polygenes are responsible for the many metabolic pathways affecting growth (Falconer,1982 and Pirchner,1983). Recent advances in biochemical genetics confirm that these metabolic pathways are responsible for the increase in cell number and size, skeletal growth, varying rate of protein and fat accretion which intrinsically forms the growth mechanism (Wagner and Mitchell,1964; Woese,1967; Levine,1969). These metabolic pathways may be considerably influenced by non-genetic factors which may mask the genetic expression of the trait being measured. Gene regulation of metabolic pathways have been extensively studied in bacteria and virus. To date it has been experimentally impossible to solve the problem of gene regulation of metabolic pathways in polygenic traits of multicellular organisms. Therefore animal geneticists have largely depended on statistical analyses to study the genetic influence on growth.

Additive genetic variance of growth characters, especially postweaning growth has been shown to have a medium to high value which has encouraged animal breeders to select for this trait. To what extent the estimated values reflect the true genetic values is still not clear. However it is strongly believed that growth to maturity is gene regulated especially postweaning growth rate. Gene regulation during preweaning growth has been shown to be masked by environmental factors especially maternal effects. The role of such environmental factors on subsequent performance of cattle is an interesting phenomena. Environmental factors such as undernutrition may induce retardation in growth rate. Growth in mammals however is hypothesized to be self-stabilizing or target seeking (Tanner,1963). It is the general opinion that early, environmentally induced retardation during the preweaning phase could be compensated for postweaning if the retarding influence is removed and irreparable cellular and tissue changes have not occurred.

Wilson and Osborne (1960) reviewed the role of compensatory growth after undernutrition in mammals and birds. They pointed out fundamental physiologic differences in response to realimentation depending on the severity and duration of restriction. Bertalanffy (1960) and Monteiro and Falconer (1966) have suggested that changes in the rate of metabolic processes (ontogeny) are related to size (body weight) rather than age. Therefore self-stabilization or compensatory growth is related to target body weight. Growth regulation perhaps may be better understood by the study of growth curves. Monteiro and Falconer (1966) noted that mice differing in their early growth rate reached the same mature size through the physiologic response of compensatory growth. Atchley (1984) studied the data of 2700 mice from over 700 cross-fostered full-sib families. Weight changes between 14 and 70 days were recorded to examine the inflection points for Gompertz growth curves. Maximum additive genetic variability occured at about 21 days which coincides with maximum growth rate. Log transformed data of Rutledge et al.(1972) similarly showed that maximum phenotypic and genetic variation occurred at the inflection point (Atchley,1984). Regulatory mechanisms controlling growth are heritable. Compensatory growth being a component of the regulatory mechanisms should therefore have a genetic component.

Not much research has been done on growth regulation in cattle. Taylor (1968) points out the inherent inadequacies of mathematical models describing growth. However available reports in the literature on growth of cattle (Laird et al.,1965; Laird,1966; Joandet and Cartwright,1969; Taylor,1971) shows that the rate of gain during any given stage of maturity is genetically positively correlated with mature size. This together with the evidence from the mice experiments suggest that important metabolic changes are related to target weight rather than age.

The influence of compensatory growth on beef production has been studied by Bohman(1955),Heineman and Van Keuren(1956),Meyer et al.(1965), Christian et al.(1965) and Moran and Holmes(1978). Like the results obtained from studies done with mice and other animals these reports indicate that the rate of compensation can be variable depending on the severity of retardation and the length of the realimentation period.

Dalton and Morris (1978) pointed out that the retarding factors such as undernutrition during early growth could be confounded within herds. The different rates of compensation may confuse the interpretation of breeding values at central test stations. They summarized literature available on compensatory growth in New Zealand and concluded that rate of compensation is related to previous undernutrition. Complete compensation for previous growth retardation may be achieved in animals exposed to undernutrition in the later part of the growth curve if the realimentation period was sufficiently long. They noted that retardation imposed early in the calf's life may never be compensated for totally.

Horton and Holmes (1978) examined feed intakes, feed digestibility and body weight gains of beef cattle following periods of restricted nutrition in two experiments. In experiment one, 12 month old Friesian and Friesian crosses weighing about 243 kg. were offered either 2.5 kg. or 5.1 kg. of a pelleted ration. Restricted barn feeding was continued for 20 weeks. This was followed by 8 weeks of forage feeding on pasture. The low intake group showed higher gains expressing compensatory gain which paralleled increased feed intake. No change in ration digestibility was observed. In experiment two, undernutrition was imposed by grazing restrictions for 24 weeks. This was followed by a 16 week finishing period where barley-alfalfa pellets were offered ad libitum. A rapid decrease in weight differences (50%) between the high and low group was noted during the first 10 weeks of realimentation. Compensatory gain during the early stages of the finishing period were associated with higher feed intakes. But gains for the last 8 weeks were slightly higher for the high performance group. Thus Dalton and Morris(1978), Morris(1981), Okantah and Curran(1982) highlighted the implications compensatory growth can have on central testing of beef bulls. There is no evidence in the literature at this time relating directly to the role of compensatory growth at central test stations.

MATERIALS AND METHODS

Station Management

Records of performance from the Manitoba Central Bull Performance Test Station formed the basis of this study. The test station is owned and operated by the Manitoba Beef Cattle Performance Association and is located at Douglas. It provides a central testing facility for beef bulls in Manitoba. Bulls from across the province are brought to the test station some time in late October or early November shortly after weaning. Only bulls meeting the minimum weight requirement of 181 kg. or a minimum weight per day of age of 0.95 kg. are accepted for the test. These bulls are also expected to have been treated for :

1. Warbles and lice, with systemic insecticide.
2. Infectious Bovine Rhinotrachitis (IBR) with intranasal vaccination.
3. Blackleg and Malignant Edema with suitable vaccine.
4. Visible ringworm and internal parasites.

The Manitoba Bull Test Station follows the recommendations of the National Bull Test Station policy established by Agriculture Canada (Anonymous,1984). The cornerstone of this policy is to test bulls for postweaning performance under uniform environmental conditions and managemental practices. Prior to the start of the test, the bulls are placed on a 28 day warm-up or adjustment period. The actual test is

140 days in duration. Start and end of test weights are calculated as the average of weights recorded on two consecutive days. Single records of interim weights are taken at 56, 84, and 112 days. Weight recording of bulls is done on a random order to minimize possible bias due to differences in fill.Backfat thickness and scrotal circumference is also measured at the end of the test. Fat cover is measured by ultrasound equipment two inches from the mid-back between the 11th and the 12th ribs.

Bulls are ranked within a breed according to an index based on average daily gain on test and weight per day of age.

To qualify for sale :-

1. Bulls should have an index of 95 or greater for both average daily gain and weight per day of age.
2. Minimum adjusted scrotal circumference of 32 cm. at 365 days of age.
3. Physically and structurally sound including the absence of any reproductive abnormalities.

Ration at the Test Station

In all the years, the bulls had free access to long native hay, concentrate mixture, salt and water during the entire period of the test. The concentrate mixture is fed in group self feeder.

On an average, across the years the mixture was composed of :-

1. Oats - steam rolled	70-75%
2. Barley - steam rolled	10-13.75%
3. Beet pulp - pelleted	10%
4. 32% Protein supplement & liquid molasses	5 - 7%
5. Minerals & vitamins	

Average ration chemical analysis - as fed basis, across years was as follows :-

	Concentrate	Hay
Dry matter %	82.8 - 86.5	77.7 - 90.03
Crude protein %	11.4 - 13.1	6.4 - 10.9
Crude fiber %	0.0 - 13.2	24.8 - 32.3
Calcium	0.32 - 0.39	0.25 - 1.00
Phosphorus	0.32 - 0.40	0.06 - 0.15

On an 'as fed' weight basis the bulls consumed about 10 - 20% of the ration as hay and 80 - 90% as concentrates. The straw provided for bedding may have also been consumed.

Description of Data

Nine years (1976 - 1984) of performance data were obtained from the Manitoba Performance Testing Station. The original dataset for the nine years contained 16 breeds. Only those breeds represented across all years with at least 20 bulls per year were included in this study. Four breeds fullfilled this requirement - Hereford, Charolais, Angus and Simmental. For the purpose of various statistical analyses this dataset comprising the four breeds was subdivided into smaller datasets, hereafter coded as in table 5.

The average distribution of bulls, sires, herds and breeds over the nine years is shown in table 6. A more complete description is given in Appendix Table 1.

Statistical Analysis

Several statistical models were constructed to analyse the data for the performance traits. The basic mixed model included year, breed, herd and sire in a hierarchical classification.

$$Y_{ijklm} = U + T_i + B_{ij} + H_{ijk} + S_{ijkl} + E_{ijklm}$$

U = Overall mean in kg.

Ti = The efffect of the ith test year, assumed fixed.

Bij = The effect of the jth breed within the ith year, assumed fixed.

Hijk = The effect of the kth herd within the jth breed and ith year, assumed random with mean 0 and variance σ^2_H

Sijkl = The effect of the lth sire within the kth herd, jth breed and the ith year, assumed random with mean 0 and variance σ^2_S

Eijklm = The effect of the mth bull ie. the error term with mean 0 and variance σ^2_e

Table 5. Description of datasets

DATASET CODE	DESCRIPTION	NUMBER OF OBSERVATIONS
1. TOTAL DATASET	Main data set comprising 4 breeds - Hereford, Charolais Angus & Simmental - across 9 years (1976-1984)	3500
2. HEREFORD DATASET	Hereford subset across 9 years (1976-1984)	1375
3. RESTRICTED DATASET	Dataset with the restriction of at least 2 bulls per sire and 2 sires per herd. Only Hereford and Charolais breeds met this restriction - across 8 years (1981 did not meet the requirement).	800
4. HEREFORD RESTRICTED DATASET	Same restriction as no. 3 on Hereford breed.	460
5. CHAROLAIS RESTRICTED DATASET	Same restriction as no. 3 on Charolais breed.	340

Table 6. Description of data structure - total dataset

BULLS PER SIRE			BULLS PER HERD			SIRES PER HERD		
No. of bulls represented per sire	Frequency	%	No. of bulls represented per herd	Frequency	%	No. of sires represented per herd	Frequency	%
1	938	51.6	1	134	13.97	1	476	49.02
2	427	23.5	2	236	24.61	2	270	27.81
3	207	11.4	3	198	20.65	3	145	14.93
4	94	0.05	4	114	11.89	4	52	0.05
5	96	-	5	80	0.08	5	23	0.02
6	23	-	6	51	-	6	5	0.01
7	15	-	7	55	-			
8	11	-	8	33	-			
9	5	-	9	16	-			
10	1	-	10	34	-			
			11	3	-			
			12	2	-			
			13	2	-			
			14	-	-			
			15	1	-			

Yijklm is the dependent variable for the production traits studied. The codes used for these are listed in Table 7. Means and standard deviations for all of these traits are listed in Table 8.

Calculation of Variance Components

A statistical computer package supplied by the Statistical Analysis System(SAS) from Raleigh, North Carolina was used for the purpose of analysis.

Variance and covariance components for the production traits were computed by the MIVQUE-O (Minimum Variance Quadratic Unbiased estimation) method of the VARCOMP procedure. This procedure is claimed to be one of the most efficient computational techniques for estimation of variance components for large animal breeding datasets with unequal subclasses (Searle,1978).

Heritability

The actual estimates of the variance components needed in the computation of heritabilities are given below :

σ^2_H = herd component of variance

σ^2_S = sire within herd component of variance

σ^2_e =error component of variance

Table 7. Codes of production traits

WEIGHTS

DELWT = Delivery weight
SOTWT = Start of test weight
W56 = Weight at 56 day on test
W84 = Weight at 84 day on test
W112 = Weight at 112 day on test
W140 = End of test weight

CUMULATIVE GAINS

CG0 = W56 - SOTWT
CG1 = W84 - SOTWT
CG2 = W112 - SOTWT
CG3 = W140 - SOTWT (Gain on test)

PERIODIC GAINS

PG D = SOTWT - DELWT
PG 0 = W56 - SOTWT
PG 1 = W84 - W56
PG 2 = W112 - W84
PG 3 = W140 - W112
BF = backfat measurement
SC = scrotal circumferance

Table 8. Means and Standard deviations of the traits

Traits	No. of Obs.	Mean(Kg.)	Std. Dev.
DELWT	3419	277.17	40.56
SOTWT	3654	310.97	45.85
W56	3612	396.95	53.00
W84	3599	439.12	56.23
W112	3573	481.12	58.85
W140	3561	524.13	60.99
CG0	3661	85.97	20.23
CG1	3598	128.13	26.30
CG2	3572	170.10	29.60
CG3	3560	213.18	33.40
PGD	3402	36.20	18.34
PG0	3611	85.97	20.31
PG1	3598	42.22	11.63
PG2	3571	41.77	15.33
PG3	3559	43.00	17.19
BF	3561	7.56(mm.)	3.96
SC	3060	338.57(mm.)	39.81

The heritability of each trait was computed from the variance components estimates on both an intraherd and interherd basis using the following formulas :

Intraherd

$$h^2 = \frac{4\sigma_S^2}{\sigma_S^2 + \sigma_e^2}$$

Interherd

$$h^2 = \frac{4\sigma_S^2}{\sigma_H^2 + \sigma_S^2 + \sigma_e^2}$$

Assumptions in the formula :

1. That epistatic gene action is negligible.
2. Random mating of sires.
3. Frequencies of the genes involved are stable.

The major advantage of using the paternal half-sib correlation to estimate heritability is that this value contains only the additive genetic variance and a small portion of epistatic gene action. The accuracy of this method of estimation depends on the number of degrees of freedom available for estimating the differences between sires and to a lesser degree on the number of offspring per sire. This method is limited by the fact that errors due to sampling of sires or incorrect estimation of the sire component are multiplied by four.

Herd Intraclass Correlations

Herd intraclass correlations were estimated to determine if bulls belonging to the same herd resembled each other more than bulls belonging to different herds.

The herd intraclass correlation was calculated by the following formula : -

$$t_H = \frac{\sigma^2_H}{\sigma^2_H + \sigma^2_S + \sigma^2_e}$$

Reliability of the half-sib Heritability and Herd Intraclass Correlation Estimates

The reliability of the half-sib heritability estimates and herd intraclass correlations was determined using a simulation study. The mean of one of the traits, CG3 (gain on test) for the total dataset and its standard deviations for year, breed, herd and sire were used to run 10 computer simulations. The distribution of years, breeds, herds and sires followed the original distribution in the Total dataset. An example of the program written to create and analyse each dataset is shown in Appendix Table 13. Heritability and herd intraclass correlation estimates were calculated for each of the simulation runs with the herd, sire and error components of variance estimated by the MIVQUE-0 procedure as in the analysis of the actual data (Appendix Table 14).

Phenotypic, Genetic and Environmental Correlations

The directly observable relationship between two traits is defined as the phenotypic correlation. The phenotypic correlation between two traits arises from the correlation between genetic and environmental effects that influence the two traits. To compute correlations, estimates of components of covariance between traits were made. This involved the computing of new traits based on the sum of pairs of the original traits. Variance components of the new trait was then computed by the same mixed model using the MIVQUE-O procedure. The variance components of this new trait contain the variances between the original trait plus twice the covariance of the original traits. This is illustrated in the following example.

Example

Calculation of genetic, Environmental and Phenotypic correlations between W140 and CG3.

1. Let W140 be x and CG3 be y.
2. A new trait is created which is the sum of the two traits.

W140 = W140 + CG3

or $z = x + y$

$$z^2 = (x + y)^2 = x^2 + y^2 + 2\,xy$$

3. Analysing the new trait z by the same mixed model by the MIVQUE-O procedure, the variance components are estimated.

σ^2_{Hz} = herd component of variance

σ^2_{Sz} = sire component of variance

$\sigma^2_{e_z}$ = error component of variance

Since,

$$\sigma^2_{Hz} = \sigma^2_{Hx} + \sigma^2_{Hy} + 2\sigma_{Hxy}$$

$$\sigma^2_{Sz} = \sigma^2_{Sx} + \sigma^2_{Sy} + 2\sigma_{Sxy}$$

$$\sigma^2_{e_z} = \sigma^2_{e_x} + \sigma^2_{e_y} + 2\sigma_{e_{xy}}$$

and since,

$$\sigma^2_{Hx}, \sigma^2_{Hy}, \sigma^2_{Sx}, \sigma^2_{xy} \text{ and } \sigma^2_{e_x}, \sigma^2_{e_y}$$

are known from the original traits, then covariances of the new trait can be calculated by the following formulae:

$$\sigma^2_{Hxy} = \frac{(\sigma^2_{Hz} - \sigma^2_{Hx} - \sigma^2_{Hy})}{2}$$

$$\sigma^2_{Sxy} = \frac{(\sigma^2_{Sz} - \sigma^2_{Sx} - \sigma^2_{Sy})}{2}$$

$$\sigma^2_{e_{xy}} = \frac{(\sigma^2_{e_z} - \sigma^2_{e_x} - \sigma^2_{e_y})}{2}$$

The correlations are then calculated from the following formulae.

Phenotypic correlation

$$r_p = \frac{\sigma_{Hxy} + \sigma_{Sxy} + \sigma_{e_{xy}}}{\left[(\sigma^2_{Hx} + \sigma^2_{Sx} + \sigma^2_{e_x})\ (\sigma^2_{Hy} + \sigma^2_{Sy} + \sigma^2_{e_y})\right]^{1/2}}$$

Genetic correlation

$$r_G = \frac{\sigma_{Sxy}}{\left[\sigma^2_{Sx}\ \sigma^2_{Sy}\right]^{1/2}}$$

Environmental correlation

$$r_E = \frac{r_P - h1h2\, r_G - f1f2\, r_f}{e1e2}$$

where,

$$h1 = \left(\frac{4\sigma^2_{Sx}}{\sigma^2_{Sx} + \sigma^2_{Hx} + \sigma^2_{e_x}} \right)^{1/2}$$

$$h2 = \left(\frac{4\sigma^2_{Sy}}{\sigma^2_{Sy} + \sigma^2_{Hy} + \sigma^2_{e_y}} \right)^{1/2}$$

$$f1 = \left(\frac{\sigma^2_{Hx}}{\sigma^2_{Sx} + \sigma^2_{Hx} + \sigma^2_{e_x}} \right)^{1/2}$$

$$f2 = \left(\frac{\sigma^2_{Hy}}{\sigma^2_{Sy} + \sigma^2_{Hy} + \sigma^2_{e_y}} \right)^{1/2}$$

$$r_f = \frac{\sigma_{Hxy}}{\left(\sigma^2_{Hx}\, \sigma^2_{Hy} \right)^{1/2}}$$

$$e1 = \left(\frac{\sigma^2_{e_x}}{\sigma^2_{Sx} + \sigma^2_{Hx} + \sigma^2_{e_x}} \right)^{1/2}$$

$$e2 = \left(\frac{\sigma^2_{e_y}}{\sigma^2_{Sy} + \sigma^2_{Hy} + \sigma^2_{e_y}} \right)^{1/2}$$

Phenotypic, genetic and environmental correlations between the production traits were calculated for the different datasets.

Tests of Significance

The Restricted dataset comprising the Hereford and Charolais breeds was used to test the significance of herd effects. Analysis of variance was done by the General Linear Model procedure for unbalanced data of the Statistical Analysis System (SAS). Age was included as a covariate in the mixed model.

$$Y_{ijklm} = U + T_i + B_{ij} + H_{ijk} + S_{ijkl} + bX_{ijklm} + E_{ijklm}$$

U = Overall mean in kg.
Ti = The effect of the ith test year assumed fixed.
Bij = The effect of the jth breed within ith year assumed fixed.
Hijk = The effect of the kth herd within jth breed & ith year assumed random.
Sijkl = The effect of the lth sire within the kth herd, jth breed and ith year assumed random.
b = Partial regression of age on dependent variable Y.
Xijklm = Age of the mth bull.
Eijklm = Error.

Significance of the herd of origin effects was further tested separately for the two breeds using the Hereford Restricted dataset and the Charolais Restricted dataset by the same General Linear Model procedure. The model included all the same effects except breed.

Analysis of Bull Ranking

A descriptive analysis to investigate changes in the rank order of bulls according to their weights between different periods of test was conducted for the Hereford and Charolais breeds. For each weighing, bulls were ranked according to their weights in a descending order within breed and year (1976 - 1984). An example of the rank order is given in Appendix Table 11.

Rank codes for each period of time on test are as follows : -

Rdelwt = Rank order of delivery weights.
Rsotwt = Rank order of start of test weights.
Rw56 = Rank order of weights at the 56th day on test.
Rw84 = Rank order of weights at the 84th day on test.
Rw112 = Rank order of weights at the 112th day on test.
Rw140 = Rank order of weights at the 140th day on test.

Changes in the rank order between any two weighings is obtained by subtracting the rank order of bulls at one weighing from the other (Eg. Appendix Table 12). Changes in the rank order were coded as follows : -

RDw140-del = Rw140 - Rdelwt
RDw140-sot = Rw140 - Rsotwt
RDw140-w56 = Rw140 - Rw56
RDw140-w84 = Rw140 - Rw84

RDw140-w112 = Rw140 - Rw112

RDw112-w84 = Rw112 - Rw84

RDw84-w56 = Rw84 - Rw56

RDw56-sot = Rw56 - Rsotwt

RDsot-del = Rsotwt - Rdelwt

Standard deviations of the changes in the rank order were obtained by a univariate analysis of variance performed by the Univariate procedure of the SAS computer package.

RESULTS AND DISCUSSION

Herd and Sire Variance Components of the Performance Traits

Estimating the components of variance is crucial in understanding the relative importance of the random sources of variation affecting a trait. Most studies concerning the estimation of variance components of growth traits at central test stations have been directed towards estimation of heritability of final weight and gains on test. Knowledge of the relative importance of the sources of variation affecting weights and gains at different intervals of the test could be useful in understanding factors affecting postweaning growth at central performance stations. In this study estimates of herd, sire and error components of variance were computed for the production traits from the different datasets (Table 9). The relative importance of herd, sire and residual components of variance expressed as a percent of total variation is presented within and across datasets for the different traits. As explained in the Materials and Methods section different datasets reflect different data structures. The Total dataset comprises 4 breeds. In this dataset there was much confounding between bulls and sires and sires and herds. 51.6% of the sires had one son each and 49.02% of herds had one sire. The same kind of bull:sire and sire:herd ratio was found in the Hereford dataset.

Table 9. Variance components of the Total dataset

Trait	Herd	Sire	Error
SOTWT	357.58	237.27	765.16
W56	394.67	280.85	1116.87
W84	394.95	275.17	1298.03
W112	402.36	332.34	1410.00
W140	427.74	309.24	1674.72
CG0	38.40	-6.96	326.90
CG1	50.00	14.11	439.29
CG2	72.74	83.90	540.93
CG3	89.52	40.26	832.42
PGD	55.19	18.98	190.00
PG0	38.40	-6.96	326.90
PG1	4.69	9.77	100.46
PG2	10.22	63.84	75.30
PG3	14.49	58.62	197.13
SC	69.36	104.95	1119.74
BF	0.43	.05	4.62

A detailed description of the data structure is provided in Table 6 and Appendix Table 1. The Restricted dataset with the requirement of at least 2 bulls per sire and 2 sires per herd was created to determine the effects of this kind of confounding. For example it was observed that with this type of restriction, the percentage of variance due to herds was much smaller than the nonrestricted dataset (Table 10).

Herd Intraclass Correlations

Performance testing involves the comparison of beef bulls reared in different herds at a central location. It is usually assumed that central testing effectively removes pretest environmental effects such as those due to herd of origin and that bulls are ranked on the basis of their true breeding values. Central performance testing therefore enables selection of beef bulls across herds. However in the world literature on central testing many authors have stressed the significance of herd effects at the beginning of the test and warned that such effects may be persistent throughout the testing period. Thus herd effects may introduce bias in the genetic evaluation of beef bulls.

Herd intraclass correlations are shown in Table 10. These figures indicate the relative proportion of the total variation due to herd effects for start of test weight and subsequent weights and gains on test. Since different datasets were used, the average of the correlations from these datasets is used for the purpose of general discussion.

Table 10. Herd intraclass correlations(x100)

Datasets	Total	H	H & CH	H	Average
			(Res.)	(Res.)	
Traits					
SOTWT	26.29	34.95	23.45	37.69	30.60
W56	22.02	32.05	14.16	19.87	22.03
W84	20.07	30.94	12.30	16.88	20.05
W112	18.76	28.82	9.64	12.62	17.46
W140	17.74	29.17	10.12	13.16	17.55
CG0	10.51	10.33	3.06	5.16	7.27
CG1	9.93	7.91	1.94	3.49	7.10
CG2	10.43	10.95	2.43	4.60	7.10
CG3	9.30	12.33	3.30	4.81	7.44
BF	8.44	12.31	17.00	18.82	14.12
SC	5.36	4.57	7.74	3.53	5.30

It was observed that the patterns of change in the herd variance components for weights and gains were highly consistent across datasets. About 30% of the variation or differences among bull weights at the start of the test was due to herd of origin effects. With progress on test these differences dropped gradually to about 17% at 112 days. However this difference was still maintained at the end of the test. A graphical illustration is presented for the Total dataset in Figure 1.

Differences among bulls for the cumulative gains were almost constant. Herd variance for cumulative gains was much lower than for absolute weights (Figure 2). Only about 5.82 - 7.44% of the total variation for the 140 day gain is attributed to herds as compared to 10.12 - 17.55% for end of test weight. Gain on test seem to be less affected by herd of origin effects than end of test weight. For periodic gains (Figure 3) herd of origin was a major source of variation for the 28 day adjustment period and the first 56 day. Herd intraclass correlations remained almost constant for the remaining three periods. On the whole the percentage of the total variance attributed to herd effects was much smaller than that reported in the literature for postweaning gain from non-central performance test data (Table 4).

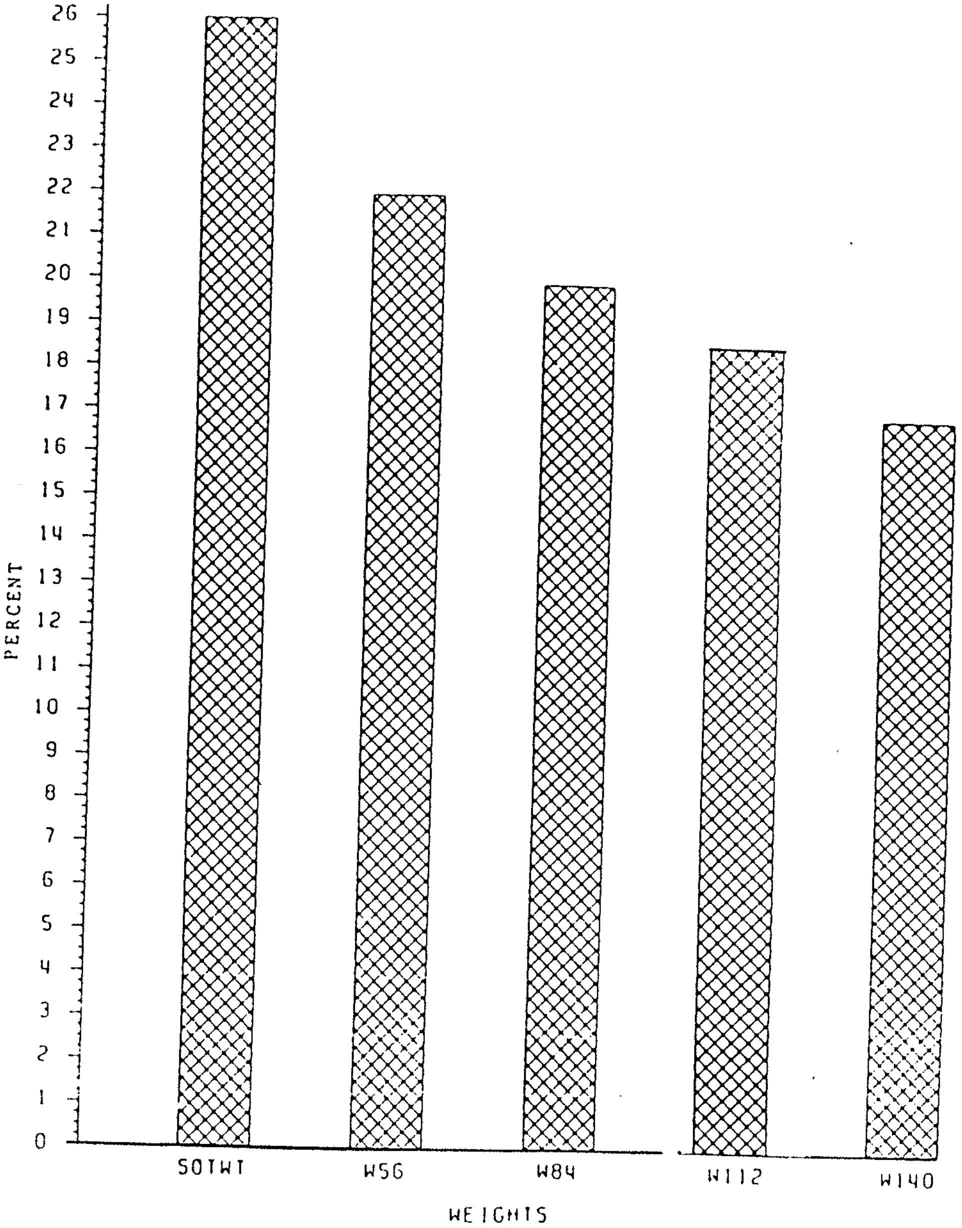

Fig.1. Herd intraclass correlations of weights at different intervals of the test (Total dataset).

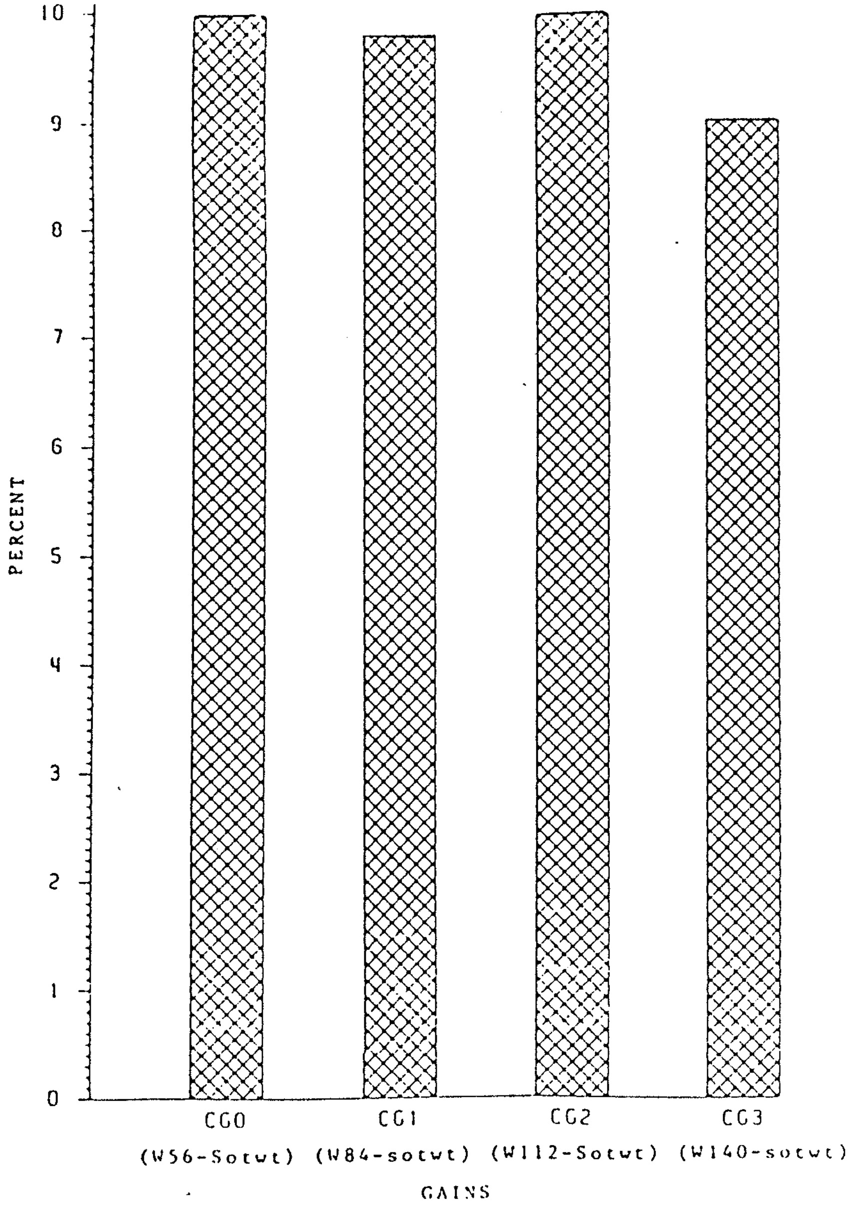

Fig. 2. Herd intraclass correlations of cumulative gains on test (Total dataset)

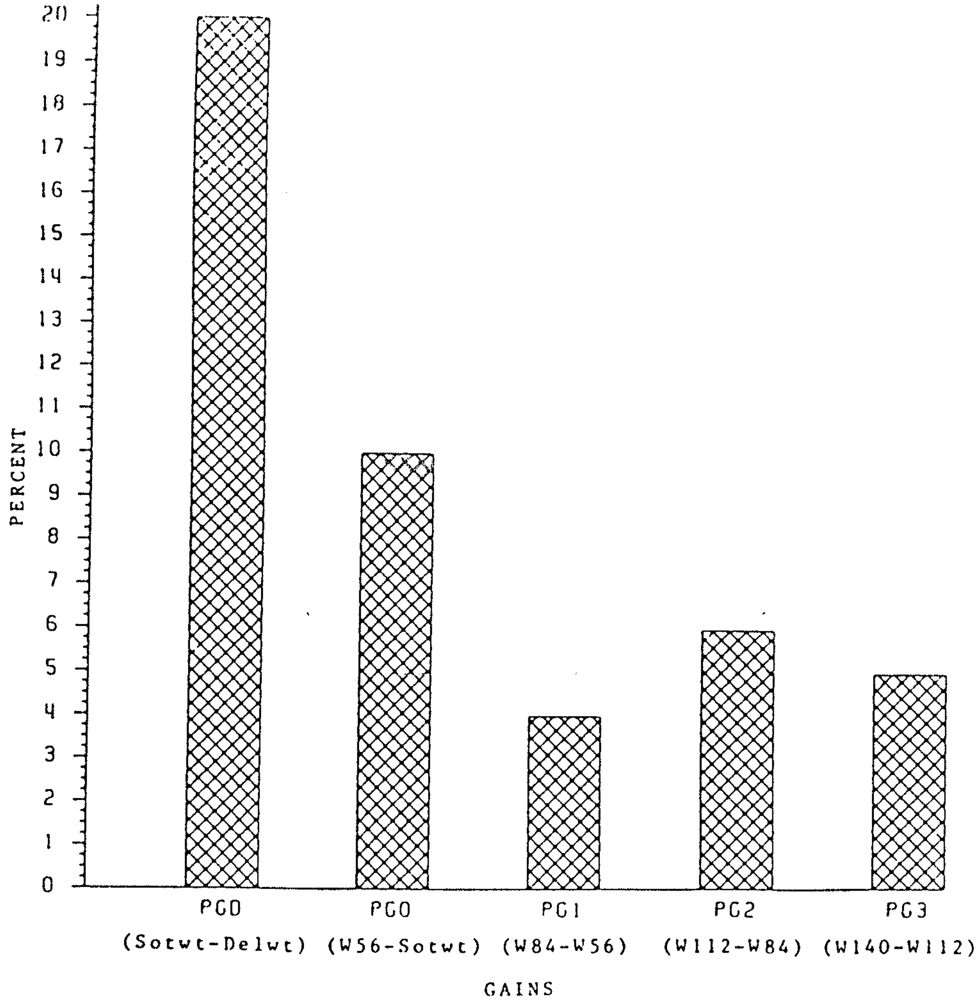

Fig. 3. Herd intraclass correlations of periodic gains on test (Total dataset).

Heritability Estimates

Performance records could be utilized effectively to evaluate, improve and monitor selection programs at central test stations. Testing procedures at central locations are mostly based on results from experimental stations. While experimental stations provide more accurate estimates of parameters they may not necessarily reflect the actual performance in a particular area or location. Therefore it is desirable to estimate genetic parameters at central testing facilities. Such estimates should provide a more realistic picture of the reliability of test stations and would be useful in implementing or improving selection procedures for economic improvement of production traits. Heritability estimates for the traits were calculated on an interherd and intraherd basis for the different datasets. Intraherd heritabilities were larger than interherd heritabilities for all datasets (Tables 11 & 12). However there was no change in the pattern of the estimates for the various weights and gains between the two methods. In general the values of heritabilities by both methods fall within the range of those reported elsewhere for the same growth traits (Tables 1,2 & 3). The estimates for weights on test were high (Figure 4). The values for gains on test ranged from low to moderate. For the remainder of this discussion the interherd heritability estimates for the different datasets will be referred to.

Table 11. Inter-herd heritability estimates

Datasets	Total	Hereford	Restricted
Traits			
SOTWT	0.70	0.63	0.26
W56	0.63	0.45	0.36
W84	0.56	0.43	0.36
W112	0.62	0.76	1.19
W140	0.51	0.46	0.50
CG0	-0.08	0.13	0.17
CG1	0.11	0.30	0.21
CG2	0.48	0.86	1.45
CG3	0.17	0.39	0.38
SC	0.32	0.23	-
BF	0.04	0.07	-

Table 12. Intra-herd heritability estimates

Datasets	Total	Hereford	Restricted
Traits			
SOTWT	0.95	0.84	0.42
W56	0.86	0.41	0.45
W84	0.67	0.49	0.37
W112	0.76	0.84	1.36
W140	0.62	0.77	0.58
CG0	-0.09	0.13	0.12
CG1	0.12	0.31	0.22
CG2	0.54	0.89	1.52
CG3	0.19	0.40	0.40
SC	0.34	0.34	-
BF	0.04	0.02	-

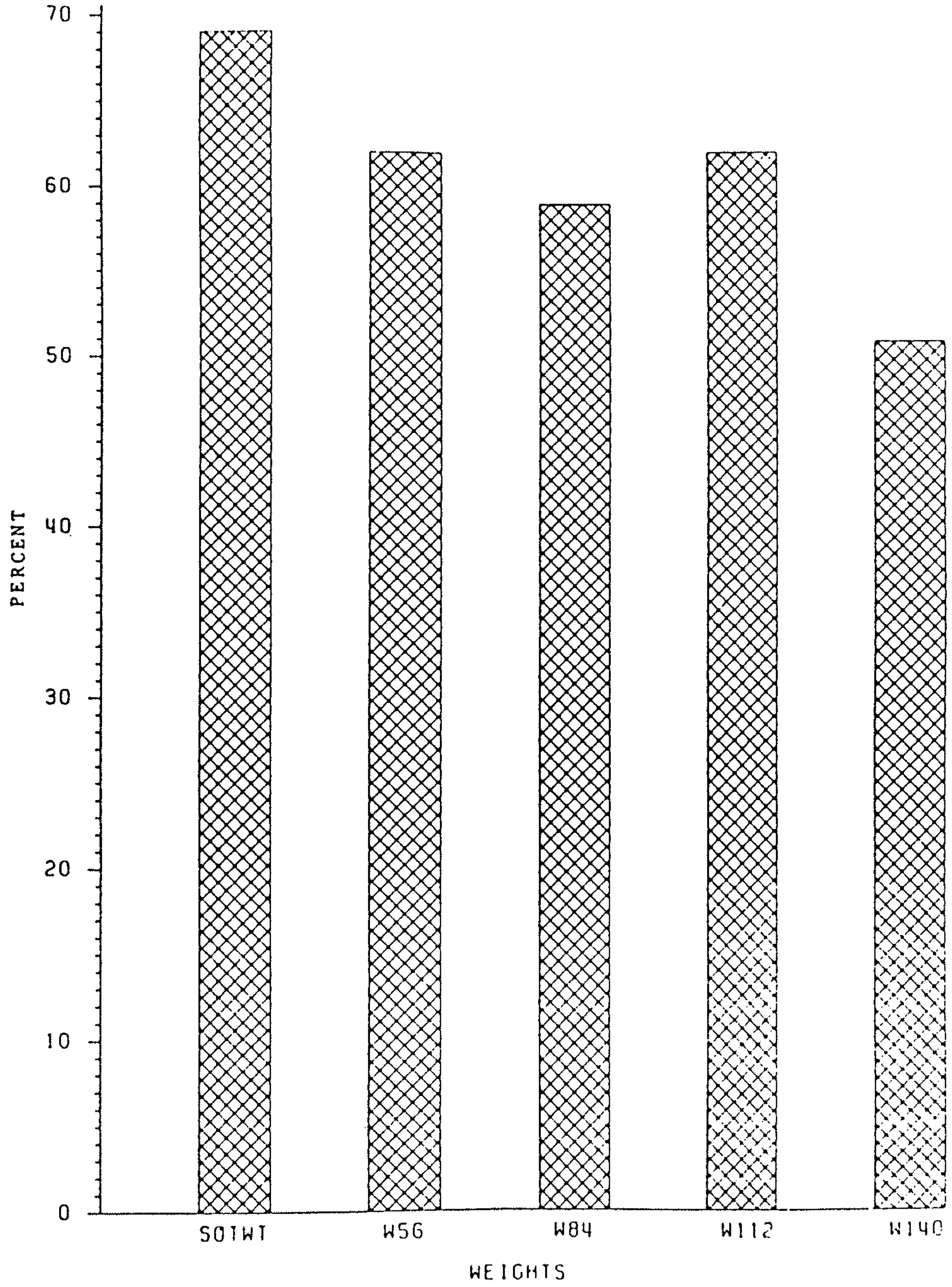

Fig. 4. Heritabilities of weights at different intervals of the test (Total dataset).

The high heritability estimates for the weights on test suggest that there exists considerable additive genetic variance for these traits in Manitoba herds. However there may be other factors that may have contributed to these heritabity estimates. The denominator may be reduced due to underestimation of σ_e^2. Though in this analysis dams are supposed to be random, mating better sires with better cows would increase the estimate of sire variance by differential or assortative mating (Falconer,1982). Factors of this kind would tend to bias the ratio of sire variance upward. With heritability estimates based on half-sib correlations any error in the sire variance component coefficient is multiplied four-fold in the heritability estimate. It is well known that the accuracy of the paternal half-sib correlation method of estimation depends on the number of degrees of freedom available for estimating the differences between sires and to a lesser degree on the number of offspring per sire. The total dataset has the maximum number of degrees of freedom for sires as compared to the other datasets and should therefore give a better estimate. Heritability of end of test weight was high (0.513) for the Total dataset. This value was consistent with the estimates from the other datasets and was in close agreement with the median value in the literature (Table 2). It was observed that the heritability of W112(weight at 112 day) was consistently higher than end of test weight for all the datasets. It is interesting to note that heritability for cumulative gains increased gradually with progress on test reaching a peak with 112 day gain. Heritability of 140 day gain was consistently lower than 112 day gain (Figure 5). Heritability of the 140 day gain was considerably smaller than reports in the literature. However values for the other datasets were in close agreement with estimates reported elsewhere (Table 1). Heritabilities of the periodic gains were calculated only for the total dataset (Table 13). Heritability estimates for the first three periods were low, estimates for the last two periods had much higher values with that for PG2 (W112-W84) exceeding unity (Figure 6).

Evaluation of genetic parameters at central test stations will not be complete without a proper understanding of growth patterns in cattle. Growth in mammals is known to be under genetic control arising from cyclic activation and repression of structural and regulatory genes. The activation repression cycles express different trajectories at different periods of the growth curve. Growth in general has been suggested to have an exponential and a linear phase (Laird et al.,1965). The inflection point marks the change from the exponential to the linear phase (Bertalanffy,1960; Monteiro and Falconer,1966). This change in the growth curve coincides with important changes in ontogeny, resulting in marked heterogeneity in growth rates. Atchley (1984) demonstrated with mice data that maximum phenotypic and genetic variance occurs at the inflection point which is the period

Table 13. Heritability estimates of periodic gains of Total dataset

Traits	Interherd	Intraherd
PGD	0.29	0.36
PG0	0.08	-0.09
PG1	0.34	0.36
PG2	1.71	1.84
PG3	0.87	0.92

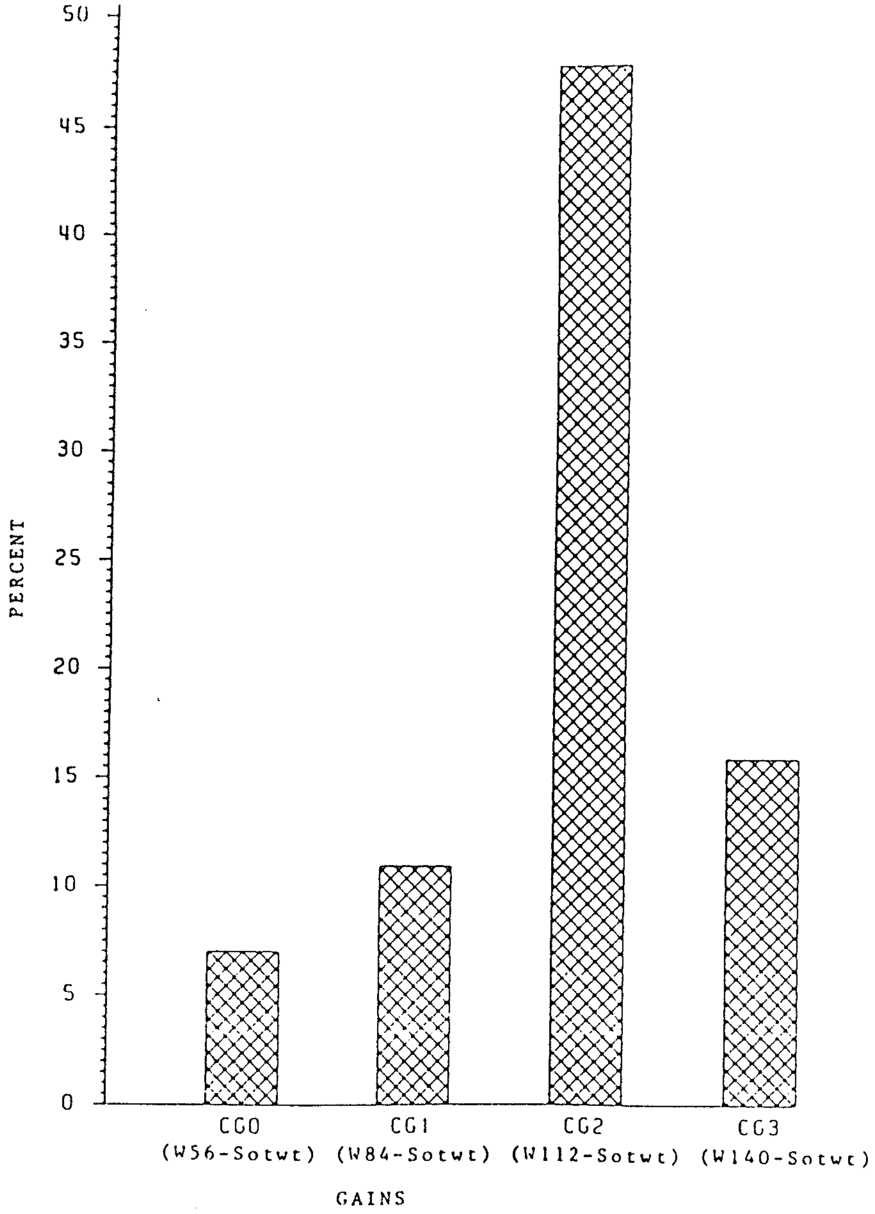

Fig. 5. Heritabilities of cumulative gains on test (Total dataset).

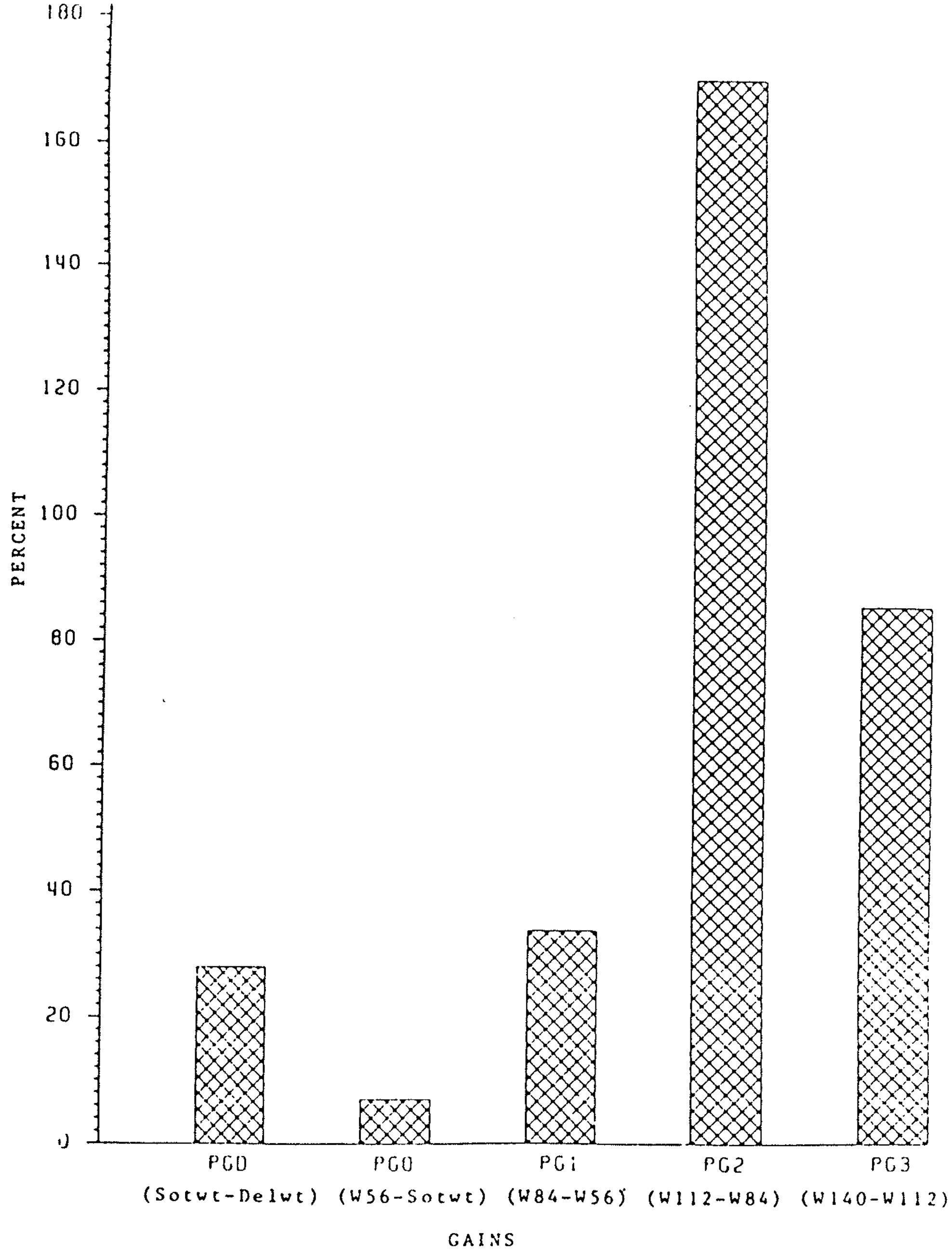

Fig. 6. Heritabilities of periodic gains on test (Total dataset).

of maximum growth rate. It is unfortunate that the growth curve in cattle is not well documented to determine the inflection point of the different breeds. Perhaps this may be one of the reasons for the wide variability in heritability estimates for growth parameters in beef cattle reported in the literature.

In the present study, the phenotypic variance was similar between W112 and W140. However W112 which corresponds to 12 month weight had maximum genetic variance (Appendix Tables 2,5 & 8). Maximum genetic variability at this period of the test is further supported by maximum genetic variability in 112 day cumulative gain and maximum variability at the W112-W84 periodic gain measurement. Perhaps it is premature to make specific conclusions from these observations as the data includes different breeds of beef bulls with obviously different growth curves. In addition it was not possible to estimate growth curves and determine inflection points from the bull data used here. Performance measurements beyond the 140 day test would be needed. It is tempting to speculate from the available information that the inflection point of these bulls under the present testing procedure falls around 12 months of age. This period of time closely corresponds to the 112 day weighing of the present testing procedure. The herd intraclass correlation estimated earlier revealed that testing beyond 112 days did not remove herd effects any further. As weight and gain at the 112 day interval on test had maximum genetic variability selection at this point may be most effective.

Reliability of the Heritability and Herd Intraclass Correlation Estimates

The reliability of the heritability and herd intraclass correlation estimates determined by the simulation study is presented. The mean and the standard deviation of the 10 heritability estimates was 0.22 and 0.08. The mean and standard deviation of the herd intraclass correlation estimates was 0.09 and 0.02. The variability of the heritability estimate was compared with an estimate derived from the basic formula developed by Fisher(1948) for the variance of intraclass correlations for one stage hierarchical analysis of equal subclasses.

The basic formula is as follows : -

$$\sigma_t^2 = \frac{2\left\{1 + (n-1)\ t\ ^2\ (1-t)^2\right\}}{n\ (n-1)\ (N-1)}$$

where N refers to the number of subclasses(eg.sires)

n = subclass size(eg.number of bulls per sire) with an average of two bulls per sire.

$$\sigma_t^2 = \frac{2\left[1 + (2-1)\ 0.05475\ ^2\ (1-0.05475)\right]}{2\ (2-1)\ (1817-1)} = 0.000579$$

$$\sigma_h^2 = 16 \times 0.000579 = 0.009264$$

$$\sigma_h = 0.09624$$

This value is in close agreement with the value estimated using the simulation study.

Phenotypic Genetic and Environmental Correlations

Estimates of phenotypic, genetic and environmental correlations are useful in setting up selection goals for efficient beef production. These estimates are important when the ranking of bulls at central locations is based on an index of two or more traits. Most previous reports on correlations of feedlot performance are based on experimental test station data involving fewer traits. This part of the analysis was designed primarily to understand relationships among weights and gains at different intervals of the test.

Estimates of the phenotypic, genetic and environmental correlations between the production traits for the different datasets are in tables 14,15&16. The magnitude of the various correlations is coded as follows for the purpose of discussion :-

< 0 - 0.25 low
0.26 - 0.50 fairly high
0.51 - 0.75 high
0.76 very high

The phenotypic correlation estimates were not only highly consistent for the different datasets but also were comparable to those reported in the literature (Preston and Willis,1974). This close agreement includes field, feedlot and experimental data. In no instance did the phenotypic correlation estimates exceed the theoretical limits of one. On the other hand the genetic and environmental correlations,

Table 14. Phenotypic, genetic and environmental correlations between the traits - Total dataset

Traits		W112	W84	W56	SOTWT
	rP	0.94	0.92	0.91	0.77
W140	rG	0.89	1.03	0.96	0.90
	rE	0.89	0.84	0.87	0.68
Traits		CG3	CG2	CG1	CG0
	rP	0.67	0.57	0.55	0.49
W140	rG	0.53	0.26	0.73	-
	rE	0.72	0.66	0.43	-
	rP	0.06	0.05	0.06	0.05
SOTWT	rG	0.16	0.04	0.10	-
	rE	0.00	0.02	-	-

Table 15. Phenotypic, genetic and environmental correlations between the traits - Hereford dataset.

Traits		W140	W112	W84	W56	SOTWT
W140	rP	-	0.95	0.92	0.89	0.80
	rG	-	0.70	0.93	0.89	0.86
	rE	-	1.41	1.27	1.27	1.10
CG3	rP	0.63	0.52	0.42	0.32	0.05
	rG	0.52	0.29	0.27	0.07	0.03
	rE	0.70	0.71	0.56	0.56	0.12
CG2	rP	0.52	0.60	0.39	0.30	0.03
	rG	0.18	0.72	0.14	-0.01	0.06
	rE	0.84	-0.33	0.64	0.70	0.00
CG1	rP	0.51	0.49	0.54	0.40	0.04
	rG	0.41	0.35	0.31	0.10	0.00
	rE	0.64	0.62	0.72	0.66	0.11
CG0	rP	0.45	0.41	0.42	0.46	0.05
	rG	0.65	0.41	0.55	0.33	0.29
	rE	0.59	0.56	0.52	0.68	0.01

Table 16. Phenotypic, genetic and environmental correlations between the traits - Restricted dataset

Traits		W140	W112	W84	W56	SOTWT
	rP	-	0.95	0.96	0.94	0.61
W140	rG	-	0.73	1.01	0.89	0.70
	rE	-	0.83	0.81	0.88	0.52
	rP	0.79	0.72	0.68	0.63	-0.01
CG3	rG	0.67	0.49	0.51	0.26	-0.07
	rE	0.64	0.60	0.58	0.67	0.02
	rP	0.72	0.77	0.66	0.61	-0.02
CG2	rG	0.43	0.81	0.42	0.20	-0.05
	rE	0.60	0.17	0.53	0.67	0.03
	rP	0.74	0.72	0.73	0.67	-0.01
CG1	rG	0.66	0.58	0.55	0.31	-0.08
	rE	0.62	0.56	0.65	0.69	0.04
	rP	0.71	0.67	0.68	0.69	-0.03
CG0	rG	0.73	0.62	0.73	0.47	0.13
	rE	0.65	0.60	0.62	0.72	-0.09

though fairly consistent across datasets had values which sometimes exceeded unity. These correlations also exhibited broader ranges when compared to those reported from other studies (Preston and Willis,1974). As numerous trait combinations were studied no attempt is made here to explain each of them. Rather, the trait combinations most important to the economics of beef production and the pattern of change of all other traits in relation to these traits were examined.

End of test weight and gain on test exhibited strong positive phenotypic, genetic and environmental relationships in all the datasets. In the Restricted dataset the genetic correlation was slightly higher than the environmental correlation. The environmental correlation was slightly higher than the genetic and phenotypic correlations in the other two datasets. Nonetheless end of test weight and gain on test were highly correlated as previously reported (Preston and Willis,1974). The correlations between weights and gains during the test period were examined to understand the nature of the part-whole relationship among them. Genetic and environmental correlations between weights and their corresponding test gains were compared for this purpose. The environmental correlations between the weights and their corresponding gains (eg. W56 & CG0, W140 & CG3) were high and persisted from one period to another during the test. The only exception to this trend was the trait combination of W112 and CG2 where the environmental correlation was remarkably lower than the rest. A similar kind of trend was observed when the end of test weight was combined with cumulative gains on test as illustrated in tables 13 and 14. If one may generalize from these observations, it seems that when there was a part-whole relationship between weights and gains on test, environmental correlations were high and persisted from one period to another. Environmental correlations did not tend to vary as greatly during the length of the testing period as the genetic correlations did. A fairly similar observation was reported by Swiger (1962).

The most important correlation found between traits in this study was perhaps between initial weight and gain on test. There are not too many citations in the literature on this correlation between initial weight and gain on test. The phenotypic correlation between initial weight and gain on test ranged from -0.01 to 0.05 across datasets. This value was not far from those reported by Ruby et al.(1948) 0.099; Patterson et al.(1955) 0.11; Dalton (1976) -0.24. Genetic and environmental correlations were also very small between these two traits. Genetic correlations were positive for both the Total dataset and Hereford dataset but were negative for the Restricted dataset. It is more likely that the small negative correlation was due to chance than to any real genetic antagonism between the two traits. The environmental correlations are important in the interpretation of carry-over effects from the pretest environment such as herd of origin. The zero environmental correlation estimated from the total dataset is a very encouraging indication that test gain is free from pretest environmental factors such as herd of origin. The small positive environmental correlation for the Hereford (0.12) and Restricted (0.02) datasets provides similar interpretations.

It may be concluded from this portion of the analysis that gain on test was environmentally independent of start of test weight. This is not surprising as initial weight is a combination of birth weight, weaning weight and pretest gain, and thus influenced largly by maternal and pretest environmental factors. The maternal reasons would include factors such as milk yield, age and parity of dam. In addition the pretest environment would include differences in nutrition such as creep-feed and management. Postweaning gain at central performance testing stations is measured under uniform nutritional and environmental conditions. The very small environmental correlation between initial weight and gain on test clearly indicates that carry-over effects from pretest environment such as herd effects are negligible. The effect of compensatory gain on the performance of bulls at this station is therefore minimum.

Test of Significance of Herd of Origin Effects

In the first part of the study, the magnitude of the herd variation in relation to the total variation was examined for weights and gains at different intervals of the test. It was observed that for the Restricted dataset herd of origin accounted for about 23% of the total variation among bulls for start of test weight, 10% for end of test weight and 3.30% for test gains. This part of the analysis was aimed at testing the significance of these variations. In addition tests of significance of year, breed, sire and age effects were conducted. Analysis of variance for the restricted dataset and Hereford and Charolais restricted datasets are presented in tables 17,18 and 19. Herd of origin of bulls was a highly significant ($P < 0.01$) influence on SOTWT (initial weight) and W140 (end of test weight) ($P < 0.05$) for the restricted dataset. Herd was not a significant source of variation for gains on test. Similar results were observed for the Hereford restricted dataset. However for the Charolais restricted dataset herd was a significant source of variation only for SOTWT. The tests of significance for initial and final weights confirm reports from test stations in New Zealand and Britain. Morris (1981) reported significant herd of origin effects for initial and end of test weight under pastoral conditions in New Zealand. In Britain, Okantah et al.(1978) observed that herd of origin had a significant effect on all test traits.

Table 17. Analysis of variance for SOTWT(initial weight) W140 (end of test) and CG3(test gain) for the Restricted dataset

		SOTWT	W140	CG3
Source	df	F	F	F
Total	807			
Year	7	0.38	0.16	0.14
Breed/Year	8	13.78**	12.86**	2.38*
Herd/Breed/Year	89	3.89**	1.41*	0.92
Sire/Herd/Breed/Year	219	1.27*	1.72**	1.84**
Age	1	158.6**	40.77**	0.02
Error	483			

$p < 0.01$

$p < 0.05$

Table 18. Analysis of variance for SOTWT(initial weight) W140 (end of test) and CG3(test gain) for the Hereford Restricted dataset

		SOTWT	W140	CG3
Source	df	F	F	F
Total	464			
Year	7	3.22*	1.85	1.11
Herd/Year	51	5.54**	1.88*	0.98
Sire/Herd/Year	131	1.20	1.29*	1.52**
Age	1	43.14**	11.54**	0.00
Error	274			

$p < 0.01$

$p < 0.05$

Table 19. Analysis of variance for SOTWT(initial weight) W140 (end of test) and CG3(test gain) for the Charolais Restricted dataset

		SOTWT	W140	CG3
Source	df	F	F	F
Total	343			
Year	7	7.92 **	2.86 *	1.38
Herd/Year	38	2.58 **	1.07	0.84
Sire/Herd/Year	88	1.33	2.14 **	2.16 **
Age	1	108.20 **	26.09 **	0.01
Error	209			

$p < 0.01$

$p < 0.05$

Initial Age on Test

The effects of age on initial weight, end of test weight and gain on test was consistent across the three datasets. Start of test age was a highly significant source of variation for initial and final weight on test. Similar results were reported by Bailey and Gilbert,1962 ($P < 0.01$) under a 140 day performance test in Nevada. Significant initial age effects on final weight were reported by Brinks et al.,1962; Schalles and Marlowe,1967; Dinkel and Busch,1973; Brown and Keaton,1974; Steane et al.,1978; Nelsen and Kress,1979. However Cain and Wilson (1983) observed non-significant initial age effects on final weight. The non-significant effect of initial age on test gain is in agreement with studies of Batra and Wilton (1972), Dinkel and Busch (1973) and Crow et al.(1978). Initial age was not a significant source of variation in gains on test in studies of Brown et al.(1974) and Nelsen and Kress (1979). The variation in the effects of initial age on test gain could perhaps be explained by observations of Swiger et al.(1963) who noted decreasing effects of initial age with increase in the length of the testing period. Therefore the variation in the literature could be due to different durations of testing period across stations. The present analysis indicates age was an important source of variation for weights at the test station.

Change in the Rank Order

In this analysis bulls were ranked according to their weights in a descending order for the different periods of the test. Bulls of the Hereford and Charolais breeds were ranked within years. The variation in the rank changes over different intervals of time were calculated to demonstrate the stability of a bull's position relative to other bulls as the test progressed.

Standard deviations of the differences in the rank order of bulls between adjacent weighings and between final weight and prior weights on test are illustrated in tables 20 and 21. The pattern of change in rank order of bulls between final weight and prior weights on test are shown in Figures 7 and 8. The greater the time duration between any two periods (eg. RD140-del) the larger the standard deviation. This is best illustrated by the Charolais data of 1984 where a decrease in the time between the weighings was reflected in a decrease in the change in rank order. In contrast the change in rank order of bulls between start of test and delivery weights(RDsot-del) and 56 day weight and start of test weight(RDw56-sot) were consistently larger than RDw84-w56, RDw112-w84 and RDw140-w112 for both the breeds across the years.There seemed to be very little variation in the pattern of change in rank order between RDw84-w56, RDw112-w84 and RDw140-w112. In other words there was a marked decrease in the change after 56 days on test and the

Table 20. Standard deviations of the changes in rank order for the Hereford breed

YEAR	1977	1978	1979	1980	1981	1982	1983	1984
NO. OB OBS.	148	152	140	192	142	183	196	148
CODES								
RDsot-del	21.41	21.45	22.37	32.36	29.12	31.16	26.36	19.94
RDw56-sot	17.01	21.49	15.74	21.61	20.98	26.75	23.19	19.84
RDw84-w56	12.42	13.53	9.80	13.57	11.39	14.72	17.81	12.54
RDw112-w84	12.76	11.78	9.60	16.95	11.68	17.36	15.21	11.90
RDw140-w112	9.42	10.55	9.52	18.07	11.22	13.26	14.91	13.42
RDw140-del	31.26	31.33	28.97	40.47	31.50	37.97	40.84	32.23
RDw140-sot	26.95	30.58	25.03	28.84	29.61	35.31	34.34	31.73
RDw140-w56	20.43	22.20	16.92	20.88	17.91	23.79	26.00	21.38
RDw140-w84	5.67	17.14	12.69	16.06	13.17	19.69	18.30	16.43
RDw140-w112	9.42	10.55	9.52	18.07	11.22	13.26	14.91	13.42

Table 21. Standard deviations of the changes in rank order for the Charolais breed

YEAR	1977	1978	1979	1980	1981	1982	1983	1984
NO. OB OBS.	74	96	121	137	156	167	177	197
CODES								
RDsot-del	9.84	14.43	15.57	17.28	22.70	18.36	19.54	21.50
RDw56-sot	9.86	17.20	14.76	14.48	19.16	19.43	19.13	22.09
RDw84-w56	5.59	11.21	7.20	8.54	13.76	12.87	11.77	14.59
RDw112-w84	5.94	9.69	7.51	7.74	12.70	13.54	11.75	15.58
RDw140-w112	5.73	10.30	8.14	8.09	12.72	13.45	12.14	14.39
RDw140-del	14.47	26.06	26.15	26.26	32.38	32.46	34.95	38.48
RDw140-sot	12.80	25.53	21.64	21.48	27.64	28.89	28.17	33.31
RDw140-w56	10.01	18.03	13.76	14.62	19.33	22.00	20.45	26.63
RDw140-w84	8.35	12.89	10.72	10.57	17.28	16.00	16.13	20.19
RDw140-w112	5.73	10.30	8.14	8.09	12.72	13.45	12.14	14.39

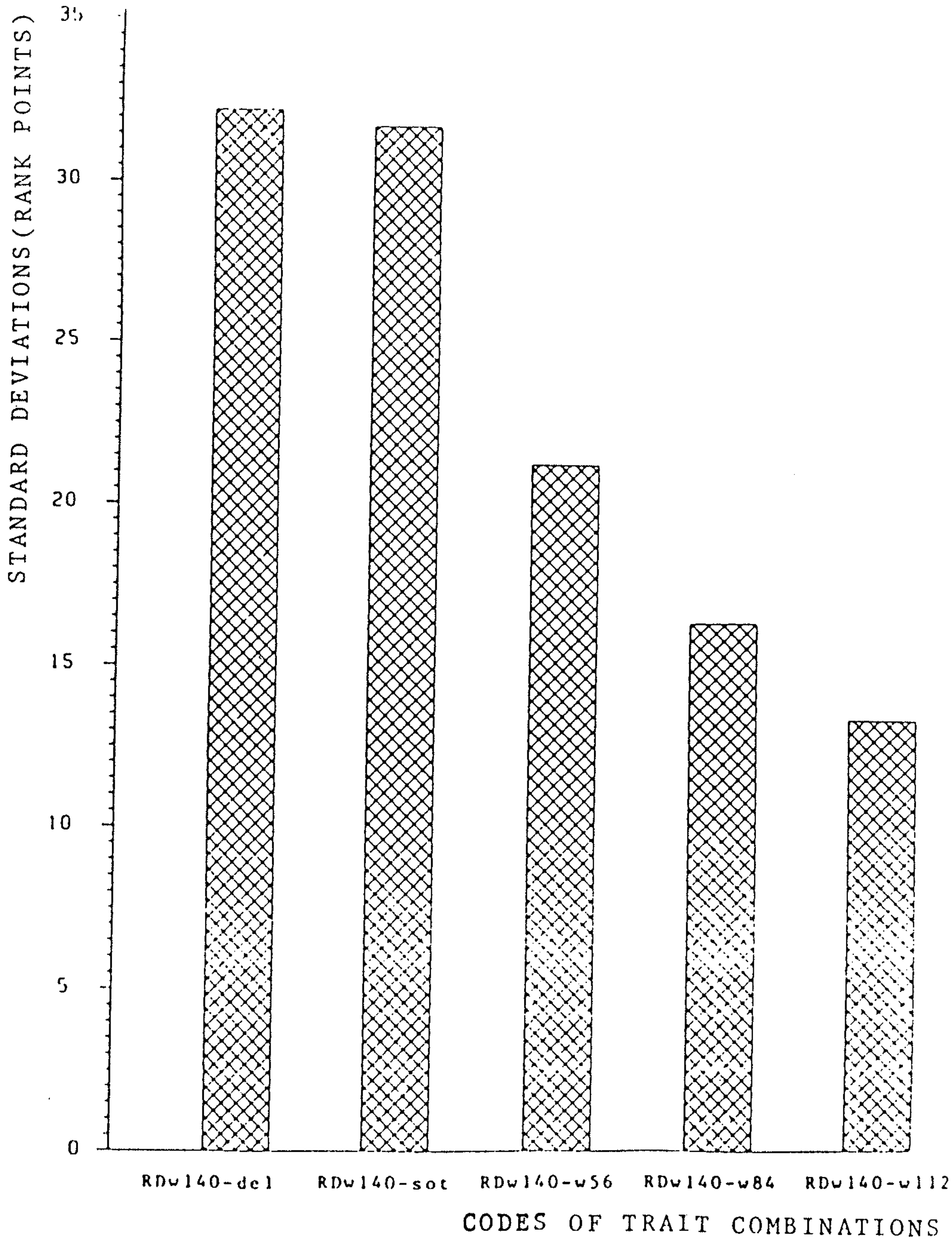

Fig. 7. Pattern of change in the rank order of bulls between final weight and prior weights on test (Hereford-1984,dataset).

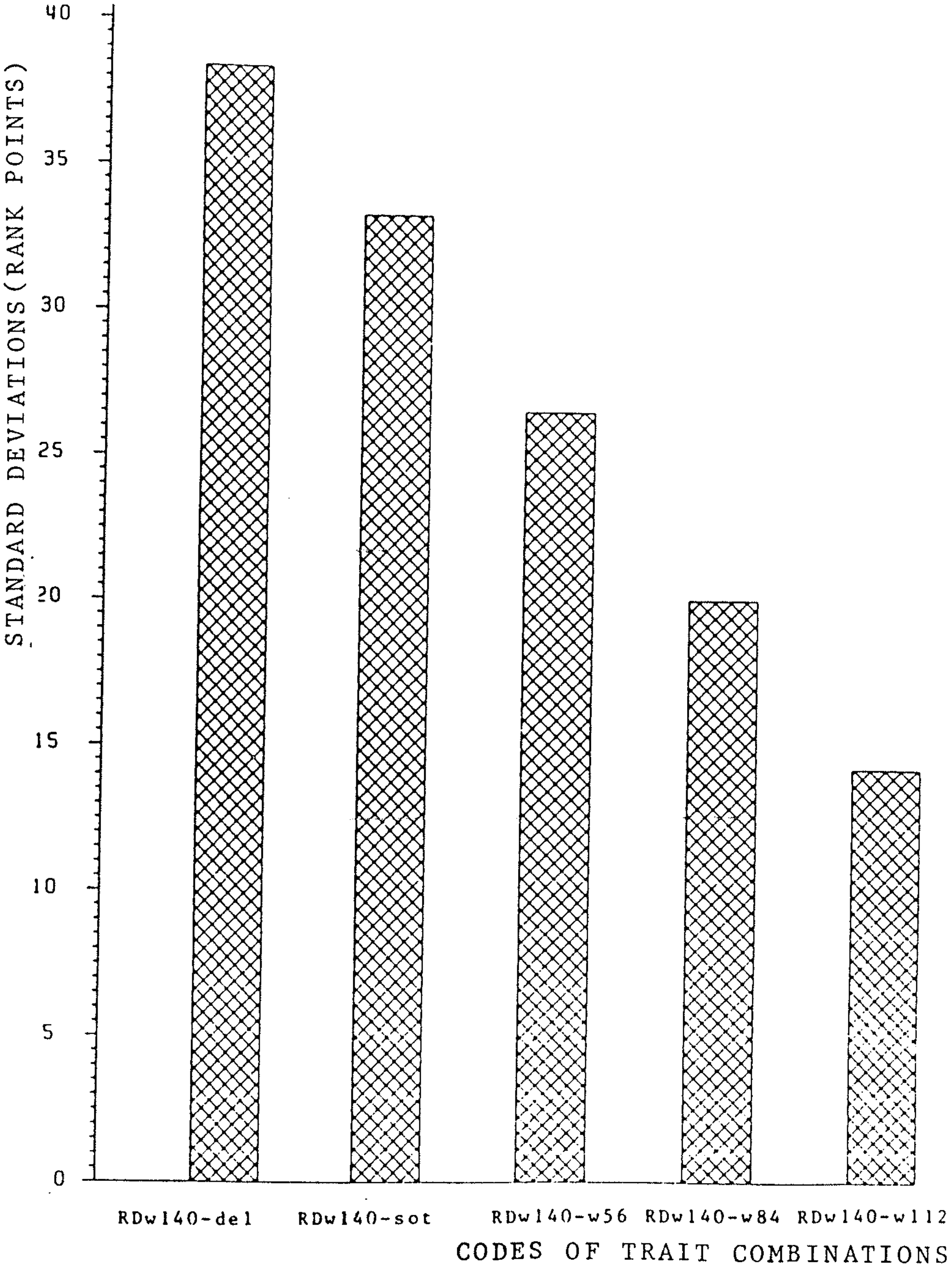

Fig. 8. Pattern of change in the rank order of bulls between final weight and prior weights on test (Charolais-1984,dataset).

difference in ranking remained quite constant after this period (Figures 9 & 10). The consistently larger standard deviations of RDsot-del and RDw56-sot relative to the rest of the rank changes may be attributed to large differences in the rate of growth due possibly to a compensatory growth mechanism rather than actual linear growth. This observation suggests that compensatory growth must have occurred during the earlier parts of the test, most likely between delivery and 56 day on test. Therefore variation due to environmental factors such as herd of origin effects should be small beyond this point.

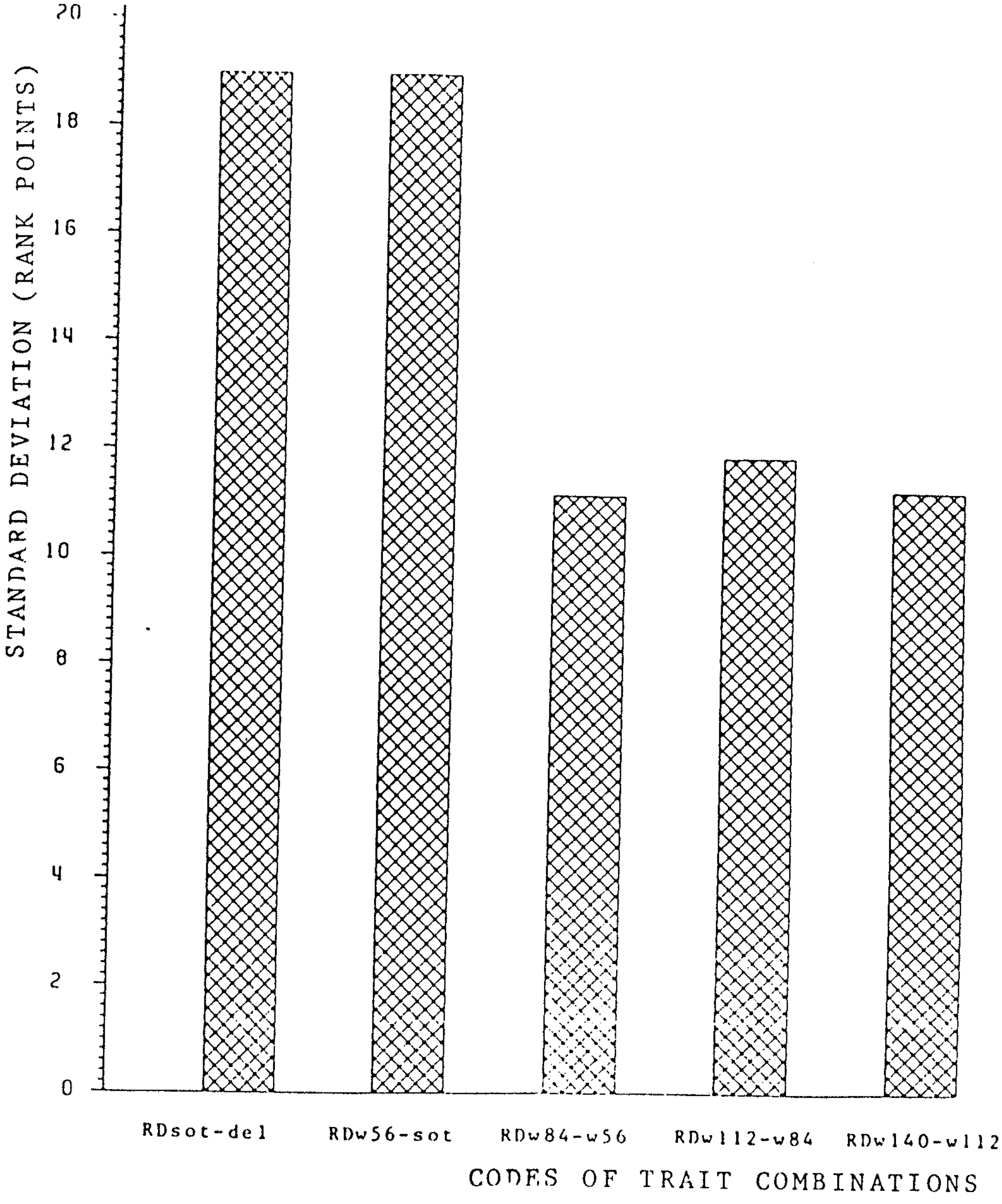

Fig. 9. Standard deviations of the changes in rank order of bulls between adjacent weights on test (Hereford-1984 dataset).

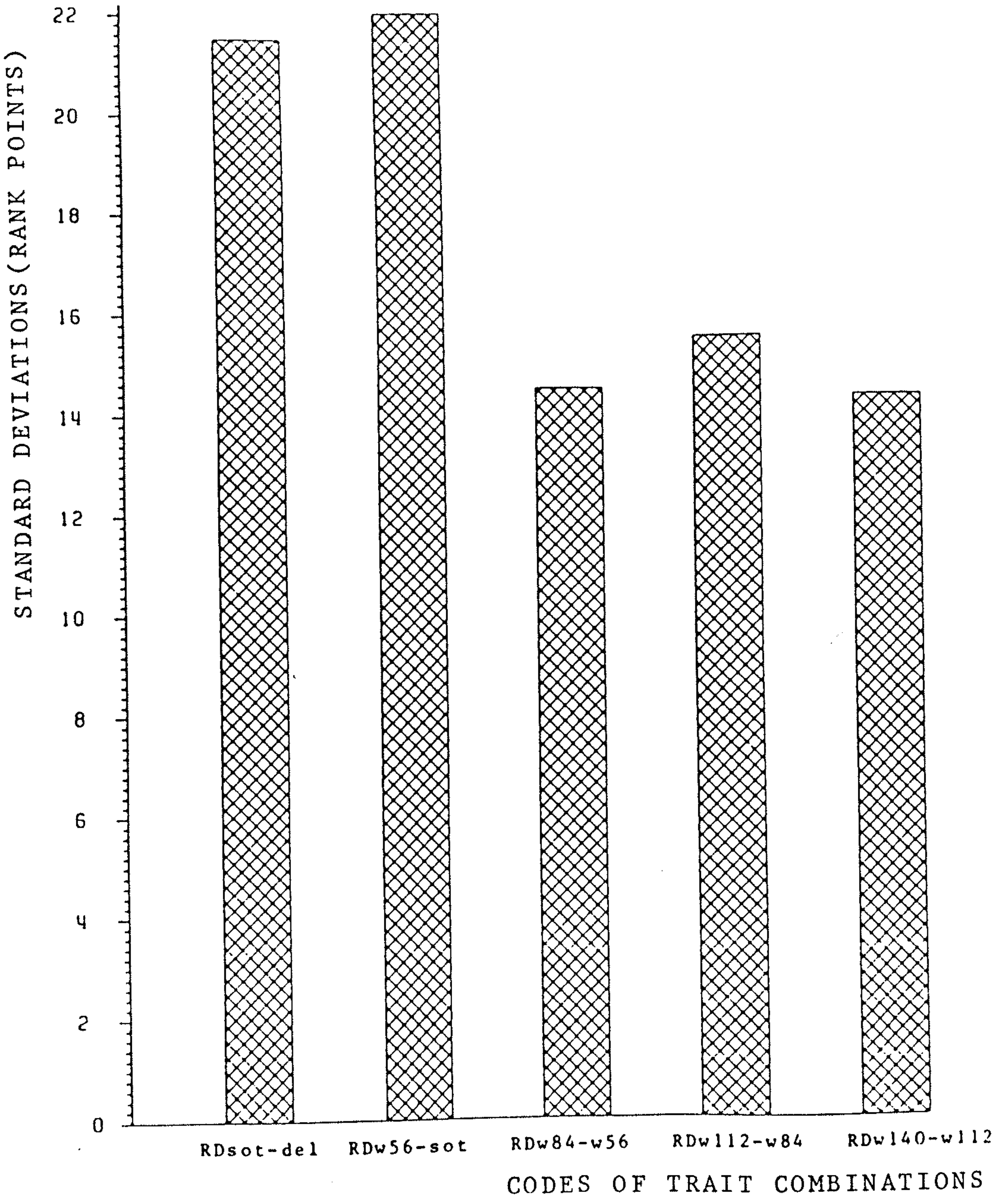

Fig. 10. Standard deviations of the changes in rank order of bulls between adjacent weights on test (Charolais-1984, dataset).

SUMMARY AND CONCLUSION

Nine years (1976 - 1984) of performance data from the Manitoba Central Performance Bull Testing Station formed the basis of this study. The total dataset comprised 4 breeds - Hereford, Charolais, Simmental and Angus with about 3500 observations. Smaller subsets of the total dataset were created to introduce flexibility in the analysis and interpretation of the data. This study was primarily designed to examine, estimate and understand herd of origin effects on the performance of station tested beef bulls. In addition other factors relating to the effectiveness of performance testing at central locations were also examined.

Estimates of herd intraclass correlations revealed that about 30% of the variation among bull weights at the start of the test was due to herd of origin effects. This variation dropped gradually to about 17% at the 112 day interval on test and was not different at 140 days, ie. the end of the test. The difference among bulls due to herd of origin effects was confirmed using the Restricted dataset ($P<0.05$). Variation among bulls due to herds was almost constant for the cumulative gains on test. Only about 7% of the total variation for the 140 day gain was attributed to herd of origin effects. Tests of significance confirm that herds were not an important source of variation for the 140 day gain on test.

Heritability estimates for weights at different time intervals of the test were of high order. This indicates that there exists considerable additive genetic variance for growth traits in Manitoba herds. Interestingly, heritability of 112 day weight, though not consistent in absolute magnitude across datasets was always higher than that for end of test weight. Heritability of end of test weight was high and in close correspondence across datasets (0.51, 0.55, 0.50). These values are also in good agreement to those reported in the literature. Heritability of cumulative gains increased gradually with progress on test reaching a peak at the 112 day weighing. Similar to that found for the weights on test, heritability estimates of 112 day gain was consistently higher than that for 140 day gain for all the datasets. Unlike the heritability estimates of the end of the test weight, estimates of the 140 day gain were quite inconsistent across datasets (0.17, 0.53, 0.39). The lower values for gain as compared to weights follows the common trend reported elsewhere. The considerably lower value estimated (0.17) from the Total dataset which comprises a large number of observations is of concern in terms of test gain as a selection criterion.

The phenotypic correlations were not only highly consistent across datasets but also were remarkably in close range to the median of values reported in the literature. The genetic and environmental correlations were fairly consistent across datasets but had values exceeding unity. Gain on test and end of test weight exhibited strong positive phenotypic, genetic and environmental correlations. The correlations between weights and their corresponding gains on test were examined. It was observed that when there was a part-whole relatioship between weights and their corresponding gains (eg. W56 & CG0, W140 & CG3), environmental correlations were high and persisted from one interval to another. Genetic correlations, however, increased gradually with increase in the ratio of the part-whole relationship of weights and gains reaching a peak at the 112 day interval ie. the trait combination of W112 and CG2.

The most important correlation found in this study is perhaps between initial weight and gain on test. The negligible correlation between these two traits seem to indicate that gain on test is independent of initial weight. The zero environmental correlation estimated from the Total dataset is a very encouraging indication that test gains are free from the carry-over effects of pretest environment such as herds.

Another important observation was the effect of age on growth traits at the test station. Age was a highly significant source of variation for initial and final weights on test. However gain on test was free of age effects. Gain on test, being free from pretest environmental effects seems to be a sound criterion for selection of beef bulls at test stations. The low heritability (0.17) for gain estimated from the total dataset is rather discouraging in this regard.

Though exact evidence cannot be provided from this study, changes in the pattern of genetic parameters over different time intervals of the test does suggest some possible explainations for the low heritability. Heritability for the cumulative gains increased gradually reaching a peak at the 112 day test interval. Correlations between weights and the corresponding gains showed that though environmental correlations were fairly constant from one period to another, the genetic correlation was maximum for the 112 day weight and 112 day gain. Heritability estimates for weights and gains were consistently higher at the 112 day interval than at end of test. The above results indicate that the high genetic variability at the 112 day point cannot be considered as a statistical accident. Perhaps growth to the 112 day point on test, which corresponds to growth to a year of age is the period of maximum genetic variability and testing beyond this point only increases environmental variation among bulls or reduces genetic variability. In addition terminating the test at a year of age may be a sound selection procedure in terms of reducing cost of evaluating animals at test stations.

In conclusion the considerable differences of bull weights due to herd of origin effects is significant and persists throughout the testing period. The 140 day test gain is reasonably free of herd of origin effects but has a considerably lower heritability estimate.

LITERATURE CITED

ANDERSEN,B.B,FREDEEN,H.T.and WEISS,G.M.1974.Correlated response in birth weight, growth rate and carcass merit under single-trait selection for yearling weighht in beef Shorthorn cattle. Can.J.Anim.Sci.54:117-125.

ANONYMOUS.1984.Canadian Beef Cattle Test Station Policy. Agriculture Canada Record of Performance for beef Cattle.

ATCHLEY,W.R.1984.Ontogeny,timing of development,and genetic variance covariance structure. Am.Nat.123:519-540.

BAILEY,C.M.and GILBERT,F.H.1962.Factors affecting performance traits of Hereford calves in lines developed in two environments. J.Anim.Sci.21:661(Abstr.)

BAKER,R.L.,CARTER,A.H.and BEATSON,P.R.1975.Progeny testing Angus and Hereford bulls for growth performance. Proc.N.Z.Soc.Anim.Prod. 35:103-111.

BAKER,F.H.1967. History and development of beef and dairy performance programmes in the United States. J.Anim.Sci.26:1261-1263.

BATRA,T.R.and WILTON,J.W.1972.Effect of age and weight on gains of beef bulls. J.Anim.Sci.35:171(Abstr.)

BEEF IMPROVEMENT FEDERATION.1970.U.S.D.A.Extension Publication, 394-379/ES-62.

BERESKIN,B.and FREEMAN,A.E.1965.Genetic and environmental factors in dairy sire evaluation.Effects of herds,months and years and seasons on variance among lactation records repeatability and heritability. J.Dairy Sci.48:347-351.

BERTALANFFY,L.von.1960.Principles and theory of growth. Pages 137-259 in W.Nowinski ed.Fundamental aspects of normal malignant growth. Elsevier,Amsterdam.

BLACKWELL,R.L.,KNOX,J.H.,SHELBY,C.E.and CLARK,R.T.1962. Genetic analysis of economic characteristics of young Hereford cattle. J.Anim.Sci.21:101-107.

BOHMAN,V.R.1955.Compensatory growth of beef cattle-The effect of hay maturity. J.Anim.Sci.14:249.

BRINKS,J.S.,CLARK,R.T.,KIEFFER,N.M.and QUESENBERRY,J.R.1962. Genetic and environmental factors affecting performance traits of Hereford bulls. J.Anim.Sci.21:777-780.

BROWN,C.J.and GACULA,M.1964.Estimates of heritability of beef cattle performance traits by regression of offspring on sire.

J.Anim.Sci.23:321.

BROWN,C.J.and GIFFORD,W.(1962).Estimates of heritability and genetic correlations among certain traits of performance tested bulls. Ark.Agric.Exp.Sta.Bull.658.

BROWN,C.J.and GALVEZ,N.M.1969.Maternal and other effects on birth weight of beef calves. J.Anim.Sci.28:162-167.

BROWN,C.J.and KEATON,L.1974.An analysis of Arkansas Cooperative beef bull tests,1962-1972.University of Arkansas Agricultural Experimental Station Bulletin 794:20pp.

BROWN,C.J,BROWN,J.E.and BUTTS,W.T.1974.Evaluating relationships among immature measures of size, shape and performance of bulls.1V.Regression models for predicting postweaning performance of young Hereford and Angus bulls using preweaning measures of sizes and shape. J.Anim.Sci.38:12-19.

BUSCH,D.A.and DINKEL,C.A.1967.Heritability estimates for certain beef traits. J.Anim.Sci.26:1465(Abstr.).

CAIN,M.F.and WILSON,L.L.1983.Factors influencing individual bull performance in central test stations. J.Anim.Sci.57:1059-1066.

CARTER,A.H.1971.Effectiveness of growth performance selection in cattle. Proc.N.Z.Soc.Anim.Prod.31:151-163.

CARTER,A.H.1973.Effectiveness of growth performance selection in pasture-fed cattle. Proc.of the III Wld.Conf.Anim.Prod.15(e) -28/29.

CARTER,R.C.and KINCAID,C.M.1959.Estimates of genetic and phenotypic parameters in beef cattle. II.Heritability estimates from parent-offspring and half-sib resemblances. J.Anim.Sci.18:323-330.

CARTER,R.C.and KINCAID,C.H.1959.Estimates of genetic and phenotypic parameters in beef cattle. III.Genetic and phenotypic correlations among economic characters. J.Anim.Sci.18:331-335.

CARTWRIGHT,T.C.,FITZHUGH,H.A.and FARRIS,J.W.1974.Factors affecting weaning weights of Santa Gertrudis calves. Beef cattle research in Texas,1974. Anim.Breed.Abstr.44(5),219.No.2016

CHRISTIAN,L.L.,HAUSER,E.R.and CHAPMAN,A.B.1965.Association of preweaning and postweaning traits with weaning weights in cattle. J.Anim.Sci.24:652-659.

CLARK,R.T.,SHELBY,C.E.,QUESENBERRY,J.R.,WOODWARD,R.R.and WILSON, F.S.1958.Production factors in range cattle under northern great plains conditions.U.S.D.A.Tech.Bul.1181.

CROW,G.H.,STRICKLIN,W.R.and NICHOLSON,H.H.1978.The influence of age of bulls on gain during the ROP test.Saskatchewan Ext.Div. Anim.Sci.Res.No.396A.

CUNDIFF,L.V.,GREGORY,K.E.and LONG,C.R.1975.Genetic variation among and within herds of Angus and Hereford cattle. J.Anim.Sci.41:1270-1280.

CUNNINGHAM,G.P.and HENDERSON,C.R.1965.Estimation of genetic and phenotypic parameters of weaning traits in beef cattle. J.Anim.Sci.24:182-187.

DALTON,D.C.1972.In Veterinary Services council course,Ruakura, New Zealand.pp. 25-31.

DALTON,D.C.1976.An analysis of Angus Central Bull Performance Tests in New Zealand. Proc. N.Z.Soc.Anim.Prod.36:210-215.

DALTON,D.C.and MORRIS,C.A.1978.A review of central performance testing of beef bulls and of recent research in New Zealand. Livest.Prod.Sci.5:147-157.

DEARBORN,D and DINKEL,C.A.(1959).Evaluation of final weight in the selection of performance tested bulls. J.Anim.Sci.18:1464(Abstr.).

DINKEL,C.A.1958.Effects of length of feeding period on heritability of postweaning gain of beef cattle. J.Anim.Sci.17:1141.(Abstr.).

DuBOSE,L.E.and CARTWRIGHT,T.C.1967.Relationships among production and carcass traits in cattle. J.Anim.Sci.26:203(Abstr.).

DINKEL,C.A.and BUSCH,D.A.1973.Genetic parameters among production carcass composition and carcass quality traits of beef cattle. J.Anim.Sci.36:832-846.

EDWARDS,J.,JOBST,D.,LEYBURN,M.,O'CONNER,L.K.,MACDONALD,A.,SMITH, G.F.and WOOD,P.1966.The Charolais report.Milk Marketing Board, Thames Ditton,47pp.

EVERITT,G.C.,PHILLIPS,D.S.M.and WHITEMEN,D.P.1968.Suckling effects on the calf and the cow.In Proc.Ruakura Fmrs'Conf. Week,New Zealand.

EVERITT,G.C.,EVANS,S.T.and FRANKS,M.1969.Genetic and environmental effects on beef production. Proc.N.Z.Anim.Prod.29:147-163.

FALCONER,D.S.1982.Introduction to Quantitative Genetics. Longman,London.365pp.

FISHER,R.A.1948.Statistical methods for research workers. 10th ed.Oliver and Boyd.Edinburgh.

FITZHUGH,H.A.,CARTWRIGHT,T.C.,KRAUSE,W.E.and TAYLOR,C.S.1967. Postweaning gains of cattle fed similar accounts. J.Anim.Sci.26:203(Abstr.).

FRANCOISE,J.J.,VOGHT,D.W.and NOLAN,J.C.1973.Heritabilities and genetic and phenotypic correlations among some economically important traits of beef cattle. J.Anim.Sci.33:635-639.

GACULA.M. and BROWN,C.J.1963.Heritability of feedlot performance of beef bulls. J.Anim.Sci.22:238(Abstr.).

GREGORY,K.E.1965.Symposium on performance testing in beef cattle: Evaluating postweaning performance in beef cattle. J.Anim.Sci.24:248-254.

GREGORY,K.E.,BLUM,C.T.and BAKER,M.L.1950.A study of some of the factors influencing the birth and weaning weights of beef calves. J.Anim.Sci.9:338.

GRIZZLE,J.E.and KINCAID,C.M.1954.The relationship between body weight,daily gain and effeciency of feed utilization in beef cattle.J.Anim.Sci.13:958(Abstr.).

HAMMES,R.O.,BLASER,R.E.,KINCAID,C.M.,BRYANT,H.T.and ENGEL,R.W.1959.Effects of full and restricted winter rations on dams and summer suckling calves fed different rations. J.Anim.Sci.18:21-31.

HEINEMAN,W.W.and KEUREN van R.W.1956.The effect of wintering plane of nutrition on subsequent gains of beef yearling steers on irrigated pasture. J.Anim.Sci.15:1097-1102.

HORTON,G.M.J.and HOLMES,W.1978.Compensatory growth by beef cattle at grassland or on an alfalfa based diet. J.Anim.Sci.46:297-303.

JENSEN,J.and ANDERSEN,B.B.1984.Performance testing of future A.I. bulls for growth rate, feed efficiency and muscularity. Genetic parameters, adjustment for systematic environmental factors, selection indices. Lives.Prod.Sci.11:475-490.

JOANDET,G.E.and CARTWRIGHT,T.C.1969.Estimation of efficiency of beef production.J.Anim.Sci.29:862-868.

KALM,E.,PABST,W.and LANGHOLZ,H.Z.1974.Estimation of Breeding values of beef bulls-Hereford and Charolais-based on data from the field recording scheme in Sweden. Lives.Prod.Sci.5:393-403.

KENNEDY,B.W.and HENDERSON,C.R.1975.Components of variance of growth traits among Hereford and Aberdeen Angus calves. Can.J.Anim.Sci.55:493-502.

KINCAID,C.M.and CARTER,R.C.1958.Estimates of genetic and phenotypic parameters in beef cattle. I.Heritability of growth rate in response to sire selection. J.Anim.Sci.17:675-683.

KNAPP,B.and BLACK,W.H.1941.Factors influencing rate of gain of beef calves during suckling period.J.Agr.Res.63:249.

KNAPP,B.and CLARK,R.T.1947.Genetic and environmental correlations between growth rates of beef cattle at different ages. J.Anim.Sci.6:174.

KNAPP,B.,and CLARK,R.T.1950.Revised estimates of heritability of economic characteristics of beef cattle. J.Anim.Sci.9:582

KNAPP,B.and CLARK,R.T.1951.Genetic and environmental correlations between weaning scores and subsequent gains in the feedlot with record of performance steers. J.Anim.Sci.10:365-370

KNAPP,B.and NORDSKOG,A.W.1946.Heritability of growth and efficiency in beef cattle.J.Anim.Sci.5:62-70.

KNOX,J.H.1957.The interrelations of type,performance and carcass characteristics. J.Anim.Sci.16:240-248.

KOCH,R.M.and CLARK,R.T.1955.Genetic and environmental relationships among economic characters in beef cattle. I.Correlations among paternal and maternal half-sibs. J.Anim.Sci.14:755.

KOCH,R.M.,CUNDIFF,L.V. and GREGORY,K.E.1982.Influence of postweaning gain interval on estimates of heritability and genetic correlations.J.Anim.Sci.55:1310-1318.

KOCH,R.M.,SWIGER,L.A.,CHAMBERS,D.and GREGORY,K.E.1963. Efficiency of feed use in beef cattle. J.Anim.Sci.22:486-494.

KRAUSSLICH,H.1974.General recommendations on procedures for performance and progeny testing for beef characteristics. Livest.Prod.Sci.1:33-45.

LAIRD,A.K.1966.Postnatal growth of birds and mammals. Growth 30:349-363.

LAIRD,A.K.,TYLER,S.A.and BARTON,A.D.1965.Dynamics of normal growth.Growth 29:233-248.

LEVINE,L.1969.Biology of the Gene.The C.W. Mosby Co.,St.Louis.

LEWIS,W.H.E.and ALLEN,D.M.1974.Performance testing for beef characteristics.Proc.First Wld.Conf.Genet.App.Livest.Prod., Madrid.1671-679.

LICKLEY,C.H.,STONAKER,H.H.,SUTHERLAND,T.M.and RIDDLE,K.H.1960. Relationship between mature size,daily gain and efficiency of feed utilization in beef cattle. Proc.West.Sec.Amer.Soc.Anim. Prod.11:9.

LUSH,J.L.1936.Genetic aspects of the Danish system of progeny testing swine. Iowa Agr.Expt.Sta.Res.Bull.204.pp.109-195.

LUSH,J.L.and Straus,F.S.1942.The heritability of butterfat production in dairy cattle. J.Dairy Sci.25:975

MAO,I.L.,HENDERSON,C.R.and MILLER.P.D.1972.Intrasire regression of daughter on herdmate performance.Nature of estimators and trends of estimates. J.Dairy Sci.55:845-850.

MARLOWE,T.J.and GAINS,J.A.1958.The influence of age and season of birth of calve and age of dam on preweaning growth rate and type score of beef calves. J.Anim.Sci.17:706-713.

MARLOWE,T.J.,MAST,C.C.and SCHALLES,R.R.1965.Some non-genetic influences on calf performance.J.Anim.Sci.24:494-501.

MAVROGENIS,A.P.,DILLARD,E.U.and ROBISON,O.W.1978.Genetic analysis of postweaning performance of Hereford bulls. J.Anim.Sci.47:1004-1013.

MEYER,J.H.,HULL,J.L.,WEITKOMP,W.K.and BONILLA,S.1965. Compensatory growth responses of fattening steers following various low energy intake regimes on hay or irrigated pasture. J.Anim.Sci.24:29-37.

MONTEIRO,L.S.and FALCONER,D.S.1966.Compensatory growth and sexual maturity in mice. Anim.Prod.8:179-192.

MOORE,D.B.,STONAKER,H.H.and RIDDLE,K.1961.Factors influencing comparisons of Hereford bulls for rate of gain. J.Anim.Sci.20:255-259.

MORAN,J.B.and HOLMES,W.1978.The application of compensatory growth in grain/cereal beef production systems in the United Kingdom. Wld.Rev.Anim.Prod.14(2):65-73.

MORRIS,C.A.1981.Herd effects on the growth of beef bulls from different sources tested together under grazing conditions. N.Z.Journal of Agri.Res.24:11-20.

MORRIS,C.A.and WILTON,J.W.1976.Influence of body size on the biological efficiency of cows:A review. Can.J.Anim.Sci.56:613-647.

NELSEN,T.C.and KRESS,D.D.1979.Estimates of heritabilities and correlations for production characters of Angus and Hereford calves. J.Anim.Sci.48:286-292.

NEVILLE,W.E.1962.Influence of dam's milk production and other factors on 120 and 240 day weight of Hereford calves. J.Anim.Sci.21:315-319.

OKANTAH,S.A.,CURRAN,M.K.and PANNISH,P.A.1978.Environmental effects and estimates of genetic parameters in central performance tested beef bulls of different breeds. Anim. Prod.26:376(Abstr.).

OKANTAH,S.A.and CURRAN,M.K.1982.A review of the effects of the environment in the central performance testing of beef cattle. Wld.Revw.Anim.Prod.18:39-48.

PABST,W.,KILKENNY,J.B.and LANGHOLZ,H.J.1977.Genetic and environmental factors influencing calf performance in pedigree beef cattle in Britain.I.The influence of environmental effects on birth,200 day and 400 day weights. Anim.Prod.24:29-39.

PATTERSON,R.E.,CARTWRIGHT,T.C.,JONES,J.H.and BAYLES,J.J.1955. Performance testing of beef breeding stock. J.Anim.Sci.14:1034-1041.

PATTERSON,R.E.,JONES,J.H.,BAYLES,J.J.and TURNBOUGH,R.V.1949. Performance-testing and progeny testing of beef breeding stock as an aid to selection.J.Anim.Sci.8:608.

PIRCHNER,F.1983.Population Genetics in Animal Breeding(2nd.Ed.) Plenum Press.New York.

PIRCHNER,F.and LUSH,J.L.1959.Genetic and environmental portions of variation among herds in butterfat production. J.Dairy Sci.42:115-122.

PRESTON,T.R.and UGARTE,J.1972.Rearing dairy calves by restricted suckling.World Anim.Revw.3:28-30.

PRESTON,T.R.and WILLIS,1974.Intensive Beef Production. Pergamon Press.Oxford.567pp.

ROBERTSON,A.and RENDEL,J.M.1954.The performance of heifers got by artificial insemination.J.Agr.Sci.Camb.44:184-192.

ROBERTSON,A,and McARTHUR,A.T.G.1955.Genetic differences between bull-breeding herds.Proc.Brit.Soc.Anim.Prod.94-101.

ROLLINS,W.C.,CARROLL,F.D.,POLLACK,J.W.T.and KUDODA,M.N.1962. Beef cattle performance and progeny test gains, efficiency carcass conformation and earliness of maturity. J.Anim.Sci.21:200-206.

RUBY,E.S.,BLUNN,C.T.,BROUSE,E.M.and BAKER,M.L.1948.Relation of initial weights and subsequent gains of weanling calves. J.Anim.Sci.17:279-282.

RUTLEDGE,J.J.,ROBINSON,J.J.,EISEN,E.J.and LEGATES,J.E.1972. Dynamics of genetic and maternal effects in mice. J.Anim.Sci.35:911-918.

SCHAEFFER,L.R.and WILTON,J.W.1974.Age of dam,sex and environmental interactions affecting preweaning average daily gain of beef cattle. Can.J.Anim.Sci.54:183-190.

SCHALLES,R.R.and MARLOWE,T.J.1967.Factors affecting test performance of beef bulls. J.Anim.Sci.26:21-26.

SEARLE,S.R.1978.A summary of recently developed methods of estimating variance components.Proceedings of the computer science and statistics eleventh annual symposium on the Interface.64-69,Raleigh,N.C.

SELLERS,H.I.,WILLHAM,R.L.and DeBACA,R.C.1970.Effects of certain factors on weaning weight of beef calves. J.Anim.Sci.31:5-11.

SHELBY,C.E.,CLARK,R.T.,QUESENBERRY,J.R.and WOODWARD,R.R.1960. Heritability of some economic characteristics in record of performance bulls. J.Anim.Sci.16:1019(Abstr.).

SHELBY,C.E.,CLARK,R.T.and WOODWARD,R.R.1955.The heritability of some economic characteristics of beef cattle. J.Anim.Sci.14:372.

SHELBY,C.E.,HARVEY,W.R.,CLARK,R.T.,QUESENBERRY,J.R.and WOODWARD,R.R.1963.Estimates of phenotypic and genetic parameters in ten years of Miles City ROP steer data. J.Anim.Sci.22:346.

SINGH,A.R.,SCHALLES,R.R.,SMITH,W.H.and KESSLER,F.B.1970.Cow weight and preweaning performance of calves. J.Anim.Sci.31:27-30.

SMITH,G.M.and FITZHUGH,H.A.1968.Homogeneity of relationships between dam and progeny weights. J.Anim.Sci.27:1129(Abstr.).

STEANE,D.E.,LEWIS,W.H.E.and JONES,D.W.1978.Estimation of phenotypic parameters in central performance tested beef bulls. Anim.Prod.26:375(Abstr.).

STONAKER,H.H.,HAZALEUS,M.H.and WHEELER,S.S.1952a.Feedlot and carcass characteristics of individually fed comprest and conventional type of Hereford steers. J.Anim.Sci.11:17-25.

STONAKER,H.H.,HAZALEUS,M.H.and WHEELER,S.S.1952b.Winter hay consumption of breeding females of large,intermediate and compress of Hereford cattle. J.Anim.Sci.11:26-33.

STUEDEMANN,J.A.,GUENTHER,J.J.,EWING,S.A.,MORRISON,R.D.and ODELL,G.V.1968.Effects of nutritional level imposed from birth to eight months of age on subsequent growth and development patterns of full fed beef calves. J.Anim.Sci.27:234-241.

SUNDGREN,P.E.1973.Studies on pig performance testing.Dept. of Animal Breeding.Agr.College of Sweden,Uppsala.
Report No.2 pp.65-70.

SWIGER,L.A.,GREGORY,K.E.,SUMPTION,L.V.,BREIDENSTEIN,B.C.and ARTHAUD,V.A.1965.Selection indexes for effeciency of beef production. J.Anim.Sci.24:418-424.

SWIGER,L.A.,GREGORY,K.E.,KOCH,R.M.,ROWDEN,W.W.,and INGALLS,J.E.1963.Evaluating postweaning gain of beef calves. J.Anim.Sci.22:524-520.

SWIGER,L.A.1962.Genetic and environmental influences on gain of beef cattle during various periods of life. J.Anim.20:183-188.

SWIGER,L.A.and HAZEL,L.N.1961.Optimum length of feeding period in selecting for gain of beef cattle. J.Anim.Sci.20:189-194.

TANNER,J.M.1963.Regulation of growth in size in mammals. Nature 199:845-850.

TAYLOR,St.C.S.1968.Time taken to mature in relation to mature weight for sexes,strains and species of domesticated mammals and birds. Anim.Prod.10:157.

TAYLOR,R.E.1971.Genetic implications in economy of feedlot gain. J.Anim.Sci.35:144-147.

TERRILL,C.E.and HAZEL,L.L.1943.Heritability of yearling fleece and traits of range rambouillet ewes. J.Anim.Sci.2:358-359(Abstr.).

TONG,A.K.W.1982.Effects of initial age and weight on test daily gains of station tested bulls. Can.J.Anim.Sci.62:671-678.

URICK,J.,FLOWER,A.E.,WILLSON,F.S.and SHELBY.C.E.1971. A genetic study in steer progeny groups during successive growth periods. J.Anim.Sci.16:217-223.

WAGNER,R.P.and MITCHELL,H.K.1964.Genetics and metabolism. 2nd.ed. John Wiley.New York.

WARWICK,B.L.and CARTWRIGHT,T.C.1955.Heritability of rate of gain in young growing beef cattle. J.Anim.Sci.14:363-371.

WIENER,G.1960.Factors influencing average milk yields of herd at two levels of production. Anim.Prod.2:117-130.

WILLEY,N.B.,BUTLER,O.D.,RIGGS,J.K.,JONES,J.H.and LYERLY,P.J. 1951.The influence of type on feedlot performance and killing qualities of Hereford steers. J.Anim.Sci.10:195.

WILSON,L.L.,DINKEL,C.A.,RAY,D.E.and MINYARD,J.A.1963.Beef cattle selection indexes involving conformation and weight. J.Anim.Sci.22:1086-1090.

WILSON,P.M.and OSBORNE,P.F.1960.Compensatory growth after under-nutrition in mammals and birds. Biol.Revw.35:324-363.

WILSON,L.L.,RISHEL,W.H.and HARVEY,W.R.1972.Influence of herd,sire and herdxsire interactions on live and carcass characters of beef cattle. J.Anim.Sci.35:502-506.

WILTON,J.W.,BURGESS,T.D.and BATRA,T.R.1973.Ultrasonic measurements of beef bulls in performance testing programs. Can.J.Anim.Sci.53:629-636.

WINCHESTER,C.F.and HOWE,P.E.1955.Relative effects of continuous and interrupted growth on beef steers.U.S.D.A.Tech.Bull.1108.

WOESE,C.R.1967.The genetic code:The molecular basis for genetic expression.Harper and Row.New York.

Appendix Table 1. Complete description of data structure

FREQ	BREED	BULLS SIRE	BULLS HERD	SIRE HERD	BULLS SIRE	BULLS HERD	SIRE HERD	BULLS SIRE	BULLS HERD	SIRE HERD	BULLS SIRE	BULLS HERD	SIRE HERD	BULLS SIRE	BULLS HERD	SIRE HERD	BULLS SIRE	BULLS HERD	SIRE HERD	BULLS SIRE	BULLS HERD	SIRE HERD	BULLS SIRE	BULLS HERD	SIRE HERD	BULLS SIRE	BULLS HERD	SIRE HERD	TOTAL BULLS SIRE	TOTAL BULLS HERD	TOTAL SIRE HERD
YEAR			76			77			78			79			80			81			82			83			84				
1				3			1	8	1		16	4	6	22	3	5	13	1	3	9	1	4	10	1	4	5	3	5	74	14	31
2		3		2	2			4		1	3	1	2	3	2	3	3	4	6	5	3	3	6	2	4	6	1	1	35	13	22
3		3	3		2	1	1	1		1	4	3	2	4	3	3		1	2		1	1	2	3	2				16	15	12
4		1	1							2	1	1	1	2	2	3	2					1	1	2	1		1		7	5	8
5									1				1	1			1	1			1		2					1	4	3	2
6			1						2			1			1		2	1		2	1					1	1		5	8	
7	AN					1					1				2			3					1	1					2	7	
8																				1							1		1	1	
9															1						2									3	
10												2												2						4	
11																															
12																															
1		10	4	13	25	3	8	22	3	9	28	11	18	33	5	17	43	3	25	35	5	19	37	5	20	30	4	29	263	43	158
2		8	4	4	4	4	5	7	2	9	10	2	5	18	7	7	20	16	14	9	4	6	17	8	12	30	15	11	123	62	73
3		3	4	3	3	3	4	3	3	2	4	2	2	6	5	4	7	12	3	11	8	8	8	9	4	14	12	10	59	58	40
4		5	1		3	1	1	4	3	1	2	2	1	4	2	3	2	6	3	4	3	1	5	4	4	3	5	1	32	27	15
5		4	2		4	5	1	7	7		6	1	2	2	3	1	1		1	4	2	2	6	6	1	3	4		37	30	8
6			1						1	1	4	4	1	2	3		3	2		1	3			2			3		10	19	2
7	CH		1			2						1			2	1	3	7		2	6		2	2		3	5		10	26	1
8			3						1			1		2	4					2	4					1	1		5	14	
9									1			1								1			2			1			4	2	
10									1			4			2									4						11	
11						1																					1			2	
12																					1									1	
13																								1						1	
15																											1			1	

Appendix Table 1. Continued

FREQ	BREED	BULLS SIRE	BULLS HERD	SIRES HERD																									TOTAL BULLS SIRE	TOTAL BULLS HERD	TOTAL SIRES HERD
YEAR					77			78			79			80			81			82			83			84					
1		12	2	16	30	2	19	25	3	16	31	6	18	46	3	22	51	3	23	58	2	14	58	6	18	47	6	13	358	33	159
2		8	3	6	13	7	8	12	5	7	23	7	9	25	12	10	22	21	14	29	10	20	24	8	13	13	10	17	169	83	104
3		14	10	3	13	8	6	11	6	6	9	10	6	12	10	8	7	9	7	13	18	11	11	10	14	5	5	4	95	76	65
4		3	3	1	4	4	1	7	7	2	2	4	3	7	6	3	2	7	1	2	8	5	6	10	1	7	5	3	40	54	20
5		4	4		8	4	1	7	3		5	3	1	4	5	2	4	2	2	4	4		4	5	3	3	4		43	34	9
6						4	1				1	1		2	1			1		1	2			2			2	1	4	13	2
7	HH					6		1		1		1			2			4			2			1			1		1	17	1
8			4						1						2	1					1		1	3		1	1		2	12	1
9						1			2			1									3					1	2		1	9	
10									4			4			5								1	3			1		1	17	
11																								1						1	
12									1																					1	
1		13	3	10	11	3	4	15	1	4	10	2	12	25	3	9	48	9	28	34	9	22	42	5	18	45	9	21	243	44	128
2		5	4	3	5	1	2	5	2	4	8	6	4	12	7	11	17	17	10	14	11	8	18	20	16	16	10	13	100	78	71
3		4	4	1	2		2	3	1	2	3	5		1	6	3	7	7	7	5	10	4	3	7	3	9	9	6	37	49	28
4		1	2					1	2	1			1	1	2	1	3	8	1	1	3		2	4	2	6	7	3	15	28	9
5		1	1	1	2	2		3	3	1				2	1		1	1	1	1	1	1	2	1			4		12	13	4
6						1	1		2		2	3		2	3			2									1		4	11	1
7	SM					1									1		2	3											2	5	
8			1								1	1		1							1			1		1	2		3	6	
9						1																					1			2	
10									1															1						2	
11																															
12																															
13															1															1	

Appendix Table 2. Variance components of the total dataset

TRAIT	HERD	SIRE	ERROR
SOTWT	357.58	237.27	765.16
W56	394.67	280.85	1116.87
W84	394.95	275.17	1298.03
W112	402.36	332.34	1410.00
W140	427.74	309.24	1674.72
CG0	38.40	- 6.96	326.90
CG1	50.00	14.11	439.29
CG2	72.74	83.90	540.93
CG3	89.52	40.26	832.42
PG0	55.19	18.98	190.00
PG1	38.40	- 6.96	326.90
PG2	4.69	9.77	100.46
PG3	10.22	63.84	75.30
PG4	14.49	58.62	197.13
SC	69.36	104.95	1119.74
BF	0.43	.05	4.62

Appendix Table 3. Covariance components of the total dataset

TRAIT COMBINATIONS	HERD	SIRE	ERROR
W140-SOT	293.17	234.66	659.93
W140-W56	426.99	286.00	1181.97
W140-W84	389.71	300.28	1310.36
W140-W112	413.02	286.42	1437.97
W140-CG0	36.92	38.83	380.27
W140-CG1	41.39	48.10	514.55
W140-CG2	58.08	42.19	639.84
W140-CG3	79.78	59.46	874.42
SOT-CG3	- 9.68	15.86	38.57
SOT-CG2	-13.98	5.54	51.96
SOT-CG1	- 6.32	11.90	46.79
SOT-CG0	- 0.66	25.27	12.41
W140-BF	5.01	4.94	8.88
W140-SC	85.70	100.26	257.68
CG3-BF	1.17	- 0.25	8.88
CG3-SC	23.24	38.95	70.83

Appendix Table 4. Components used in the calculation of environmental correlations of total dataset

Trait Combinations	rP	rG	h1h2	f1f2	rf	e1e2
W140-SOT	0.769	0.899	0.598	0.216	0.898	0.624
W140-W56	0.911	0.962	0.567	0.197	1.039	0.657
W140-W84	0.918	1.029	0.535	0.189	0.948	0.650
W140-W112	0.940	0.893	0.563	0.166	0.996	0.676
W140-CG0	0.490	-	0.200	0.138	0.288	0.796
W140-CG1	0.548	0.730	0.240	0.133	0.283	0.778
W140-CG2	0.571	0.262	0.497	0.136	0.329	0.734
W140-CG3	0.665	0.533	0.293	0.128	0.408	0.775
SOT-CG0	0.0530	-	0.233	0.168	-0.0055897	0.716
SOT-CG1	0.0633	0.096	0.280	0.162	-0.04722	0.701
SOT-CG2	0.0468	0.0392	0.579	0.165	-0.08668	0.661
SOT-CG3	0.0561	0.162	0.342	0.156	-0.0541	0.698
W140-BF	0.170	1.25	0.143	0.122	0.369	0.793
W140-SC	0.251	0.557	0.407	0.0978	0.498	0.775
CG3-BF	0.140	-0.175	0.0817	0.845	0.186	0.885
CG3-SC	0.120	0.599	0.233	0.071	0.295	0.865

Appendix Table 5. Variance components of the Hereford dataset

TRAIT	HERD	SIRE	ERROR
SOTWT	340.59	152.28	481.60
W56	395.03	174.82	662.69
W84	422.16	175.81	766.69
W112	431.95	325.60	741.23
W140	465.06	219.65	909.81
CG0	22.23	5.65	187.27
CG1	25.03	27.69	263.56
CG2	53.43	193.40	241.17
CG3	67.98	73.03	9.30
SC	37.62	47.81	738.06
BF	0.57	0.09	4.01

Appendix Table 6. Covariance components of the Hereford dataset

TRAIT COMBINATIONS	HERD	SIRE	ERROR
W140-SOT	362.59	157.98	475.83
W140-W56	420.20	173.56	652.21
W140-W84	438.50	183.28	735.83
W140-W112	448.85	187.39	828.41
W140-CG0	69.63	22.94	172.27
W140-CG1	75.28	31.67	256.93
W140-CG2	79.96	36.69	342.45
W140-CG3	99.35	65.94	426.37
W112-CG0	46.34	17.42	168.21
W112-CG1	68.17	33.32	236.43
W112-CG2	73.71	181.71	256.75
W112-CG3	89.24	43.95	342.68
W84-CG0	40.23	17.34	168.54
W84-CG1	54.69	21.63	277.46
W84-CG2	58.87	25.36	234.90
W84-CG3	75.25	30.92	255.62
W56-CG0	40.83	10.25	186.90
W56-CG1	52.40	6.81	182.40
W56-CG2	49.09	- 1.07	180.53
W56-CG3	65.21	11.67	184.81
SOT-CG0	16.21	8.45	- 3.09
SOT-CG1	14.07	- 2.08	10.77
SOT-CG2	18.99	-10.04	9.23
SOT-CG3	28.25	- 2.83	9.46
W140-BF	5.38	3.24	17.11
W140-SC	71.59	70.16	189.96
CG3-BF	3.07	19.25	91.67
CG3-SC	2.13	- 1.13	8.99

Appendix Table 7. Components used in the calculation of environmental correlations of the Hereford dataset

Trait Combinations	rP	rG	h1h2	f1f2	rf	e1e2
W140-SOT	0.799	0.864	0.587	0.320	0.911	0.531
W140-W56	0.889	0.887	0.523	0.286	0.980	0.554
W140-W84	0.920	0.933	0.533	0.300	0.990	0.567
W140-W112	0.947	0.701	0.692	0.290	0.100	0.532
W140-CG0	0.452	0.651	0.240	0.173	0.685	0.705
W140-CG1	0.512	0.406	0.439	0.152	0.698	0.690
W140-CG2	0.520	0.178	0.934	0.178	0.507	0.531
W140-CG3	0.632	0.521	0.541	0.190	0.559	0.652
W112-CG0	0.409	0.406	0.302	0.173	0.473	0.657
W112-CG1	0.491	0.351	0.552	0.151	0.656	0.643
W112-CG2	0.599	0.724	1.173	0.177	0.485	0.495
W112-CG3	0.524	0.285	0.679	0.189	0.521	0.607
W84-CG0	0.417	0.550	0.233	0.178	0.415	0.700
W84-CG1	0.538	0.309	0.425	0.156	0.532	0.685
W84-CG2	0.391	0.138	0.904	0.183	0.392	0.527
W84-CG3	0.417	0.273	0.523	0.196	0.444	0.647
W56-CG0	0.462	0.326	0.228	0.170	0.436	0.684
W56-CG1	0.403	0.097	0.417	0.149	0.527	0.669
W56-CG2	0.295	- .006	0.888	0.175	0.338	0.515
W56-CG3	0.318	0.071	0.514	0.187	0.398	0.632
SOT-CG0	0.047	0.288	0.256	0.190	0.186	0.656
SOT-CG1	0.041	- .003	0.468	0.166	0.152	0.642
SOT-CG2	0.025	0.059	0.996	0.195	0.141	0.494
SOT-CG3	0.476	0.027	0.577	0.208	0.186	0.606
W140-BF	0.298	0.747	0.200	0.190	0.329	0.701
W140-SC	0.289	0.685	0.358	0.116	0.541	0.716
CG3-SC	0.202	0.454	0.197	0.124	0.341	0.799
CG3-SC	0.169	0.326	0.351	0.075	0.061	0.816

Appendix Table 8. Variance components of the restricted dataset

TRAIT	HERD	SIRE	ERROR
SOTWT	253.22	174.32	652.27
W56	281.60	225.24	1482.02
W84	281.23	245.74	1758.95
W112	255.20	500.11	1892.98
W140	291.35	327.01	2259.31
CG0	29.69	31.53	907.70
CG1	23.65	92.51	1104.39
CG2	39.51	351.11	1235.78
CG3	60.23	176.81	1586.45
SC	128.72	7.44	1526.69
BF	0.71	0.29	3.19

Appendix Table 9. Covariance components of the restricted dataset

TRAIT COMBINATIONS	HERD	SIRE	ERROR
W140-SOT	242.06	167.88	656.22
W140-W56	87.46	240.59	1716.33
W140-W84	285.76	284.98	1883.62
W140-W112	276.62	296.12	2052.92
W140-CG0	43.71	74.47	1062.25
W140-CG1	43.83	114.24	1235.18
W140-CG2	24.06	144.82	1397.25
W140-CG3	49.24	161.94	1599.92
W112-CG0	29.14	77.39	979.37
W112-CG1	30.21	125.42	1129.99
W112-CG2	17.88	340.67	1240.84
W112-CG3	31.78	145.42	1405.08
W84-CG0	28.08	64.47	922.63
W84-CG1	26.54	82.66	1104.78
W84-CG2	9.26	123.31	1131.31
W84-CG3	30.60	112.71	1244.30
W56-CG0	30.80	39.80	891.28
W56-CG1	30.92	44.23	962.75
W56-CG2	26.03	55.04	1020.81
W56-CG3	33.32	52.71	1111.52
SOT-CG0	- 0.61	9.70	-38.98
SOT-CG1	2.18	-10.55	1.15
SOT-CG2	-18.77	-12.66	2.47
SOT-CG3	-11.05	-12.06	10.30
W140-BF	6.83	5.08	18.87
W140-SC	161.03	-22.88	1120.41
CG3-BF	6.17	- 0.55	16.31
CG3-SC	67.44	1.01	1036.14

Appendix Table 10. Components used in the calculation of environmental correlations of the restricted dataset

Trait Combinations	rP	rG	h1h2	f1f2	rf	e1e2
W140-SOT	0.605	0.703	0.543	0.154	0.891	0.688
W140-W56	0.938	0.886	0.454	0.120	1.004	0.745
W140-W84	0.957	1.005	0.443	0.117	0.998	0.777
W140-W112	0.951	0.732	0.587	0.099	1.014	0.750
W140-CG0	0.707	0.733	0.244	0.0560	0.471	0.858
W140-CG1	0.743	0.657	0.371	0.0439	0.528	0.848
W140-CG2	0.724	0.427	0.628	0.0500	0.224	0.773
W140-CG3	0.791	0.673	0.421	0.0579	0.372	0.827
W112-CG0	0.668	0.616	0.314	0.055	0.335	0.819
W112-CG1	0.715	0.583	0.478	0.043	0.389	0.810
W112-CG2	0.770	0.813	0.808	0.049	0.178	0.738
W112-CG3	0.720	0.489	0.542	0.056	0.256	0.789
W84-CG0	0.682	0.732	0.236	0.062	0.308	0.849
W84-CG1	0.728	0.548	0.361	0.048	0.325	0.839
W84-CG2	0.655	0.420	0.610	0.056	0.088	0.765
W84-CG3	0.680	0.541	0.409	0.064	0.235	0.818
W56-CG0	0.693	0.472	0.243	0.066	0.337	0.835
W56-CG1	0.666	0.306	0.370	0.052	0.379	0.826
W56-CG2	0.613	0.196	0.626	0.059	0.247	0.753
W56-CG3	0.629	0.264	0.420	0.069	0.256	0.805
SOT-CG0	-0.0292	0.131	0.290	0.085	-0.007	0.752
SOT-CG1	-0.00629	-0.0831	0.442	0.067	0.028	0.744
SOT-CG2	-0.02186	-0.0511	0.748	0.076	-0.188	0.678
SOT-CG3	-0.009132	-0.0687	0.502	0.088	-0.090	0.725
W140-BF	0.280	0.519	0.090	0.135	0.474	0.772
W140-SC	0.575	-0.464	0.375	0.131	0.832	0.849
CG3-BF	0.2509	-0.07666	0.330	0.075	0.941	0.751
CG3-SC	0.634	0.0278	0.052	0.051	0.766	0.894

Appendix Table 11. An example of rank order of bulls based on weights

OBS	YEAR	BULL	TT	BREED	RDELWT	RSOTWT	RW56	RW84	RW112	RW140
1	79	9	LHL12K	HH	61	.	.	.	.	.
2	79	10	KJY28K	HH	65	40	43	71	70	70
3	79	11	TSD2K	HH	76	118	120	122	125	128
4	79	12	TSD10K	HH	101	116	113	107	103	103
5	79	13	TSD24K	HH	97	102	113	103	99	95
6	79	14	ALA1K	HH	7	4	5	9	10	14
7	79	15	ACHH3K	HH	37	33	65	90	93	109
8	79	16	ACHH26K	HH	93	89	108	116	116	104
9	79	17	ACHH18K	HH	66	35	59	52	55	70
10	79	18	VDK8K	HH	81	68	42	38	18	30
11	79	19	VDK6K	HH	133	125	117	113	108	114
12	79	20	UUD1K	HH	104	81	94	80	70	63
13	79	21	AATS57K	HH	48	35	14	20	12	13
14	79	22	AATS71K	HH	140	132	123	118	114	111
15	79	23	AATS72K	HH	96	112	98	82	63	77
16	79	24	AATS51K	HH	9	37	31	11	16	18
17	79	25	AATS61K	HH	72	111	81	74	55	60
18	79	26	MPO6K	HH	36	79	88	88	80	105
19	79	27	MPO6K	HH	79	106	110	112	110	120
20	79	28	MPO6K	HH	3	9	9	16	22	28
21	79	29	OFP45K	HH	119	73	69	56	53	37
22	79	30	OFP16K	HH	111	84	86	77	91	70
23	79	31	OFP33K	HH	91	59	68	67	80	80
24	79	32	OFP30K	HH	91	73	74	80	83	74
25	79	33	AEOH01K	HH	41	92	72	59	59	86
26	79	34	10K	HH	41	42	25	28	22	23
27	79	35	AEOH021K	HH	115	126	122	105	96	94
28	79	36	NRD50K	HH	143	141	139	139	135	136
29	79	37	NRD24K	HH	131	125	116	117	114	118
30	79	38	NRD27K	HH	127	134	132	130	138	138
31	79	39	CJN16K	HH	124	125	134	136	139	139
32	79	40	CJN5K	HH	100	94	92	103	97	102
33	79	41	CJN10K	HH	93	103	115	119	121	122
34	79	42	XL3K	HH	41	62	45	76	72	90
35	79	43	XL11K	HH	70	62	75	92	95	100
36	79	44	WPHF8K	HH	74	97	57	65	45	65
37	79	45	CRR29K	HH	107	108	122	124	117	115
38	79	46	CRR17K	HH	104	86	80	63	67	64
39	79	47	SSHF36K	HH	57	97	106	116	112	108
40	79	48	PRH13K	HH	28	23	37	45	38	37
41	79	49	PRH15K	HH	31	8	26	36	43	48
42	79	50	ACRR14K	HH	16	5	16	19	20	17
43	79	51	ACRR12K	HH	70	50	74	70	71	83
44	79	52	XBA5K	HH	139	135	137	135	132	135
45	79	53	XBA14K	HH	86	62	51	86	92	99
46	79	54	XBA8K	HH	141	137	135	131	126	126
47	79	55	UU23K	HH	48	40	70	60	57	62
48	79	56	UU78K	HH	121	125	124	128	130	129
49	79	57	UU8K	HH	87	94	120	120	122	125
50	79	58	UU59K	HH	48	68	79	70	62	55
51	79	59	UU64K	HH	65	37	72	70	99	111
52	79	60	UU32K	HH	73	78	99	95	106	107
53	79	61	UU2K	HH	34	58	65	56	67	72
54	79	62	UU28K	HH	38	20	35	34	33	38
55	79	63	UU38K	HH	86	102	97	97	87	83
56	79	64	UU11K	HH	55	46	42	42	40	41

Appendix Table 11. Continued

OBS	YEAR	BULL	TT	BREED	RDELWT	RSOTWT	RW56	RW84	RW112	RW140
57	79	65	AGMZK16	HH	132	120	109	110	109	112
58	79	66	AGMZK22	HH	134	127	125	121	118	119
59	79	67	AGMZK7	HH	59	43	19	12	19	39
60	79	68	AGMZK10	HH	138	138	126	125	124	130
61	79	69	LAR22K	HH	68	49	52	50	41	76
62	79	70	LAR17K	HH	100	56	33	29	33	43
63	79	71	VSP17K	HH	91	56	50	47	44	35
64	79	72	VSP24K	HH	116	111	106	99	107	92
65	79	73	VSP40K	HH	131	92	94	111	111	96
66	79	74	VSP7K	HH	91	85	78	83	74	76
67	79	75	WCHF33K	HH	81	69	63	86	76	88
68	79	76	WCHF36K	HH	124	115	127	127	129	138
69	79	77	WCHF46K	HH	124	125	131	138	137	134
70	79	78	WCHF17K	HH	95	54	59	46	51	57
71	79	79	WCHF19K	HH	107	105	102	114	120	127
72	79	80	WCHF3K	HH	129	140	133	133	128	124
73	79	81	WCHF4K	HH	119	84	68	62	47	44
74	79	82	CLT58K	HH	5	3	2	3	1	5
75	79	83	CLT73K	HH	68	64	63	50	59	66
76	79	84	MYZ14K	HH	18	44	39	56	67	72
77	79	85	CLT56K	HH	43	87	77	59	90	93
78	79	86	MYZ10K	HH	31	49	40	38	67	54
79	79	87	CLT8K	HH	14	23	21	18	14	33
80	79	88	CLT40K	HH	17	27	23	22	28	23
81	79	89	CLT77K	HH	84	98	106	106	104	98
82	79	90	NHU10K	HH	42	66	55	35	24	20
83	79	91	MYZ11K	HH	8	15	25	14	8	4
84	79	92	HIR7K	HH	22	16	15	27	25	19
85	79	93	HIR21K	HH	23	17	38	42	35	34
86	79	94	HIR17K	HH	52	66	85	99	87	85
87	79	95	AHEF5K	HH	121	92	89	82	84	78
88	79	96	AHEF23K	HH	135	139	138	137	136	133
89	79	97	AHEF17K	HH	109	109	107	94	62	50
90	79	98	DTY9K	HH	76	114	85	96	85	87
91	79	99	DTY3K	HH	115	41	50	57	80	79
92	79	100	ICI17K	HH	48	118	.	.	.	.
93	79	101	ICI20K	HH	20	74	77	66	83	59
94	79	102	ICI15K	HH	58	105	85	78	46	46
95	79	103	BIV323K	HH	51	32	20	16	16	12
96	79	104	BIV506K	HH	100	100	63	61	53	51
97	79	105	BIV521K	HH	94	71	87	88	90	83
98	79	106	BIV331K	HH	53	63	54	48	49	42
99	79	107	BIV624K	HH	27	24	66	72	75	54
100	79	108	BIV259K	HH	50	19	32	32	39	29
101	79	109	BIV613K	HH	65	54	45	34	37	40
102	79	110	BIV561K	HH	44	31	35	30	42	45
103	79	111	BIV520K	HH	25	10	17	23	27	24
104	79	112	BIV511K	HH	11	11	3	2	5	10
105	79	113	BGU27K	HH	55	88	48	43	30	15
106	79	114	BGU34K	HH	16	26	11	4	6	3
107	79	115	BGU72K	HH	49	29	12	13	11	9
108	79	116	BGU93K	HH	35	49	7	6	2	1
109	79	117	BGU84K	HH	79	76	54	76	90	70
110	79	118	RFZ42K	HH	136	131	131	129	133	131
111	79	119	RFZ13K	HH	105	58	102	103	95	102
112	79	120	RFZ37K	HH	113	80	91	91	102	91

Appendix Table 11. Continued

OBS	YEAR	BULL	TT	BREED	RDELWT	RSOTWT	RW56	RW84	RW112	RW140
113	79	121	RFZ15K	HH	79	82	96	74	73	54
114	79	122	RFZ5K	HH	102	76	91	93	83	89
115	79	123	RFZ34K	HH	84	97	63	52	57	50
116	79	124	OZV12K	HH	84	99	100	104	100	97
117	79	125	OZV16K	HH	117	129	128	132	135	132
118	79	126	OZV52K	HH	137	133	129	135	128	118
119	79	127	OZV53K	HH	142	142	140	140	140	140
120	79	128	OZV36K	HH	10	40	47	42	50	47
121	79	129	OZV80K	HH	125	113	114	108	102	85
122	79	130	OZV70K	HH	61	46	29	32	36	31
123	79	131	OZV88K	HH	127	128	118	123	123	123
124	79	132	OZV71K	HH	21	18	18	24	31	27
125	79	133	OZV87K	HH	113	107	96	90	80	62
126	79	134	LBHR2K	HH	128	131	136	127	132	122
127	79	135	ABIV8K	HH	2	1	1	1	3	2
128	79	136	ABIV4K	HH	1	51	57	65	68	59
129	79	137	RGCC10K	HH	24	12	27	22	23	16
130	79	138	RGCC1K	HH	72	70	113	109	120	116
131	79	139	AKIK2K	HH	111	120	106	103	115	106
132	79	140	AIYN2K	HH	65	77	85	86	105	113
133	79	141	AIYN16K	HH	109	136	.	.	.	.
134	79	142	ABWF84K	HH	29	29	46	45	60	74
135	79	143	ABWF125K	HH	4	6	4	10	9	8
136	79	144	ABWF91K	HH	12	26	36	39	26	32
137	79	145	ABWF122K	HH	6	3	6	5	4	6
138	79	146	ABWF83K	HH	13	13	10	8	13	11
139	79	147	ABWF87K	HH	26	8	14	26	35	23
140	79	148	ABWF82K	HH	33	23	31	53	48	56
141	79	149	ABWF89K	HH	20	14	9	7	7	7
142	79	150	ABWF75K	HH	33	54	23	25	30	27
143	79	151	ABWF94K	HH	57	30	28	18	17	25

Appendix Table 12. Changes in rank order of bulls

	RDw140-del	RDw140-sot	RDw140-w56	RDw140-w84	RDsot-del	RDw56-sot	RDw84-w56	RDw112-w84	RDw140-w112
1			.		.			.	
2	-25		28		0			17	
3	42	2	2	-	3	52	10	8	6
4	15	-3	-6	-4	0	2	-13	-10	-4
5	5	11	-10	-4	-4	-2	-7	-18	-8
6	-3	1	4	1	4	7	10	9	5
7	-4	32	25	3	16	72	76	44	19
8	-4	19	8	0	-12	11	15	-4	-12
9	-31	24	-7	3	15	4	35	11	18
10	-13	-26	-4	-20	12	-51	-38	-12	-8
11	-8	-8	-4	-5	6	-19	-11	-3	1
12	-23	13	-14	-10	-7	-41	-18	-31	-17
13	-13	-21	6	-8	1	-35	-22	-1	-7
14	-8	-9	-5	-4	-3	-29	-21	-12	-7
15	16	-14	-16	-19	14	-19	-35	-21	-5
16	28	-6	-20	5	2	9	-19	-13	7
17	39	-30	-7	-19	5	-12	-51	-21	-14
18	43	9	0	-8	25	69	26	17	17
19	27	4	2	-2	10	41	14	10	8
20	6	0	7	6	6	25	19	19	12
21	-46	-4	-13	-3	-16	-82	-36	-32	-19
22	-27	2	-9	14	-21	-41	-14	-16	-7
23	-32	9	-1	13	0	-11	21	12	13
24	-18	1	6	3	-9	-17	1	0	-6
25	51	-20	-13	0	27	45	-6	14	27
26	1	-17	3	-6	1	-18	-19	-2	-5
27	11	-4	-17	-9	-2	-21	-32	-28	-11
28	-2	-2	0	-4	1	-7	-5	-3	-3
29	-6	-9	1	-3	4	-13	-7	2	1
30	7	-2	-2	8	0	11	4	6	8
31	1	9	2	3	0	15	14	5	3
32	-6	-2	11	-6	5	2	8	10	-1
33	10	12	4	2	1	29	19	7	3
34	21	-17	31	-4	18	49	28	45	14
35	-8	13	17	3	5	30	38	25	8
36	23	-40	8	-20	20	-9	-32	8	0
37	1	14	2	-7	-2	8	7	-7	-9
38	-18	-6	-17	4	-3	-40	-22	-16	1
39	40	9	10	-4	-4	51	11	2	-8
40	-5	14	8	-7	-1	9	14	0	-8
41	-23	18	10	7	5	17	40	22	12
42	-11	11	3	1	-3	1	12	1	-2
43	-20	24	-4	1	12	13	33	9	13
44	-4	2	-2	-3	3	-4	0	-2	0
45	-24	-11	35	6	7	13	37	48	13
46	-4	-2	-4	-5	0	-15	-11	-9	-5
47	-8	30	-10	-3	5	14	22	-8	2
48	4	-1	4	2	-1	8	4	5	1
49	7	26	0	2	3	38	31	5	5
50	20	11	-9	-8	-7	7	-13	-24	-15
51	-28	35	-2	29	12	46	74	39	41
52	5	21	-4	11	1	34	29	8	12
53	24	7	-9	11	5	38	14	7	16
54	-18	15	-1	-1	5	0	18	3	4
55	16	-5	0	-10	-4	-3	-19	-14	-14
56	-9	-4	0	-2	1	-14	-5	-1	-1
57	-12	-11	1	-1	3	-20	-8	3	2
58	-7	-2	-4	-3	1	-15	-8	-6	-2
59	-16	-24	-7	7	20	-20	-4	20	27
60	0	-12	-1	-1	6	-8	-8	4	5
61	-19	3	-2	-9	35	8	27	24	26
62	-44	-23	-4	4	10	-57	-13	10	14
63	-35	-6	-3	-3	-9	-56	-21	-15	-12
64	-5	-5	-7	8	-15	-24	-19	-14	-7
65	-39	2	17	0	-15	-35	4	2	-15
66	-6	-7	5	-9	2	-15	-9	-2	-7
67	-12	-6	23	-10	12	7	19	25	2
68	-9	12	0	2	9	14	23	11	11
69	1	6	7	-1	-3	10	9	3	-4
70	-41	5	-13	5	6	-38	3	-2	11
71	-2	-3	12	6	7	20	22	25	13
72	11	-7	0	-5	-4	-5	-16	-9	-9
73	-35	-16	-6	-15	-3	-75	-40	-24	-18
74	-2	-1	1	-2	4	0	2	3	2
75	-4	-1	-13	9	7	-2	2	3	16
76	26	-5	17	11	5	54	28	33	16
77	44	-10	-18	31	3	50	6	16	34
78	18	-9	-2	29	-13	23	5	14	16
79	9	-2	-3	-4	19	19	10	12	15
80	10	-4	-1	6	-5	6	-4	0	1
81	14	8	0	-2	-6	14	0	-8	-8
82	24	-11	-20	-11	-4	-22	-46	-35	-15
83	7	10	-11	-6	-4	-4	-11	-21	-10
84	-6	-1	12	-2	-6	-3	3	4	-8
85	-6	21	4	-7	-1	11	17	-4	-8
86	14	19	14	-12	-2	33	19	0	-14
87	-29	-3	-7	2	-6	-43	-14	-11	-4
88	4	-1	-1	-1	-3	-2	-6	-5	-4
89	0	-2	-13	-32	-12	-59	-59	-57	-44
90	38	-29	11	-11	2	11	-27	2	-9
91	-74	9	7	23	-1	-36	38	29	22
92	70	.	.	.	.	.	.	.	.
93	54	3	-11	17	-24	39	-15	-18	-7
94	47	-20	-7	-32	0	-12	-59	-39	-32
95	-19	-12	-4	0	-4	-39	-20	-8	-4
96	0	-37	-2	-8	-2	-49	-49	-12	-10
97	-23	16	1	2	-7	-11	12	-4	-5
98	10	-9	-6	1	-7	-11	-21	-12	-6
99	-3	42	6	3	-21	27	30	-12	-18
100	-31	13	0	7	-10	-21	10	-3	-3

Appendix Table 12. Continued

101	-11	-9	-11	3	3	-25	-14	-5	6
102	-13	4	-5	12	3	1	14	10	15
103	-15	7	6	4	-3	-1	14	7	1
104	0	-8	-1	3	5	-1	-1	7	8
105	33	-40	-5	-13	-15	-40	-73	-33	-28
106	10	-15	-7	2	-3	-13	-23	-8	-1
107	-20	-17	1	-2	-2	-40	-20	-3	-4
108	14	-42	-1	-4	-1	-34	-48	-6	-5
109	-3	-22	22	14	-20	-9	-6	16	-6
110	-5	0	-2	4	-2	-5	0	0	2
111	-47	44	1	-8	7	-3	44	0	-1
112	-33	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0
113	3	14	-22	-1	-19	-25	-28	-42	-20
114	-26	15	2	-10	6	-13	13	-2	-4
115	13	-34	-11	5	-7	-34	-47	-13	-2
116	15	1	4	-4	-3	13	-2	-3	-7
117	12	-1	4	3	-3	15	3	4	0
118	-4	-4	6	-7	-10	-19	-15	-11	-17
119	0	-2	0	0	0	-2	-2	0	0
120	30	7	-5	8	-3	37	7	0	5
121	-12	1	-6	-6	-17	-40	-28	-29	-23
122	-15	-17	3	4	-5	-30	-15	2	-1
123	1	-10	5	0	0	-4	-5	5	0
124	-3	0	6	7	-4	6	9	9	3
125	-6	-11	-6	-10	-18	-51	-45	-34	-28
126	3	5	-9	5	-10	-6	-9	-14	-5
127	-1	0	0	2	-1	0	1	1	1
128	50	6	8	3	-9	58	8	2	-6
129	-12	15	-5	1	-7	-8	4	-11	-6
130	-2	43	-4	11	-4	44	46	3	7
131	9	-14	-3	12	-9	-5	-14	0	3
132	12	8	1	19	8	48	36	28	27
133	27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
134	0	17	-1	15	14	45	45	28	29
135	2	-2	6	-1	-1	4	2	4	-2
136	14	10	3	-13	6	20	6	-4	-7
137	-3	3	-1	-1	2	0	3	0	1
138	0	-3	-2	5	-2	-2	-2	1	3
139	-18	6	12	9	-12	-3	15	9	-3
140	-10	8	22	-5	8	23	33	25	3
141	-6	-5	-2	0	0	-13	-7	-2	0
142	21	-31	2	5	-3	-6	-27	4	2
143	-27	-2	-10	-1	8	-32	-5	-3	7

Appendix Table 13. Example of simulation program

```
DATA;
 MU=213.233;
YEARSD=1.145;
BREEDSD=15.65;
  HERDSD=09.4615;
  SIRESD=06.3451;
  ERRORSD=28.8517;
  SEED1=1792126;
  SEED2=3537485;
  SEED3=4826601;
  SEED4=0198425;
  SEED5=6573509;
  SEED6=7932813;
  SEED7=1336742;
  SEED8=4325987;
  SEED9=5991026;
DO YEAR = 1 TO 9;
XY= YEARSD * RANNOR(SEED1);
DO BREED= 1 TO 4;
XR=BREEDSD * RANNOR(SEED2);
DO HERD = 1 TO 27;
XH = HERDSD * RANNOR(SEED3);
NS=RANTBL(SEED5,.49,.28,.15,.08);
DO S= 1 TO NS;
SIRE=HERD*100+S;
XS=SIRESD * RANNOR(SEED6);
NB=RANTBL(SEED7,.52,.24,.12,.05,.05,.02);
DO B=1 TO NB;
```

Appendix Table 13. Continued

```
XB=ERRORSD*RANNOR(SEED8);
G=MU+XY+XR+XH+XS+XB;
OUTPUT;
END;
  END;
   END;
    END;
     END;
DROP MU HERDSD SIRESD ERRORSD SEED1 SEED2 SEED3 SEED4;
DROP SEED5 SEED6 SEED7 SEED8 XY XR XH XS XB;
DROP SEED9   S   B YEARSD BREEDSD;
PROC VARCOMP;
CLASSES YEAR BREED HERD SIRE;
MODEL G=YEAR BREED(YEAR) HERD(YEAR BREED)
         SIRE(YEAR BREED HERD)/FIXED= 2
```

Appendix Table 14. Variance components from the simulation runs.

Herd	Sire	Error
119.44	34.04	832.96
85.41	69.04	821.60
36.79	68.43	824.40
91.05	23.94	844.70
52.81	47.82	807.02
105.91	23.05	855.16
104.29	60.91	768.66
83.17	70.62	774.38
72.19	46.54	842.37
85.40	72.55	786.83

Appendix Table 15. Analysis of variance for SOTWT(initial weight) W140(end of test weight) and CG3(test gain) for the Restricted dataset

		SOTWT			W140			CG3		
Source	df	Mean SS	F	PR > F	Mean SS	F	PR > F	Mean SS	F	PR > F
Total	807									
Year	7	11733.70	00.38	0.8891	08748.89	00.16	0.9882	7589.43	0.137	0.3319
Breed(Year)	8	30746.29	13.78	0.0001	56442.44	12.86	0.0001	5533.03	2.38	0.0226
Herd(Year*breed)	89	02229.44	03.89	0.0001	04388.17	1.41	0.0225	2325.35	0.92	0.6791
Sire(Year*breed*herd)	219	572.51	1.27	0.0163	3107.54	1.72	0.0001	2538.96	1.84	0.0001
Age	1	71328.03	158.6	0.0001	73593.21	40.77	0.0001	20.98	0.02	0.9018
Error	483	499.79			1805.27			1376.38		

Appendix Table 16. Analysis of variance for SOTWT(initial weight) W140(end of test weight) and CG3(test gain) for the Hereford Restricted dataset

		SOTWT			W140			CG3		
Source	df	Mean SS	F	PR > F	Mean SS	F	PR > F	Mean SS	F	PR > F
Total	464									
Year	7	7633.95	3.22	0.0067	5977.39	1.85	0.0967	1679.49	1.11	0.3709
Herd(Year)	51	2369.82	5.54	0.0001	3227.22	1.88	0.0024	1511.91	0.98	0.5188
Sire(Year*Herd))	131	427.64	1.20	0.1035	1720.52	1.29	0.0429	1540.93	1.52	0.0023
Age	1	15329.74	43.14	0.0001	15389.40	11.54	0.0008	2.30	0.00	0.9621
Error	274	355.34			1333.98			1014.72		

Appendix Table 17. Analysis of variance for SOTWT(initial weight) W140(end of test weight) and CG3(test gain) for the Charolais Restricted dataset

		SOTWT			W140			CG3		
Source	df	Mean SS	F	PR > F	Mean SS	F	PR > F	Mean SS	F	PR > F
Total	343									
Year	7	15113.94	7.92	0.0001	15748.75	2.86	0.0169	4620.35	1.38	0.2427
Herd(Year)	38	1908.18	2.58	0.0001	5508.64	1.07	0.3861	3352.69	0.84	0.7279
Sire(Year*Herd))	88	739.68	1.33	0.0505	5139.05	2.14	0.0001	4011.65	2.16	0.0001
Age	1	60147.28	108.20	0.0001	62792.26	26.09	0.0001	22.31	0.01	0.9128
Error	209	555.91			2406.83			1855.25		