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UNIVERSITY OF ALBERTA

FACTORS AFFECTING PERFORMANCE OF BEEF BULLS IN TEST STATION

by

M. F. LIU

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

IN

ANIMAL BREEDING AND GENETICS

DEPARTMENT OF ANIMAL SCIENCE

EDMONTON, ALBERTA

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Department of Animal Science
University of Alberta

April 4, 1991

Faculty of Graduate Studies and Research
University of Alberta
Edmonton, Alberta

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This is to certify that I permit Mr. Ming Fu Liu of Department of Animal Science, University of Alberta to use the materials from the following publication for his Ph.D. Dissertation.

Liu, M. F., M. Makarechian and A. K. W. Tong. 1991. Relationships between measures of absolute growth rate and between measures of relative growth rate in growing meat animals. Journal of Animal Breeding and Genetics. (In press).

Sincerely yours,

Prof. M. Makarechian

Agriculture Canada Research Station
Lacomb, Alberta TOC 1SO

April 4, 1991

Faculty of Graduate Studies and Research
University of Alberta
Edmonton, Alberta

To whom it may concern:

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Sincerely yours,

Dr. A. K. W. Tong

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....

M. Makarechian, supervisor

....

R. T. Berg

R T Berg

....

M. A. Price

....

K. W. Smillie

....

A. K. W. Tong

....

J. A. Newman, external examiner

Date: May 14, 1991

DEDICATION

To

My family

&

My teachers

ABSTRACT

Performance test records of 2445 beef bulls tested at the Ellerslie Bull Test Station, Alberta, Canada from 1974 to 1987 were used to study the relative importance of factors influencing the performance of beef bulls in test station and to determine the optimum adjustment and test periods.

The effects of age of dam and age of bull on growth rate, weight, feed to gain ratio, backfat thickness and scrotal circumference of the bulls were not of practical importance, as they explained only a small amount of the variation in the traits.

Weight of the bull at the start of test had significant effects on weight, feed to gain ratio, backfat thickness and scrotal circumference of the bulls, but it explained less than 5% of the variation in these traits.

Herd of origin of the bull was a very important factor influencing weight, growth rate, feed efficiency, backfat thickness and scrotal circumference. The measures of absolute growth rate were influenced by the herd of origin effect to a lesser degree than the measures of relative growth rate, indicating that the measures of absolute growth rate were more appropriate for evaluating growth potentials of the bulls than the measures of relative growth rate under station test conditions.

The period between day 28 and day 112 of the test was found to be the optimum test period. Average daily gain and linear regression coefficient of weight on days on test in this period were least affected by herd of origin. Heritability estimates of the two traits in this period were relatively high, which would be indicative of satisfactory selection response.

The results indicated that in order to properly evaluate growth potentials of beef bulls and use the testing facility economically, it would be appropriate to have an adjustment period of 56 days followed by a test period of 84 days. Such a test scheme would result in reduction in management costs, in addition to providing more accurate evaluation of growth potentials of young beef bulls.

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CHAPTER 1

GENERAL INTRODUCTION

1.1. APPLICATION OF STATION PERFORMANCE TEST

Central growth performance testing of beef bulls has been widely used in a number of countries. It has been used for over 35 years in the U.S., over two decades in the U.K. and about two decades in New Zealand and Canada (Tong 1982, Dalton and Morris 1978). The purpose of the central performance test is to identify genetically superior bulls for use in commercial herds. Breeding bulls are tested in bull test stations so that their genetic potentials for gain could be evaluated under standard conditions.

The advantages of a station performance test are: 1) it makes it possible to compare genetic potentials of bulls across herds; 2) using station performance test instead of progeny test can reduce generation intervals which could result in increased rate of genetic improvement in growth rate; and 3) compared to progeny test, station performance test is easier and cheaper to run.

1.2. EFFECTIVENESS OF STATION PERFORMANCE TEST

Studies in New Zealand have indicated that central performance tests as currently organized there, by starting the test on pasture when bulls are 6 to 10 months of age, were of limited value in ranking the bulls for traits such as growth rate (Carter 1971, Wickham 1977, Dalton and Morris 1978, Baker et al. 1984). Several studies on the effectiveness of performance test in central stations have also been reported in Canada, the United States and Europe (Alenda-Jimenez 1980, Tong 1982, Collins-Lusweti and Curran 1985, Wilton and McWhir 1985, Amal and Crow 1987, Crow et al. 1988). These studies suggest that some important factors, especially herd of origin, influence the results of the test. The lasting effects of the pre-test environment and large variation in compensatory growth among bulls could reduce the reliability of the results (Tong 1982, Baker et al. 1984, Amal and Crow 1987). The low accuracy of the central test results was reflected by the low regression of growth rate and carcass traits of the progeny on the performance traits of their sires (Baker et al. 1984).

As was pointed out, the studies done in New Zealand and those done in Canada showed very different results. The study in New Zealand (Baker et al. 1984) showed that regressions of progeny's growth and carcass traits on different growth traits of their sires were in almost all cases statistically nonsignificant. Therefore, they concluded that central performance tests, as conducted in New Zealand, were of limited value for ranking bulls for growth rate. However, studies by Wilton and McWhir (1985) and Crow et al. (1988) in Canada showed that performance test in central test stations could result in moderate improvement in subsequent progeny performance. As another example, New Zealand data showed that post-weaning gain had low heritability. The low heritability was the decisive factor in persuading those involved in central testing to use final weight instead of test gain as evaluation criterion (Dalton and Morris 1978). In contrast, Canadian data showed moderate to high heritability for gain on test in stations (Wilton and McWhir 1985, Amal and Crow 1987), which supports the widespread use of test gain in the test stations across Canada.

The different results are probably due to the differences in management, statistical procedures and beef cattle populations in the two countries.

In New Zealand the bulls from 6 to 10 months of age were tested on pasture. In contrast, in Canada, bulls were weaned at 6 to 8 months of age and given a 1-mo adjustment period before being tested in a central location (Wilton and McWhir 1985). During the test period, the bulls were fed a high energy diet. The differences between the two programs in the two countries could significantly affect the results of the tests. The data of Collins-Lusweti and Curran (1985) fully support this explanation. They showed that herd of origin on the average accounted for 50% and 18% of the total phenotypic variances of performance traits for field tests and station tests, respectively. The results indicated that more uniform treatments in central test stations compared with field tests could dramatically reduce the influence attributed to herd of origin, one of the most important factors which influence the performance test results, although the influence persisted during the entire period of the performance test at the stations. The fact that the central station test in Canada was more effective than in New Zealand could be explained by the above results. Obviously, the nutritional treatment in the feedlot was much more uniform than that on pasture. In addition, the range of start of test age of calves was narrower in Canada compared to that of calves in New Zealand.

Secondly, the fact that different researchers used different data sets and employed different statistical procedures may have also contributed to the different results obtained in the two countries.

Finally, there were genetic differences between the beef cattle populations in the two countries. Some of the breeds were different. Even for the same breeds, they had been selected with different goals. These differences could also lead to different results.

1.3. PROBLEMS IN STATION PERFORMANCE TEST

Although beef bull station performance testing has been in use for a long time, there are still several problems which deserve further studies. These problems are: 1) the impact of the pre-test environmental factors on growth performance of the young bulls; 2) identification of growth traits which are less affected by the pre-test environment; 3) the optimum adjustment and test periods; and 4) removal of the pre-test environmental effects.

In addition, with the improvement of genetic potential for gain and change in the grading system in favor of leaner carcasses as well as the improvement in management, it seems to be necessary to re-examine the station performance test program in order to properly evaluate growth potentials of young bulls.

In an attempt to minimize the pre-test environmental effects, bulls are started on test at a much younger age in Europe, for instance, 45 days in Denmark, 50 days in Germany and 90 days in Norway, and 30 days in Sweden (Fimland 1973, Krausslich 1974, Lewis and Allen 1974). However, the management in Canada dictates that start of test age can't be further reduced in this country (Tong 1982).

The objectives of this study were, therefore, fourfold: 1) to examine the mathematical relationships between the measures of postweaning growth rate; 2) to assess the relative importance of some major factors influencing growth performance on test; 3) to compare the degree of influence of herd of origin on the measures of growth rate and identify alternative measures of postweaning growth rate which may be less affected by herd of origin effect; and 4) to determine the optimum adjustment and test periods in feedlot.

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CHAPTER 2

RELATIONSHIPS BETWEEN MEASURES OF ABSOLUTE GROWTH RATE AND BETWEEN MEASURES OF RELATIVE GROWTH RATE[1]

2.1. INTRODUCTION

Growth is a complex phenomenon which has attracted the attention of many researchers. Development of the theory and techniques for fitting growth curves may be traced both through time and across scientific disciplines. In particular, the theory and methodology of fitting growth curves owe much to mathematicians, demographers and economists.

In 1825, Benjamin Gompertz proposed an asymmetric sigmoid curve (The Gompertz equation) to describe human mortality. Winsor (1932) discussed the application of the Gompertz equation to the growth of an organism for cases where the relative growth rate decreased exponentially with time.

The logistic or autocatalytic function was first proposed by P. F. Verhulst in 1838 to describe the cumulative growth of a population (Yule 1925, Olinick 1978), and was independently developed by T. B. Robertson in 1908

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[1] A version of this chapter has been published. M. F. Liu, M. Makarechian and A. K. W. Tong 1991. Journal of Animal Breeding and Genetics 108:187-191.

for describing the chemical basis of growth (Bliss 1970, Parks 1982). A generalized logistic equation which allows a variable point of inflection was proposed by Nelder (1961).

In animal sciences, the most widely used growth equation is the Brody's monomolecular equation (Brody 1945). Brody described the growth as "self accelerating" before and "self inhibiting" after the point of inflection (growth spurt), and proposed two equations to describe growth. His stepwise description of growth, therefore, did not allow the direct estimation of growth spurt.

The Bertalanffy's equation was proposed in 1957 (von Bertalanffy 1957). Among plant scientists, Richards (1959, 1969) was the first to apply the Bertalanffy's equation to describe animal growth. Richards' equation is an empirical construct with the advantage of generality. This equation encompasses monomolecular, logistic, Gompertz's and Bertalanffy's equations (Brown et al. 1976, Fitzhugh 1976).

Chanter (1976) devised a function (Chanter's equation), which is a hybrid of the logistic and Gompertz's equations. Chanter's equation is similar but not identical to the Richards' equation (France and Thornley 1984).

In The Origin of Species, Darwin (1859) used a phrase "mystery of correlated growth" to describe the relationships among different organs of an individual. Although allometric function had been used in zoological studies on a few occasions, Huxley (1924, 1932) was considered the first to stress its biological applicability, discuss its significance and popularize its use (Richards 1969).

Berg and Butterfield (1976), using both dissection techniques and Huxley's techniques, thoroughly studied the anatomical composition of the beef carcasses and provided much new information concerning the relationships among the components of the carcasses at different stages of growth.

Brody (1945) suggested that instantaneous (or true) growth rate as a measure of relative growth rate should be the measure of choice. The advantage of instantaneous growth rate is that it takes body weight into account and therefore could serve as an indirect measure of biological efficiency. At present, in most performance test programs, average daily gain calculated as gain on test divided by the period on test is used as a measure of absolute growth rate. Periodical weighing is practised in almost all beef bull test stations. For instance, most bull test stations in Canada and the United States weigh bulls at 28-d intervals (Beef Improvement Federation 1986). These periodic body weight measurements make it possible to use the linear regression coefficient of body weight on days on test as an alternative measure of absolute growth rate. In addition, average relative growth rate (Fitzhugh and Taylor 1971) can also be used as a measure of relative growth rate. In order to compare the measures of growth rate, it is essential to study the relationships, either empirical or mathematical, between different measures of growth rate.

In practice, it would be useful to know the relationships between different measures of growth rate in a population, i.e., their empirical relationships (genetic, phenotypic and environmental correlations). Brown et al. (1988) and Kemp (1990) have studied some of these empirical relationships in beef bulls.

The objective of the present study was to derive the relationships between two measures of absolute growth rate (linear regression coefficient of weight on days on test and average daily gain) and between two measures of relative growth rate (instantaneous percentage growth rate and average relative growth rate) using an analytical procedure in a general way so that the results could also be applied to a variety of performance test programs.

2.2. DERIVATION OF RELATIONSHIPS

2.2.1. Relationship between Linear Regression Coefficient of Weight on Days on Test (REG) and Average Daily Gain (ADG).

In a performance test program, animals are weighed periodically, at either equal or unequal intervals. Therefore, a set of weights (W_i), taken on different dates, (t_i) are available to estimate growth rate of the animals, where $i = 1, 2, \ldots, n$. In most test stations, bulls are weighed 6 times at 28-d intervals over a 140-d period (Beef Improvement Federation 1986). For this special case, $n = 6$.

The linear regression coefficient of weight on days on test is defined as the estimate of ß (b) in the following equation.

$$E(W_i) = \mu + \beta(t_i - \bar{t}) \qquad (1)$$

$$\text{or } E(W_i) = \alpha + \beta t_i,\ \alpha = \mu - \beta\bar{t} \qquad (2)$$

where, $i = 1, 2, \ldots, n$.

$E(W_i)$ is the predicted value of W_i.

μ is population mean of W_i.

α is constant.

β is the regression coefficient of weight on days on test.

$\bar{t}$ is the mean of t_i.

Using least squares procedure, the estimate of ß (b) can be obtained as

$$b = \frac{\sum_{i=1}^{n} (t_i - \bar{t})(W_i - \bar{W})}{\sum_{i=1}^{n} (t_i - \bar{t})^2} \qquad (3)$$

and the estimate of α (a) is

$$a = \bar{W} - b\bar{t} \qquad (4)$$

where, $\bar{W}$ is the mean of W_i.

Equation (2) can be expressed as

$$\hat{W}_i = a + bt_i \qquad (5)$$

where, $\hat{W}$ is the estimate of $E(W_i)$.

Algebraically b can also be expressed as a linear combination of the weights involved.

$$b = \sum_{i=1}^{n} k_i W_i \qquad (6)$$

where

$$k_i = \frac{(t_i - \bar{t})}{\sum_{i=1}^{n} (t_i - \bar{t})^2}$$

$$\sum_{i=1}^{n} k_i = 0$$

$$\sum_{i=1}^{n} (k_i)^2 = \frac{1}{\sum_{i=1}^{n} (t_i - \bar{t})^2}$$

When only start and end of test weights are used,

$$b = k_1 W_1 + k_n W_n$$

$$= \frac{(t_1 - \bar{t})}{(t_1 - \bar{t})^2 + (t_n - \bar{t})^2} W_1 + \frac{(t_n - \bar{t})}{(t_1 - \bar{t})^2 + (t_n - \bar{t})^2} W_n$$

$$= \frac{((t_n - t_1)/2)(W_n - W_1)}{2((t_n - t_1)/2)^2}$$

$$= \frac{W_n - W_1}{t_n - t_1} \qquad (7)$$

$= \text{ADG}$

where $t_1 - \bar{t} = -(t_n - t_1)/2$

$t_n - \bar{t} = (t_n - t_1)/2$

Therefore, ADG can be considered as a special case of linear regression coefficient when only start and end of test weights are used to estimate absolute growth rate.

Furthermore, it can be shown that ADG is also a pooled estimate of pairwise linear regressions each of which uses two consecutive weights. According to equation (7), the following pairwise linear regression coefficient can be defined as

$$b_{ij} = \frac{W_j - W_i}{t_j - t_i} \qquad (8)$$

where b_{ij} is pairwise linear regression coefficient and i and j refer to the two pairs of measurements, $i = 1, 2, \ldots, n-1$, $j = i+1$, $j > i$.

The sum of the numerators of the pairwise linear regression coefficients of equation (8) is

$$\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} (W_j - W_i) = W_n - W_1 \qquad (9)$$

And the sum of the denominators of equation (8) is

$$\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} (t_j - t_i) = t_n - t_1 \qquad (10)$$

Therefore, the pooled linear regression coefficient

$$b_{pooled} = (W_n - W_1)/(t_n - t_1) \quad (11)$$

$$= ADG.$$

Thus, ADG can also be considered as a pooled estimate of linear growth rate and REG is an overall estimate of linear growth rate. The difference between the two estimates of linear growth rate depends on the differences among the pairwise linear regressions. The relationship between ADG and REG for the same animal is attributable to both genotype of the animal and environmental influences, since both attributes affect the fitting of the pairwise regression lines. Therefore ADG is, to a certain degree, a function of REG, given a set of weight measurements on the same animal.

2.2.2. Relationship between Instantaneous Percentage Growth Rate (K) and Average Relative Growth Rate (RGR).

Instantaneous relative (or true) growth rate can be estimated from Brody's function

$$W_t = Ae^{kt} \quad (12)$$

where k is defined as instantaneous growth rate and K = 100k is defined as instantaneous percentage growth rate (percentage increase in body weight per day); W_t is the weight measured at time t (days on test); A is a constant;

and e is the base of natural logarithm. In contrast to ADG and REG which assume a linear growth pattern, function (12) is applicable to curvilinear growth patterns. The parameters of function (12) can be estimated by some nonlinear estimation procedures, but more simply by applying log-transformation to function (12).

$$\ln W_t = \ln A + kt \tag{13}$$

then instantaneous growth rate (k) can be estimated using the simple regression equation,

$$k = \frac{\sum_{i=1}^{n} (t_i - \bar{t})(\ln W_i - \overline{\ln W})}{\sum_{i=1}^{n} (t_i - \bar{t})^2} \tag{14}$$

$i = 1, 2, \ldots, n.$

$\overline{\ln W}$ is the mean of $\ln W_i$'s, and the instantaneous percentage growth rate $K = 100k$, therefore, can be obtained. The estimate of lnA is

$$\ln A = \overline{\ln W} - k\bar{t} \tag{15}$$

Similar to equation (6), K can also be expressed as a linear combination of log-transformed weights.

$$K = 100\sum_{i=1}^{n} k_i \ln W_i,\ i = 1, 2, \ldots, n. \tag{16}$$

where k_i is the same as in equation (6).

If only W_1 and W_n are used, then equation (16) is reduced to average relative growth rate (RGR).

$$K = 100\sum_{i=1}^{n} k_i \ln W_i$$

$$= 100((\ln W_n - \ln W_1)/(t_n - t_1)) \qquad (17)$$

$$= RGR$$

Therefore, average relative growth rate (RGR) is a special case of instantaneous percentage growth rate (K), when only start and end of test weights are used to estimate relative growth rate.

Equation (17) is the same as that reported by Fitzhugh and Taylor (1971), except that a constant coefficient (100) is included here. The derivation of equation (17) is the same as that shown in equation (7), except that W_i is replaced by $\ln W_i$ and a constant coefficient (100) is included so that RGR is also defined as percentage increase in body weight per day.

It can be shown that RGR is also a pooled estimate of relative growth rate, while K is an overall estimate of relative growth rate. The proof is the same as shown in equations (8), (9), (10) and (11), except that W_i is replaced by $\ln W_i$ and a constant coefficient (100) is included.

2.2.3. Comparisons of the Accuracy of ADG, REG, RGR and K.

Since ADG and REG can be considered as the regressions of weight on days on test and RGR and K can be considered as the regressions of log-transformed weight on days on test, the accuracy of these measures of growth rate can be evaluated by comparing their variances (or standard errors), i.e. comparing the variances of regression coefficients.

It has been shown that the variance of a regression coefficient (Steel and Torrie 1980) is

$$s^2_b = \frac{\sum_{i=1}^{n} (W_i - \hat{W}_i)^2}{(n-2)\sum_{i=1}^{n} (t_i - \bar{t})^2} \qquad (18)$$

where, $i = 1, 2, \ldots, n$.

$\hat{W}_i$ is the estimate of $E(W_i)$.

When $n = 2$, s^2_b is indeterminate; when n approaches 2 but larger than 2, s^2_b approaches $+\infty$; when n approaches $+\infty$, s^2_b approaches 0; and when $2 < n < +\infty$, $+\infty > s^2_b > 0$ (Willard 1976).

Equation (18) is applicable to ADG and REG. With W_i replaced by $\ln W_i$, it can be applicable to RGR and K.

Since s^2_b cannot be negative, ADG and RGR ($n = 2$) can be considered as the extreme cases with indeterminate variances, though the variances cannot be estimated. REG and K ($n > 2$) have smaller variances than ADG and RGR, indicating that REG is more accurate than ADG and K is more accurate than RGR.

2.3. DISCUSSION

It was shown that average daily gain and average relative growth rate are special cases of linear regression of weight on days on test and instantaneous percentage growth rate, respectively, when only start and end of test weights are used. Although the measures of growth rate are all related, the accuracy with which the parameters are estimated are different. Regression of weight on days on test and instantaneous percentage growth rate use more information and are more accurate than conventional average daily gain and average relative growth rate in estimating absolute and relative growth rates, respectively. Whenever more than two weight measurements are available in a performance test program, regression of weight on days on test and instantaneous percentage growth rate should be used, especially when the test period is long enough so that conventional average daily gain and average relative growth rate may deviate much from regression of weight on days on test and instantaneous percentage growth rate, respectively. If gain is emphasized, regression of weight on days on test should be chosen instead of conventional average daily gain; and if improving biological efficiency is the goal, instantaneous percentage growth rate should be chosen rather than conventional average relative growth rate.

The calculation of ADG involves two weight measurements, whereas growth rate measured in terms of regression of weight on days on test (REG) requires more than two weight measurements. Therefore, it is not possible to convert the value of ADG to REG without knowing the weight measurements. The same is true for average relative growth rate and instantaneous percentage growth rate.

The derivation of the relationships between the measures of growth rate reveals the intrinsic relationships between these measures which provide a basis for comparing different measures and consequently choosing the appropriate measure to reach breeding goals.

In addition to the theoretical advantages of using regression of weight on days on test and instantaneous percentage growth rate over conventional average daily gain and average relative growth rate, respectively, they are of practical importance as they minimize the probable errors caused by the deviation of the first day and the last day weights due to sickness, appetite and gut fill.

2.4. SUMMARY

An analytic procedure was used to derive the relationships between two measures of absolute growth rate and between two measures of relative growth rate. The results showed that the conventional average daily gain and average relative growth rate are special cases of linear regression of weight on days on test and of instantaneous percentage growth rate, respectively, when only start and end of test weights are used to estimate absolute and relative growth rate. Linear regression of weight on days on test and instantaneous percentage growth rate are more accurate than the conventional average daily gain and average relative growth rate based on the amount of information utilized and the magnitude of their variances. The theoretical and practical advantages of these measures were also discussed.

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CHAPTER 3

EFFECTS OF AGE OF DAM, AGE AND WEIGHT AT START OF TEST AND HERD OF ORIGIN ON GROWTH PERFORMANCE OF BEEF BULLS IN A TEST STATION

3.1. INTRODUCTION

Station performance testing provides a facility to compare bulls from different herds under standard conditions in order to identify genetically superior bulls for use in commercial herds to improve beef production.

Age of dam is considered an important factor influencing the performance of the calf. Cows influence preweaning growth of their calves both by the genes they transmit to the calves and by the maternal environment they provide up to weaning. The maternal environment which affects preweaning performance of the calf may also influence postweaning performance of the calf, if the carry-over effect is important. Pabst et al. (1977) indicated that the effect of age of dam on postweaning weight was not important, accounting for a very small proportion of the variation. In contrast, Simm et al (1985) showed that age of dam was an important source of variation in performance test.

The reports on the effect of age of calf on postweaning growth performance are inconsistent. Some investigators suggested that the effect of age was significant for weight of the calf up to weaning, but not for postweaning gain (Batra and Wilton 1972, Wilton et al. 1973, Tong 1982, Amal and Crow 1987). Significant effect of age of calf on postweaning performance of calf was reported by several investigators (Moore et al. 1961, Schalles and Marlowe 1967, Lewis and Allen 1974). However, little attention has been paid to the contribution of age of calf to the total variation, i.e. the proportion of the variation explained by age of calf.

The effect of start of test weight on average daily gain has been reported by several researchers (Moore et al. 1961, Rollins et al. 1962, Schalles and Marlowe 1967, Batra and Wilton 1972, Wilton et al. 1973, Tong 1982). These studies except Rollins et al. (1962) indicate that there exists a positive relationship between start of test weight and average daily gain.

Many studies showed that pre-test environmental effects, especially the herd of origin, might interfere with the fair comparison of growth traits during the test period (Kraüsslich 1974, Lewis and Allen 1974, Dalton 1976, Dalton and Morris 1978, Morris 1981, Okantah and Curran 1982, Tong 1986, Amal and Crow 1987). Research in New Zealand indicated that central performance tests as organized in New Zealand were of limited value in ranking bulls for growth rate due largely to the herd of origin effect (Carter 1971, Wickham 1977, Dalton and Morris 1978, Baker et al. 1984). Studies in Canada (Tong 1982, Wilton and McWhir 1985, Amal and Crow 1987, Crow et al. 1988) and Europe (Alenda-Jimenez 1980, Collins-Lusweti and Curran 1985) indicated that herd of origin was an important factor influencing the results of the tests. The carry-over effect of herd of origin could have reduced the reliability of the results. These studies indicated that the herd of origin effect could contribute to the variation in weight at the start of the test and consequently to the variation in gain on test, which would persist up to the end of the test.

The objectives of this study were to examine the effects of age of dam, age of bull, start of test weight and herd of origin on bull weight and growth rate in test station.

3.2. MATERIALS AND METHODS

3.2.1. Description of the Data

The records of beef bulls from ten breeds tested at the Ellerslie Test Station, Alberta, Canada, collected from 1974 to 1987, were used for this study. The information on the data collection, management in the station and the classification of these breeds into two relatively homogeneous breed groups is given in Appendix 1. Two data sets corresponding to the two breed groups were used for statistical analysis. Data set I (small size breed group) included Angus, Hereford, Limousin and Shorthorn. Data set II (large size breed group) included Blonde d'Aquitaine, Charolais, Gelbvieh, Maine-Anjou, Salers and Simmental. It should be noted that while the Limousin's rate of gain placed it with the British breeds, it was the opposite extreme for rate of maturity. The number of bulls, sires, herds and years the data covered within each breed are shown in Table 3.1.

Weight measurements at 28-day intervals included start of test weight (SOTW), weights on day 28 (W28), day 56 (W56), day 84 (W84), day 112 (W112) and day 140 (W140) of the test.

The measures of growth rate were calculated as follows:

1. Average daily gain on test (ADG) was calculated as the gain in the test period divided by the number of days of the test period.
2. Linear regression coefficient of weight on days on test (REG) was calculated from the six available weights and dates.
3. Instantaneous percentage growth rate (K) was calculated from the six weights and dates based on Brody's function (Brody 1945, $W_t = Ae^{kt}$ and $K=100k$, where, W_t is the weight at time t, A is a constant, e is the base of natural logarithm and k is instantaneous relative growth rate.).

4. Average relative growth rate (RGR) was calculated as 100(lnW140 - lnSOTW)/140 (Fitzhugh and Taylor 1971).

5. Absolute (maximum) growth rate (AGRL) at the point of inflection of the growth curve and relative growth rate (RGRL) at the point of inflection of the growth curve were derived from a generalized logistic growth curve (Appendix 2).

6. Periodic gains (PG) were calculated as the difference between weights taken on two successive weighings (PG1 = W28 - SOTW, PG2 = W56 - W28, PG3 = W84 - W56, PG4 = W112 - W84 and PG5 = W140 - W112).

7. Cumulative gains (CG) were calculated by subtracting SOTW from successive weights: CG28 = W28 - SOTW = PG1, CG56 = W56 -SOTW, CG84 = W84 - SOTW, CG112 = W112 - SOTW and CG140 = W140 - SOTW.

8. Periodic relative growth rates (PR) were calculated as follows: PR1 = 100(lnW28 - lnSOTW)/28, PR2 = 100(lnW56 - lnW28)/28, PR3 = 100(lnW84 - lnW56)/28, PR4 = 100(lnW112 - lnW84)/28 and PR5 = 100(lnW140 - lnW112)/28.

9. Cumulative relative growth rates (CR) were calculated as follows: CR28 = 100(lnW28 - lnSOTW)/28, CR56 = 100(lnW56 - lnSOTW)/56, CR84 = 100(lnW84 - lnSOTW)/84, CR112 = 100(lnW112 - lnSOTW)/112 and CR140 = 100(lnW140 - lnSOTW)/140.

AGRL and RGRL were included as measures of growth rate only for exploring purpose. It could not be appropriate to estimate these parameters from a logistic function when only a few weight measurements were availabe.

Periodic and cumulative measurements of gains and average relative growth rates were used to examine the influence of the herd of origin effect in different periods of the test on different measures of growth rate. The means, standard deviations and the grouping of these measurements are shown in Table 3.2.

3.2.2. Statistical Analysis

Two mixed models were used for the statistical analysis and they were applied to the two breed groups separately. Model I which was used to describe traits measured in the test station was:

$$y_{ijklm} = \mu + t_i + d_j + b_1a_{ijklm} + b_2w_{ijklm} + h_{ik} + s_{ikl} + e_{ijklm}$$

where y_{ijklm} was an observation on the m^{th} bull for a given trait, μ was the population mean for that trait, t_i was a fixed effect common to bulls of the i^{th} breed-year group, d_j was a fixed effect of the j^{th} age group of dam ($j = 2, 3,\ldots,6+$), b_1 was the partial regression coefficient of the trait on age of bull, a_{ijklm} was start of test age, b_2 was the partial regression coefficient of the trait on start of test weight of the bull, w_{ijklm} was start of test weight of the bull, h_{ik} was a random effect of the k^{th} herd within the i^{th} breed-year group [$\sim NIID(0, \sigma^2_h)$], s_{ikl} was a random effect associated with the additive genetic value of the 1^{th} sire [~NIID(0, σ^2_s)], and e_{ijklm} was a random residual effect associated with the m^{th} bull [~NIID(0, σ^2_e)], where NIID meant "normal, independent and identically distributed". For the analysis of start of test weight, the covariate start of test weight was dropped from the model. The assumptions of the model were that sires were unrelated and were randomly mated to dams in the herds where the sires belonged, that dams were unrelated and represented in the data by only one son, that environmental errors within and between half-sib groups were uncorrelated, that all interactions were insignificant, and that single pooled regression coefficients on age and start of test weight of bull were appropriate for all the breeds in each breed groups. Due to lack of sufficient information, the model did not take into account the relationships among bulls and genetic trend. A hierarchical arrangement of herds within breed-year groups and sires within herd was assumed, similar to that done by Amal and Crow (1987), even though this was not the case in practice. The same herd, for instance, appeared in several years and some sires had progeny in several herds and years within a breed. Ignoring the cross-classified nature of the data, especially with respect to sires, part of the genetic variation (due to differential usage of sires from herd to herd) among herds would not be removed (Amal and Crow 1987). However, the treatment would avoid the loss in the degree of connectedness of the data. Model I was used to determine the contribution of each factor to the total variation in weight and growth rate on test. The contribution of a factor was calculated as the percentage of the sum of squares due to that factor (after adjusting for the other factors in the model) in the corrected total sum of squares. This was equivalent to the reduction in the coefficient of determination (R^2) after dropping that factor from the full model. The approximate F test was used to determine the significance of the influence of a factor in the model. Herd mean squares and sire mean squares were used to test the influence of breed-year and herd of origin, respectively.

The results from Model I (which will be discussed later) showed that the contributions of age of dam, age and start of test weight of bull to the variation in postweaning growth rate and weight were small and not important in the present data. The dropping of these three factors would increase the degrees of freedom in the analysis of the data. Model II was a modification of Model I with age of dam and age and start of test weight of bull dropped from Model I. Model II was used for the analysis of variance components to estimate the fraction of the total phenotypic variance which was due to the herd of origin effect, i.e. "intraherd correlation" ($t_h = \sigma^2_h/(\sigma^2_h + \sigma^2_s + \sigma^2_e)$ and to estimate heritability ($h^2 = 4\sigma^2_s/(\sigma^2_h + \sigma^2_s + \sigma^2_e)$.

The restricted maximum likelihood procedure (Patterson and Thompson 1971, SAS Institute Inc. 1985) was used to estimate variance components. The estimates of variance for all the traits converged within 20 rounds of iterations. The convergence value of the objective function was 10^{-8}. Approximate standard errors for t_h and h^2 were derived using the general procedure of error propagation as shown in Appendices 3 and 4, respectively. An additional assumption for Model II was that all breeds in each of the breed groups had similar genetic and environmental variances. Although the assumption might not be correct in the strict sense, it would minimize sampling errors and would allow the use of sufficient data for variance estimation (Tong 1986). The consequence of this assumption would be that while the estimators would be still unbiased, the sampling errors of the estimators would be larger (Henderson 1975).

3.3. RESULTS AND DISCUSSION

3.3.1. Factors Influencing Growth Performance

The relative influence of the factors affecting growth rate and body weight in terms of the reduction in the coefficient of determination (R^2) are presented in Table 3.3. The significance levels are labeled beside the observed values of the reductions in R^2, as the approximate F test for the influence of a factor in the model is equivalent to the test for the reduction in R^2. It must be mentioned that approximately half of the data were used in Model I to examine the effect of age of dam simultaneously (373 out of 732 and 875 out of 1302 of the bulls, for the two breed groups, respectively) due to the lack of information on age of dam for the remaining bulls.

3.3.1.1. The effect of breed-year

Breed-year had a significant effect on all the traits ($P < 0.01$) in both breed groups (Table 3.3). The breed-year effect was mainly due to the fluctuations in environmental factors associated with year, and to a lesser degree a result of the genetic changes and disproportional representation of the breeds over years. The effect of the disproportional representation of the breeds over years could be assumed to be insignificant, since the breeds in each breed group were homogeneous in growth performance.

The largest reductions in R^2 for weights were those for start of test weight, 14.31% and 6.21% for the small and large breed groups, respectively. The reductions in R^2 for the subsequent weights were less than 5%. The results indicated that start of test weight of bulls varied to some degree over years, especially for the small size breed group.

3.3.1.2. The effect of age of dam

Most of the variables were not significantly influenced by age of dam, except for start of test weight as dependent variable for which age of dam was significant ($P < 0.001$, Table 3.3). However, the amount of variation explained by age of dam was too small (0.01 -1.27 %) to be worthy of practical consideration.

The results from the present study were in general agreed with those obtained by Pabst et al. (1977), who reported that age of dam had a highly significant effect on 200-d weight and a less pronounced effect on 400-d weight for the seven breeds studied. In contrast, Simm et al. (1985) found that 20-30% of the variation in weights between 200 and 400 days of age for bulls weaned at 168 days was due to age of dam. For bulls weaned at birth or at 84 days of age, the effect of age of dam was not important as a source of variation in bull weights.

Amal and Crow (1987) discussed the probability that age of dam could contribute partly to the herd of origin variation for bull weight and cumulative gain, as the number of bulls from each age of dam category would probably vary among herds. They also suggested that the effect of age of dam should be further studied.

Based on the results of the present study, it would not be necessary to adjust for the effect of age of dam. Even if the representation of age of dam varied among herds, it would not contribute much to the variation due to herd of origin, as the contribution of age of dam to the total variation was small.

In a preliminary study, when the effect of herd of origin was removed from Model I, the variation due to age of dam remained unchanged. In another preliminary study, herd of origin component of variance was estimated by Henderson's Method III (Henderson 1953) based on Model I and a reduced model with the effect of age of dam dropped from Model I. The estimates of variance component due to herd of origin from the two models were similar. These results suggested that the contribution of age of dam to the herd of origin variation in postweaning growth rate and weight was not important.

3.3.1.3. The effect of age of bull

The effect of age of bull was significant only on start of test weight as a dependent variable in both breed groups ($P < 0.001$) and on absolute (maximum) growth rate at the point of inflection of the growth curve (AGRL), periodic gain and periodic relative growth rate in the 4th 28-day period of the test in small size breed group (Table 3.3). The reductions in R^2 were however less than 7%. For the other traits which were not significantly affected by age of bull, the reductions in R^2 were less than 1%.

The partial regression coefficients of the traits on age of bull are presented in Table 3.4. The partial regression coefficients were significant only for start of test weight as a dependent variable in both breed groups and for absolute (maximum) growth rate at the point of inflection of the growth curve (AGRL), periodic gain and periodic relative growth rate in the 4th 28-day period of the test in the small size breed group. Most of the regression coefficients were negative in sign and the magnitude was too small to be of practical importance.

Removing the effect of herd of origin from Model I resulted in no changes in the reductions in R^2 due to age of bull, indicating that the effect of age of bull was not confounded with the effect of herd of origin.

There are many reports on the effect of age of bull or heifer calves on growth performance. No significant linear or quadratic effect of age of bull on ADG was reported from a study of 327 Angus and 458 Hereford bulls during 1970 in ten test stations in the United States and Canada (Batra and Wilton 1972), and from a similar study of 229 Angus, Charolais and Hereford bulls tested at the Arkell Bull Test Station (Wilton et al. 1973). Tong (1982) studied the effect of age of bull on ADG in 8620 beef bulls of the Angus, Charolais, Hereford, Limousin, Simmental and Shorthorn breeds, tested in 15 test stations across Canada, and reported that age of bull had little effect on ADG within the age range covered by the data. Amal and Crow

(1987) studied the effect of age of bull on gain and weight measurements on test using the records of 3435 beef bulls of the Angus, Hereford, Charolais and Simmental breeds tested at the Manitoba Bull Test Station, and reported that there was seldom any relationship between test gain and age, although age of bull had a significant influence on all weights. Rollins et al. (1962) also reported an insignificant partial regression of gain on age (-0.2g/d) in a study of 200 Hereford steers.

Significant partial regression of ADG on age of bull was reported (3g/d) from 364 bulls of British breeds (Schalles and Marlowe 1967) and a regression of -2.9g/d at a constant start of test weight from 414 bulls (Moore et al. 1961). Lewis and Allen (1974) citing an earlier study reported that younger bulls on test showed above average weight gains.

The present study indicated that in general age of bull was not an important factor in the evaluation of gain potentials of bulls within the range of age covered by the data, since it only explained a very small amount of variation of growth rate.

3.3.1.4. The effect of start of test weight

Start of test weight had significant effects on weights, absolute (maximum) growth rate at the point of inflection of the growth curve (AGRL), relative growth rate and instantaneous percentage growth rate in both breed groups. It also had significant effects on periodic and cumulative gains, except for periodic gain in the 4th 28-day period of the test (Table 3.3). In general, start of test weight had significant effects on periodic and cumulative relative growth rates (Table 3.3). However, the variation in growth rate explained by start of test weight was small (less than 5%), although the variation in subsequent weights explained by start of test weight ranged from 4.32 to 8.23%.

The significance levels of the partial regression coefficients of the traits on start of test weight (Table 3.4) were generally in agreement with those of the corresponding reductions in R^2 shown in Table 3.3. In general, apart from weights, start of test weight was not important in the evaluation of the growth potentials of the bulls. The partial regression coefficients of ADG on start of test weight (positive but insignificant) agreed with those obtained by Rollins et al. (1962). Most of the partial regression coefficients of relative growth rates on start of test weight were negative, indicating that heavier bulls had lower relative growth rate than lighter bulls.

3.3.1.5. The effect of herd of origin

Herd of origin had significant effects on most traits, especially in the small size breed group (Table 3.3). Herd of origin had a significant effect on start of test weight as a dependent variable, with the reductions in R^2 being 31.03% and 29.13% for the small and large size breed groups, respectively. Nevertheless, it had little influence on the subsequent weights for which the reductions in R^2 were less than 8%. The decrease in the variations of subsequent weights explained by herd of origin was due to the fact that the weights had been adjusted for the start of test weight. Excluding the start of test weight effect from the model resulted in the increase in the reductions in R^2 due to the herd of origin effect for the subsequent weights, indicating that the variation in weights due to herd of origin was mainly due to the variation in start of test weight among herds.

Apart from weights, herd of origin explained a substantial fraction of variation in the measures of growth rate. The reductions in R^2 ranged from 14.05% to 38.48% and most of them were around 26.00% to 30.00% (Table 3.3). Excluding the start of test weight effect from the model did not change the magnitude of variation explained by herd of origin for the measures of growth rate. Obviously, herd of origin was an important factor to be considered.

The results were similar to the report by Tong (1982) which showed that the sum of squares due to the fixed herd-year effect expressed as a percentage of the corrected total sum of squares for ADG accounted for 25% in the pre-test period, a maximum of 54.3% in the adjustment period and then decreased to 6.8% in the test period.

In addition to the environmental factors, herd of origin contains a genetic component as well. The data for this study did not permit the estimation of the genetic component. The characteristics of the herd of origin component of variance at different stages of the test will be discussed later in sub-section 3.3.2.

3.3.1.6. The effect of sire

The influence of sire on different measures of growth rate and weight were estimated in terms of the reductions in R^2 due to sire effect (Table 3.3). It seemed that the effect of sire had a greater impact on the measures of growth rate than on weights. This could be due to the fact that weights were highly correlated and more influenced by pre-test environmental factors than growth rates. The reductions in R^2 for the measures of growth rate ranged from 5.83% to 30.79%, whereas they ranged from 0.57% to 7.56% for weight measurements. The heritability estimates of certain measures of growth rate and weight will be discussed in sub-section 3.3.3.

3.3.2. The Intraherd Correlations

3.3.2.1. The intraherd correlations for weights

The proportions of herd of origin components of variance relative to the total phenotypic variances or intraherd correlations (t_h) are presented in Table 3.5 and depicted in Figure 3.1. Intraherd correlation measured the degree to which herdmates were more similar than non-herdmates. Herd of origin component of variance accounted for the largest fraction of the total phenotypic variance in weights, decreasing from 52% to 35% and from 37% to 30% from the start to the end of the test in the small and large size breed groups, respectively (Figure 3.1). Body weight in the large size breed group was much less affected by herd of origin than that in the small size breed group (Figure 3.1). Similar results were reported by Amal and Crow (1987), where the herd of origin effect on body weight in the large size Chrolais-Simmental group was less than that in the small size Angus-Hereford group. This could be related to the different mature size of the breeds. The small size breeds are generally early mature except Limousin which was a late mature breed. Given the same chronological age, the bulls in the small size breed group could be physiologically older than the bulls in the large size breed group. On the other hand, studies showed that the younger the bulls entered the test station, the less important the herd of origin effect was (Collins-Lusweti and Curran 1985). Therefore, the effect of pre-test environmental factors associated with herd of origin would be large and last longer in the physiologically older bulls in small size breed group compared with that in the physiologically younger bulls in the large size breed group.

3.3.2.2. The intraherd correlations for the measures of absolute growth rate

The regression coefficient of weight on time (days) on test (REG) was the measure of absolute growth rate which was least affected by herd of origin (t_h was approximately 7 - 8 %), followed by average daily gain on test (ADG) (t_h was approximately 11%). Absolute (maximum) growth rate at the point of inflection of the growth curve was most affected by herd of origin (t_h was approximately 23 - 27%).

Herd of origin had less impact on periodic and cumulative absolute gains compared with periodic and cumulative relative growth rates, accounting for less than 16% of the phenotypic variance. The impact of herd of origin on periodic absolute gains dropped dramatically as the test advanced (Figure 3.2). The change in the impact of herd of origin in different periods indicated that at least part of the herd of origin effect was temporary in nature. The bulls would compensate for pre-test environmental differences for at least 28 days in addition to the 28-day adjustment period. During this period, the bulls from nutritionally more restricted herds tended to grow faster than those from more liberally fed herds. Therefore, in order to reduce the impact of herd of origin to 16% or less, 56 days should be the minimum length of the adjustment period.

The least affected period by herd of origin started from day 28 and day 56 in the large and small size breed groups, respectively, and lasted until day 112 of the test. However, in the last 28-day period, there was an increase in the impact of herd of origin in both breed groups.

It is difficult to explain the rise in t_h in the last 28-day period. This was perhaps partly due to the fact that the bulls from the more liberally fed herds did not gain according to their genetic potentials during the previous periods and started to compensate. This hypothesis, however, could not be tested in the present study due to the lack of necessary information.

The impact of herd of origin on cumulative gains decreased as the test advanced to 112 d and then increased again, indicating that 140-d period may not be the best test period for evaluating gain potentials of bulls (Figure 3.3). Instead, the periods between day 28 and day 112 and between day 56 and day 112 of the test, for the large and small size breed groups, respectively, were more accurate, since gains in these periods were less affected by herd of origin.

3.3.2.3. The intraherd correlations for the measures of relative growth rate

The measures of relative growth rate, RGR and K were highly affected by herd of origin (Table 3.5). The t_h's were approximately 41% and 25% in small and large size breed groups, respectively. RGRL was less affected by herd of origin compared with RGR and K, accounting for 14% and 11% of the total phenotypic variances for the small and large size breed groups, respectively.

Periodic and cumulative measures of relative growth rate were highly affected by herd of origin. The impact of herd of origin on periodic relative growth rate was relatively stable up to day 84, then decreased dramatically in the 4th 28-day period, and increased dramatically again in the last 28-day period (Figure 3.4). The least affected period was too short to be considered for evaluating growth potentials of the bulls, as growth rate calculated in a short period tended to be affected by temporary environmental factors. The impact of herd of origin on cumulative relative growth rate showed increasing trends as the test advanced (Figure 3.5).

3.3.2.4. Discussion on intraherd correlations

In general, the results suggested that measures of absolute growth rate measured in mid-period of the test as was described above were least affected by herd of origin, and thus were suitable for evaluating growth potentials of bulls in a station performance test system. More studies are needed to determine the optimum test period.

Amal and Crow (1987) also treated herd of origin as a random effect in their study and calculated the proportion of the total phenotypic variance which was due to herd of origin, assuming that the total phenotypic variance was composed of three components (herd of origin, sire and error components of variance). Their results showed that at the start of the test, 39% and 33% of the total phenotypic variance among bull weights were due to the herd of origin effect for the Angus-Hereford and Charolais-Simmental data sets, respectively. The proportion dropped gradually to 30 and 22% at the 112-day weighing for the two data sets, respectively, and remained at these levels for the 140-day weight. For periodic gains, herd of origin was a major source of variation for the 28-d adjustment period, accounting for 45% and 34% of the total phenotypic variance for the two data sets, respectively, but had little effect on the subsequent periods. Herd of origin accounted for 15% and 16% of the total phenotypic variance in 140-d cumulative gain for the two data sets, respectively. Based on the above results, it was suggested that emphasis should be given to gain as opposed to weight in evaluating bulls for growth potentials. Amal and Crow (1987) also found the rise in t_h in the last 28-day period of test for the Charolais-

Simmental data set and attributed the rise to genetic differences among herds.

3.3.3. Heritability Estimates

The estimates of heritability for two weights, three measures of absolute growth rate and three measures of relative growth [illegible] shown in Table 3.6. Surprisingly, only a few of the [illegible]es were significantly different from zero. In general, the heritability estimates in the small size breed groups were higher than those in the large size breed group. The heritability estimates of start of test weight were 0.47±0.18 and 0.24±0.64 for the small and large size breed groups, respectively. Amal and Crow (1987) reported the heritability estimates of 0.33 and 0.61 for Angus-Hereford and Charolais-Simmental breed groups, respectively. The heritability estimates of end of test weight were 0.86±0.25 and 0.17±0.77 for the small and large size breed groups, respectively, while Amal and Crow (1987) reported the heritability estimates of 0.24 and 0.47 for Angus-Hereford and Charolais-Simmental breed groups, respectively. Average daily gain was highly heritable with heritability estimates of 0.69±0.45 and 0.43±0.34 for the small and large size breed groups, respectively. These estimates were generally larger than those reported in the literature. Kemp (1990) estimated the heritablity of average daily gain on test to be 0.29. Wilton and McWhir (1985) and de Rose et al. (1988) reported the estimates of 0.50 and 0.44, respectively. A value of 0.08 for 140-day test gain was reported by McWhir and Wilton (1987). Brown et al. (1988) reported the heritability estimates to be 0.33 and 0.36 for Hereford and Angus bulls, respectively. Linear regression coefficient of weight on days on test was highly heritable with heritabilities of 0.97±0.70 and 0.46±0.36 for the small and large size breed groups, respectively. The heritability estimates for average relative growth rate were 0.37±0.19 and 0.34±0.27 for for the small and large breed groups, respectively. Fitzhugh and Taylor (1971) estimated the heritability of average relative growth rate to be 0.47 for the period of 6 to 12 months of age. The heritability of average relative growth rate from 200 to 396 days for Hereford, Angus and Shorthorn was -0.07 as reported by Smith et al. (1976). The heritability estimates for instantaneous percentage growth rate were of the same magnitude as those for average relative growth rate. The heritability estimates of absolute (maximum) growth rate at the point of inflection of the logistic growth curve in both breed groups and that of relative growth rate at the point of inflection of the logistic growth curve in large size breed group were close to zero. The heritability estimate of relative growth at the point of inflection of the logistic growth curve in the small size breed group was 0.36±0.26. These nil heritability estimates could be the results of the lack of fit of the logistic growth curve, as only six weight-age classes were available. Literature estimates of heritabilities for regression coefficient of weight on days on test, instantaneous percentage growth rate, absolute (maximum) growth rate at the point of inflection of the logistic growth curve and relative growth rate at the point of inflection of the logistic growth curve were not available for comparison purposes.

3.4. SUMMARY AND CONCLUSIONS

Performance records of beef bulls tested at the Ellerslie Test Station from 1974 to 1987 were used to examine the effects of herd of origin, age of dam and age of bull on bull weight and growth rate in the test station.

Based on the results of this study, several conclusions were drawn as follows:

1. The effects of age of dam, age and weight of bull at start of test were not of practical importance for evaluating growth potentials of bulls for growth rate as they each accounted for a small amount of variation in growth rate. Adjusting for these factors would therefore not be of practical importance.

2. The effect of herd of origin was important. The impact of herd of origin on absolute gain was important at

the beginning of the test. The gain in the mid-period of the test was least affected by herd of origin. The impact of the herd of origin effect increased again during the last 28-day period.

3. Considering the impact of herd of origin and the heritabilities, it seemed that absolute growth rate (the linear regression of weight on days on test if available would be recommended) was the most appropriate measure for evaluating growth potentials of bulls in the test station.

TABLE 3.1. STRUCTURE OF THE DATA.

Breed	No. of bulls	No. of sires	No. of herds	No. of years
Angus	335	160	72	9
Hereford	169	69	30	9
Limousin	103	48	25	5
Shorthorn	125	62	35	6
Main-Anjou	214	100	59	8
Salers	167	84	51	6
Simmental	415	180	84	11
Blonde d'Aquitaine	117	60	25	5
Charolais	200	91	46	7
Gelbvieh	189	71	30	7
Total	2034	931		

TABLE 3.2. MEANS AND STANDARD DEVIATIONS OF THE PERFORMANCE TRAITS.

Trait[b]	Breed[a]									
	AN	HE	LM	SS	BD	CH	GV	MA	SA	SM
					Weights					
SOTW (Kg)	296.24±41.98	266.61±38.85	285.38±35.34	267.87±29.78	302.25±40.29	322.11±45.91	334.08±49.92	321.63±40.92	313.08±39.53	337.93±53.64
W28 (Kg)	331.36±45.59	298.46±39.54	316.88±36.78	300.76±31.20	345.85±49.50	361.34±49.12	375.28±50.42	358.11±42.60	359.09±44.70	379.89±56.91
W56 (Kg)	362.15±46.62	331.95±41.31	349.02±39.54	334.99±31.58	386.55±46.91	401.09±51.13	410.57±51.84	396.80±44.19	397.45±46.55	418.59±58.33
W84 (Kg)	396.00±49.79	363.17±42.45	378.99±39.61	361.08±34.29	425.43±50.37	436.82±52.74	447.03±53.06	435.47±46.55	435.40±50.41	456.89±61.02
W112 (Kg)	430.18±51.20	394.86±43.44	413.53±42.09	398.26±37.13	468.02±50.87	480.82±54.23	488.04±54.11	478.24±49.25	474.36±54.01	498.71±61.43
W140 (Kg)	466.16±51.74	433.10±45.59	443.57±40.71	431.31±36.69	506.31±52.62	524.83±55.72	525.08±52.94	520.30±50.51	510.51±55.64	539.66±60.67
					Absolute Growth Rates in the Entire Test Period					
ADG (Kg/d)	1.21±0.16	1.19±0.17	1.13±0.11	1.17±0.14	1.45±0.20	1.45±0.19	1.36±0.16	1.42±0.18	1.41±0.20	1.44±0.17
REG (Kg/d)	1.20±0.16	1.18±0.16	1.13±0.12	1.16±0.44	1.45±0.20	1.44±0.19	1.35±0.16	1.42±0.19	1.40±0.20	1.44±0.17
AGRL(kg/d)	1.32±0.26	1.27±0.21	1.31±0.25	1.23±0.18	1.60±0.24	1.54±0.22	1.48±0.24	1.50±0.20	1.54±0.25	1.58±0.25
					Absolute Growth Rate: Periodic Gains					
PG1 (Kg)	34.99±11.39	32.44±8.40	31.50±9.60	32.89±6.78	43.61±12.80	39.28±9.55	41.10±9.48	36.48±9.86	46.01±14.27	42.17±9.98
PG2 (Kg)	30.79±10.57	32.80±7.35	32.14±7.90	34.12±7.47	40.25±8.83	39.81±10.17	35.29±8.70	38.67±9.46	38.36±11.61	38.64±10.58
PG3 (Kg)	33.84±8.78	31.22±6.98	29.97±8.10	26.15±8.00	38.88±9.73	36.16±10.21	36.46±[illegible]	39.02±9.61	37.86±11.03	38.34±10.78
PG4 (Kg)	34.00±8.10	32.28±9.55	34.63±9.28	37.18±7.13	42.59±7.82	43.46±7.33	40.78±8.46	42.45±9.70	38.95±10.63	42.10±10.41
PG5 (Kg)	35.52±11.33	38.24±11.80	30.04±11.05	33.05±8.23	38.28±11.97	44.02±9.86	37.27±10.95	42.06±8.31	36.15±9.46	40.95±12.23
					Absolute Growth Rate: Cumulative Gains					
CG28 (Kg)	34.99±11.39	32.44±8.40	31.50±9.60	32.89±6.78	43.61±12.80	39.28±9.55	41.10±9.48	36.48±9.86	46.01±14.27	42.17±9.98
CG56 (Kg)	65.93±12.09	65.58±11.27	63.46±12.59	66.91±9.97	83.86±16.53	79.16±15.39	76.37±13.48	75.26±14.46	84.37±15.64	80.84±15.48
CG84 (Kg)	99.74±16.82	96.80±14.12	93.61±14.72	93.21±13.13	122.74±23.14	115.27±18.82	112.72±16.13	114.28±18.82	122.30±22.46	119.21±17.42
CG112 (Kg)	134.00±19.59	128.93±19.08	128.35±18.72	130.39±16.29	165.33±25.59	158.96±21.47	153.49±19.68	156.78±23.20	161.26±25.91	161.27±20.83
CG140 (Kg)	169.68±22.27	167.17±23.49	158.39±16.65	163.44±19.69	203.62±28.33	202.98±26.50	190.78±22.14	198.83±25.15	197.40±28.36	202.23±24.07

TABLE 3.2. MEANS AND STANDARD DEVIATIONS FOR THE PERFORMANCE TRAITS (Cont'd).

Trait	Breed									
	AN	HE	LM	SS	BD	CH	GV	MA	SA	SM
				Relative Growth Rates in the Entire Test Period						
RGR (%/d)	0.33±0.05	0.35±0.05	0.32±0.04	0.34±0.04	0.37±0.05	0.35±0.05	0.33±0.05	0.35±0.05	0.35±0.04	0.34±0.05
K (%/d)	0.32±0.05	0.35±0.05	0.32±0.04	0.34±0.04	0.37±0.05	0.35±0.05	0.32±0.05	0.35±0.05	0.35±0.04	0.34±0.05
RGRL (%/d)	0.42±0.12	0.40±0.10	0.48±0.18	0.40±0.09	0.49±0.13	0.43±0.12	0.45±0.13	0.42±0.11	0.50±0.12	0.45±0.13
				Periodic Relative Growth Rates						
PR1 (%/d)	0.40±0.12	0.42±0.12	0.38±0.12	0.41±0.09	0.48±0.13	0.41±0.10	0.42±0.11	0.38±0.11	0.49±0.14	0.43±0.10
PR2 (%/d)	0.32±0.11	0.37±0.08	0.35±0.08	0.39±0.09	0.48±0.09	0.38±0.10	0.32±0.08	0.37±0.09	0.37±0.11	0.35±0.10
PR3 (%/d)	0.32±0.08	0.32±0.08	0.30±0.09	0.27±0.08	0.34±0.08	0.31±0.09	0.31±0.08	0.34±0.08	0.33±0.09	0.32±0.09
PR4 (%/d)	0.30±0.07	0.31±0.09	0.31±0.08	0.35±0.06	0.34±0.07	0.34±0.06	0.32±0.07	0.33±0.07	0.31±0.08	0.32±0.09
PR5 (%/d)	0.29±0.09	0.33±0.10	0.25±0.10	0.29±0.08	0.28±0.09	0.32±0.07	0.27±0.08	0.30±0.06	0.26±0.07	0.29±0.09
				Cumulative relative Growth Rates						
CR28 (%/d)	0.40±0.12	0.42±0.12	0.38±0.12	0.41±0.09	0.48±0.13	0.41±0.10	0.42±0.11	0.38±0.11	0.49±0.14	0.43±0.10
CR56 (%/d)	0.36±0.07	0.40±0.07	0.36±0.07	0.40±0.07	0.44±0.08	0.40±0.08	0.37±0.08	0.38±0.08	0.43±0.07	0.39±0.08
CR84 (%/d)	0.35±0.06	0.37±0.06	0.34±0.06	0.36±0.05	0.41±0.07	0.37±0.06	0.35±0.06	0.36±0.06	0.39±0.07	0.36±0.06
CR112 (%/d)	0.34±0.05	0.36±0.06	0.33±0.05	0.36±0.04	0.39±0.06	0.36±0.05	0.34±0.05	0.36±0.05	0.37±0.05	0.35±0.05
CR140 (%/d)	0.33±0.05	0.35±0.05	0.32±0.04	0.34±0.04	0.37±0.05	0.35±0.05	0.33±0.05	0.35±0.05	0.35±0.04	0.33±0.05

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[a] AN, HE, LM, SS, BD, CH, GV, MA, SA and SM are Angus, Hereford, Limousin, Shorthorn, Blonde d'Aquitaine, Charolais, Gelbvieh, Maine-Anjou, Salers and Simmental, respectively.

[b] SOTWT is start of test weight, Wx is weight taken on the xth day of the test, ADG is average daily gain on test, REG is linear regression of weight on days on test, AGRL is absolute (maximum) growth rate at the point of inflection of the growth curve, PGx is periodic gain in the xth 28-day period, CGx is is cumulative gain in the period between the start and the xth day of the test, RGR is average relative growth rate, K is instantaneous growth rate, RGRL is relative growth rate at the point of inflection of the growth curve, PRx is periodic average relative growth rate in the xth 28-day period, CRx is cumulative average relative growth rate in the period between the start and the xth day of the test.

TABLE 3.3. THE REDUCTIONS IN THE COEFFICIENTS OF DETERMINATION (R', %) DUE TO THE FACTORS INFLUENCING THE GROWTH PERFORMANCE.

Trait[b]	Small size breed group[a]						Large size breed group[a]					
	Breed-Year	Dam age	Bull age	SOTWT	Herd	Sire	Breed-Year	Dam age	Bull age	SOTWT	Herd	Sire
						Weights						
SOTW (Kg)	14.31***	0.75**	3.35***	———	31.03***	5.84*	6.21***	0.65***	6.93***	———	29.13***	7.56
W28 (Kg)	0.80***	0.03	0.00	5.73***	1.36*	0.57	1.35***	0.01	0.00	8.23***	1.74	0.93*
W56 (Kg)	1.18***	0.02	0.01	5.42***	2.76*	1.15	2.13***	0.02	0.00	8.02***	3.03**	1.39
W84 (Kg)	1.60***	0.02	0.00	4.32***	3.85*	1.58	3.30***	0.01	0.00	7.13***	4.33*	2.05
W112 (Kg)	2.02***	0.03	0.07	4.91***	5.18*	2.14	3.39***	0.01	0.00	6.97***	5.86*	2.80
W140 (Kg)	3.00***	0.10	0.06	4.69***	7.57***	2.61	4.99***	0.02	0.00	6.48***	7.68**	3.42
					Absolute Growth Rates in the Entire Test Period							
ADG (Kg/d)	14.56***	0.47	0.30	0.17	36.68***	12.64	23.02***	0.08	0.01	0.01	35.48**	15.80
REG (Kg/d)	11.51***	0.39	0.33	0.22	38.17**	13.69	21.08***	0.08	0.01	0.02	35.72*	16.67
AGRL (Kg/d)	1.13**	0.30	0.62*	0.83*	35.22**	24.10**	12.67***	0.07	0.27	0.94***	35.29*	17.22
					Absolute Growth Rate: Periodic Gains							
PG1 (Kg)	18.09***	0.76	0.08	0.33	30.64*	12.89	24.67***	0.15	0.06	0.07	31.85	17.03*
PG2 (Kg)	14.45***	0.31	0.09	0.21	35.11*	16.20	20.36***	0.65	0.03	0.05	33.48	21.35**
PG3 (Kg)	12.36***	0.16	0.17	0.14	27.79	16.26	29.56***	0.15	0.00	0.01	30.40	16.50
PG4 (Kg)	9.19***	0.34	2.53***	1.16*	34.92	22.43	14.26***	0.12	0.04	0.05	34.93	21.42
PG5 (Kg)	46.44***	0.47	0.00	0.03	14.05*	6.33	40.62***	0.04	0.00	0.07	22.53*	10.81
					Absolute Growth Rate: Cumulative Gains							
CG28 (Kg)	18.09***	0.76	0.08	0.33	30.64*	12.89	24.67***	0.15	0.06	0.07	31.85	17.03
CG56 (Kg)	15.45***	0.26	0.07	0.19	36.24*	15.09	23.12***	0.22	0.00	0.12	32.89**	15.13
CG84 (Kg)	13.80***	0.19	0.00	0.01	33.13**	13.64	24.54***	0.06	0.00	0.04	32.08*	15.23
CG112 (Kg)	13.37***	0.21	0.44	0.35	34.19*	14.16	19.91***	0.08	0.01	0.07	34.44*	16.47
CG140 (Kg)	14.56***	0.47	0.30	0.17	36.68***	12.64	23.02***	0.08	0.01	0.01	38.48**	15.80

TABLE 3.3. THE REDUCTIONS IN THE COEFFICIENTS OF DETERMINATION (R^2, %) DUE TO THE FACTORS INFLUENCING THE GROWTH PERFORMANCE (Cont'd).

Trait	Small size breed group						Large size breed group					
	Breed-Year	Dam age	Bull age	SOTWT	Herd	Sire	Breed-Year	Dam age	Bull age	SOTWT	Herd	Sire
Relative Growth Rates in the Entire Test Period												
RGR (%/d)	8.60***	0.28	0.26	2.60***	20.40**	7.32	11.02***	0.04	0.00	4.63***	18.19**	7.95
K (%/d)	7.28***	0.25	0.29	2.55***	22.21**	8.07	10.20***	0.04	0.00	4.59***	18.70*	8.60
RGRI (%/d)	4.28**	0.30	0.01	0.01	36.43	30.79***	13.41***	0.13	0.11	0.06	37.16*	17.18
Periodic Relative Growth Rates												
PR1 (%/d)	16.38***	1.27	0.19	0.27	28.34**	10.86	22.01***	0.14	0.06	1.19***	26.89	15.18
PR2 (%/d)	12.56***	0.24	0.10	0.42	29.10*	13.35	16.80***	0.53	0.04	1.09***	27.23	17.39**
PR3 (%/d)	12.83***	0.23	0.19	2.09***	29.56	17.32	26.03***	0.22	0.01	1.81***	28.85	15.37
PR4 (%/d)	7.27***	0.34	2.54***	0.00	28.79	19.22	11.79***	0.10	0.01	1.30***	26.79	17.61*
PR5 (%/d)	41.13***	0.47	0.01	0.55	10.86	5.83	35.58***	0.06	0.01	1.45***	18.59	9.64
Cumulative Relative Growth Rates												
CR28 (%/d)	16.38***	1.27	0.19	0.27	28.34**	10.86	22.01***	0.14	0.06	1.19***	26.89	15.18
CR56 (%/d)	11.66***	0.20	0.10	1.70***	27.46*	11.65	16.49***	0.13	0.00	2.13***	24.14**	10.97
CR84 (%/d)	11.61***	0.13	0.00	3.41***	27.58**	10.74	16.79***	0.05	0.00	3.22***	22.19*	10.37
CR112 (%/d)	9.61***	0.17	0.44	2.36***	23.55**	9.61	11.09***	0.04	0.00	3.88***	19.95*	9.49
CR140 (%/d)	8.60***	0.28	0.26	2.60***	20.40**	7.32	11.02***	0.04	0.00	4.63***	18.19**	7.95

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[a] Small size breed group includes Angus, Hereford, Limousin and Shorthorn; Large size breed group includes Blonde d'Aquitaine, Charolais, Gelbvieh, Maine-Anjou, Salers and Simmental.

[b] SOTWT is start of test weight, Wx is weight taken on the xth day of the test, ADG is average daily gain on test, REG is linear regression of weight on days on test, AGRL is absolute (maximum) growth rate at the point of inflection of the growth curve, PGx is periodic gain in the xth 28-day period, CGx is is cumulative gain in the period between the start and the xth day of the test, RGR is average relative growth rate, K is instantaneous growth rate, RGRL is relative growth rate at the point of inflection of the growth curve, PRx is periodic average relative growth rate in the xth 28-day period, CRx is cumulative average relative growth rate in the period between the start and the xth day of the test.

***, **, *, Significant at $P<0.001$, $P<0.01$ and $P<0.05$, respectively, The degrees of freedom are 10, 4, 1, 1, 137, 90 and 130 in Small Size Breed Group and are 28, 4, 1, 1, 358, 220, and 262 in Big Size Breed Group for breed-year, age of dam, age of bull, start of test weight, herd of origin, sire and residual, respectively.

TABLE 3.4. PARTIAL REGRESSION COEFFICIENTS OF GROWTH TRAITS ON AGE (b_1) AND START OF TEST WEIGHT (b_2) OF BULL.[a]

Trait[b]	Small size breed group[c]		Large size breed group[c]	
	b_1	b_2	b_1	b_2
		Weights		
SOTW (Kg)	0.81±0.10***	———	1.32±0.11***	———
W28 (Kg)	-0.04±0.06	1.05±0.04***	-0.04±0.04	1.02±0.02***
W56 (Kg)	-0.04±0.07	1.05±0.05***	-0.01±0.06	1.04±0.03***
W84 (Kg)	0.01±0.09	1.01±0.06***	-0.01±0.08	1.03±0.04***
W112 (Kg)	-0.17±0.11	1.12±0.08***	-0.04±0.09	1.04±0.05***
W140 (Kg)	-0.17±0.12	1.10±0.09***	-0.03±0.10	1.02±0.05***
		Absolute Growth Rates in the Entire Test Period		
ADG (g/d)	-1.20±0.80	0.70±0.60	-0.20±0.70	0.10±0.40
REG (g/d)	-1.30±0.90	0.80±0.60	-0.20±0.70	0.20±0.40
AGRL (g/d)	-2.20±1.00*	1.90±0.80*	-1.90±1.00	1.80±0.50***
		Absolute Growth Rates: Periodic Gains		
PG1 (Kg)	-0.04±0.06	0.05±0.04	-0.04±0.04	0.02±0.02
PG2 (Kg)	-0.04±0.05	0.04±0.04	0.02±0.04	0.02±0.02
PG3 (Kg)	0.05±0.05	-0.04±0.04	-0.01±0.04	-0.01±0.02
PG4 (Kg)	-0.19±0.06***	0.10±0.04*	-0.03±0.04	0.02±0.02
PG5 (Kg)	0.01±0.05	-0.02±0.03	0.00±0.04	-0.02±0.02

TABLE 3.4. PARTIAL REGRESSION COEFFICIENTS OF GROWTH TRAITS ON AGE (b_1) AND START OF TEST WEIGHT (b_2) OF BULL.[a] (Cont'd).

Trait[b]	Small size breed group[c]		Large size breed group[c]	
	b_1	b_2	b_1	b_2
		Absolute Growth Rates: Cumulative Gains		
CG28 (Kg)	-0.04±0.06	0.05±0.04	-0.04±0.04	0.02±0.02
CG56 (Kg)	-0.04±0.07	0.05±0.05	-0.01±0.06	0.04±0.03
CG84 (Kg)	0.01±0.09	0.01±0.06	-0.01±0.08	0.03±0.04
CG112 (Kg)	-0.17±0.11	0.12±0.08	-0.04±0.09	0.04±0.05
CG140 (Kg)	-0.17±0.12	0.10±0.09	-0.03±0.10	0.02±0.05
		Relative Growth Rates in the Entire Test Period		
RGR (%/d)	-0.0003±0.0002	-0.0008±0.0001***	-0.0001±0.0001	-0.0008±0.0001***
K (%/d)	-0.0029±0.0017	-0.0064±0.0012***	-0.0001±0.0012	-0.0066±0.0006***
RGRL (%/d)	-0.0001±0.0005	0.0001±0.0004	-0.0005±0.0005	-0.0002±0.0002
		Periodic Relative Growth Rates		
PR1 (%/d)	-0.0006±0.0007	-0.0006±0.0005	-0.0004±0.0004	-0.0009±0.0002***
PR2 (%/d)	-0.0004±0.0005	-0.0006±0.0004	0.0003±0.0003	-0.0007±0.0002***
PR3 (%/d)	0.0005±0.0005	-0.0012±0.0003***	-0.0001±0.0003	-0.0008±0.0001***
PR4 (%/d)	-0.0017±0.0005***	0.0001±0.0004	-0.0001±0.0002	-0.0006±0.0001***
PR5 (%/d)	0.0002±0.0004	-0.0008±0.0003**	0.0001±0.0003	-0.0007±0.0001***

TABLE 3.4. PARTIAL REGRESSION COEFFICIENTS OF GROWTH TRAITS ON AGE (b_1) AND START OF TEST WEIGHT (b_2) OF BULL.[a] (Cont'd).

Trait[b]	Small size breed group[c]		Large size breed group[c]	
	b_1	b_2	b_1	b_2
		Cumulative Relative Growth Rates		
CR28 (%/d)	-0.0006±0.0007	-0.0006±0.0005	-0.0004±0.0004	-0.0009±0.0002***
CR56 (%/d)	-0.0003±0.0003	-0.0009±0.0003***	-0.0001±0.0002	-0.0008±0.0001***
CR84 (%/d)	-0.0001±0.0003	-0.0010±0.0002***	-0.0001±0.0002	-0.0008±0.0001***
CR112 (%/d)	-0.0004±0.0002	-0.0008±0.0002***	-0.0001±0.0002	-0.0008±0.0001***
CR140 (%/d)	-0.0003±0.0002	-0.0008±0.0001***	-0.0001±0.0001	-0.0008±0.0001***

[a] Age of bull is in days.

[b] SOTW is start of test weight, Wx is weight on the xth day of the test, ADG is average daily gain on test, REG is linear regression coefficient of weight on days on test, AGRL is absolute (maximum) growth rate at the point of inflection of the growth curve, PGx is the periodic gain in xth 28-day period, CGx is the cumulative weight gain in the period between the start and the xth day of the test, RGR is average relative growth rate, K is instantaneous percentage growth rate, RGRL is relative growth rate at the point of inflection of the growth curve, PRx is the periodic relative growth rate in the xth 28-day period, and CRx is the cumulative relative growth rate in the period between the start and the xth day of the test.

[c] Small size breed group includes Angus, Hereford, Limousin and Shorthorn; large size breed group includes Blonde d'Aquitaine, Charolais, Gelbvieh, Maine-Anjou, Salers and Simmental.

***, ** and *, significant at $P < 0.001$, $P < 0.01$ and $P < 0.05$, respectively.

TABLE 3.5. INTRAHERD CORRELATION ESTIMATES (t_h, %) AND THEIR STANDARD ERRORS (SE(t_h)).

Trait[a]	Small size breed group[b]	Large size breed group[b]
	Weights	
SOTW	51.51±5.72*[c]	36.66±6.94*
W28	47.09±6.04*	34.47±6.91*
W56	45.43±6.10*	31.07±6.78*
W84	39.15±6.41*	29.82±6.91*
W112	39.58±6.35*	29.53±6.90*
W140	35.06±6.58*	30.35±7.03*
	Absolute Growth Rates in the Entire Test Period	
ADG	10.54±6.64	10.64±7.03
REG	7.93±6.70	7.28±7.02
AGRL	23.21±6.00	27.47±4.97*
	Absolute Growth Rates: Periodic Gains	
PG1	14.19±6.15*	15.01±4.45*
PG2	15.79±4.97*	8.04±4.38*
PG3	8.29±5.67	10.19±4.76*
PG4	3.12±6.37	0
PG5	13.60±5.55*	13.67±5.75*
	Absolute Growth Rates: Cumulative Gains	
CG28	14.19±6.15*	15.01±4.45*
CG56	10.01±6.27	11.19±6.05*
CG84	7.06±5.83	7.82±6.00
CG112	7.28±6.15	4.94±6.87
CG140	9.57±6.83	10.64±6.84

TABLE 3.5. INTRAHERD CORRELATION ESTIMATES (t_h, %) AND THEIR STANDARD ERRORS (SE(t_h)) (Cont'd).

Trait	Small size breed group	Large size breed group
	Relative Growth Rates in the Entire Test Period	
RGR	42.47±5.08*	26.21±6.28*
K	41.34±5.22*	24.89±6.26*
RGRL	13.59±5.23*	10.59±4.19*
	Periodic Relative Growth Rates	
PR1	23.09±4.46*	18.02±4.52*
PR2	14.36±6.44*	22.50±4.89*
PR3	28.00±5.73*	13.40±4.78*
PR4	4.27±6.53	2.06±6.14
PR5	20.94±5.64*	14.23±5.69*
	Cumulative Relative Growth Rates	
CR28	23.09±4.46*	18.02±4.52*
CR56	28.10±6.04*	26.56±6.14*
CR84	36.58±5.54*	25.87±4.67*
CR112	36.29±4.93*	23.54±6.54*
CR140	42.47±5.08*	26.21±6.28*

[a] SOTW is start of test weight, Wx is weight on the xth day of the test, ADG is average daily gain on test, REG is linear regression coefficient of weight on days on test, AGRL is absolute (maximum) growth rate at the point of inflection of the growth curve, PGx is the periodic gain in xth 28-day period, CGx is the cumulative weight gain in the period between the start and the xth day of the test, RGR is average relative growth rate, K is instantaneous percentage growth rate, RGRL is relative growth rate at the point of inflection

of the growth curve, PRx is the periodic relative growth rate in the xth 28-day period, and CRx is the cumulative relative growth rate in the period between the start and the xth day of the test.

[b] Small size breed group includes Angus, Hereford, Limousin and Shorthorn and large size breed group includes Blonde d'Aquitaine, Charolais, Gelbvieh, Maine-Anjou, Salers and Simmental.

[c] $t_h \pm SE(t_h)$.

*, significant at $P < 0.05$ for one-tailed t test.

TABLE 3.6. HERITABILITY ESTIMATES (h^2) AND THEIR STANDARD ERRORS ($SE(h^2)$) OF SOME MEASURES OF GROWTH.

Trait[a]	Small size breed group[b]	Large size breed group[b]
	Weights	
SOTW	0.47±0.18*[c]	0.24±0.64
W140	0.86±0.25*	0.17±0.77
	Absolute Growth Rates	
ADG	0.69±0.45	0.43±0.34
REG	0.97±0.70	0.46±0.36
AGRL	0.06±0.24	0.02±0.22
	Relative Growth Rates	
RGR	0.37±0.19*	0.34±0.27
K	0.37±0.19*	0.34±0.27
RGRL	0.36±0.26	0

[a] ADG is average daily gain on test, REG is regression coefficient of weight on days on test, AGRL is absolute (maximum) growth rate at the point of inflection of the growth curve, RGR is average relative growth rate, K is instantaneous growth rate and RGRL is relative growth rate at the point of inflection of the growth curve.

[b] Small size breed group includes Angus, Hereford, Limousin and Shorthorn; large size breed group includes Blonde d'Aquitaine, Charolais, Gelbvieh, Maine-Anjou, Salers and Simmental.

[c] $h^2 \pm SE(h^2)$.

*, significant at $P < 0.05$ for one-tailed t test.

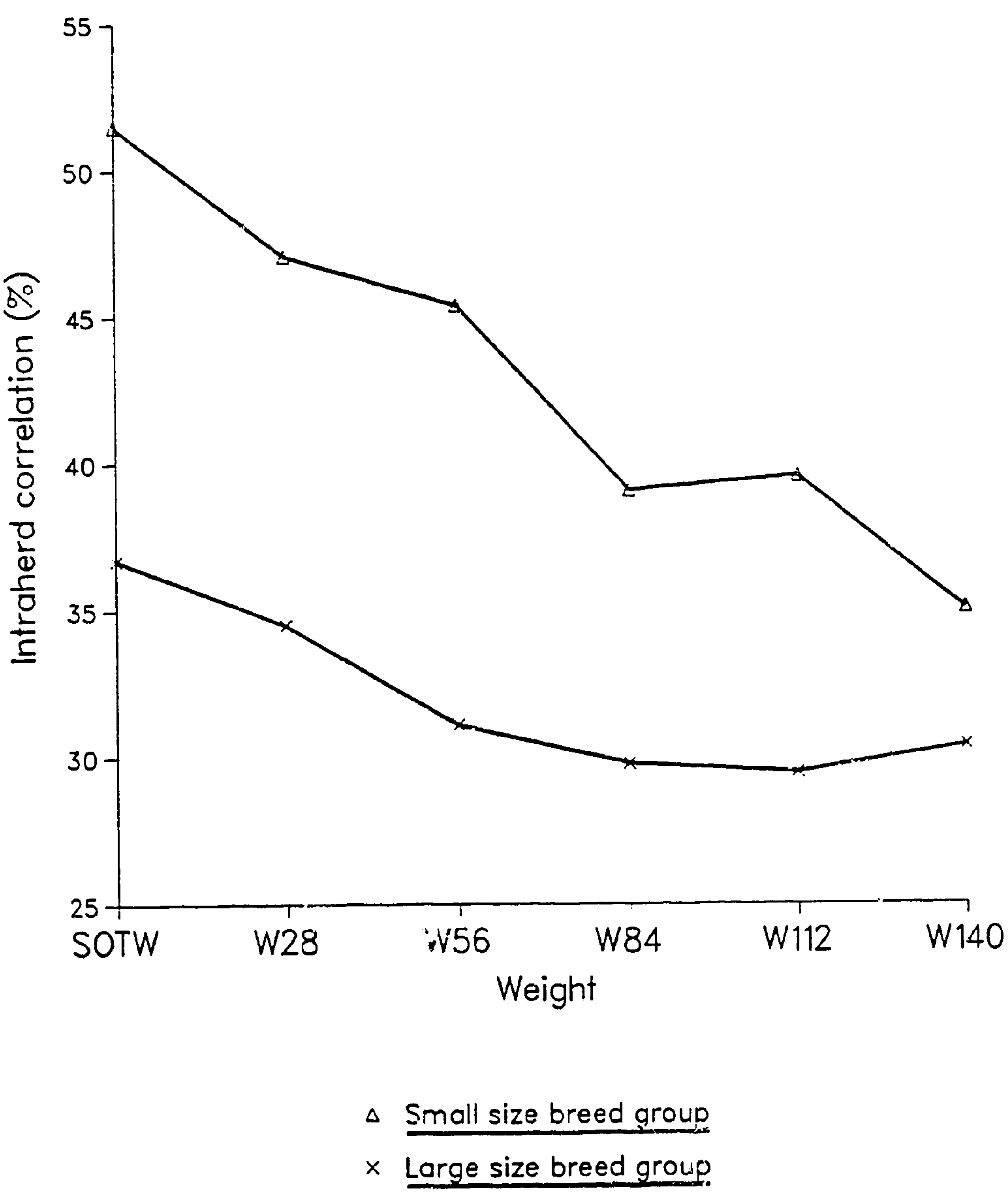

Figure 3.1. Intraherd correlations (%) for bull's weight in different periods during the test.

SOTWT: start of test weight.

Wx: weight taken on the xth day of the test.

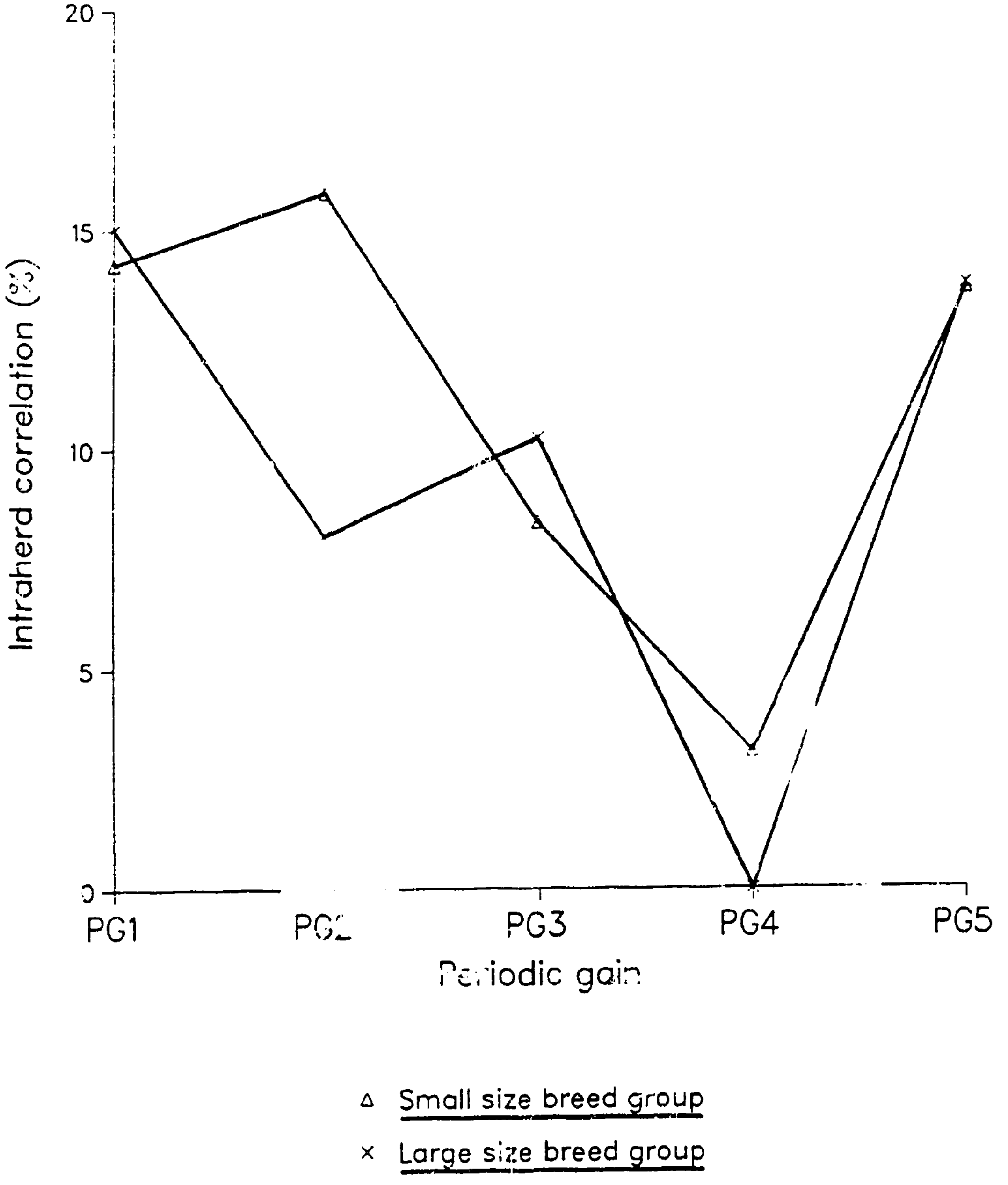

Figure 3.2. Intraherd correlations (%) for bull's periodic gain in different periods during the test.

PGx: gain in the xth 28-day period of the test.

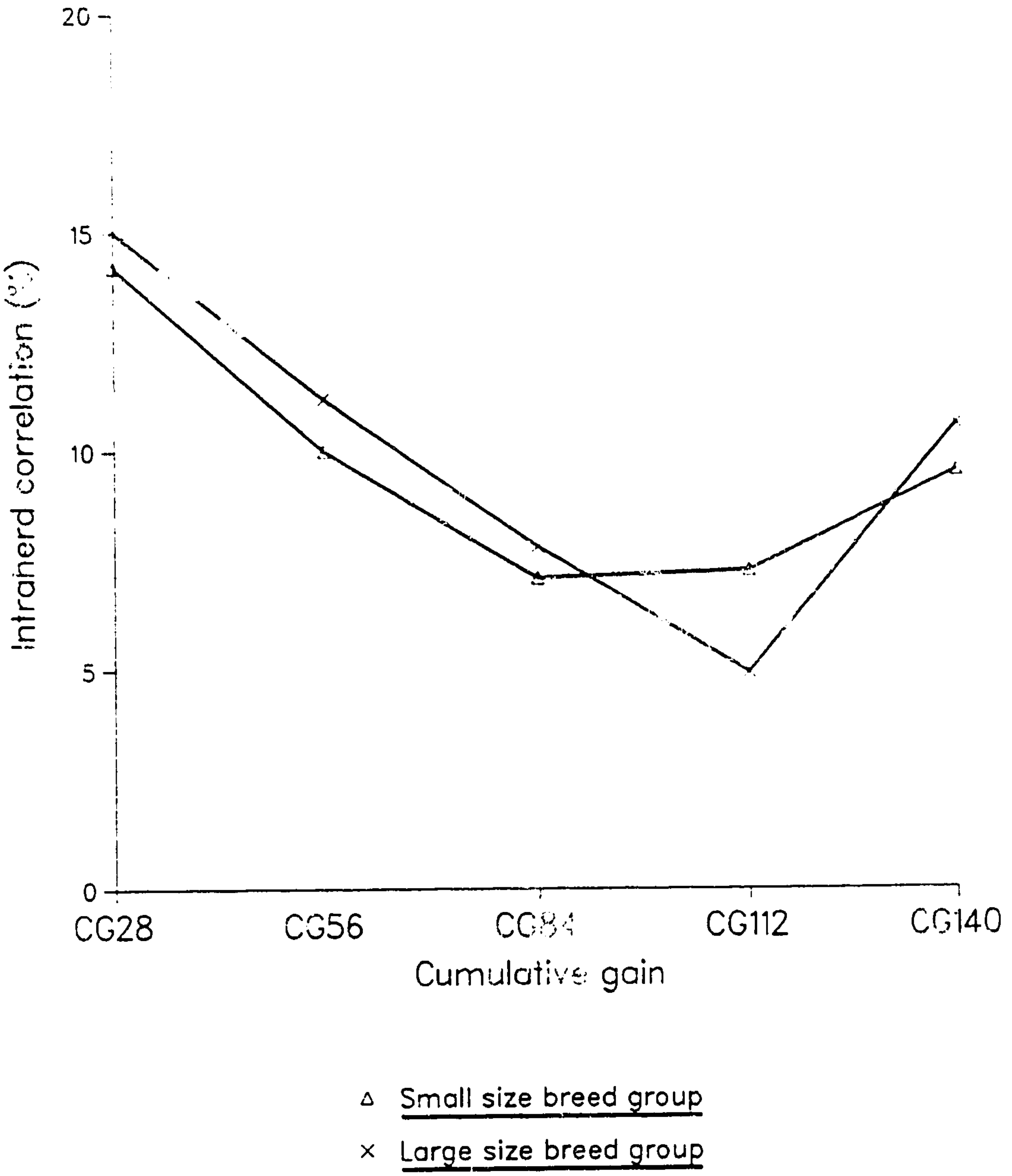

Figure 3.3. Intraherd correlations (%) for bull's cumulative gain in different periods during the test.

CGx: gain in the period between the start and the xth day of the test.

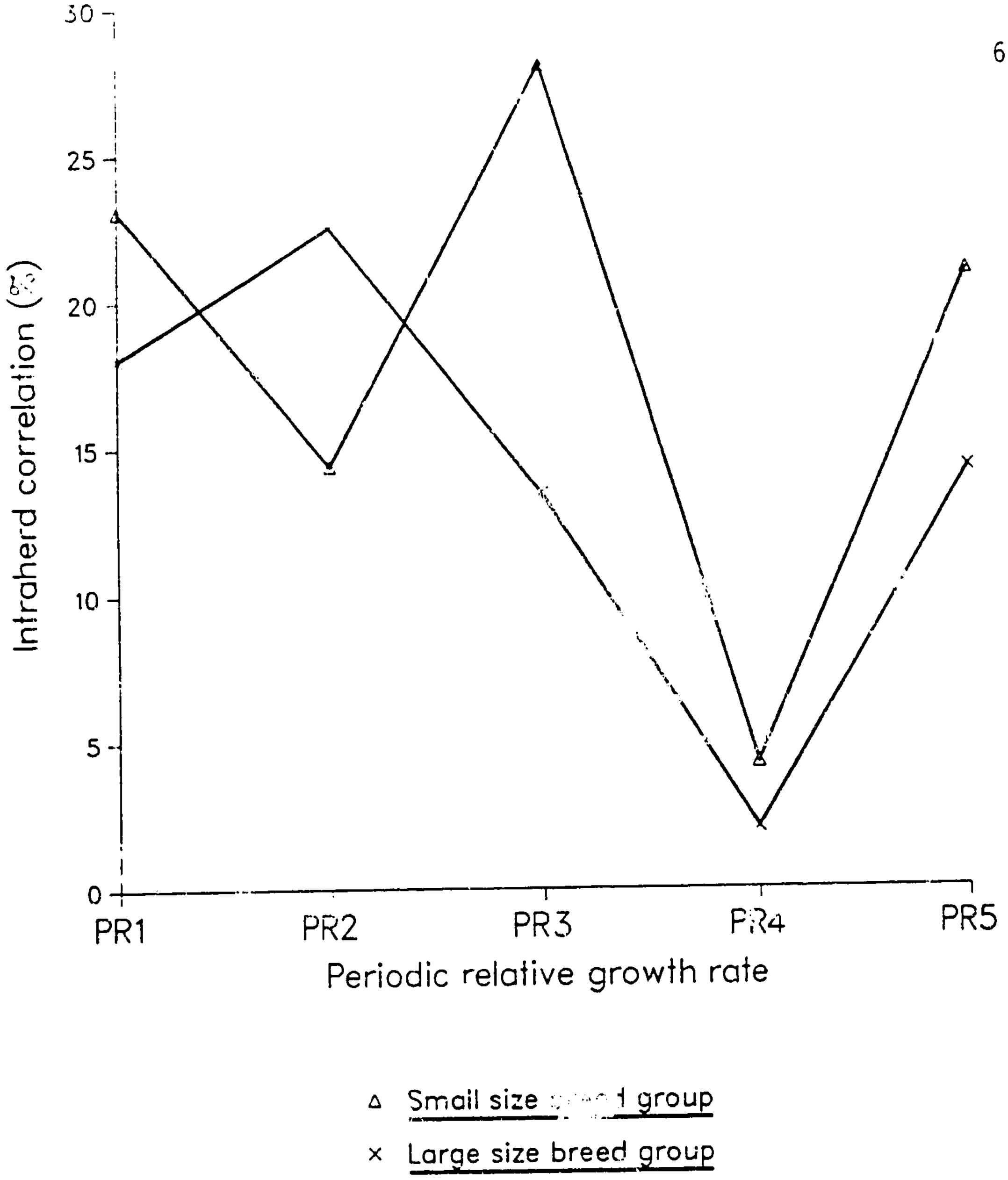

Figure 3.4. Intraherd correlations (%) for bull's periodic relative growth rate in different periods during the test.

PRx: relative growth rate in the xth 28-day period of the test.

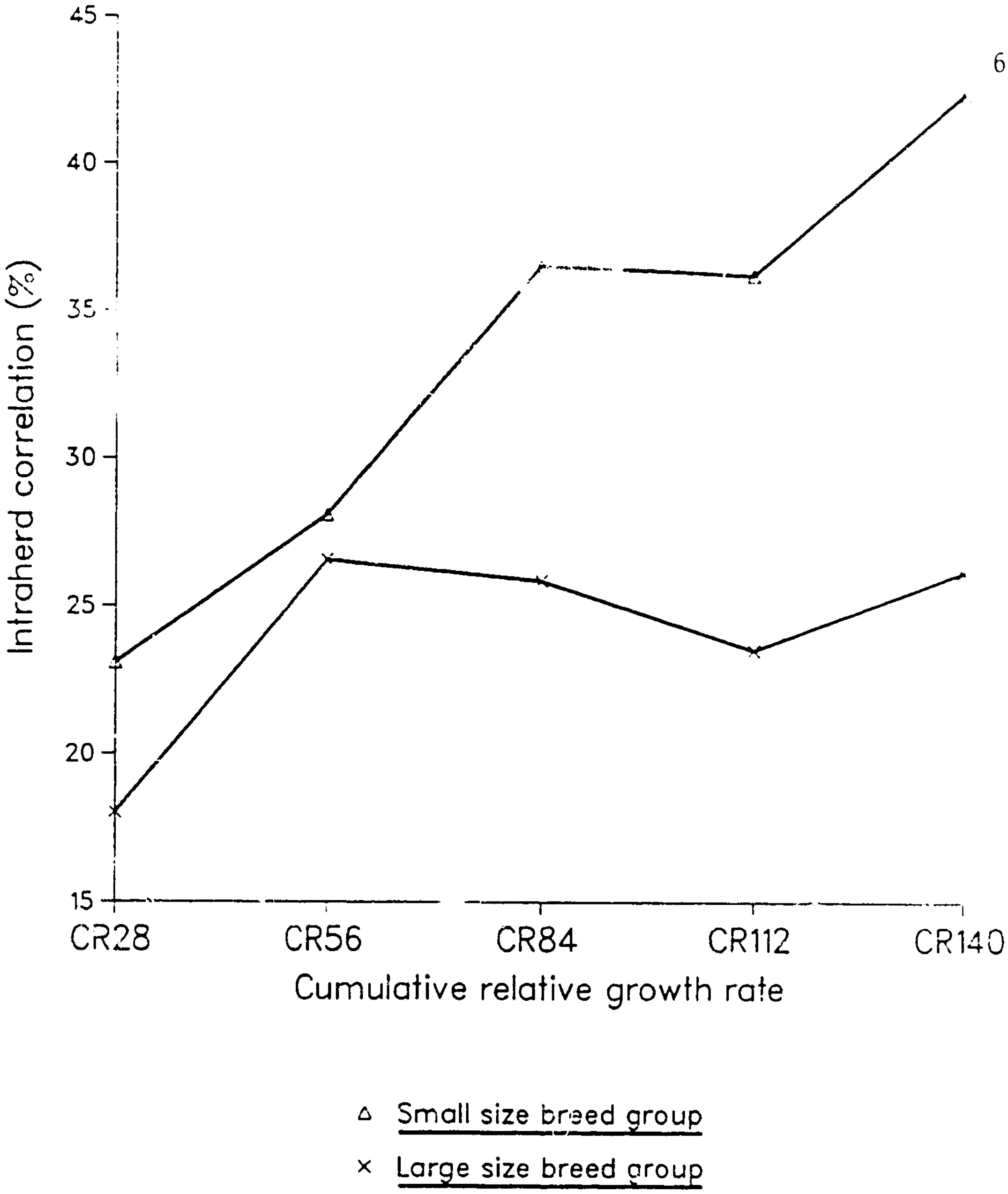

Figure 3.5. Intraherd correlations (%) for bull's cumulative relative growth rate in different periods during the test.

CRx: relative growth rate in the period between the start and the xth day of the test.

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CHAPTER 4

SELECTION OF OPTIMUM TEST PERIOD AND ASSOCIATIONS AMONG DIFFERENT TEST PERIODS FOR GROWTH RATES ON TEST

4.1. INTRODUCTION

The range in test period in most bull test stations is between 140 and 150 days. The advantage of a long period is that the effect of temporary fluctuations in gain tend to be averaged out. In other words, gain in a short period tends to be much influenced by temporary environmental factors.

There are a few reports on the comparison of 140 days vs. shorter test periods (Buchanan and McPeake 1986; Ronchietto 1989; Kemp 1990).

Three criteria are important in choosing a test period in test stations. First, the measurement in the period should be least affected by non-genetic factors such as herd of origin. Second, the measurement should have relatively high heritability to ensure satisfactory selection response. Third, a short test period would reduce the costs. Research has showed that approximately 80% of the variation among herds was non-genetic (Cundiff et al. 1975). Therefore, the minimization of herd effect may not sacrifice much genetic variation among herds. On the other hand, it may increase the accuracy to identify bulls which were genetically superior.

The objectives of this study were to investigate the feasibility of choosing a shorter test period and to study the associations of the growth rates in different test periods for accurate evaluation for growth potentials of young beef bulls in a test station.

4.2. MATERIALS AND METHODS

4.2.1. Description of the Data

The records of beef bulls from ten breeds tested at the Ellerslie Test Station, Alberta, Canada, collected from 1974 to 1987 were used for this study. The management in the station and the classification of these breeds into two homogeneous breed groups were described in Appendix 1. Two data sets corresponding to the two breed groups were used for statistical analysis. Data set I (small size breed group) included Angus, Hereford, Limousin and Shorthorn. Data set II (large size breed group) included Blonde d'Aquitaine, Charolais, Gelbvieh, Maine-Anjou, Salers and Simmental.

The average daily gains (G) in different test periods were calculated. These measurements included average daily gains from day 0 to day 140 (G0_140), from day 0 to day 112 (G0_112), from day 28 to day 140 (G28_140), from day 0 to day 84 (G0_84), from day 28 to day 112 (G28_112), from day 56 to day 140 (G56_140), from day 0 to day 56 (G0_56), from day 28 to day 84 (G28_84), from day 56 to day 112 (G56_112), from day 84 to day 140 (G84_140) and five 28-d periodic average daily gains (G0_28, G28_56, G56_84, G84_112 and G112_140). The regression coefficients of weight on days on test in different test periods (B) were calculated, and denoted in the same way as the average daily gain except that G was replaced by B (for example, B28_112 was the linear regression of weight on days on test in the period between day 28 and day 112 of the test).

4.2.2. Statistical Analysis

The same statistical model was applied to the two breed groups, separately. The mixed model was

$y_{ijkl} = \mu + t_i + h_{ij} + s_{ijk} + e_{ijkl}$

where y_{ijkl} was an observation on the l^{th} bull, μ was the population mean, t_i was a fixed effect common to bulls of the i^{th} breed-year, h_{ij} was a random effect of the j^{th} herd within the i^{th} breed-year [$\sim$NIID($0,\sigma^2_h$)], s_{ijk} was a random effect associated with the additive genetic value of the k^{th} sire [$\sim$NIID($0,\sigma^2_s$)], and e_{ijkl} is a random residual associated with the l^{th} bull [$\sim$NIID($0,\sigma^2_e$)], where NIID meant "normal, independent and identically distributed". The assumptions of the model were that sires were unrelated and were mated randomly to dams in the herds where the sires belonged, that dams were unrelated and represented in the data by only one son, that environmental errors within and between half-sib groups were uncorrelated, and that all interactions were insignificant. The model did not take into account the relationships among bulls and genetic trend due to lack of sufficient information. Similar to a study by Amal and Crow (1987), a hierarchical arrangement of herds within breed-year and sires within herd was assumed, even though this was not the case in practice. The same herd, for instance, appeared in several years and some sires had progeny in several herds and years within a breed. Ignoring the cross-classified nature of the data, especially with respect to sires, would prevent the removal of part of the genetic variation (due to differential usage of sires from herd to herd) among herds (Amal and Crow 1987). However, the treatment would avoid the loss in the degree of connectedness of the data. An additional assumption for the model was that all breeds in each of the breed groups had similar genetic and environmental variances. This assumption might not be correct in the strict sense. However, it ensured that sufficient data were available for variance estimation (Tong 1986).

The restricted maximum likelihood procedure (Patterson and Thompson 1971; SAS Institute Inc. 1985) was used to estimate variance components. The estimates of variance for all the traits converged within 20 rounds of iterations. The convergence value of the objective function was 10^{-8}.

Intraherd correlations (a measure of the similarity among herdmates compared with non-herdmates was defined as the fraction of herd of origin component of variance to the total phenotypic variance: $t_h = \sigma^2_h/(\sigma^2_h + \sigma^2_s + \sigma^2_e)$ were estimated to determine the impact of herd of origin on average daily gain and regression coefficient of weight on days on test in different test periods, so that the period which was least affected by the herd of origin effect could be identified. The heritabilities ($h^2 = 4\sigma^2_s/(\sigma^2_h + \sigma^2_s + \sigma^2_e)$) of the traits in these periods were also estimated. Approximate standard errors for t_h and h^2 were derived using the general procedure of error propagation as shown in Appendices 3 and 4, respectively.

Spearman rank correlations (R) were calculated between average daily gain in the entire test period (G0_140) and the average daily gains in other test periods and between the regression coefficient of weight on days on test in the entire test period (B0_140) and the regression coefficients in other test periods. These rank correlations were calculated on a within breed-year basis (Appendix 5), since the selection of bulls was made within breed and contemporary test group (year). These Spearman correlations were used to evaluate the associations of the traits in the period which was least affected by the herd of origin effect with those in the entire 140-day test period.

4.3. RESULTS AND DISCUSSION

4.3.1. Estimates of Intraherd Correlations and Heritabilities

The estimates of intraherd correlations and heritabilities are presented in Tables 4.1 and 4.2, respectively. In both breed groups, G28_112, B28_112, G84_112 and B84_112 were least affected by the herd of origin effect (Table 4.1). Most estimates of t_h were not significant because of large sampling errors. However, the statistical test revealed the fact that the measurements in the test periods near the start and end of the test were significantly affected by the herd of origin effect (Table 4.1).

The estimates of heritability of the measures of growth rate in most of the periods were not consistent in the two breed groups. However, the heritabilities of G28_112 and B28_112 were relatively high and significant in both breed groups. The same was true for G56_140 and B56_140 (Table 4.2).

Based on the results, the mid-period between day 28 and day 112 of the test could be considered as the optimum test period which met the three criteria: i.e. The growth rates in this period were least affected by the herd of origin effect; the growth rates in this period were highly heritable; and the period was relatively short.

The heritability estimates for G0_140, G0_112 and G28_140 obtained in the present study were higher than the estimates reported by Kemp (1990). There were no published reports on heritability estimates for other test periods.

4.3.2. Spearman Correlations

The Spearman correlations (R) between the entire 140-day test period and shorter test periods for average daily gain and regression coefficient of weight on days on test in the two breed groups are presented in Table 4.3. The associations between the entire 140-day test period and other test periods were similar in the two breed groups. The optimum test period (between day 28 and day 112 of the test) did not have the maximum association with the standard 140-day test period. Therefore, comparison of shorter test periods with the standard 140-day test period would not provide useful information for evaluating gain potentials of bulls in a shorter test period. In fact, growth rates in the 140-day test period (G0_140 and B0_140) were more influenced by the herd of origin effect than growth rates in the short test period.

These results indicated that it would be appropriate to increase the adjustment period by 28 days (original 28-d adjustment period plus the first 28-day period of the test) and terminate the test 28 days earlier. The test period then would be the period between day 28 and day 112 of the test, which would result in reduction in management costs, in addition to providing more accurate evaluation for growth potentials of the young beef bulls under station test conditions.

4.4. SUMMARY AND CONCLUSIONS

The records of beef bulls from 10 breeds tested at Ellerslie Test Station, Alberta, Canada, collected from 1974 to 1987 were used to investigate the feasibility of choosing a shorter test period and study the associations of the growth rates in different test periods for accurate evaluation for growth potentials of young beef bulls in test station.

The results indicated that the test period between day 28 and day 112 was the optimum short test period. The average daily gain and linear regression of weight on days on test in this period were least affected by the herd of origin effect. These two traits in this period also had relatively high heritabilities which would ensure satisfactory selection response. In order to properly evaluate gain potentials of beef bulls and economically make use of the testing facilities, it would be appropriate to have an adjustment period of 56 days (original 28 days plus the first 28-day period of the test) followed by a test period of 84 days (between day 28 and day 112 of the test). Such a test would result in the reduction in management costs in addition to providing a more accurate evaluation of growth potentials of young beef bulls.

TABLE 4.1. ESTIMATES OF INTRAHERD CORRELATIONS (t_h) AND THEIR STANDARD ERRORS (SE(t_h)).

Trait[a]	Small size breeds[b]	Large size breeds[b]
G0_140	0.10±0.07[c]	0.11±0.07
B0_140	0.08±0.07	0.07±0.07
G0_112	0.07±0.06	0.05±0.07
B0_112	0.07±0.06	0.09±0.06
G28_140	0.10±0.07	0.09±0.07
B28_140	0.08±0.07	0.07±0.06
G0_84	0.08±0.06	0.08±0.06
B0_84	0.20±0.08*	0.09±0.05*
G28_112	0.06±0.06	0.00±0.00
B28_112	0.07±0.06	0.02±0.06
G56_140	0.14±0.07*	0.13±0.07*
B56_140	0.12±0.07*	0.05±0.06
G0_56	0.10±0.06	0.11±0.06
B0_56	0.10±0.06	0.13±0.05
G28_84	0.07±0.06	0.06±0.06
B28_84	0.07±0.06	0.03±0.05
G56_112	0.09±0.06	0.05±0.07
B56_112	0.09±0.06	0.02±0.05
G84_140	0.11±0.06*	0.04±0.07
B84_140	0.11±0.06*	0.02±0.06
G0_28	0.14±0.06*	0.15±0.04*
G28_56	0.16±0.05*	0.08±0.04*
G56_84	0.08±0.06	0.10±0.05*
G84_112	0.03±0.06	0.00±0.00
G112_140	0.14±0.06*	0.14±0.06*

[a] Gx_y and Bx_y are average daily gain and regression of weight on days on test in the period between the xth day and the yth day of the test, respectively.

[b] Small size breeds include Angus, Hereford, Limousin and Shorthorn; large size breeds include Blonde d'Aquitaine, Charolais, Gelbvieh, Maine-Anjou, Salers and Simmental.

[c] t_h±SE(t_h).

*, significant at $P < 0.05$ for one-tailed t test.

TABLE 4.2. ESTIMATES OF HERITABILITIES (h^2) AND THEIR STANDARD ERRORS (SE(h^2).

Trait[a]	Small size breeds[b]	Large size breeds
G0_140	0.69±0.45[c]	0.43±0.34
B0_140	0.98±0.33*	0.46±0.36
G0_112	0.75±0.32*	0.33±0.36
B0_112	0.84±0.32*	0.22±0.30
G28_140	0.92±0.33*	0.52±0.36
B28_140	0.87±0.34*	0.52±0.31*
G0_84	0.75±0.32*	0.11±0.32
B0_84	0.26±0.40	0.12±0.29
G28_112	0.64±0.33*	0.56±0.25*
B28_112	0.68±0.33*	0.41±0.32*
G56_140	0.70±0.33*	0.61±0.34*
B56_140	0.63±0.33*	0.82±0.31*
G0_56	0.92±0.31*	0.06±0.33
B0_56	0.92±0.31*	0.10±0.30
G28_84	0.82±0.32*	0.07±0.31
B28_84	0.82±0.32*	0.29±0.30
G56_112	0.29±0.32	0.42±0.36
B56_112	0.30±0.32	0.40±0.31
G84_140	0.45±0.32	0.91±0.36*
B84_140	0.45±0.32	0.90±0.33*
G0_28	0.26±0.28	0.00±0.00
G28_56	0.00±0.00	0.00±0.00
G56_84	0.48±0.32	0.00±0.00
G84_112	0.17±0.32	0.64±0.25*
G112_140	0.44±0.30	0.23±0.31

[a] Gx_y and Bx_y are average daily gain and regression of weight on days on test in the period between the xth day and the yth day of the test, respectively.

[b] Small size breeds include Angus, Hereford, Limousin and Shorthorn; large size breeds include Blonde d'Aquitaine, Charolais, Gelbvieh, Maine-Anjou, Salers and Simmental.

[c] h_2±SE(h_2).

*, significant at $P < 0.05$ for one-tailed t test.

TABLE 4.3. SPEARMAN RANK CORRELATIONS (R) BETWEEN 140-DAY AND SHORTER TEST PERIODS FOR AVERAGE DAILY GAIN AND REGRESSION OF WEIGHT ON DAYS ON TEST.

Trait[a]	Small size breeds[b]	Large size breeds[b]
G0_112	0.90*	0.91*
B0_112	0.93*	0.95*
G28_140	0.90*	0.89*
B28_140	0.95*	0.94*
G0_84	0.82*	0.83*
B0_84	0.82*	0.85*
G28_112	0.81*	0.81*
B28_112	0.90*	0.91*
G56_140	0.83*	0.81*
B56_140	0.84*	0.83*
G0_56	0.71*	0.74*
B0_56	0.67*	0.71*
G28_84	0.69*	0.71*
B28_84	0.76*	0.81*
G56_112	0.70*	0.69*
B56_112	0.77*	0.78*
G84_140	0.71*	0.67*
B84_140	0.66*	0.66*
G0_28	0.53	0.54*
G28_56	0.52	0.56*
G56_84	0.48	0.49*
G84_112	0.47	0.49*
G112_140	0.50	0.49*

[a] Gx_y and Bx_y are average daily gain and regression of weight on days on test in the period between the xth day and the yth day of the test, respectively.

[b] Small size breeds include Angus, Hereford, Limousin and Shorthorn; large size breeds include Blonde d'Aquitaine, Charolais, Gelbvieh, Maine-Anjou, Salers and Simmental.

*, significant at $P < 0.05$.

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CHAPTER 5

EFFECTS OF AGE OF DAM, AGE AND WEIGHT AT START OF TEST AND HERD OF ORIGIN ON FEED EFFICIENCY, BACKFAT THICKNESS AND SCROTAL CIRCUMFERENCE IN TEST STATION BULLS

5.1. INTRODUCTION

Station performance testing provides a basis to compare bulls from different herds under standard conditions in order to identify genetically superior bulls for growth rate. In addition to growth rate, carcass quality and fertility of the breeding bulls are also important and deserve particular attention. Many test stations measure backfat thickness ultrasonically and scrotal circumference, providing additional information for their customers.

Studies have shown that pre-test environment, especially herd of origin, has significant influence on weight and gain measurements taken in test stations (Carter 1971, Kraüsslich 1974, Lewis and Allen 1974, Dalton 1976, Wickham 1977, Dalton and Morris 1978, Morris 1981, Okantah and Curran 1982, Baker et al. 1984, Tong et al. 1986, Amal and Crow 1987). However, little attention has been paid to the influence of pre-test environmental factors on feed efficiency, backfat thickness and scrotal circumference.

The objectives of this study were to examine the effects of age of dam, age of bull, start of test weight of bull and herd of origin on feed to gain ratio, backfat thickness and scrotal circumference of test station bulls.

5.2. MATERIALS AND METHODS

5.2.1. Description of the Data

The records of beef bulls from 10 breeds (Beef Synthetic and Dairy Synthetic were composite breed-groups from the University of Alberta Beef Cattle Research Ranch at Kinsella, Alberta, Canada) tested at the Ellerslie Test Station, Alberta, Canada, collected from 1981 to 1987 were used for this study. Performance test at the station started in mid-November (18-28th) each year after an adjustment period of 28 days and the test period was 140 days. The average age of the bulls was approximately 240 days ranging from 181 to 322 days. However, the range in age in each year (test group) did not exceed 90 days. Bulls were fed ad libitum a high energy diet composed of a concentrate mixture and hay (Appendix tables 2 to 7). The composition of the diet was relatively constant over years, with changes to avoid bloat in some years.

Feed conversion was measured from 1981 to 1987 and was calculated from feed intake as feed to gain ratio (feed/gain, FGR). Feed intake was measured by Pinpointers[1]. From 1985, backfat thickness (FAT) and scrotal circumference were also measured on the Pinpointer fed bulls at the end of the test. Bulls were measured ultrasonically for backfat thickness between the 12th and 13th ribs on the right side using a Scanogram[2]. Scrotal circumference was measured at the widest portion with testes fully descended in the scrotal sac with a Lane[3] scrotal tape (Sorensen 1979; Ball et al. 1983). The number of bulls, sires, herds and years the data covered within each breed is shown in Table 5.1. The breed means for these measurements are given in Table 5.2.

5.2.2. Statistical Analysis

Three mixed models were used for statistical analysis. The first model (Model I) used to describe the traits was:

$$y_{ijklm} = \mu + t_i + d_j + b_1 a_{ijklm} + b_2 w_{ijklm} + h_{ik} + s_{ikl} + e_{ijklm}$$

where y_{ijklm} was an observation on the mth bull, μ was the population mean, t_i was a fixed effect common to bulls of the ith breed-year, d_j was a fixed effect of the jth age group of dam ($j = 2, 3, \ldots, 6+$), b_1 and b_2 were partial regression

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[1] Efficiency Testing Equipment, Model 4000A, Universal Identidentification System Corp., Cookeville, TN, USA.

[2] Model 722, Ithaca, N.Y. USA.

[3] Lane Manufacturing Inc., Denver, Colorado.

coefficients of the trait on the age and start of test weight of a bull, a_{ijklm} was age (covariate in days) at the start of the test, w_{ijklm} was start of test weight (covariate in kg.), h_{ik} was a random effect of the k^{th} herd within the i^{th} breed-year [~NIID(0,σ^2_h)], s_{ikl} was a random effect associated with the additive genetic value of the l^{th} sire [~NIID(0,σ^2_s)], and e_{ijklm} was a random residual associated with the m^{th} bull [~NIID(0,σ^2_e)], where NIID meant "normal, independent and identically distributed". The assumptions of the model were that sires were unrelated and were randomly mated to dams in the herds where the sires belonged, that dams were unrelated and represented in the data by only one son, that environmental errors within and between half-sib groups were uncorrelated, that all interactions were insignificant, and that single pooled regression coefficients on age and start of test weight of bull were appropriate for all breeds in the same breed group. The model did not take into account the relationships among bulls and genetic trend due to lack of sufficient information. A hierarchical arrangement of herds within breed-year and sires within herd was assumed as did by Amal and Crow (1987), even though this was not the case in practice. The same herd, for instance, appeared in several years and some sires had progeny in several herds and years within a breed. Ignoring the cross-classified nature of the data, especially with respect to sires, would prevent the removal of part of the genetic variation (due to differential usage of sires from herd to herd) among herds (Amal and Crow 1987). However, the procedure would avoid the loss in the degree of connectedness of the data. Model I was used to estimate the contribution of each factor to the total variation of the traits. The contribution of a factor was calculated as the percentage of the sum of squares (due to the factor after adjusting for the other factors in the model) in the corrected total sum of squares. This was equivalent to the reduction in the coefficient of determination (R^2) after dropping that factor from the full model.

The second model (Model II) was a reduced model of Model I with start of test weight dropped from Model I to examine the degree of confounding of age with start of test weight.

The third model (Model III) was another reduced model with age of dam, age of bull and start of test weight dropped from Model I. The results from Model I (which will be discussed later) showed that the contributions of age of dam, age of bull and start of test weight were very small in the present data. Model III was used for the analysis of variance components in estimating the fraction of the total phenotypic variance due to herd of origin effect or intraherd correlation ($t_h = \sigma^2_h/(\sigma^2_h + \sigma^2_s + \sigma^2_e)$ and estimating the heritabilities of the traits using half sib analysis ($h^2 = 4\sigma^2_s/(\sigma^2_h + \sigma^2_s + \sigma^2_e)$.

The restricted maximum likelihood procedure (Patterson and Thompson 1971; SAS Institute Inc. 1985) was used to estimate variance components. The estimates of variance for all the traits converged within 30 rounds of iterations. The convergence value of the objective function was 10^{-8}. Approximate standard errors for t_h and h^2 were derived using the general procedure of error propagation as shown in Appendices 3 and 4, respectively. An additional assumption for Model III was that all breeds had similar genetic and environmental variances. This assumption might be incorrect in the strict sense. However, it minimized the sampling errors and ensured that sufficient data were available for variance estimation (Tong 1986).

5.3. RESULTS AND DISCUSSION

5.3.1. Factors Influencing Feed Efficiency, Backfat Thickness and Scrotal Circumference

The influences of the different factors on the traits under consideration were expressed as the reduction in the coefficient of determination (R^2) due to each specific factor considered, and are presented in Table 5.3. The significance levels are labeled beside the observed values of the reductions in R^2, since the approximate F test for the influence of the factors in the model is equivalent to the test for the reduction in R^2.

5.3.1.1. The effect of breed-year

Breed-year had a significant effect on all the traits studied ($P < 0.001$). This was mainly due to the fluctuations of environment over years, the genetic changes and disproportional representation of the breeds over years. Backfat thickness was more influenced by breed-year than was feed to gain ratio and scrotal circumference. This could be partly due to the differences in age at maturity among the breed groups.

5.3.1.2. The effect of age of dam

None of the dependent variables were significantly influenced by the age of dam effect (Table 5.3). The amount of variation explained by the age of dam was too small (0.09 - 0.35%) for practical consideration.

Smith et al. (1989a) studied the relationships between sire's scrotal circumference and offspring's reproduction and growth rate using the data collected at San Juan Basin Research Center, Hesperus, Colorado. Their results indicated that the influence of age of dam on scrotal circumference of the male offspring was insignificant.

5.3.1.3. The effect of age of bull

The effect of age of bull was not significant for the traits studied (Table 5.3). The reductions in the coefficient of determination (R^2) ranged from 0.01 to 0.23%. The regression coefficients of the traits on age of bull were insignificant, except for the regression of feed to gain ratio on age of bull obtained from Model II which did not include the start of test weight effect. This indicated that the effect of age of bull was negligible and that this effect could be considered as a component of start of test weight.

Brown et al. (1988) also reported insignificant regressions of feed to gain ratio on age of bull in Angus and Hereford bulls. Smith et al. (1989a) reported a significant regression of scrotal circumference on age of bull (0.025cm/d). The regression of scrotal circumference on age of bull in the present study (b = 0.008cm/d) was similar to that reported by Coulter et al. (1987) in Polled Hereford (b = 0.0089cm/d).

5.3.1.4. The effect of start of test weight

Start of test weight had significant effects on all the three traits, though it only explained less than 5% of the total variation (Table 5.3). Feed to gain ratio was more affected by start of test weight than backfat thickness and scrotal circumference (3.45% vs. 0.41% and 0.61%). The regressions of the traits on start of test weight were significant and positive, 0.016±0.002/kg., 0.013±0.005cm/kg. and 0.02±0.01cm/kg. for feed to gain ratio, backfat thickness and scrotal circumference, respectively. The results suggested that lighter bulls entering the test were generally more efficient than heavier bulls in feed utilization, that heavier bulls were fatter than lighter bulls, and that heavier bulls had larger scrotal circumference than lighter bulls. These results also suggested that growth patterns, within limits, tended to be weight dependent, but not age dependent as was suggested by Berg and Butterfield (1975). Makarechian et al. (1985) reported a linear regression of scrotal circumference on body weight (b = 0.32cm/kg.) in young beef bulls. Goonewardene et al. (1989) showed the allometric relationship between scrotal circumference and body weight in young beef bulls.

5.3.1.5. **The effect of herd of origin**

Herd of origin accounted for the largest fraction of the variation; 16.13%, 16.11% and 24.77% for feed to gain ratio, backfat thickness and scrotal circumference, respectively, though approximate F tests were not significant, perhaps due to the small size of the sample. The magnitude of the reduction in the coefficient of determination (R^2, %) due to herd of origin was, however, large enough to warrant its consideration. Further studies on the subject are still needed for more conclusive results. Comparable estimates in the literature are not available.

5.3.1.6. The effect of sire

The sire effect was significant for backfat thickness and scrotal circumference with the reductions in R^2 being 10.0% and 10.9%, respectively. but it was not significant for feed to gain ratio. The reduction in R^2 was 6.47%. for feed to gain ratio.

5.3.2. Intraherd Correlations

Based on the analysis of variance components using Model III, the variance components due to herd of origin (σ^2_h), sire (σ^2_s) and residual (σ^2_e) were estimated. The fractions of the total phenotypic variances due to the herd of origin effects (t_h) are presented in Table 5.5. Herd of origin component of variance accounted for 24.18%, 1.73% and 2.02% of the phenotypic variances for feed to gain ratio, backfat thickness and scrotal circumference, respectively. The only significant fraction was that of feed to gain ratio. The fact that over 20% of the total phenotypic variance of feed to gain ratio was accounted for by the herd of origin effect was probably attributable to the significant impact of the herd of origin effect on weight measurements. Many studies have shown the impact of herd of origin effect on weight measurements (Tong 1986; Amal and Crow 1987).

5.3.3. Estimates of Heritabilities

Estimates of the heritabilities are shown in Table 5.5. The estimate of heritability of scrotal circumference was out of the parameter range (larger than unity), which was due to sampling error, since the sample size was small. The estimates of heritabilities of feed to gain ratio (h^2=0.60±0.44) and backfat thickness (h^2=0.84±0.60) were not significant because of the large sampling errors.

Brown et al. (1988) estimated the heritability of feed to gain ratio in Angus (h^2=0.14±0.07) and Hereford (h^2=0.13±0.08) bulls. McWhir and Wilton (1987) reported an estimate of the heritability of backfat thickness (h^2=0.28±0.22) using pooled within-breed regression of son on sire using the data from Ontario test stations. There are many estimates of the heritability of scrotal circumference in the literature, ranging from near zero to near unity (Coulter et al. 1976, Coulter and Foote 1979, Latimer et al. 1982, Lunstra 1982, Neely et al. 1982, King et al. 1983, Knights et al. 1984, Bourdon and Brinks 1986, Coulter et al. 1987, Smith et al. 1989a, 1989b).

5.4. SUMMARY AND CONCLUSIONS

The records on 391 young beef bulls tested at the Ellerslie Test Station from 1981 to 1987 were used to examine the effects of herd of origin, age of dam, age and weight of bull at start of test on feed to gain ratio, backfat thickness and scrotal circumference.

Based on the results of this study, several conclusions were drawn as follows:

1. The effect of age of dam was not of practical importance. It explained a negligible amount of variation (0.09-0.35%).

2. Adjusting for the effect of age of bull would not improve the test within the age range of the tested beef bulls.

3. Start of test weight had, to a small degree, significant effect on feed efficiency, backfat thickness and scrotal circumference.

4. Herd of origin explained a substantial amount of variation in feed to gain ratio, backfat thickness and scrotal circumference. The variance component due to the herd of origin effect was over 20% of the total phenotypic variance for feed to gain ratio.

5. Feed to gain ratio, backfat thickness and scrotal circumference seemed to all be highly heritable.

TABLE 5.1. STRUCTURE OF THE DATA.

Breed[a]	No. of bulls			No. of sires			No. of herds			No. of years		
	FGR	FAT	SCR[b]	FGR	FAT	SCR	FGR	FAT	SCR	FGR	FAT	SCR
Angus		50	50		16	16		27	27		1	1
Blonde d'Aquitaine	40	75	75	9	20	20	17	20	20	1	2	2
Charolais	30	25	25	7	7	7	9	19	19	1	1	1
Gelbvieh	15	49	49	7	15	15	4	16	16	1	1	1
Maine-Anjou	27	49	49	8	7	7	13	22	22	2	1	1
Salers	80	40	40	25	13	13	35	21	21	2	1	1
Dairy Synthetic	13			5			1			2		
Simmental	37	49	49	14	12	12	11	30	30	1	1	1
Shorthorn		31	31		12	11		15	15		1	1
Beef Synthetic	14			6			1			2		

[a] Dairy Synthetic and Beef Synthetic were composite breed-groups from the University of Alberta Beef Cattle Research Ranch at Kinsella, Alberta, Canada.

[b] FGR, FAT and SCR represent feed to gain ratio (kg./kg.), backfat thickness (mm) and scrotal circumference (cm), respectively.

TABLE 5.2. BREED MEANS AND STANDARD ERRORS OF THE MEANS.

Breed[a]	Feed to gain ratio kg./kg.	Backfat Thickness mm	Scrotal circumference cm
Angus		7.58±0.29	32.86±0.35
Blonde d'Aquitaine	6.36±0.11[b]	2.08±0.11	28.58±0.26
Charolais	6.04±0.12	3.12±0.22	33.12±0.45
Gelbvieh	6.67±0.30	2.80±0.16	32.66±0.32
Maine-Anjou	6.36±0.13	2.31±0.17	33.17±0.29
Salers	7.35±0.07	6.35±0.39	33.73±0.41
Dairy Synthetic	6.26±0.10	9.89±1.16	35.67±0.91
Simmental	7.95±0.13	3.04±0.21	35.67±0.84
Shorthorn		5.87±0.24	31.23±0.43
Beef Synthetic	5.98±0.10	9.30±0.97	34.80±0.86

[a] Dairy Synthetic and Beef Synthetic were composite breed-groups from the University of Alberta Beef cattle Research Ranch at Kinsella, Alberta, Canada.

[b] Mean±Standard error.

TABLE 5.3. THE REDUCTIONS IN THE COEFFICIENTS OF PARTIAL DETERMINATION (R^2, %) DUE TO THE FACTORS CONSIDERED IN MODEL I.

Trait[a]	Breed-Year	Age of Dam	Age of Bull	Start of test weight	Herd	Sire
FGR (kg./kg.)	12.78***	0.47	0.23	3.45***	16.13	6.47
FAT (mm)	25.32***	0.09	0.01	0.40*	16.11	10.00**
SCR (cm)	13.51***	0.20	0.02	0.61**	24.77	10.93**

[a] FGR, FAT and SCR represent feed to gain ratio, backfat thickness and scrotal circumference, respectively.

***, ** and *, significant at $P < 0.001$, $P < 0.01$ and $P < 0.05$, respectively.

TABLE 5.4. PARTIAL REGRESSION COEFFICIENTS OF THE TRAITS ON AGE AND START OF TEST WEIGHT OF BULL.

Trait	Age of bull (day)	Start of test weight (kg.)
Feed to gain ratio	-0.0080±0.0047	0.0156±0.0024***
(kg./kg.)	(0.0117±0.0045*)[a]	———
Backfat thickness	-0.0033±0.0106	0.0130±0.0052*
(mm)	(0.0137±0.0083)	———
Scrotal circumference	0.0080±0.0135	0.0196±0.0066**
(cm)	(0.0338±0.0108)	———

[a] The regression coefficients and their standard errors in the parentheses are obtained from Model II.

***, ** and *, significant at $P < 0.001$, $P < 0.01$ and $P < 0.05$, respectively.

TABLE 5.5. THE ESTIMATES OF INTRAHERD CORRELATION (t_h, %) AND HERITABILITY (h^2) OF THE TRAITS.

Trait	t_h±SE (%)	h^2±SE
Feed to gain ratio	24.18±10.22**	0.60±0.44
Backfat thickness	1.73±8.46	0.84±0.60
Scrotal circumference	2.02±8.90	a

[a] The estimate was out of the parameter range.

**, significant at $P < 0.01$ for one-tailed t test.

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CHAPTER 6

GENERAL DISCUSSION

6.1. SUMMARY

Central performance testing for evaluation of growth potential of young beef bulls has been widely used for over three decades (Dalton and Morris 1978, Tong 1982). Initially, this program was thought to be ideal, since young bulls were managed together under the same environmental conditions. Research has shown that pre-test environmental factors, especially herd of origin, affect the results of the test. The carry-over effect of pre-test environment could reduce the reliability of the test (Tong 1982, Baker et al. 1984, Amal and Crow 1987). However, reports on the effectiveness of central performance testing have not been consistent (Dalton and Morris 1978, Baker et al. 1984, Wilton and McWhir 1985, Crow et al. 1988).

In the present study, attempts were made to examine the mathematical relationships of the measures of growth rate in order to search for alternative measures of postweaning growth rate, to assess the effects of some major factors on growth performance on test, and to investigate the feasibility of shortening the length of the test period.

The first part (Chapter 2) provided some theoretical considerations on the mathematical relationships between measures of absolute growth rate and between measures of relative growth rate. It was shown that average daily gain and average relative growth rate (Fitzhugh and Taylor 1971) were in fact special cases of linear regression of weight on days on test and instantaneous percentage growth rate (Brody 1945), respectively, when only start and end of test weights were used. Linear regression of weight on days on test and instantaneous percentage growth rate were considered to be more accurate than conventional average daily gain and average relative growth rate based on the amount of information utilized and the magnitude of the variances of these measurements.

The effects of age of dam on growth rate and weight (Chapter 3) were not large enough to be of practical importance, as they explained a small amount of variation. The results agreed with those reported by Pabst et al. (1977), but were different from those reported by Simm et al. (1985). The effects of age of dam on feed to gain ratio, backfat thickness and scrotal circumference (Chapter 5) were also not of practical importance.

Adjusting for the effect of age of bull was found not to be necessary within the age range of the tested bulls for growth rate (Chapter 3), feed efficiency, backfat thickness and scrotal circumference (Chapter 5). The results agreed with most other reports (Batra and Wilton 1972, Wilton et al. 1973, Tong 1982, Amal and Crow 1987, Brown 1988).

Start of test weight was a significant factor affecting weights, feed to gain ratio, backfat thickness and scrotal circumference. Nevertheless, it explained less than 5% of the variation in growth rate (Chapter 3), feed to gain ratio, backfat thickness and scrotal circumference (Chapter 5). Generally lighter bulls entering the test were more efficient than heavier bulls in feed utilization in feedlot, that heavier bulls entering the test were fatter than lighter bulls at the end of the test, and that as expected, heavier bulls had larger scrotal circumference than lighter bulls.

Herd of origin was found to be an important factor; its impact on measures of absolute growth rate was important at least up to day 28 of the test (plus 28 days warm up period). Gain in the mid-period between day 28 and day 112 of the test was least affected by the herd of origin effect. But its impact increased again during the last 28-day period (Chapter 3). The trends of the impact of herd of origin on absolute gain measurements agreed with those reported by Amal and Crow (1987). Herd of origin also explained a substantial part of variation in feed efficiency, backfat thickness and scrotal circumference (Chapter 5). The variance component due to the herd of origin effect was over 20% of the total phenotypic variance for feed to gain ratio, which was probably due to the impact of herd of origin on weight measurements.

The test period between day 28 and day 112 could be considered as an optimum short test period (Chapter 4). The average daily gain and regression coefficient of weight on days on test in this period were least affected by the herd of origin effect. The heritabilities of the two traits in this period were relatively high and consistent in both breed groups which should ensure satisfactory selection response. In order to properly evaluate growth potentials of the beef bulls and economically make use of the testing facility, it would be appropriate to have an adjustment period of 56 days (original 28-day adjustment period plus the period between start of the test and day 28 of the test), followed by a test period of 84 days (the period between day 28 and day 112 of the test). Such a test period would result in reduction in management costs, in addition to the advantage of more accurate evaluation of growth potentials of the young bulls.

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APPENDIX 1

SOURCE OF DATA

COLLECTION OF DATA

Records of young beef bulls collected over the past 13 years (1974 - 1987) at the Ellerslie Bull Test Station, Ellerslie, Alberta which was managed jointly by the University of Alberta and Alberta Agriculture provided a reliable source of data for this study.

Station performance test records of 2445 bulls of 21 breeds from 505 herds were available for the study. The breeds were Aberdeen Angus, Blonde d'Aquitaine, Beefalo, Brown Swiss, Chianina, Charolais, Gelbvieh, Hereford, Limousin, Maine-Anjou, Murray Grey, Meuse-Rhine-Ijssel, Marchigiana, Pinzgauer, Romagnola, Salers, Simmental, Shorthorn, Tarentaise, Beef Synthetic and Dairy Synthetic. Beef Synthetic and Dairy Synthetic were composite breed-groups (Berg et al. 1986). Some crosses of these breeds were also involved. The variables included measurements of 17 traits and 9 identification and pedigree indicators. They were year, station number, breed, tattoo, sire, % sire breed, breed of dam, age of dam at birth, birth date, birth weight, ration, and for Pinpointer[1] fed bulls 4 feed

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[1] Efficiency Testing Equipment, Model 4000A, Universal Identification System Corp., Cookeville, TN, USA.

conversion measurements (140-d, 84-d, 56-d and 28-d), start of test date, start of test weight, pre-test ADG, 28-d weight, 56-d weight, 84-d weight, 112-d weight, 140-d weight, backfat thickness, scrotal circumference, and adjusted yearling weight. The distribution of the breed-groups, number of bulls and number of variables are presented in Appendix Table 1.

MANAGEMENT IN THE TEST STATION

The Ellerslie Test Station was a central testing facility for beef bulls in the province of Alberta. The management in the station, to a large degree, followed the Guidelines for Uniform Beef Improvement Programs (Beef Improvement Federation 1972,1976, 1981 and 1986). Bulls from across Alberta were brought to the station in late October or early November shortly after weaning. The average age of the bulls at the start of the test was approximately 240 days. The maximum allowable range in age in each test group was 90 days, and the fluctuation of average age over years was very small.

The bulls were placed on a 28-day adjustment period prior to the start of the test. The test period was 140 days and lasted until the following April. The bulls were fed ad libitum a high energy diet composed of concentrate mixture and hay in pens containing 5 bulls each. High quality hay was available at all times. The diets were relatively consistent over the years. Some changes in the diet were made to avoid bloat in some years. The diet fed to bulls in pens equipped with pinpointers was somewhat different from the regular diet. The compositions of the concentrate mixtures are presented in Appendix Tables 2. to 7.

During the test period, the bulls were weighed at 28-day intervals. The start of test weight (SOTW) and end of test weight (W140) were each the average of two weights taken on successive days to minimize variation due to gut fill. Single weights were recorded at day 28 (W28), day 56 (W56), day 84 (W84) and day 112 (W112) of the test. Weighing of the bulls was done on a random pen order in order to minimize the possible bias due to the differences in gut fill.

Starting from 1981, Pinpointers were installed in 10 of the 40 pens, and individual feed intake of the bulls in these pens were recorded to calculate feed efficiency, i.e. feed to gain ratio (FGR).

Starting in 1985, backfat thickness (FAT) and scrotal circumference (SCR) were also measured on the Pinpointer fed bulls at the end of the test. Bulls were measured ultrasonically for backfat thickness between the 12th and the 13th ribs on the right side using a Scanogram[2]. Scrotal circumference was measured at the widest portion with testes fully descended in the scrotal sac with a Lane[3] scrotal type (Sorensen 1979; Ball et al. 1983).

DATA SETS

The collected data were edited for statistical analysis. The records of the breeds which had only a few tested bulls were excluded. The remaining ten popular breeds were classified into two breed groups based on their similarity in growth performance (Liu and Makarechian 1990) and accordingly two data sets were created . This classification of the breeds coincided with the size (body weight) of the breeds. The small size breed group (data set I) included Angus, Hereford, Limousin and Shorthorn. The large size breed group (data set II) included Blonde d'Aquitaine, Charolais, Gelbvieh, Maine-Anjou, Salers and Simmental. It should be noted that while the Limousin's rate of gain placed it with the British breeds, it was the opposite extreme for rate of maturity. The purpose of the classification of the breeds was to have enough observations for statistical analysis. Statistical analysis was,

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[2] Model 722, Ithaca, N.Y., USA.

[3] Lane Manufacturing Inc., Denver, Colorado.

therefore, carried out for each breed group instead of each breed.

APPENDIX TABLE 1. DISTRIBUTIONS OF THE NUMBER OF BREEDS, THE NUMBER OF THE BULLS AND THE NUMBER OF THE VARIABLES OVER YEARS.

Years	No. of Breeds	No. of Bulls	No. of Variables
74-75	11	200	20
75-76	15	195	20
76-77	13	200	20
77-78	11	200	20
78-79	11	200	20
79-80	4	150	20
80-81	8	150	20
81-82	9	150	24
82-83	8	200	24
83-84	8	200	24
84-85	8	200	24
85-86	6	200	26
86-87	6	200	24

APPENDIX TABLE 2. COMPOSITION OF THE CONCENTRATE MIXTURE USED FROM NOVEMBER 1974 TO APRIL 1978[a].

Ingredients	Quantities (Kg)	%
Oats	409.1	45.0
Barley	382.7	42.1
Rapeseed (linseed or soybean) meal	54.5	6.0
Molasses (wet)	36.4	4.0
Urea	3.7	0.3
Dicalcium phosphate	12.7	1.4
Trace mineralized salt	9.1	1.0
Vitamin premix[b]	0.9	0.1

[a] Bulls were fed ad libitum the diet composed of 40% of the concentrate and 60% of hammered (1.5 in. screen) hay in the first 12 weeks and the diet composed of 50% of the concentrate and 50% of hammered hay in the rest of the test.

[b] Vitamin premix contained 9,900,000 I.U. Vit. A, 990,000 I.U. Vit. D and 99,000 I.U. Vit. E per kilogram.

APPENDIX TABLE 3. COMPOSITION OF THE CONCENTRATE MIXTURE USED FROM NOVEMBER 1978 TO APRIL 1981[a].

Ingredients	Quantities (Kg)	%
Barley	450.0	45.0
Oats	427.0	42.7
Rapeseed (or soybean) meal	60.0	6.0
Molasses (wet)	40.0	4.0
Dicalcium phosphate	13.0	1.3
Trace mineralized salt	9.1	0.9
Vitamin premix[b]	0.9	0.1

[a] Bulls were fed ad libitum the diet which consisted of 50% of the concentrate and 50% of hammered hay.

[b] Vitamin premix contained 9,900,000 I.U. Vit. A, 990,000 I.U. Vit. D and 99,000 I.U. Vit. E per kilogram.

APPENDIX TABLE 4. COMPOSITION OF THE CONCENTRATE MIXTURES USED FROM NOVEMBER 1982 to APRIL 1983.

Ingredients	Quantities			
	Mixture 1[a]		Mixture 2[b]	
	Kg	%	Kg	%
Barley	450.0	45.00	398.0	39.71
Oats	400.0	40.00	320.0	31.93
Canola meal	58.0	5.80	3.3	0.33
Cy-phos	2.3	0.20	0.7	0.07
Limestone	7.7	0.80	3.7	0.37
Cobalt salt	10.0	1.00	5.0	0.50
Permapel	10.0	1.00	10.0	1.00
Urea	10.0	1.00	9.3	0.93
Premix	1.6	0.20	1.2	0.12
Molasses	50.0	5.00	50.0	4.99
Simar 200	1.0	0.10	1.0	0.10
Rovimix E50	0.2	0.01	0.1	0.01
Sun-cured alfalfa			200.0	19,95

[a] Hand fed bulls were fed ad libitum the diet composed of 60% of mixture 1 and 40% of chopped hay.

[b] Pinpointer fed bulls were fed ad libitum Mixture 2 as a complete diet.

APPENDIX TABLE 5. COMPOSITION OF THE CONCENTRATE MIXTURES USED FROM NOVEMBER 1983 TO APRIL 1984.

Ingredients	Quantities (%)		
	Mixture 1[a]	Mixture 2[b]	Mixture 3[b]
Barley	41.50	33.00	18.50
Oats	40.00	40.00	60.00
Dairy supplement	10.00		
Cattle supplement	3.00		
Molasses	5.00	2.50	2.50
Salt	0.40	1.00	2.50
Selenium	0.03		
Alfalfa pellets		20.00	
Urea		1.00	1.00
Lime		0.60	1.50
Permapel		1.00	1.00
Dynamate		0.50	0.50
Dical		0.20	0.50
Semar 200		0.07	0.07
Pmx CB		0.05	0.05
Pmx CC		0.02	0.02
Beet pulp			10.00
Mineral oil			1.50

[a] Hand fed bulls were fed ad libitum the diet composed of 60% of mixture 1 and 40% of cut mixed hay. Mixture 1 was changed from pelleted to steam rolled about mid-December to reduce blcat problem.

[b] Mixture 3 replaced mixture 2 on March 6, 1984 to avoid bloat. Pinpointer fed bulls were fed ad libitum mixture 2 and mixture 3 as a complete diet.

APPENDIX TABLE 6. COMPOSITION OF THE CONCENTRATE MIXTURES USED FROM NOVEMBER 1984 TO APRIL 1985.

Ingredients	Quantities			
	Mixture 1[a]		Mixture 2[b]	
	Kg	%	Kg	%
Steam rolled oats	400.0	34.72	415.0	36.16
Steam rolled barley	400.0	34.72	200.0	17.42
Molasses	50.0	4.34	25.0	2.18
Custom supplement	150.0	13.02	150.0	13.07
Barley	119.6	10.38	9.0	0.78
Salt	10.0	0.87	10.0	0.87
Urea	9.0	0.78	5.0	0.44
Calcium carbonate	5.0	0.43	12.5	1.09
Dicalcium phosphate	3.5	0.30	5.0	0.44
Vitamin premix	2.5	0.22	1.3	0.11
Vitamin E (500 I.U./Kg)	0.01	0.001		
Permapel	2.3	0.20		
Beet pulp			200.0	17.42
Mineral oil			10.0	0.87
Canola meal			100.0	8.71
Dynamate			5.0	0.44

[a] Hand fed bulls were fed ad libitum the diet composed of 60% of Mixture 1 and 40% of cut alfalfa hay.

[b] Pinpointer fed bulls were fed ad libitum Mixture 2 as a complete diet.

APPENDIX TABLE 7. COMPOSITION OF THE CONCENTRATE MIXTURES USED FROM NOVEMBER 1986 to APRIL 1987.

Ingredients	Quantities (%)	
	Mixture 1[a]	Mixture 2[b]
Barley	53.40	
Oats	40.00	69.50
Canola meal		10.00
Beet pulp		10.00
Mixed screenings		2.70
Molasses	3.50	2.50
Limestone	0.80	1.30
Salt		1.00
Cobalt salt	1.00	
Canola oil		1.00
Dynamate		0.50
Urea	0.90	
Monocalcium phophate		0.50
Lignosol		0.20
Vitamin E premix		0.13
Dicalcium phosphate	0.36	
Tallow		0.11
Beef vitamin premix		0.10
Beef trace mineral premix		0.05
Beef micro premix	0.15	

[a] Mixture 1 made up 60% of the diet for hand fed bulls in the first 12 weeks and 70% in the rest period. The balance was cut mixed hay.

[b] Mixture 2 was the complete diet for Pinpointer fed bulls.

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APPENDIX 2

GENERALIZED LOGISTIC FUNCTION AS A GROWTH CURVE

The main reference for this appendix is Brown et al. (1976). The logistic or autocatalytic function was first proposed by P. F. Verhulst in 1838 (Yule 1925, Olinick 1978) for describing the cumulative growth of human population and by T. B. Robertson independently in 1908 for describing the chemical basis of growth (Bliss 1970, Parks 1982). The original logistic curve has a fixed point of inflection right in the middle of the sigmoid curve (Fitzhugh 1976). Nelder (1961) modified the original function and developed a generalized form which allows a variable point of inflection.

Nelder's three-parameter function is as follows.

$$W_t = A[1 + \exp(-kt)]^{-M} \qquad (1)$$

where

W_t is weight at age t.

A is asymptotic weight as $t \to \infty$. A is generally interpreted as mature weight.

k is rate of maturing.

t is age.

M is inflection parameter.

The parameters (A, k and M) in equation (1) can be estimated by some nonlinear estimation procedures, such as Marquardt method (Marquardt 1963). Then, Weight at the point of inflection of the growth curve is

$W_I = A(M/M+1)^M$ (2)

Age at the point of inflection of the growth curve is

$t_I = k^{-1} \ln M$ (3)

Absolute (maximum) growth rate at the point of inflection of the growth curve is

$AGRL = dW/dt = MkW_I\{\exp[-kt_I]/1 + \exp[-kt_I]\}$ (4)

Relative growth rate at the point of inflection of the growth curve is

$RGRL = dW/dt/W = Mk\{\exp[-kt_I]/1 + \exp[-kt_I]\}$. (5)

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APPENDIX 3

DERIVATION OF THE APPROXIMATE STANDARD ERROR OF INTRAHERD CORRELATION

In this appendix, the approximate asymptotic variance of the intraherd correlation or its square root, the approximate standard error of the intraherd correlation, is derived based on Gaussian Law of Error Propagation (Freiberger et al. 1960; Bartsch 1974; Shapiro and Gross 1981; Stuart and Ord 1987).

From variance component analysis using Maximum Likelihood (ML) or Restricted Maximum Likelihood (REML) procedures or other procedures, the variance components are usually available from computer programs like SAS VARCOMP (SAS Institute Inc. 1985) and BMD-P3V (Dixon et al. 1981). The approximate asymptotic variances and covariances of these variance components are usually available from the output (they are the inverse of information matrix in ML or REML estimation) or can be obtained from linear combinations of mean squares in generalized ANOVA estimation (Searle 1971, 1989). In animal breeding , these variance components are used to construct or describe some genetic and environmental parameters, such as heritability, repeatability, intraclass correlation, etc. The constructed variables are then functions of these variance components each of which is subjected to sampling error. As a result, the constructed variables are also subjected to sampling error, since their constituents are. It is therefore necessary to estimate the sampling error of the constructed variable (usually called standard error which is the square root of the sampling variance).

A commonly used procedure is Gaussian Law of Error Propagation or General Formula of Error Propagation, assuming that the samples are large enough so that the sampling distribution of the statistics tend to be normal. A detailed account of the methodology is given in Kendall's Advanced Theory of Statistics (Stuart and Ord 1987) and in Statistical Modelling Techniques (Shapiro and Gross 1981).

By definition, intraherd correlation is defined as

$$\hat{t}_h = \frac{\hat{\sigma}^2_h}{\hat{\sigma}^2_h + \hat{\sigma}^2_s + \hat{\sigma}^2_e}$$

$$= \frac{\hat{\sigma}^2_1}{\hat{\sigma}^2_1 + \hat{\sigma}^2_2 + \hat{\sigma}^2_3}$$

$$= \frac{\hat{X}}{\hat{Y}} \qquad (1)$$

The substitution of notations is used for brevity in derivation.

Then according to Gaussian Law of Error Propagation, the approximate asymptotic variance of the intraherd correlation is

$$\mathrm{Var}(\hat{t}_h) = \sum_{i=1}^{3}(\partial\hat{t}_h/\partial\hat{\sigma}^2_i)^2\mathrm{Var}(\hat{\sigma}^2_i)$$

$$+ \sum_{i\neq j=1}^{3}\sum(\partial\hat{t}_h/\partial\hat{\sigma}^2_i)(\partial\hat{t}_h/\partial\hat{\sigma}^2_j)\mathrm{Cov}(\hat{\sigma}^2_i,\hat{\sigma}^2_j) \qquad (2)$$

It can be shown that equation (2) can be expressed as

$$\mathrm{Var}(\hat{t}_h) = \mathrm{Var}(\hat{X})/\hat{Y}^2 + \hat{X}^2\,\mathrm{Var}(\hat{Y})/\hat{Y}^4 - 2\,\hat{X}\,\mathrm{Cov}(\hat{X},\hat{Y})/\hat{Y}^3 \qquad (3)$$

Where,

$\hat{X} = \hat{\sigma}^2_h$,

$\hat{Y} = \hat{\sigma}^2_h + \hat{\sigma}^2_s + \hat{\sigma}^2_e$,

$\mathrm{Var}(\hat{X}) = \mathrm{Var}(\hat{\sigma}^2_h)$,

$$\mathrm{Var}(\hat{Y}) = \mathrm{Var}(\hat{\sigma}^2_h) + \mathrm{Var}(\hat{\sigma}^2_s) + \mathrm{Var}(\hat{\sigma}^2_e) + 2\mathrm{Cov}(\hat{\sigma}^2_h,\hat{\sigma}^2_s) + 2\mathrm{Cov}(\hat{\sigma}^2_h,\hat{\sigma}^2_e) + 2\mathrm{Cov}(\hat{\sigma}^2_s,\hat{\sigma}^2_e),$$

$$\begin{aligned}\mathrm{Cov}(\hat{X},\hat{Y}) &= \mathrm{Cov}(\hat{\sigma}^2_h,\hat{\sigma}^2_h + \hat{\sigma}^2_s + \hat{\sigma}^2_e)\\ &= \mathrm{Var}(\hat{\sigma}^2_h) + \mathrm{Cov}(\hat{\sigma}^2_h,\hat{\sigma}^2_s) + \mathrm{Cov}(\hat{\sigma}^2_h,\hat{\sigma}^2_e).\end{aligned}$$

Then the standard error of $\hat{t}_h$ is

$$\sigma(\hat{t}_h) = \sqrt{\mathrm{Var}(\hat{t}_h)} \qquad (4)$$

It should be noted that although approximate asymptotic variances can be obtained for the estimated variance components and the functions of theses variance components using the above procedure (it may be the only available procedure), unfortunately, for the higher components in particular, the size of the approximate asymptotic variances are often too large to be useful. Normal-theory approximations for the variance components are generally vary poor (McCullagh and Nelder 1983).

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APPENDIX 4

DERIVATION OF THE APPROXIMATE STANDARD ERROR OF HERITABILITY

The procedure used to derive the approximate asymptotic variance of the heritability or its square root, the approximate standard error of it, is the same as that used in Appendix 3 for the derivation of intraherd correlation.

The heritability is defined as

$$\hat{h}^2 = \frac{4\hat{\sigma}^2{}_s}{\hat{\sigma}^2{}_h + \hat{\sigma}^2{}_s + \hat{\sigma}^2{}_e}$$

$$= \frac{4\hat{\sigma}^2{}_2}{\hat{\sigma}^2{}_1 + \hat{\sigma}^2{}_2 + \hat{\sigma}^2{}_3}$$

$$= 4\,\frac{\hat{X}}{\hat{Y}} \qquad (1)$$

The substitution of notations is used for brevity in derivation.

Then according to Gaussian Law of Error Propagation, the approximate asymptotic variance of the interherd heritability is

$$\mathrm{Var}(\hat{h}^2) = \sum_{i=1}^{3}(\partial\hat{h}^2/\partial\hat{\sigma}^2{}_i)^2\mathrm{Var}(\hat{\sigma}^2{}_i)$$

$$+ \sum\sum_{i\neq j=1}^{3}(\partial\hat{h}^2/\partial\hat{\sigma}^2{}_i)(\partial\hat{h}^2/\partial\hat{\sigma}^2{}_j)\mathrm{Cov}(\hat{\sigma}^2{}_i,\hat{\sigma}^2{}_j) \qquad (2)$$

It can be shown that equation (2) can be expressed as

$$\mathrm{Var}(\hat{h}^2) = 4^2\{\mathrm{Var}(\hat{X})/\hat{Y}^2 + \hat{X}^2\ \mathrm{Var}(\hat{Y})/\hat{Y}^4 - 2\ \hat{X}\ \mathrm{Cov}(\hat{X},\hat{Y})/\hat{Y}3\} \quad (3)$$

Where,

$\hat{X} = \hat{\sigma}^2{}_s$,

$\hat{Y} = \hat{\sigma}^2{}_h + \hat{\sigma}^2{}_s + \hat{\sigma}^2{}_e$,

$$\mathrm{Var}(\hat{X}) = \mathrm{Var}(\hat{\sigma}^2{}_s),$$

$$\mathrm{Var}(\hat{Y}) = \mathrm{Var}(\hat{\sigma}^2{}_h) + \mathrm{Var}(\hat{\sigma}^2{}_s) + \mathrm{Var}(\hat{\sigma}^2{}_e) + 2\mathrm{Cov}(\hat{\sigma}^2{}_h, \hat{\sigma}^2{}_s) + 2\mathrm{Cov}(\hat{\sigma}^2{}_h, \hat{\sigma}^2{}_e) + 2\mathrm{Cov}(\hat{\sigma}^2{}_s, \hat{\sigma}^2{}_e),$$

$$\mathrm{Cov}(\hat{X}, \hat{Y}) = \mathrm{Cov}(\hat{\sigma}^2{}_s, \hat{\sigma}^2{}_h + \hat{\sigma}^2{}_s + \hat{\sigma}^2{}_e) = \mathrm{Cov}(\hat{\sigma}^2{}_h, \hat{\sigma}^2{}_s) + \mathrm{Var}(\hat{\sigma}^2{}_s) + \mathrm{Cov}(\hat{\sigma}^2{}_s, \hat{\sigma}^2{}_e).$$

Then the standard error of $\hat{t}_h$ is

$$\sigma(\hat{h}^2) = \sqrt{\mathrm{Var}(\hat{h}^2)} \qquad (4)$$

APPENDIX 5

SPEARMAN'S RANK CORRELATION IN THE PRESENCE OF A BLOCKING VARIABLE

In this appendix, Spearman's rank correlation (Spearman 1904) in the presence of a blocking variable is briefly described and is based on Jeremy M. G. Taylor's paper (1987) and E. L. Korn's paper (1984).

Spearman's rank correlation in a single block, say the k^{th} block by definition is the rank analogue of the product-moment correlation coefficient (Taylor 1987; SAS Institute Inc. 1985).

$$r_k = \frac{\sum_{i}^{n_k}(u_i - \bar{u})(v_i - \bar{v})}{\left[\sum_{i}^{n_k}(u_i - \bar{u})^2(\sum_{i}^{n_k} v_i - \bar{v})^2\right]^{1/2}}$$

where

r_k is Spearman's rank correlation in the k^{th} block.

n_k is the number of pairs of observations in the block.

u_i is the rank of the i^{th} value of variable X.

v_i is the rank of the i^{th} value of variable Y.

$i = 1, 2, 3, \ldots, n_k$.

$\bar{u}$ and $\bar{v}$ are means of the u_i and v_i values, respectively.

Average ranks are used if there are ties.

Under the hypothesis (Ho) that X and Y are of conditional independence, $E(r_k) = 0$ and $Var(r_k) = (n_k - 1)^{-1}$. r_k has a nice property that the variance conditional on the set of ranks is $(n_k - 1)^{-1}$, even when there are ties in the data (Kendall and Stuart 1973).

When there exists a blocking variable B with b levels, i.e. k = 1, 2, 3, ..., b, it may be useful to get a pooled Spearman's rank correlation so that the effect of the blocking variable can be adjusted for. One way to do this is to estimate the weighted average Spearman's rank correlation (R) over the levels of the blocking variable.

$$R = \frac{\sum_{k}^{b} w_k r_k}{\sum_{k}^{b} w_k}$$

where

the weight of the k^{th} block (w_k) is the reciprocal of $\mathrm{Var}(r_k)$, i.e. $n_k - 1$. if the population values of R are constant across blocks, then w_k maximises the efficacy of R for testing Ho.

To test Ho, the variance of R (Var(R)) is needed. Var(R) can be obtained by Gaussian law of error propagation (Bartsch 1974; Shapiro and Gross 1981).

$$\mathrm{Var}(R) = \frac{\sum_{k}^{b}[(w_k)^2 \mathrm{Var}(r_k)]}{(\sum_{k}^{b} w_k)^2}$$

$$= \frac{\sum_{k}^{b}(n_k - 1)^2}{(\sum_{k}^{b}(n_k - 1))^2}$$

Assuming R follows an approximately normal distribution, statistic $Z = R/(\text{Var}(R))^{1/2}$ is needed to be compared with standard normal distribution.

In order to check the homogeneity of the rank correlations among the b blocks, an assumption is needed that each r_k is roughly normally distributed. This leads to a test statistic

$$\sum_{k}^{b} w_k(r_k - R)^2$$

to be compared with the theoretical chi-square distribution on b - 1 degrees of freedom.

The same procedure can be used when there exist two or more blocking variables by treating the combinations of the levels of the blocking variables as the levels of a single blocking variable. For instance, in the case of two blocking variables each with two levels, it can be treated as a single blocking variable with four levels (2 x 2).

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VITA

NAME	M. F. Liu
PLACE OF BIRTH	Dalian, CHINA
YEAR OF BIRTH	1954

POST-SECONDARY EDUCATION

M.Sc.	Animal Breeding and Genetics, 1985, Northeast Agricultural University Harbin, CHINA
B.Sc. (Hons)	Agriculture - Animal Science, 1982, Shenyang Agricultural University Shenyang, CHINA

HONORS AND AWARDS

1989-1990	Graduate Assistantship (Research), University of Alberta, CANADA
1986-1989	The Minister of Advanced Education Scholarship, The Province of Alberta, CANADA
1983	First Prize for the Improvement of Technology (shared with the members of the Animal Quantitative Genetics Cooperation Group), Chinese Department of Agriculture, Forestry and Fishery, CHINA

1978-1985	China Government Bursary, Shenyang Agricultural University and Northeast Agricultural University, CHINA

RELATED WORK EXPERIENCE

1985-1986	Lecturer, Northeast Agricultural University, Harbin, CHINA
1982	Assistant Researcher, Chaoyang Institute of Animal Science, Chaoyang, CHINA
1972-1978	Veterinarian and Specialist in chicken, hog and mink production Dalian, CHINA

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