DIRECT AND CORRELATED RESPONSES TO SELECTION FOR INCREASED WEANING AND YEARLING WEIGHTS IN ANGUS CATTLE

By

DEBRA KAY AARON

Bachelor of Science in Agriculture
University of Kentucky
Lexington, Kentucky
1978

Master of Science
University of Kentucky
Lexington, Kentucky
1981

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Thesis Approved:

Richard R Frahm
Thesis Adviser

Ronald W McNew

David S. Buchanan

Joe W Holderman

Laval M. Verhalen

Dean of the Graduate College

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CHAPTER I

INTRODUCTION

Selection is one of the primary forces by which breeders can change the genetic composition of their herds. Selection can be thought of as a differential reproductive rate in that some animals are allowed to produce more offspring than others. Although it is the change in the mean phenotypic value of the trait that is observable, the primary genetic effect of selection is to change the gene frequency. Thus, the magnitude of the phenotypic change brought about by selection depends on the amount of change that occurs in the gene frequencies. Selection does not create new genes; it simply allows those animals possessing desirable genes or gene combinations to leave more offspring than those with less desirable gentoypes (Lush, 1945).

Since most economically important traits are controlled by many pairs of genes, changes at individual loci cannot be detected. Thus means, variances and covariances must be used to describe the effects of selection. Also, the effects of selection on the genetic composition of a herd may be difficult to measure directly because of changes in managerial procedures, changes in selection concepts and year to year environmental fluctuations that have large effects on animal performance. In addition, the effects of selection accumulate over generations.

Although a breeder may use a particular trait such as weaning weight or yearling weight as the primary selection criterion, it is the improvement in "net merit" of an animal that is important to a successful breeding program. Selection for one trait cannot be considered in isolation but will have consequences for other traits as well (Pirchner, 1969). Therefore, it is of interest to evaluate both the improvement that occurs in the trait being selected for directly and the correlated changes in other economically important traits that occur because of the genetic relationships among traits.

The increasing demand for faster growing, efficient cattle has made selection for growth rate a primary objective for the beef industry. While numerous selection experiments have evaluated the effectiveness of selection for growth rate in poultry and laboratory animals (Lerner and Demster, 1951; Falconer, 1955; Clayton et al., 1957; Roberts, 1966; Collins et al., 1970; Sutherland et al., 1970; Eisen, 1974; Frahm and Brown, 1975), few studies have been designed to evaluate the effectiveness of selection for growth rate in livestock. Therefore, this long term study was conducted to (1) quantify selection pressure and measure direct and correlated responses to selection for weaning or yearling weights in beef cattle, (2) determine the genetic relationship between the two traits, and (3) compare genetic response obtained from selection for weaning weight based on individual performance with that obtained from selection based on a combination of individual and progeny test information.

CHAPTER II

REVIEW OF LITERATURE

Selection Theory

Selection is aptly described as a differential reproductive rate since it is the process of causing or allowing certain types of individuals to produce more offspring than other types (Lush, 1945). This is one of the primary forces available to the animal breeder to change the genetic composition of a population. The basic genetic effect of selection is to change the gene frequency and all other effects are consequences of that change. Selection creates no new genes, it merely allows the possessors of desirable genes or gene combinations to leave more offspring than those individuals which have less favorable genotypes (Lush, 1945).

Most traits of economic importance to animal breeders are classified as metric or quantitative characters. Quantitative traits are those affected by several pairs of genes, many of which have small, individual phenotypic effects. Since many loci are involved, the changes in individual gene frequency are almost totally obscured. Thus, the effects of selection must be described in terms of means, variances and covariances while keeping in mind the fact that the underlying cause is the change in gene frequency (Falconer, 1960).

Response to selection is defined as the difference between mean performance of offspring from selected parents and mean performance of the parental generation before selection (Falconer, 1960). If selection is for a single trait, response per generation can be predicted by multiplying the observed selection differential by the heritability of the trait (Falconer, 1960; Pirchner, 1969). The selection differential is simply the mean phenotypic value of individuals selected as parents expressed as a deviation from the population mean, and heritability refers to the fraction of that difference expected to be transmitted to the offspring. Genetic progress per year depends on the selection intensity as measured by the standardized selection differential, the heritability of the trait being selected and the generation interval.

Heritability generally serves to predict selection gains; however, Falconer (1955) introduced the concept of realized heritability. Realized heritability is calculated as the ratio of response to selection differential. This ratio provides the most useful empirical description of the effectiveness of selection and allows comparison of different experiments to be made even when the intensity of selection is not the same (Falconer, 1960).

Selection for one trait cannot be considered in isolation but will have consequences for other traits due to genetic correlations that exist among traits (Pirchner, 1969). The magnitude of the correlated response will depend on the size and sign of the genetic correlation between the traits. The correlated response to selection can be predicted by the following formula:

$$CR_y = r_g \sigma_{a_y} h_x i_x \text{ (Falconer, 1960),}$$

where CR_y is the correlated response in trait y from selection for trait x, r_g is the genetic correlation between trait x and y, σ_{a_y} is the additive standard deviation of trait y, h_x is the square root of the heritability of trait x and i_x is the selection intensity of trait x.

There are many consequences of selection that can be discovered only through experimental studies (Falconer, 1960). Some important questions that may be answered by experiment concern the long term effects of selection such as magnitude of the genetic change and possible selection limits.

Results of Selection Experiments in Species Other than Beef Cattle

Numerous experiments have been conducted to evaluate the effectiveness of selection for growth rate in species other than beef cattle. The results of these experiments can be a useful aid in understanding more clearly the nature of selection response. Most of the empirical evidence for selection theory has been demonstrated with laboratory animals (Chapman, 1951). Biological characteristics such as short generation intervals and high reproductive rates as well as low maintenance costs have made them desirable subjects for long term selection studies. Also, environmental conditions can be closely regulated to minimize random fluctuations in performance from generation to generation (Hill, 1972). Experiments with laboratory animals are useful to indicate changes in genetic variation and thus methods of selection required for continued gain (Dickerson, 1969). These results should indicate probable changes in long range cattle selection programs. Also, results from earlier selection studies in sheep and swine provide useful information on approaches used to measure selection response in cattle.

Mice. Many studies have been conducted to evaluate the effectiveness of selection for various growth traits in mice. A summary of these reports (and a few with rats) is presented in table 1. Additional discussion of some of these studies is pertinent.

Falconer (1960) noted that a surprising feature of results in many selection experiments was the inequality or asymmetry of responses to selection in opposite directions. This observation was partially based on results he reported earlier (Falconer, 1953; Falconer, 1955). Legates (1969) and Baker and Chapman (1975) found asymmetry of response to selection for the same trait in opposite directions with greater response being observed for downward selection. MacArther (1949) and Falconer (1973) also reported asymmetric responses but greater responses were observed for upward selection.

McLellan and Frahm (1973) evaluated seven generations of selection for increasing and decreasing hindleg weight in mice. Selection was effective but the realized heritability was larger for downward selection than upward selection (.70 vs .24).

McPhee and Neill (1976) evaluated 25 generations of selection for increased and decreased weight at eight weeks. Results indicated near equality of response between the high and low lines; however, the shapes of the response curves were dissimilar with the low line showing a greater curvilinear trend.

Goodale (1938) selected for large body size at 60 days in albino mice with the objective being to determine the limits of change which could be made by selection. Although no control was maintained, the change in body weight from 23.6 to 32.2 g in 12-16 generations indicates selection was responsible for genetic change. Variability was greater in later generations than in earlier generations, thus indicating the limit of selection had not been reached.

Wilson et al. (1971) continued the experiment reported by Goodale (1938). Selection was practiced for a total of 84 generations; however, a distinct leveling of response was observed after 35 generations with no appreciable change occurring after that point. Prior to the leveling off, 60-day weight was increased 72%. Results of this study indicate that there is a point at which genetic variation is depleted. Also, this particular study emphasizes the value of laboratory animals in selection experiments. A study of this size and scope in beef cattle would be inconceivable.

The majority of results indicate that selection for growth rate in mice can be successful; however, most two way selection studies agree that responses are asymmetric. Generally, positive correlated responses were observed in upward selection lines while negative correlated responses were observed in downward selection lines.

Poultry. Several experiments have been conducted to evaluate the effect of selection on increased body weight in chickens and turkeys. Selected experiments are summarized in table 2. Results of these studies indicate that selection for body weight has been successful in poultry. In agreement with results reported from two way selection in mice, selection for high and low lines in chickens resulted in asymmetric responses (Maloney, 1963; Festing and Nordskog, 1967; Benoff and Renden, 1983).

Sheep. Selection studies conducted with sheep are limited in number and scope and many studies have yielded little genetic information because of poor design (Dalton and Baker, 1979). However, a few studies have been reported in the literature.

Terrill (1958) reviewed progress made by selection in sheep over a 50-year period. He concluded definite progress had been achieved but more improvement was still possible. However, he did note that some of the observed change was due to improved environmental conditions.

Osman and Bradford (1965) evaluated selection for 120-day weight in crossbred sheep maintained at two locations. One flock was maintained in a harsh environment and the other in a favorble environment. Rams were replaced in each flock each year. After five years of selection, realized heritabilities were .18 and .22 in the harsh and favorable environments, respectively.

Pattie (1965a,b) examined the effects of four generations of selection for increasing and decreasing weaning weight in Merino sheep. Results indicated no significant asymmetry between the high and low lines. Realized heritabilities were .33 and .18 for ewes and rams, respectively, in the high line. In the low line realized heritabilities were .22 and .23 for ewes and rams, respectively. Also, milk production data were evaluated in this study and, as expected, lamb growth rate and milk volume were positively correlated.

Vesley and Peters (1975) estimated responses to selection for weight per day of age to 170 days in Rambouillet and Romnelet sheep after two generations of selection. Two methods were used to evaluate response in this study: (1) difference of phenotypic regression and within sire regression to estimate one half the genetic response and (2) repeat matings to estimate environmental trends. Direct response, pooled within breeds and methods of estimation, was 8.15 g/generation while correlated responses were .91 and .52 kg/generation for weaning weight and total postweaning gain, respectively. Realized heritabilities for weight per day of age were .28 and .20 for Rambouillets and Romnelets, respectively.

Ebmeier (1977) evaluated results obtained from lines of Hampshire sheep selected for 180-day weight or 365-day weight. Also, a control line was maintained. After six years of selection, realized heritabilities were .17 for 180-day weight and .67 for 365-day weight. Realized genetic correlations between 180-day weight and birth weight, 70-day weight and 365-day weight were -.19, 1.94 and .64, respectively, while realized genetic correlations between 365-day weight and birth weight, 70-day weight and 180-day weight were .64, 1.27 and 1.71, respectively.

Although limited data are available evaluating the effect of selection for growth rate in sheep, realized heritibilities indicate selection can be moderately effective.

Swine. Results from several experiments evaluating selection for various growth traits in swine are summarized in table 3. In general most observed responses were less than predicted.

Craft (1958) summarized fifty years of progress in swine breeding and concluded improvements had been made in various growth and carcass traits. In agreement with Terrill (1958), he noted that these improvments were due to improved environmental conditions as well as selection.

Fredeen (1958) summarized thirty years of selection using Danish field records collected on Landrace and Large White swine. Positive trends were reported for carcass length, belly thickness and average daily gain while negative trends were observed for backfat thickness and feed efficiency (kg feed/kg gain). Fredeen pointed out that most selection studies in swine had been conducted relative to the formation of inbred lines. He also noted few studies utilized a control; therefore, the precision with which genetic responses were calculated was questionable.

The majority of studies agree that selection for growth traits in swine can be reasonably effective; however, varying degrees of response have been reported.

Results of Selection Experiments in Beef Cattle

Selection experiments with beef cattle are expensive to conduct and require several years to obtain meaningful results. These problems can be attributed to long generation intervals, low reproductive rates and high maintenance costs. Also, evaluating environmental trend in beef cattle is complicated since environmental conditions are nearly impossible to regulate from year to year. Despite the problems associated with conducting beef cattle selection studies, several reports are available in the literature attesting to the effectiveness of selection for various growth traits. A summary of many of these reports is presented in table 4; however, some studies designed specifically to evaluate response to selection merit further discussion.

Brinks et al. (1965) evaluated responses obtained from 25 years of selection for increased weight and gain (with some attention to conformation) in closed lines of Hereford cattle. Selection indexes in retrospect were calculated for sires (I_s) and dams (I_d) as follows:

I_s = .21 birth weight + .13 weaning weight + .26 weaning conformation score + 1.20 final weight

I_d = .01 birth weight + .14 weaning weight + .11 weaning conformation score - .16 yearling weight + .39 18-month weight + .08 18-month conformation score - .11 mature fall weight + .03 producing ability.

Large phenotypic trends were reported for all traits except postweaning gain in heifers. In general, observed phenotypic trends were at least as large as expected responses based on indexes and parameter estimates. Genetic trends were computed for birth weight and weaning traits using the repeat mating technique to estimate environmental trends.

Newman et al. (1973) and Anderson et al. (1974) investigated response to 10 years of selection for yearling weight in two replicate herds of Shorthorn cattle. Also, a control line was maintained. These authors introduced the method of calculating cumulative selection differentials by adding the mean cumulative selection differential of all parents of a contemporary group to an individual's own deviation from that group. This is in contrast to the method proposed by Pattie (1965a) in which only the average of the individual's own parents' selection differential was added to the individual's deviation. Mean cumulative selection differentials in the final year of the study were 68.4 and 57.9 kg for sires and dams, respectively. Positive genetic trends were observed for yearling weight as well as for birth weight, preweaning gain and weaning weight.

Koch et al. (1974a,b) summarized the first 10 years of selection in three 150-cow, 6-sire lines of Hereford cattle. Lines were selected for weaning weight (WWL), 425-day (bulls) or 550-day (heifers) yearling weight (YWL) or an index of yearling weight and muscling score (IXL). Average generation interval was 4.6 years and after 10 years, 2.0, 1.8

and 1.9 generations of selection had been practiced in the WWL, YWL and IXL, respectively. Comparisons of actual selection differentials of selected parents with potential selection differentials revealed that 77 to 97% of the potential selection opportunity was attained in bulls and 50 to 71% was realized in heifers. These authors evaluated response by several methods: (1) expected genetic change based on paternal half-sib analyses of covariance, (2) intra-year regression on generation coefficient, (3) intra-year regression of progeny phenotype on midparent cumulative selection differentials, and (4) expected genetic change based on both intra-line and inter-line regressions of offspring on midparent in an unselected population. Average estimated response, expressed in standard measure per generation, in the WWL, YWL and IXL were: weaning weight, .23, .17 and .15; yearling weight, .36, .43 and .33; muscling score, -.03, .01 and .24, respectively.

Buchanan et al. (1982a,b) continued the study reported by Koch et al. (1974a,b) and reported results through 1977. After 17 years, approximately 3.7 generations of selection had occurred. These authors estimated 86 to 95% of potential selection opportunity was achieved in bulls and 62 to 74% in heifers. Indexes in retrospect were calculated for sires (I_s) and dams (I_d). Indexes in retrospect with their selection differentials per generation (ΔI) in standard measure for the three lines were:

WWL : ΔI_s = .22 birth weight + .65 weaning weight + .32 yearling weight + .01 muscle score = 1.65

ΔI_d = .09 birth weight + .84 weaning weight + .12 yearling weight + .07 muscle score = .44

YWL : ΔI_s = .07 birth weight - .05 weaning weight + 1.00 yearling weight - .01 muscle score = 1.80

$$\Delta I_d = .17 \text{ birth weight} + .26 \text{ weaning weight} + .68 \text{ yearling weight} + .10 \text{ muscle score} = .34$$

$$\text{IXL}: \Delta I_s = .16 \text{ birth weight} + .15 \text{ weaning weight} + .40 \text{ yearling weight} + .62 \text{ muscling score} = 1.85$$

$$\Delta I_d = .21 \text{ birth weight} + .09 \text{ weaning weight} + .77 \text{ yearling weight} + .13 \text{ muscling score} = .43.$$

Genetic change in each line was predicted from genetic parameter estimates and the indexes in retrospect. Genetic parameters were estimated using both paternal half-sib analyses of variance and covariance and offspring-parent regressions. Predicted responses (averaged over the two methods) in standard measure per generation in WWL, YWL and IXL, respectively, were: birth weight, .26, .27 and .29; weaning weight, .24, .24 and .21; yearling weight, .29, .39 and .34; muscling score, .00, .03 and .22.

Frahm et al. (1985a,b) quantified selection pressure and estimated selection response in two 50-cow 4-sire Hereford lines maintained contemporary to the Angus lines evaluated in this dissertation. Lines were selected for weaning weight (WWL) and 365-day (bulls) or 425-day (heifers) yearling weight (YWL). An Angus control line was utilized to estimate environmental trend. After 15 years, 3.22 generations of selection had occurred in both the WWL and YWL. Mean cumulative selection differentials in standard measure per generation in the WWL and YWL, respectively, were: birth weight, .44 and .51; weaning weight, .97 and .85; weaning conformation score, .66 and .57; yearling weight, .80 and 1.05; yearling conformation score, .63 and .62. These authors also calculated indexes in retrospect for sires (I_s) and dams (I_d). Indexes in retrospect with their selection differentials per generation (ΔI) in standard measure for the two lines were:

WWL : ΔI_s = .035 birth weight + .760 weaning weight + .132 weaning conformation grade + .024 weaning condition score − .021 yearling weight + .267 yearling conformation score − .056 yearling condition score = 1.418

ΔI_d = .140 birth weight + .838 weaning weight − .469 weaning conformation grade + .187 weaning condition score + .210 yearling weight + .051 yearling conformation score + .134 yearling condition score = .630

YWL : ΔI_s = .038 birth weight + .039 weaning weight + .358 weaning conformation grade − .319 weaning condition score + .880 yearling weight − .183 yearling conformation score + .205 yearling condition score = 1.667

ΔI_d = .125 birth weight + .531 weaning weight − .228 weaning conformation grade − .113 weaning condition score + .489 yearling weight + .044 yearling conformation score + .070 yearling condition score = .537.

Estimated genetic responses per generation in standard measure in WWL and YWL, respectively, were: birth weight, .27 and .25; weaning weight, .23 and .20; weaning conformation grade, .24 and .25; yearling weight, .12 and .19; yearling conformation grade, .21 and .14.

The majority of selection experiments in beef cattle have utilized time trends to separate genetic and environmental components of phenotypic response. Few studies reported in the literature have estimated genetic response from select-control line deviations. In general, most studies agree that selection can be an effective means of improving growth rate in beef cattle.

Genetic Parameters in Beef Cattle

Numerous studies have reported estimates of heritabilities and genetic correlations for various traits in beef cattle. Woldehawariat et al. (1977) summarized various estimates reported in the literature. Table 5 is constructed from information reported by these authors. Heritabilities (presented on the diagonal of table 5) were calculated as the average of estimates obtained from both paternal half-sib analyses of variance and covariance and offspring-dam regressions, weighted by the number of estimates in each method. Averages (and ranges) of heritability estimates for the seven traits were: birth weight .45 (-.29 to .94); preweaning daily gain .30 (-.34 to .63); weaning weight .24 (-.06 to .71); weaning conformation score .38 (.00 to .71); feedlot gain .38 (-.08 to .88); final feedlot weight .46 (.03 to .92); feedlot conformation score .36 (.07 to .92). Phenotypic and genetic correlations (weighted averages) are also presented in table 5.

In general, most growth traits appear to be moderately heritable. Also, most genetic correlations among growth traits and between growth and conformation traits are positive. However, not all of these relationships are favorable since an increase in birth weight may also be associated with an increase in dystocia and calf death loss.

Maternal Influence on Growth in Beef Cattle

The weight of a calf at weaning is influenced by the environment it is reared in as well as its own genotype for growth. Maternal effects are one source of environmental variation that may be very important to preweaning growth in beef cattle. Maternal effects are difficult to control and may complicate evaluation of response to selection, thus knowledge of the genetics of maternal effects is of value when investigating the effects of selection for preweaning growth traits.

Koch and Clark (1955) reported that phenotypic correlations between a cow's weaning weight and weaning weight and preweaning daily gain of her offspring were .06 and .03, respectively. Also, these authors suggested that the correlation between direct and maternal effects on preweaning daily gain was between -.65 and -.68.

Christian et al. (1965) found a phenotypic correlation of .07 between dam weaning weight and offspring weaning weight. Also, these authors milked cows as they were being nursed and reported negative correlations between dam weaning weight and milk production (-.10 to -.20) and butterfat production (-.18 to -.27). These results support the hypothesis that there is an alternating generation phenomena for weaning weight in beef cattle.

Deese and Koger (1967) evaluated direct and maternal genetic effects in purebred Brahman and crossbred Brahman-Shorthorn cattle. These authors reported that the covariance between direct and maternal effects was near zero in Brahman cattle but in the crossbred cattle it was negative and contributed 30% of the total variation in weaning weight.

Mangus and Brinks (1971) divided Hereford heifers into three groups (low, medium and high) on the basis of individual weaning weight. Performance of these heifers' offspring, grand offspring and great grand offspring was then evaluated. The medium weaning weight group performed similarly through three generations. The low weaning weight group approached the level of the medium group in generation two but did not change appreciably in the third generation. Calves in the high group were lightest in the first generation, heaviest in the second generation and again lightest in the third generation. The results obtained from the high group indicate high preweaning nutritional levels may have detrimental effects on cow productivity.

Koch (1972) reviewed available estimates of genetic correlation between maternal environment and individual growth potential for weaning weight. He reported the average genetic correlation between maternal environment and calf weaning weight potential was -.50. Correlations between direct and maternal effects for preweaning gain were also negative.

Willham (1972) developed formulas to evaluate the fraction of the selection differential realized if selection is on the calf's phenotype. If direct (G), maternal (Gm) and phenotypic (P) effects are included, the fraction of the selection differential realized is (Var (G) + 3/2 Cov (GGm) + 1/2 Var (Gm))/Var (P). If grandmaternal (Gn) effects are also included, this becomes (Var (G) + 3/2 Cov (GGm) + 5/4 Cov (GGn) + 1/2 Var (Gm) + 3/4 Cov (GmGn) + 1/4 Var (Gn))/Var (P). If the covariance terms are positive, selection for traits affected by maternal and grandmaternal effects can be increased; however, positive covariances between direct and maternal effects are generally not supported by the literature.

Kress and Burfening (1972) and Boston et al. (1975) reported small (.15 to .20), but significant, positive correlations between a heifer's weaning weight and the weaning weight of her calf.

Van Vleck et al. (1977) considered theoretical responses to selection for weaning weight by several methods and a formula was presented to estimate response. These authors suggested that if a genetic antagonism exists between direct and maternal effects, long term response to selection for weaning weight could be intensified by selecting bulls for direct genetic values and heifers for maternal values.

Brown et al. (1978) analyzed 18 years of Angus data utilizing a model which included maternal and grandmaternal effects. Genetic correlations between direct and maternal effects were -.51 and -.26 for birth weight and weaning weight, respectively. The correlatins between direct and grandmaternal effects were .93 and -.12 for the two traits. The environmental correlations between direct and maternal effects were .14 and -.56 for birth weight and weaning weight, respectively.

In general, results presented in the literature support the concept of a negative covariance between direct and maternal effects for preweaning growth rate in beef cattle.

TABLE 1

RESULTS OF SELECTION EXPERIMENTS IN MICE AND RATS

Reference	Selection criteria	Number of generations	Trait	Direct or correlated response	Realized h^2 or r_g
Baker and Chapman (1975)[a]	+3-9 wk gain	13	3-9 wk gain		.25
Baker et al. (1975)[a]	+3-9 wk gain	13	3-9 wk gain	+	.25
Bakker et al. (1976)[a]	+3-6 wk gain	36	3 wk wt	+28%	
			3-6 wk gain	+70%	
			6 wk wt	+50%	
Bradford (1971)	+3-6 wk gain	24	3 wk wt	+30%	
			3-6 wk gain	+76%	$.20 \pm .01$
			6 wk wt	+54%	
Carter (1972)	+3 wk wt	21	3 wk wt	+20%	
			6 wk wt	+15%	
	+3-6 wk wt	21	3 wk wt	+20%	
			6 wk wt	+33%	
	+6 wk wt	21	3 wk wt	+ 7%	
			6 wk wt	+33%	
Dalton (1967)[a]	+3-6 wk gain (full feed)	13	3-6 wk gain		.23
	-3-6 wk gain (full feed)	13	3-6 wk gain		.21
	+3-6 wek gain (diluted diet)	13	3-6 wk gain		.30
	-3-6 wk gain (diluted diet)	13	3-6 wk gain		.22

TABLE 1 (Continued)

Reference	Selection criteria	Number of generations	Trait	Direct or correlated response	Realized h^2 or r_g
Eisen (1978)	+6 wk wt		6 wk wt		.55±.07
Falconer (1953)	+6 wk wt	11	6 wk wt	+17%	.22
			3 wk wt	0	
	−6 wk wt	11	6 wk wt	−33%	.49
Falconer (1955)	+6 wk wt	21	6 wk wt	+45%	.175
	−6 wk wt	19	6 wk wt		.518
Falconer (1973)[a]	+6 wk wt	23	3 wk wt	+38%	
			3-6 wk gain	+29%	
			6 wk wt	+45%	.40(10 gen)
	−6 wk wt	23	3 wk wt	0	
			3-6 wk gain	−23%	
			6 wk wt	−38%	.33(10 gen)
Frahm and Brown (1975)[a]	+3 wk wt	14	3 wk wt	+31%	.17±.01
			3-6 wk gain	+17%	
			8 wk wt	+19%	
	+3-6 wk wt	14	3 wk wt	+21%	
			3-6 wk gain	+53%	.27±.02
			8 wk wt	+46%	
Harvey (1972)[a]	+12-21 d gain	10	12-21d gain	+62%	.17(over lines)
	+51 d wt		51 d wt	+34%	.27(over lines)
	+12-21 d gain	10	12-21 d gain	−19%	
	−51 d wt		51 d wt	−26%	
	−12-21 d gain	10	12-21 d gain	+26%	
	+51 d wt		51 d wt	+36%	

TABLE 1 (Continued)

Reference	Selection criteria	Number of generations	Trait	Direct or correlated response	Realized h^2 or r_g
	-12-21 d gain	10	12-21 d gain	-34%	
	-51 d wt		51 d wt	-30%	
Hull (1960)	+3 wk wt	5	3 wk wt	+	.74±.14
			4 1/2 wk wt	+	1.16
			6 wk wt	+	1.01
	+4 1/2 wk wt	5	3 wk wt	+	.76
			4 1/2 wk wt	+	.44±.27
			6 wk wt	+	.71
	+6 wk wt	5	3 wk wt	+	.63
			4 1/2 wk wt	+	1.17
			6 wk wt	+	.57±.20
LaSalle et al. (1974)	+3-6 wk gain	12	3-6 wk gain	+54%	.24±.02
Legates (1969)	+6 wk wt	15	6 wk wt		.13
			6-8 wk gain	-	
	-6 wk wt	15	6 wk wt		.42
			6-8 wk gain	-	
MacArthur (1949)	+60 d wt	21	60 d wt	+74%	
	-60 d wt	21	60 d wt	-47%	
McLellan and Frahm (1973)[a]	+hindleg wt (84d)	7	hindleg wt (84d)	+12%	.24±.06
			3 wk wt	+ 3%	
			3-6 wk gain	+ 9%	
			6 wk wt	+ 8%	
			12 wk wt	+14%	

TABLE 1 (Continued)

Reference	Selection criteria	Number of generations	Trait	Direct or correlated response	Realized h^2 or r_g
	-hindleg wt (84d)	7	hindleg wt (84d)	-18%	.70±.17
			3 wk wt	- 9%	
			3-6 wk gain	-24%	
			6 wk wt	-17%	
			12 wk wt	-11%	
McPhee and Neill (1976)[a]	+8 wk wt	25	8 wk wt	+35%	
	-8 wk wt	25	8 wk wt	-33%	
Notter (1974) (rats)	+lean gain (3-9 wk)	3	lean gain		.38±.09
	+lean gain efficiency (3-9 wk)	3	lean gain efficiency		.33±.10
Rahnefeld et al. (1963)[a]	+18-42 d gain	17	18-42 d gain	+58%	.18
Sutherland et al. (1970)[a]	+4-11 wk gain	21	4-11 wk gain	+89%	.24±.19
Wilson (1973)[a]	+3-6 wk gain	8	3 wk wt	+ 9%	.26
			6 wk wt	+24%	.66
			9 wk wt	+25%	.60
			3-6 wk gain	+40%	.23
			6-9 wk gain	+30%	.39
			3-9 wk gain	+38%	.68
			3-6 wk gain/3-9 wk gain	+ 2%	.02

TABLE 1 (Continued)

Reference	Selection criteria	Number of generations	Trait	Direct or correlated response	Realized h^2 or r_g
	3-6 wk gain/3-9 wk gain	8	3 wk wt	- 1%	-.12
			6 wk wt	- 1%	-.02
			9 wk wt	- 8%	-.31
			3-6 wk gain	- 2%	
			6-9 wk gain	-51%	-.58
			3-9 wk gain	-13%	-.13
			3-6 wk gain/3-9 wk gain	+114%	.09
Wilson et al. (1971)	+60 d wt	84	60 d wt	+72%	.32
Zucker (1960) (rats)	±9 wk wt	10	9 wk wt	+30%	.40

[a]Control line used to estimate response.

TABLE 2

RESULTS OF SELECTION EXPERIMENTS IN CHICKENS AND TURKEYS

Reference	Selection criteria	Number of generations	Trait	Direct or correlated response	Realized h^2
Abplanalp et al. (1963)[a] (turkeys)	+8 wk wt	7	8 wk wt	+33%	.43
			24 wk wt	+13%	
	+24 wk wt	5	8 wk wt	+21%	
			24 wk wt	+27%	.62
	index (8 and 24 wk wt)	7	8 wk wt	+26%	
			24 wk wt	- 4%	
Benoff and Renden (1983)[a]	+20 wk wt	3	20 wk wt	+34%	.47
	-20 wk wt	3	20 wk wt	-26%	.58
Festingand and Nordskog (1967)[a]	+32 wk wt	8	32 wk wt		.34
	-32 wk wt	8	32 wk wt		.52
Maloney et al. (1963)	+12 wk wt	10	6 wk wt	+	
			12 wk wt	+51%	.34
	-12 wk wt	10	6 wk wt	0	
			12 wk wt	-27%	.07

[a]Control line used to estimate response.

TABLE 3

RESULTS OF SELECTION EXPERIMENTS IN SWINE

Reference	Selection criteria	Number of generations	Trait	Direct or correlated response	Realized h^2
Cleveland (1978)	+Index (ADG and backfat)	5	Index	+5.8 units/gen	
			ADG	+22 g/d/gen	
			Backfat	-.05 cm/gen	
Craig et al. (1956)	+180 d wt (or 154 d wt)	10	154 d wt	+.68 kg/gen (+13%)	.17[b]
			birth wt	0	
			21 d wt	+	
			56 d wt	+	
			180 d wt	+1.27 kg/gen (+19%)	.16[b]
			birth wt	0	
			21 d wt	+	
			56 d wt	+	
	-180 d wt (or 154 d wt)	8	154 d wt	-2.27 kg/gen (-34%)	
			birth wt	0	
			21 d wt	-	
			56 d wt	-	
			180 d wt	-1.86 kg/gen (-22%)	
			birth wt	0	
			21 d wt	-	
			56 d wt	-	
Dettmers et al. (1965)	-140 d wt	10	birth wt	-14%	
			56 d wt	-23%	
			140 d wt	-29%	.41
Dettmers et al. (1971)	-140 d wt	17	140 d wt	-34% (last 9 gen)	.67

TABLE 3 (Continued)

Reference	Selection criteria	Number of generations	Trait	Direct or correlated response	Realized h^2
Dickerson and Grimes (1947)	+feed requirements (72 d to 102 kg)	5	feed/45.4 kg gain	+5.4 kg/gen	
			ADG	-	
			birth wt	-	
			72 d wt	-	
	-feed requirements (72 d to 102 kg)	5	feed/45.4 kg gain	-3.9 kg/gen	
			ADG	-	
			birth wt	-	
			72 d wt	-	
Fredeen (1977)[a]	+gain (birth to 90.7 kg)	9	gain	+599 g/gen	
			backfat	-.61 cm/gen	
	-backfat at 90.7 kg	9	gain	1597 g/gen	
			backfat	-2.0 cm/gen	
	Index (gain and backfat)	9	gain	.6%	
			backfat	-1.8%	
Krider et al. (1946)	+180 d wt (or +150 d wt)	4	birth wt	+9%	
			21 d wt	+16%	
			56 d wt	-10%	
			150 d wt	-13%	.16
			180 d wt	-9%	.19
	-180 d wt (or 150 d wt)	4	birth wt	+1%	
			21 d wt	+11%	
			56 d wt	-26%	
			150 d wt	-27%	
			180 d wt	-25%	

TABLE 3 (Continued)

Reference	Selection criteria	Number of generations	Trait	Direct or correlated response	Realized h^2
Rahnefeld (1971)[a]	+postweaning ADG (42 d to mkt wt)	7	postweaning ADG	+9%	.13
Rahnefeld (1973)	+postweaning ADG	9	weaning wt	.03 kg/gen	
			feed efficiency	.59 kg/gen	
Rahnefeld and Garnet (1976)	+postweaning ADG	11	postweaning ADG	14 g/d/gen	.20
			birth wt	0	
			preweaning ADG	+4 g/d/gen	
			weaning wt	+18 kg/gen	

[a]Control line used to estimate response.
[b]Heritability estimated from divergence.

TABLE 4

RESULTS OF SELECTION EXPERIMENTS IN BEEF CATTLE

Reference	Selection criteria	No. of years	Description of study	Trait	Phenotypic response/yr	Direct or correlated genetic response/yr	Realized h^2
Anderson et al. (1974)	+yearling wt	11	Shorthorn; control used; replicated at 2 locations.	yearling wt	+4.4 kg (bulls) +2.8 kg (heifers)		.50 (bulls) .39 (heifers)
Armstrong et al. (1965)	multiple traits (inbred lines)	17	Hereford; 862 calves; control used; inbreeding over 30%.	weaning wt	+.20 kg	negative for all traits	
				weaning score	+.02 units		
				final grade	+.05 units		
Bailey et al. (1971)	+postweaning gain	12	Hereford; 1488 calves; replicated at 2 location; response based on regression on dam birth yr.	postweaning gain	+.91 kg		.78
				feed efficiency	+.51		
				yearling conf.	+.62 units		
	+feed efficiency (gain/TDN)	12		postweaning gain	+.15 kg		
				feed efficiency	+.09		.52
				yearling conf.	+.06 units		
	+yearling conf.	12		postweaning gain	-.06 kg		
				feed efficiency	+.02		
				yearling conf.	-.05 units		0
Barlow et al. (1978)	+gain birth to yearling	first generation results	Angus; control used; sires replaced each yr.	yearling gain			
				birth wt	+		
				preweaning gain	+		
				postweaning gain	+		
				yearling wt	+		

TABLE 4 (Continued)

Reference	Selection criteria	No. of years	Description of study	Trait	Phenotypic response/yr	Direct or correlated genetic response/yr	Realized h^2
Benson et al. (1972)	+index (+ yearling wt/d of age - back-fat/CWT)	8	Hereford; 387 calves; environmental trends estimated by repeat matings.	birth wt	+.11 kg	-.57 kg	
				weaning wt	-1.35 kg	+1.39 kg	
				final wt	+7.41 kg	+21.25 kg	
				yearling wt/d of age	+18 g	+14 g	
				fat thickness	+.08 cm	+.03 cm	
				yearling wt	+.16 kg	-3.01 kg	
				550 d wt	+.57 kg	-.85 kg	
Brinks et al. (1961, 1965)	+wt and gain +gain with some emphasis on conf. in closed line	25	Hereford; 2027 calves; environmental trends estimated by repeat matings; detrimental inbreeding effect.	birth wt	+.17 kg	+.17 kg	
				weaning wt	+1.09 kg	+.54 kg	
				feed test gain		.36 kg	
Chapman et al. (1969, 1972)	+weaning wt	7	Polled Hereford; control used.	birth wt	+.11 kg		
				weaning wt	-3.76 kg		.33
				weaning score	+.01 units		
				preweaning gain	-4.08 kg		
	+postweaning gain	7		birth wt	+.48 kg		
				weaning wt	-6.08 kg		
				weaning score	+.10 units		
				preweaning gain	-6.49 kg		
	+yearling type score	7		birth wt	.54 kg		
				weaning wt	-2.81 kg		
				weaning score	+.15 units		
				preweaning gain	-3.45 kg		

TABLE 4 (Continued)

Reference	Selection criteria	No. of years	Description of study	Trait	Phenotypic response/yr	Direct or correlated genetic response/yr	Realized h^2
Chevraux and Bailey (1977)	+postweaning growth rate (140 d test)	19	Hereford; 414 calves; increased inbreeding over study.	weaning wt	+3.28 kg		
				postweaning gain	+4.32 kg		.35
Fahmy and Lalande (1973)	+preweaning gain		Shorthorn; used maternal and paternal half-sib differences to estimate environmental trends.	birth wt		+.11 kg	
				weaning wt		-.48 kg	
Flower et al. (1964)	multiple trait plus progeny test	8	Hereford; 550 calves; environmental trends estimated by repeat matings.	birth wt	-.47 kg	+.29 kg	
				weaning wt	-2.22 kg	+2.22 kg	
Koch et al. (1974a,b)	weaning wt	10	Hereford; 2956 calves; responses estimated by combination of several methods	birth wt	+.40 kg		
				weaning wt	+.50 kg		
				yearling wt	-1.59 kg (bulls) +3.58 kg (heifrs)		
	yearling wt	10		birth wt	+.40 kg		
				weaning wt	+.41 kg		
				yearling wt	-3.08 kg (bulls) +2.90 kg (heifers)		
	+index (yearling wt and muscling score)	10		birth wt	+.50 kg		
				weaning wt	+.50 kg		
				yearling wt	-2.09 kg (bulls) +4.58 kg (heifers)		

TABLE 4 (Continued)

Reference	Selection criteria	No. of years	Description of study	Trait	Phenotypic response/yr	Direct or correlated genetic response/yr	Realized h^2
Nelms and Stratton (1967)	+final feedlot wt (168 d)	12	Hereford; 11% inbreeding.	birth wt	+.30 kg		
				180 d wt	+.68 kg		
				postweaning ADG	+9 g/d		
				final wt	+2.5 kg		
Newman et al. (1973)	+yearling wt	10	Shorthorn; control used; cattle at 2 locations.	yearling wt	+11.66 (bulls) +8.35 (heifers)	+4.44 (bulls) +2.81 (heifers)	.50 (bulls) .39 (heifers)
Stanforth (1974)	+weaning wt	9	Hereford; 827 calves; earlier report of data in Frahm et al. (1985b).	weaning wt	+3.76 kg		.43
				yearling wt	+4.58 kg		
	+yearling wt	9		weaning wt	+3.45 kg		
				yearling wt	+6.99 kg		.53
Willms et al. (1980)	+growth	15-20	Hereford (H), beef synthetic (BS), dairy synthetic (DS); environmental trends estimated by repeat matings.	preweaning ADG		+3 g/d (H) +8 g/d (BS) +9 g/d (DS)	
				weaning wt		+.10 kg (H) -.90 kg (BS) +1.30 kg (DS)	
				postweaning ADG		+2 g/d (H) +26 g/d (BS) +22 g/d (DS)	
				yearling wt		+1.30 kg (H) +6.70 kg (BS) +6.80 kg (DS)	
				18 mo wt		-4.58 kg (H) -4.22 kg (BS) -3.99 kg (DS)	

TABLE 5

SUMMARY OF HERITABILITY AND CORRELATION ESTIMATES FOR GROWTH AND CONFORMATION TRAITS IN BEEF CATTLE[a]
(Woldehawariat et al., 1977)

Trait[b]	BW	WDG	WW	WC	FDG	FW	FC
BW	.45	.34	.54	.33	.51	.60	.07
WDG	.23	.30	.99	.35	.22	.67	-
WW	.37	.98	.24	.24	.71	.12	-.06
WC	.15	.34	.40	.38	.17	.33	.68
FDG	.28	.12	.70	.00	.34	.82	.34
FW	.43	.69	.20	.30	.74	.46	.34
FC	.15	-	.20	.40	.40	.41	.36

[a]Heritabilities (weighted average of regression and paternal half sib estimates) along diagonal, genetic correlations (weighted average) above diagonal, phenotypic correlations (weighted average) below diagonal.

[b]BW=birth wt, WDG=preweaning daily gain, WW=weaning wt, WC=weaning conformation, FDG=feedlot daily gain, FW=final feedlot weight, FC=final feedlot conformation.

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CHAPTER III

DIRECT AND CORRELATED RESPONSES TO SELECTION FOR INCREASED WEANING AND YEARLING WEIGHTS IN ANGUS CATTLE. I. MEASUREMENT OF SELECTION APPLIED

D. K. Aaron, R. R. Frahm and D. S. Buchanan

Oklahoma State University, Stillwater 74078

Summary

Four 50-cow, 4-sire lines of Angus cattle were established as part of a long term selection project. Performance data through yearling age were collected on 2,749 calves during the 16-yr period, 1964-1979. Lines were selected for individual weaning weight (WWL), individual yearling weight (YWL) and a combination of individual and progeny weaning weights (PTL). The fourth line was maintained as an unselected control line (CL) to monitor yearly environmental changes. Criteria in the CL were zero selection differentials for both weaning and yearling weights. Traits analyzed were birth weight (BW), preweaning daily gain (WDG), weaning weight (WW), weaning conformation grade (WG), weaning condition score (WC), weaning to yearling daily gain (YDG), yearling weight (YW), yearling conformation grade (YG) and yearling condition score (YC). Over the 16-yr period, 3.87 and 3.72 generations of selection had occurred in the WWL and YWL, respectively. The PTL was terminated in 1978 and 2.68 generations of selection had occurred to that point. Mean cumulative selection differentials (CSD's) were calculated for each contemporary line-yr-sex group. In 1979 (1978 for PTL) CSD's expressed in standard measure, in the WWL, YWL, PTL and CL, respectively, were: BW, 1.61, 1.66, 1.24, .09; WDG, 3.70, 2.87, 3.32, .19; WW, 3.75, 2.99, 3.32, .22; WG, 1.93, 1.70, 1.81, .32; WC, 2.11, 1.39, 1.46, .17; YDG, .61, 3.20, 1.38, 1.08; YW, 2.71, 3.87, 2.99, .72; YG, 1.80, 3.44, 1.49, .99; YC, 1.03, 1.76, .50, .71. Selection indexes in retrospect were also calculated.

(Key Words: Beef cattle, Selection differential, Weaning weight, Yearling weight, Angus)

Introduction

Selection, a differential reproductive rate resulting from the deliberate choice of animals to be the parents of the next generation, is one of the primary force by which breeders can improve the genetic composition of their herds. Genetic progress per year depends on the selection intensity as measured by standardized selection differentials, the heritability of the trait being selected and the generation interval.

A long term project was initiated in 1960 at the Oklahoma Agricultural Experiment Station to evaluate direct and correlated responses to selection for increased weaning and yearling weight in beef cattle. The objective of this portion of the study was to quantify the selection pressure applied in three lines of Angus cattle after 14 years of selection for growth traits.

Materials and Methods

Formation and Description of the Lines. Three selection lines and an unselected control line were established from a common base of Angus cattle. Foundation cows originated from several herds in the southwestern and midwestern United States and were the daughters of 30 different Angus sires. Foundation cows were randomly allotted to four 50-cow lines in 1963. Twenty-five foundation sires, also originating from several sources, were used from 1963 through 1966. During the breeding seasons in these years, foundation sires were bred to cows in all four Angus lines. By 1968, all lines were closed to outside breeding and all replacement breeding animals were selected on line criteria within each line from that point. In addition to the four Angus lines utilized in this study, two Hereford lines, selected for weaning and yearling weight, respectively, were formed as part of this long term project. General procedures and results obtained from the Hereford lines were presented by Frahm et al. (1985). Only the data from the Angus lines were analyzed in this study.

Selection criteria for replacement breeding animals in the Angus lines were heaviest individual 205-d weaning weight in the weaning weight line (WWL), heaviest individual 365-d (bulls) or 425-d (heifers) yearling weight in the yearling weight line (YWL) and a combination of individual and progeny 205-d weaning weights in the progeny test line (PTL). An animal was considered "selected" only if it produced at least one offspring in the selection line. The fourth line was maintained as an unselected control line (CL), and replacement breeding animals were chosen to have as near zero selection differentials for both weaning and yearling weight as possible. Originally, the CL was designed as a progeny test line for yearling weight; however, in 1969 it was converted to a control line to monitor yearly environmental changes. Since only two calf crops had been sired by progeny tested bulls up to that point, very little selection had actually been practiced. However, to counteract the effects of any selection that might have occurred, cows in this line were artifically inseminated during the 1969 breeding season with frozen semen collected from the foundation sires. In addition, clean-up bulls having near zero selection differentials for both weaning and yearling weights were used following the period of artificial insemination. Foundation cows were allowed to remain in the line as long as possible, thus requiring replacement heifers were required from the 1970 and 1971 calf crops.

Beginning with the 1965 calf crop, two bulls were selected each year in the WWL, YWL and CL based on the respective line criteria. Bulls were first used as two year olds through the 1970 breeding season and as yearlings in subsequent years. In the PTL five bulls were selected on the basis of individual 205-d weaning weight and mated to cows in an Angus test herd. Two bulls were subsequently selected on the basis of progeny weaning weight. Bulls were three years old when they were first mated to cows within the PTL. This process was followed in the PTL from 1966 through 1970; thereafter, two bulls were selected each year based on individual performance. Selected bulls in all lines were used for two years. Thus, four bulls were used per year in each line, two being used for the first time and two being used for the second time. In each line the third ranking bull, based on line criteria, was kept as an alternate for use in the event a selected bull had to be culled before completing two years of service. During the length of the study only one bull in each of the WWL, PTL and CL failed to complete the two year service period. The total numbers of sires selected over the 16 year period were 28, 26, 22 and 29 for the WWL, YWL, PTL and CL, respectively.

Fifty breeding-age females were maintained in each of the four lines. In order to achieve a 20 percent replacement rate, 10 cows were culled in each line each year and replaced with the top 10 bred heifers based on the respective line criteria. Initially, the 13 highest ranking heifers in each line (zero selection differentials for both weaning and yearling weights in the CL) were bred to selected bulls. Of the 13 heifers exposed, the top 10 diagnosed pregnant following the breeding season were selected to remain in the line. Cows were culled only on the basis of (1) serious unsoundness, (2) reproductive failure, and (3) oldest age. No selection was practiced on cows based on progeny performance. During the length of the experiment, 142, 130, 112 and 121 heifers were selected in the WWL, YWL, PTL and CL, respectively.

Management and Data Collection. Cattle were maintained at the Southwestern Livestock and Forage Research Station at El Reno, Oklahoma. To ensure that environmental conditions were as uniform as possible, all lines were managed as a single herd during most of the year. The only exceptions were during the breeding season and occasionally when forage availability made multiple herds necessary. Cows were grazed most of the year on native tall grass range and bermudagrass pasture typical of central Oklahoma. In winter, cows had access to wheat pasture and milo stubble and were supplemented with prairie hay, alfalfa or cottonseed cake whenever necessary.

Breeding females were stratified by age within each of the four lines and then randomly allotted to the appropriate bulls. Bulls were placed with cows in single-sire breeding pastures on May 1 of each year. Length of the breeding season was 90 days through 1968 and 60 days throughout the remaining years of the study. To minimize inbreeding, matings between half-sibs or more closely related individuals were prohibited. Inbreeding coefficients for the final set of 16 bulls selected from the four lines ranged from 1 to 9% with an average inbreeding coefficient of 4.4%.

Calves were born from February through April each year. Within 24 hours after birth, all calves were tagged and tattooed for identification and birth weights were recorded. Calves were allowed to run with their dams on pasture and received no creep feed. Weaning weights, conformation grades and condition scores were recorded in the fall when the average age of all calves was approximately 205 days.

Following weaning, bull calves were given a two week warm up period and then placed on a 160-d gain test through 1971 and a 140-d gain test from 1972 through 1979. Bulls were fed a corn-based ration ad libitum from self feeders. Test rations underwent three basic changes with TDN and crude protein of the rations ranging from 62.4 to 66.2% and 10.5 to 13.2%, respectively, during the 16-yr period. At the end of the gain test, weights, conformation grades and condition scores were recorded on all bulls.

Heifer calves were placed on pasture gain tests following weaning and were supplemented with prairie hay, alfalfa, cottonseed cake or grain as needed to achieve gains ranging from .34 to .45 kg/d. Weights, conformation grades and condition scores were recorded when the average age of all heifers was 425 days.

Complete performance data were collected on all calves through 365 days for bulls and 425 days for heifers. Traits analyzed were birth weight (BW), preweaning daily gain (WDG), weaning weight (WW), weaning conformation grade (WG), weaning condition score (WC), weaning to yearling daily gain (YDG), yearling weight (YW), yearling conformation grade (YG) and yearling condition score (YC). Weaning weights were adjusted to a 205-d basis by multiplying WDG by 205 and adding BW. These weights were further adjusted for age of dam. Yearling weights (365-d for bulls and 425-d for heifers) were calculated by multiplying YDG by 160 for bulls and 220 for heifers and adding 205-d age of dam adjusted WW.

From the beginning of the study through the 1969 calf crop, weaning weights were adjusted to a mature dam basis by multiplying the 205-d WW by 1.15, 1.10 and 1.05 for 2-, 3- and 4-yr old cows at the time of calving, respectively. Beginning with the 1970 calf crop and continuing through subsequent years, additive age of dam correction factors were used as developed by Cardellino and Frahm (1971) from analysis of the weaning weight records collected on cattle in this study from 1964 through 1968. The additive correction factors used during this period were 27.2, 15.9 and 4.5 kg for Angus cows that were 2-, 3- and 4-yr old at the time of calving, respectively.

All calves were independently scored for conformation and condition at weaning and yearling age by a committee of at least three persons. Average conformation grades and condition scores were recorded for each calf. Conformation grades were based on a 17 point scale with 13 representing average choice. Condition scores were based on a 9 point scale with 5 representing average fat cover.

After all data were collected, age of dam correction factors were developed in retrospect for the nine primary traits evaluated in this study. Least-squares analyses were conducted within sex with the statistical model including fixed effects for age of dam, year and age of dam by year interaction. Prior to further analysis all traits were directly adjusted to a mature dam basis using the additive correction factors determined from these data as presented in table 1.

Records were expressed in both actual and standard measure. Standardized records were obtained by deviating each particular record from its contemporary line-yr-sex mean and dividing by the appropriate intra line-yr-sex standard deviation.

Measurement of Selection Applied

Generations of Selection. Generation turnover during the 16-yr period was evaluated by calculating the number of generations back to the initiation of the experiment in 1964. Generation coefficients were calculated using a formula described by Brinks et al. (1961): CGC = [(SGC + DGC)/2] + 1 where CGC, SGC and DGC refer to calf, sire and dam generation coefficients, respectively. Foundation animals were assigned generation coefficients of zero and progeny generation coefficients increased by one over the average of the parents. The generation coefficient of an individual measures one more than the number of generations of selection; therefore, generations of selection were obtained by subtracting one from the generation coefficient.

Cumulative Selection Differentials. Cumulative selection differentials (CSD's) are a measure of the total amount of selection that has been applied to any point in time. When compared to the total direct response for a particular trait, CSD's can be used to evaluate the effectiveness of selection. When generations are discrete, CSD's can be calculated by simply adding selection differentials of successive generations; however, in species such as cattle where considerable overlap exists in generations producing calves within a year, additional formulas are needed. Cumulative selection differentials were calculated using the method of Newman et al. (1973): CSD = ID + MAS where CSD equals the individual cumulative selection differential, ID is the individual's own deviation from the contemporary line-yr-sex group and MAS is the mean accumulated selection of all parents contributing progeny to the contemporary group. The MAS is calculated as half the average CSD for all sires and dams of the contemporary group. The CSD for an individual can be thought of as the average prior selection practiced for the contemporary group plus the additional selection practiced in the individual. Cumulative selection differentials were calculated in standardized units for all nine primary traits in the four lines. Also, average yearly midparent CSD's were regressed on year to estimate yearly trends. The method utilized in this study differs from that described by Pattie (1965) in which an individual's CSD was obtained by adding the individual's ID to the average of the individual CSD's of its parents. Newman's method was more appropriate for these data because selected individuals were deviated from their contemporary line-yr-sex mean rather than the average of progeny of the individual's parents.

Actual vs Maximum Selection Differentials. Selection differentials per generation were calculated in actual and standard measure for selected sires (ΔS) and selected dams (ΔD) by averaging the deviated and standardized selection differentials for sires and dams of all progeny excluding those from foundation parents. Maximum potential selection differentials were calculated by averaging individual deviations of the bulls and heifers (two bulls and 10 heifers per line) with the largest values based on selection criteria in each line each year. Maximum potential selection differentials for the CL were calculated for those individuals that were closest to zero selection differentials for both weaning and yearling weight. Comparing actual and maximum potential selection differentials provides an estimate of the proportion of the possible selection that was actually applied toward the primary trait in each line. Although strict adherence to selection criteria was attempted during this study, some high ranking individuals may have been culled because of physical defects, injury or reproductive failure.

Indexes in Retrospect. Indexes using various combinations of the nine traits evaluated were determined in retrospect as described by Dickerson et al. (1954). Although selection for a single trait was strictly adhered to in this study, it is the net effect of that direct selection as well as the indirect selection which occurs that is of ultimate interest. Selection for one trait cannot be considered in isolation, but will have consequences for other traits as well because of genetic correlations that exist among traits. Indexes in retrospect show the relative emphasis placed on traits included in the index.

Indexes in retrospect were calculated using both actual and maximum potential selection differentials as described by Chenette (1981) and

Buchanan et al. (1982). Phenotypic correlations, used to calculate these indexes, were obtained from pooled sums of squares and crossproducts within lines and years for bulls and heifers. Two sets of indexes were calculated from these data. Index 1 included BW, WW, WG, WC, YW, YG and YC while Index 2 substituted WDG for WW and YDG for YW. Thus, Index 1 provides a check on selection intentions; and Index 2 indicates the relative selection for growth rate at various stages.

Results and Discussion

The number of bulls and heifers with weaning or yearling records is presented in table 2 for each line and year. Over the 16-year period the numbers of weaning and yearling records collected were 694 and 660, 691 and 646, 666 and 625, and 698 and 662 for the WWL, YWL, PTL and CL, respectively. Line means across years and standard deviations for the nine traits analyzed are shown in table 3 for bulls and heifers. Standard deviations were calculated from sums of squares pooled over all line-yr-sex subclasses. Variation among bulls and heifers was similar for all traits except YDG where heifers were more variable.

Generations of Selection. Average generation coefficients, which measure one more than the number of generations of selection, are presented in table 4 for each line and year. Over the 16-year period, 3.87 and 3.72 generations of selection had occurred in the WWL and YWL, respectively. The generation turnover in the CL was slightly slower with 3.40 generations of selection occurring by the time the 1979 calf crop was produced. Comparable results involving two Hereford lines, selected for weaning or yearling weight as part of this same selection project, were presented by Frahm et al. (1985). After 15 years of selection, generation turnover rates were 3.22 and 3.21 generations for the Hereford weaning and yearling weight lines, respectively. Also, Buchanan et al. (1982) reported that after 17 years, 3.69, 3.56 and 3.67 generations of selection had occurred in lines selected for weaning weight, yearling weight, and an index of yearling weight and muscling score, respectively.

Generation coefficients were also calculated for the PTL in the present study. This line was terminated with the 1978 calf crop and 2.68 generations of selection had occurred to that point. As was expected, generation turnover in this line was slower than in the other three lines because the progeny testing process lengthens the generation interval.

Cumulative Selection Differentials (CSD's). Average midparent CSD's, which measure the amount of selection pressure that has accumulated through the parents of calves born in a given year, are presented in table 5, along with their regression on year, for the nine traits in the WWL, YWL and PTL. Corresponding values for the CL are presented in table 6. The CSD's increased at the rate of .27 standard deviations (σ)/year for WW in the WWL and .25 σ/year for YW in the YWL. These indicate that direct selection accumulated at very similar rates in the two lines. These results agree well with the .26 σ/year and .27 σ/year increases reported by Frahm et al. (1985) for the Hereford WWL and YWL, respectively. Also, Buchanan et al. (1982) reported increases of .24 σ/year for both WWL and YWL.

Correlated CSD's accumulated at the rate of .18 σ/year for YW in the WWL and .21 σ/year for WW in the YWL. Compared to direct selection for

YW in the YWL, YW in the WWL increased at a rate of 72% as fast. Similarly, selection pressure for WW in the YWL increased 70.3% as fast as direct selection for WW in the WWL. These correlated rates of increase are more similar than the corresponding values of 77.8 and 84.6% presented by Frahm et al. (1985) for the Hereford lines.

In the PTL, direct and correlated CSD's increased at the rate of .25 σ/year for WW and .21 σ/year for the YW. These values are quite similar to those obtained in the WWL.

Correlated CSD's for the remaining traits accumulated at slower rates. Unfortunately, selection pressure for BW increased at the rate of .12 σ/year in both the WWL and YWL and .09 σ/year in the PTL. Conformation grades and condition scores also showed increasing CSD's/year. These results agree quite closely with results presented by Frahm et al. (1985).

The rate of accumulation of selection pressure can be converted to a per generation basis by dividing average midparent CSD's for the final year (1979 for WWL and YWL, 1978 for PTL) by the number of generations of selection. Selection pressure accumulated at rates of .97, 1.04 and 1.24 σ/generation for WW in the WWL, YW in the YWL and WW in the PTL, respectively. Even though fewer generations of selection had occurred in the PTL, selection pressure accumulated at a faster rate per generation than in the WWL or YWL. Frahm et al. (1985) reported selection pressure had accumulated at rates of 1.06 and 1.12 σ/generation for WW in the WWL and YW in the YWL, respectively. Results in the present study and in the study reported by Frahm et al. (1985) were slightly higher than values of .94 and .96 σ/generation calculated from data reported for WW and YW by Buchanan et al. (1982).

As shown in table 6, a slight amount of selection occurred in the CL. Average midparent CSD's increased slightly each year for all traits except BW and WC. This may be explained by the small amount of selection which was practiced prior to the time this line was converted to an unselected control line.

Actual vs Maximum Selection Differentials. Average selection differentials per generation (in standard measure) are presented in table 7 for selected sires (ΔS), selected dams (ΔD) and midparents (ΔM). Midparent selection differentials per generation were .97 and 1.00 σ/generation for WW in the WWL and YW in the YWL, respectively. These are in close agreement with values of .97 and 1.05 σ/generation reported by Frahm et al. (1985) utilizing the Hereford WWL and YWL. Also, Buchanan et al. (1982) reported similar values of 1.00 and 1.06 σ/generation in Hereford lines selected for weaning and yearling weight, respectively. In the PTL the midparent selection differential per generation for WW was 1.24σ which was higher than all other values. Other reports of midparent selection differentials per generation include .82σ for final weight (Nelms and Stratton, 1965) and .93σ for postweaning ADG (Chevraux and Bailey, 1977).

The proportion of selection pressure attributable to selected sires vs selected dams can be evaluated by comparing the relative magnitude of the average midparent selection differential (ΔM) due to sires (ΔS) and dams (ΔD). Using this method, the proportion of selection due to sires was 67% for WW in the WWL and 76% for YW in the YWL. In the PTL, 72% of the selection pressure for WW was due to sire selection. Utilizing the Hereford data, Frahm et al. (1985) calculated similar values of 70 and 76% for the proportion of the selection pressure due to sires in the weaning and yearling weight lines, respectively. Buchanan et al. (1982) reported that sire selection accounted for 78 and 84% of the selection pressure for WW and YW, respectively. The increased importance of dam selection in the present study may have been due to the fairly rapid replacement rate for females in these lines (10/50 cows per line per year).

Maximum potential selection differentials for sires (ΔS) and dams (ΔD) based on line criteria are presented in standard measure in table 8. Comparing the maximum potential selection differentials with actual selection differentials for WW in the WWL and YW in the YWL provides an evaluation of the effectiveness relative to intended selection. In the WWL the actual selection differentials/generation for WW were 94 and 81% of the maximum potential for sires and dams, respectively, while corresponding values for YW in the YWL were 100 and 64%. In the YWL, the top ranked bulls for YW sired progeny in all cases; however, the potential selection realized for dams was quite low. Frahm et al. (1985) reported values of 88 and 70% and 100 and 67% for sires and dams in the weaning and yearling weight lines, respectively.

In the PTL, actual selection differentials for WW were 95 and 82% of the maximum potential for sires and dams, respectively. Although final selection of bulls in this line was based on progeny weaning weight, in most cases the sires which were selected on this criterion were also the top sires based on individual WW as well.

Since selection criteria were strictly followed throughout the study, failure to achieve the maximum selection pressure possible must be explained by the development of serious unsoundness, illness or death of top ranked individuals prior to their use in the selection line. In heifers, reproductive failure during the first breeding season was the primary reason for loss of selection pressure. Another potential source of selection error would be possible changes in rankings of individuals after weaning and yearling weights were recalculated utilizing age of dam corrections determined from these data (table 1) after selection had terminated.

Indexes in Retrospect. Indexes in retrospect were calculated in standard measure for sires and dams using both actual and maximum potential selection differentials per generation. Pooled within line and year phenotypic correlations for bulls and heifers used in these calculations are presented in table 9. Two sets of indexes were calculated from these data.

The first set of indexes in retrospect included BW, WW, WG, WC, YW, YG and YC as component traits and are presented in table 10 for the WWL, YWL and PTL. Midparent index selection differentials, obtained by averaging sire and dam index selection differentials (ΔI), indicate 1.0 and 1.1 σ of selection per generation occurred for this index in the WWL and YWL, respectively. These values are comparable to selection pressure directly applied per generation (table 7). Frahm et al. (1985) reported results similar to these utilizing the Hereford data. These results are also in close agreement with index selection differentials presented by Buchanan et al. (1982). In the PTL, the midparent index selection differential was 1.3 σ/generation which was also similar to selection pressure directly applied to WW per generation.

Comparison of sire and dam index selection differentials revealed the proportion of total selection pressure attributable to sire selection was 67, 74 and 72% in the WWL, YWL and PTL, respectively.

Index 1 standard partial regression coefficients (β_{IP_k}) should provide a check on how closely selection criteria were followed since both WW and YW are included in the index. In the WWL, selection pressure was greatest for WW for both sires and dams, as evidenced by the index weightings (β_{IP_k}). When maximum potential selection differentials were used to calculate Index 1 in the WWL, the index weightings for WW increased for both sires and dams; however, unintended positive selection pressure for BW and negative selection pressure for YW were indicated for both sires and dams. In the YWL, the principle selection pressure appeared to be for YW for both sires and dams; however, some unintended selection for BW was indicated for dams. Index 1, calculated with maximum potential selection differentials for the YWL, indicated similar results with the weightings being slightly larger for YW. Also, a smaller weighting was observed for YC in dams. The unintended selection for YC may reflect the practice of only retaining pregnant heifers. Those heifers that did not conceive may have tended to be in lower body condition at 425 days which was close to the start of the breeding season. In the PTL, the primary selection pressure was for WW, but for unexplainable reasons, the index weighting for dams was substantially larger than for sires. This was also true when maximum potential selection differentials were used. In all lines index weightings indicated some unintended selection pressure for both conformation grade and condition score; however, these were inconsistent and in conflict with known selection practices.

Indexes in retrospect for Index 2 (WDG and YDG replacing WW and YW, respectively) are presented in table 11. Evaluation of the index weightings for WDG and YDG indicates the relative selection for growth rate during two different gain periods. In the WWL and PTL selection pressure was large for WDG relative to YDG in both sexes; however, index weightings were similar in size for both WDG and YDG in the YWL. Similar results were presented by Frahm et al. (1985).

During the conduct of this study, strict adherence to selection criteria was practiced, the only exceptions being the few cases where biological factors prevented animals from being selected. While indexes in retrospect show the relative emphases of traits included in the index, it is important to realize that they are a function of estimated phenotypic correlations among the traits as well as direct and correlated selection differentials.

TABLE 1

ADDITIVE AGE OF DAM CORRECTION FACTORS TO ADJUST TRAITS TO A MATURE DAM BASIS

Trait[a]	Age of dam	Bulls	Heifers
BW, kg	2	+4.1	+ 3.2
	3	+1.8	+ 1.4
	4	+ .9	+ .4
WDG, g/d	2	+132	+109
	3	+ 82	+ 64
	4	+ 36	+ 23
WW, kg	2	+31.8	+24.9
	3	+18.1	+14.5
	4	+ 8.6	+ 5.4
WG[b]	2	+ 1.0	+ .8
	3	+ .7	+ .5
	4	+ .4	+ .2
WC[c]	2	+ .7	+ .7
	3	+ .5	+ .4
	4	+ .3	+ .2
YDG[d], g/d	2	+ 0	-45
	3	+ 0	-23
	4	+ 0	-14
YW, kg	2	+32.2	+15.4
	3	+20.0	+ 9.5
	4	+ 7.2	+ 3.2
YG[b]	2	+ .4	+ .3
	3	+ .3	+ .2
	4	+ 0	+ .1
YC[c]	2	+ .4	+ .2
	3	+ .4	+ .1
	4	+ .3	+ .1

[a] BW=birth wt, WDG=preweaning daily gain, WW=weaning wt, WG=weaning conformation grade, WC=weaning condition score, YDG=weaning to yearling daily gain, YW=yearling wt, YG=yearling conformation grade, YC=yearling condition score.

[b] Conformation grade on a 17 point scale with 12=low choice, 13=average choice.

[c] Condition score on a 9 point scale from 1=thin to 9=very fat.

[d] Age of dam was not a significant source of variation for bull calves.

TABLE 2

NUMBER OF CALVES WITH WEANING OR YEARLING RECORDS FOR EACH YEAR AND LINE

	WWL[a]				YWL				PTL				CL			
	Weaning		Yearling		Weaning		Yearling		Weaning		Yearling		Weaning		Yearling	
Year	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers
1964	16	13	15	13	15	16	14	15	15	15	14	15	11	18	10	18
1965	24	21	24	21	24	20	24	20	24	17	24	17	20	22	20	22
1966	21	25	17	14	21	21	16	15	22	24	13	16	18	25	14	15
1967	21	26	20	26	18	29	17	29	24	23	24	15	25	21	24	15
1968	18	25	16	25	25	19	23	19	23	22	22	21	31	17	31	17
1969	24	20	22	19	22	20	19	19	21	27	16	27	25	14	25	14
1970	21	22	20	22	19	22	17	21	22	26	20	25	26	25	24	25
1971	18	26	18	26	22	23	22	22	23	17	23	17	28	17	28	17
1972	26	16	23	16	28	21	24	21	22	24	21	24	21	25	21	24
1973	27	20	25	19	22	27	22	27	19	22	19	22	23	23	22	23
1974	26	19	24	19	26	22	25	21	22	19	21	19	29	16	29	16
1975	26	20	25	20	18	22	15	22	26	24	26	24	26	22	23	21
1976	23	23	22	23	22	24	20	22	27	21	27	21	28	19	25	18
1977	23	24	22	24	19	26	15	25	28	21	27	20	33	15	33	15
1978	22	23	22	23	17	26	14	26	27	19	27	18	25	19	25	17
1979	13	22	13	22	20	15	20	15					18	13	18	13
Total	349	345	328	332	338	353	307	339	345	321	324	301	387	311	372	290

[a]WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line, CL=control line.

TABLE 3

LINE MEANS POOLED WITHIN YEAR AND STANDARD DEVIATIONS POOLED WITHIN LINE AND YEAR FOR BULLS AND HEIFERS

Trait[b]	Sex of calf	Line[a] WWL	YWL	PTL	CL	Standard deviation
BW, kg	Bulls	32.7	33.1	32.6	30.8	3.7
	Heifers	30.7	31.2	30.1	29.0	3.6
WDG, g/d	Bulls	859	870	872	835	91
	Heifers	791	794	797	760	79
WW, kg	Bulls	208.6	211.6	211.6	202.1	19.8
	Heifers	192.9	194.0	193.5	184.8	17.5
WG[c]	Bulls	13.0	13.1	13.0	13.2	.75
	Heifers	13.0	13.2	13.0	12.9	.70
WC[d]	Bulls	4.8	4.8	4.7	4.9	.63
	Heifers	5.0	4.9	4.9	5.0	.69
YDG, g/d	Bulls	1260	1259	1294	1189	166
	Heifers	347	341	352	319	72
YW, kg	Bulls	410.7	414.0	419.9	392.9	36.6
	Heifers	248.1	249.0	250.2	236.1	20.3
YG[c]	Bulls	13.2	13.2	13.2	13.1	.74
	Heifers	12.8	12.9	12.9	12.6	.68
YC[d]	Bulls	5.4	5.4	5.4	5.4	.68
	Heifers	4.9	4.8	4.8	4.8	.59

[a] WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line, CL=control line.

[b] BW=birth wt, WDG=preweaning daily gain, WW=weaning wt, WG=weaning conformation grade, WC=weaning condition score, YDG=weaning to yearling daily gain, YW=yearling wt, YG=yearling conformation grade, YC=yearling condition score.

[c] Conformation grade on a 17 point scale with 12=low choice, 13=average choice.

[d] Condition score on a 9 point scale with 1=thin to 9=very fat.

TABLE 4

AVERAGE GENERATION COEFFICIENTS FOR EACH YEAR AND LINE

	Generation coefficients[a]			
Year	WWL	YWL	PTL	CL
1964	1.00	1.00	1.00	1.00
1965	1.00	1.00	1.00	1.00
1966	1.08	1.07	1.09	1.09
1967	1.40	1.33	1.16	1.18
1968	1.72	1.66	1.20	1.63
1969	1.88	1.91	1.59	1.92
1970	2.19	2.19	1.76	1.82
1971	2.53	2.42	2.10	1.94
1972	2.74	2.75	2.19	2.53
1973	3.19	3.01	2.37	2.73
1974	3.57	3.35	2.71	3.08
1975	3.71	3.74	3.02	3.40
1976	3.87	3.87	3.18	3.68
1977	4.30	4.21	3.36	4.02
1978	4.54	4.35	3.68	4.21
1979	4.87	4.72	--	4.40

[a]WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line, CL=control line.

TABLE 5

AVERAGE YEARLY MIDPARENT CUMULATIVE SELECTION DIFFERENTIALS (CSD) EXPRESSED IN STANDARD MEASURE FOR THE SELECTION LINES

Year (Y)	Trait[a] BW	WDG	WW	WG	WC	YDG	YW	YG	YC
				Weaning wt line (WWL)					
1966	.00	.00	.00	-.01	-.02	-.02	-.01	-.02	-.01
1967	.38	.27	.32	.14	.20	.16	.34	.13	.28
1968	.72	.46	.56	.30	.35	.39	.53	.30	.39
1969	.10	.72	.66	.38	.36	.25	.52	.25	.12
1970	.10	1.14	1.06	.83	.70	.42	.94	.66	.42
1971	1.07	1.30	1.43	.77	1.04	.40	1.11	.61	.50
1972	.85	1.54	1.59	.59	.98	.26	1.08	.61	.53
1973	.87	2.19	2.18	1.20	1.35	.42	1.58	1.11	.58
1974	1.08	2.49	2.50	1.14	1.61	.02	1.54	1.05	.42
1975	1.19	2.65	2.67	1.11	1.42	-.02	1.63	.91	.45
1976	1.47	2.93	2.98	1.62	1.79	.33	2.02	1.30	.80
1977	1.46	3.22	3.26	1.43	1.79	.32	2.17	1.25	.69
1978	1.50	3.51	3.55	1.69	1.76	.38	2.44	1.69	.71
1979	1.61	3.70	3.75	1.93	2.11	.61	2.71	1.80	1.03
$b_{CSD \cdot Y}$[b]	.12	.27	.27	.13	.15	.02	.18	.12	.06
				Yearling wt line (YWL)					
1966	.00	.03	.03	.03	.01	.02	.04	.05	.03
1967	.11	.18	.18	.24	.20	.15	.24	.36	.15
1968	.41	.75	.77	.64	.21	.51	.77	.68	.35
1969	.61	1.24	1.29	.80	.43	.84	1.23	1.08	.33
1970	.47	1.21	1.24	.85	.71	1.12	1.42	1.35	.43
1971	.39	1.27	1.25	.66	.43	1.21	1.53	1.13	.36
1972	.46	1.30	1.30	.63	.39	1.35	1.65	1.50	.51
1973	.79	1.41	1.47	.69	.43	1.67	1.94	1.58	.76
1974	.88	1.87	1.92	.87	.62	2.03	2.46	1.88	1.03
1975	1.32	2.14	2.24	1.06	.62	2.58	3.04	2.43	1.06
1976	1.25	2.18	2.27	1.18	.88	2.70	3.09	2.50	1.33
1977	1.49	2.15	2.31	1.05	.87	3.02	3.33	2.66	1.75
1978	1.83	2.64	2.82	1.49	1.19	3.17	3.73	3.26	1.78
1979	1.66	2.87	2.99	1.70	1.39	3.20	3.87	3.44	1.76
$b_{CSD \cdot Y}$[b]	.12	.19	.21	.10	.08	.28	.25	.23	.13
				Progeny test line (PTL)					
1966	.01	.02	.01	-.03	.00	.02	.03	.04	.04
1967	.07	.07	.08	.01	.02	.08	.04	.09	.04
1968	.11	.15	.16	.04	.00	.06	.15	.10	.03
1969	.55	.71	.77	.38	.45	.46	.77	.56	.18
1970	.34	.87	.87	.56	.56	.35	.72	.30	.39
1971	.43	1.21	1.21	.36	.37	.48	1.00	.34	.27
1972	.64	1.52	1.55	.64	.39	.56	1.25	.20	-.03
1973	.76	1.83	1.86	1.00	.66	.82	1.68	.35	-.10
1974	.68	2.00	1.98	.99	.42	1.22	2.09	.98	.28
1975	.65	2.34	2.26	1.14	.78	1.03	2.06	1.04	.53
1976	.96	2.47	2.40	1.00	1.17	.43	1.76	.82	.44
1977	1.23	3.06	3.08	1.53	1.27	.80	2.41	1.22	.80
1978	1.24	3.32	3.32	1.81	1.46	1.38	2.99	1.49	.50
$b_{CSD \cdot Y}$[b]	.09	.25	.25	.13	.10	.09	.21	.10	.04

[a] BW=birth wt, WDG=preweaning daily gain, WW=weaning wt, WG=weaning conformation grade, WC=weaning condition score, YDG=weaning to yearling daily gain, YW=yearling wt, YG=yearling conformation grade, YC=yearling condition score.

[b] $b_{CSD \cdot Y}$=regression of cumulative selection differential on year. Standard error was .01 for all traits in all lines.

TABLE 6

AVERAGE YEARLY MIDPARENT CUMULATIVE SELECTION DIFFERENTIALS (CSD) EXPRESSED IN STANDARD MEASURE FOR THE CONTROL LINE

	Trait[a]								
Year (Y)	BW	WDG	WW	WG	WC	YDG	YW	YG	YC
				Control line (CL)					
1966	.03	.00	.01	-.04	.00	.02	.02	.02	.01
1967	.10	.01	.03	-.02	-.02	.05	.06	.06	.04
1968	.31	.17	.22	.11	.16	.65	.59	.64	.53
1969	.16	.19	.22	-.36	-.01	.72	.56	.40	.60
1970	-.05	.04	.04	-.31	-.15	.70	.44	.47	.34
1971	.02	.17	.16	.02	-.01	.34	.26	.32	.37
1972	.08	.20	.20	.20	.04	.70	.50	.70	.74
1973	.25	.20	.25	-.16	-.24	.66	.44	.47	.32
1974	-.04	.21	.20	.07	-.40	.71	.46	.71	.61
1975	.19	.14	.19	.13	-.01	.91	.58	.81	.68
1976	-.05	.19	.20	.19	-.14	.98	.61	.84	.72
1977	.04	.26	.28	.38	-.15	1.01	.68	.92	.64
1978	.08	.35	.36	.41	.16	.93	.70	.79	.63
1979	.09	.19	.22	.32	.17	1.08	.72	.99	.71
$b_{CSD \cdot Y}$[b]	.00	.02	.02	.03	.00	.07	.05	.07	.05

[a]BW=birth wt, WDG=preweaning daily gain, WW=weaning wt, WG=weaning conformation grade, WC=weaning condition score, YDG=weaning to yearling daily gain, YW=yearling wt, YG=yearling conformation grade, YC=yearling condition score.

[b]$b_{CSD\ Y}$=regression of cumulative selection differential on year. Standard error was .01 for all traits.

TABLE 7

MEAN SELECTION DIFFERENTIALS PER GENERATION FOR SELECTED SIRES (ΔS), DAMS (ΔD) AND MIDPARENTS (ΔM) EXPRESSED IN STANDARD MEASURE[a]

		Trait[c]								
Line[b]	Item	BW	WDG	WW	WG	WC	YDG	YW	YG	YC
WWL	Δ S	.524	1.284	1.298	.541	.710	.161	.806	.513	.278
	Δ D	.333	.630	.638	.426	.346	.060	.535	.357	.166
	Δ M	.428	.957	.968	.484	.528	.110	.670	.435	.222
YWL	Δ S	.550	1.077	1.121	.629	.451	1.304	1.520	1.324	.638
	Δ D	.368	.329	.367	.116	.145	.420	.487	.378	.323
	Δ M	.459	.703	.744	.373	.298	.862	1.004	.851	.481
PTL	Δ S	.669	1.784	1.783	.858	.686	.810	1.533	.640	.406
	Δ D	.252	.709	.659	.372	.279	.104	.591	.347	.119
	Δ M	.460	1.246	1.239	.615	.482	.457	1.062	.494	.262
CL	Δ S	-.198	.009	-.021	.088	-.068	.410	.250	.266	.104
	Δ D	.203	.161	.191	.088	.062	.330	.243	.393	.352
	Δ M	.002	.085	.085	.088	-.003	.370	.246	.330	.228

[a]Averages of selected parents, weighted by the number of progeny, excluding foundation parents.

[b]WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line, CL=control line.

[c]BW=birth wt, WDG=preweaning daily gain, WW=weaning wt, WG=weaning conformation grade, WC=weaning condition score, YDG=weaning to yearling daily gain, YW=yearling wt, YG=yearling conformation grade, YC=yearling condition score.

TABLE 8

MAXIMUM POTENTIAL SELECTION DIFFERENTIALS FOR SIRES (ΔS) AND DAMS (ΔD) BASED ON LINE CRITERIA, EXPRESSED IN STANDARD MEASURE[a]

Line[b]	Item	Trait[c] BW	WDG	WW	WG	WC	YDG	YW	YG	YC
WWL	Δ S	.680	1.378	1.427	.431	.656	.158	.843	.362	.268
	Δ D	.452	.789	.791	.480	.371	-.072	.612	.295	.091
YWL	Δ S	.423	1.137	1.147	.443	.492	1.276	1.513	1.023	.624
	Δ D	.518	.607	.663	.322	.261	.400	.752	.408	.254
PTL	Δ S	.693	1.865	1.870	.773	.596	.592	1.413	.782	.547
	Δ D	.300	.812	.803	.394	.317	-.020	.641	.307	.129
CL	Δ S	.003	.009	.019	.138	-.088	-.069	-.048	-.136	-.241
	Δ D	.012	.103	.098	.123	.151	-.022	.004	.073	.064

[a] Average selection differentials for the top bulls and heifers (2 bulls and 10 heifers per line) each year according to line criteria.
[b] WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line, CL=control line.
[c] BW=birth wt, WDG=preweaning daily gain, WW=weaning wt, WG=weaning conformation grade, WC=weaning condition score, YDG=weaning to yearling daily gain, YW=yearling wt, YG=yearling conformation grade, YC=yearling condition score.

TABLE 9

PHENOTYPIC CORRELATIONS AMONG TRAITS IN THE ANGUS LINES FOR BULLS AND HEIFERS[a,b]

Trait[c]	BW	WDG	WW	WG	WC	YDG	YW	YG	YC
BW		.288	.405	.085	.039	.292	.424	.260	.093
WDG	.278		.981	.533	.472	.221	.675	.427	.244
WW	.465	.978		.517	.452	.262	.715	.449	.247
WG	.208	.558	.557		.615	.036	.293	.424	.311
WC	.055	.474	.447	.609		-.016	.222	.303	.405
YDG	.202	-.108	-.059	-.169	-.198		.858	.476	.292
YW	.513	.785	.832	.381	.275	.485		.582	.338
YG	.259	.367	.392	.385	.351	.331	.520		.332
YC	.088	.166	.172	.241	.411	.258	.295	.555	

[a]Correlations for bulls are to the right of the diagonal and to the left of the diagonal for heifers.
[b]Pooled within lines.
[c]BW=birth wt, WDG=preweaning daily gain, WW=weaning wt, WG=weaning conformation grade, WC=weaning condition score, YDG=weaning to yearling daily gain, YW=yearling wt, YG=yearling conformation grade, YC=yearling condition score.

TABLE 10

SELECTION INDEXES IN RETROSPECT EXPRESSED IN STANDARD MEASURE FOR ACTUAL AND MAXIMUM POTENTIAL SELECTION β_{IP_k} FOR INDEX 1[a]

Line[b]	Parental type	BW	WW	WG	WC	YW	YG	YC	ΔI
		Trait[c]							
		Actual sire or dam selection[d]							
WWL	Sire	.026	1.126	-.273	.230	-.202	.043	-.027	1.342
	Dam	.081	.864	.084	.186	-.081	.192	-.027	.654
YWL	Sire	-.085	.052	.002	-.035	.695	.411	.031	1.618
	Dam	.323	.022	-.268	.036	.584	.196	.313	.560
PTL	Sire	-.077	.751	.081	-.025	.436	-.254	.048	1.867
	Dam	-.166	1.052	-.032	-.092	-.007	.203	.064	.710
		Maximum potential sire or dam selection[e]							
WWL	Sire	.106	1.208	-.348	.170	-.237	-.106	.022	1.525
	Dam	.172	1.019	.050	.035	-.189	.024	.061	.804
YWL	Sire	-.193	.169	-.183	.100	.846	.167	.051	1.563
	Dam	.240	.113	-.030	.070	.735	-.001	.051	.772
PTL	Sire	-.084	1.095	-.078	-.178	.033	-.033	.120	1.910
	Dam	-.118	1.245	-.097	-.089	-.165	.056	.032	.772

[a] β_{IP_k}=standard partial regression of the index on the k^{th} trait.
[b] WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line.
[c] BW=birth wt, WDG=preweaning daily gain, WW=weaning wt, WG=weaning conformation grade, WC=weaning condition score, YDG=weaning to yearling daily gain, YW=yearling wt, YG=yearling conformation grade, YC=yearling condition score.
[d] Calculated with selection differentials of parents actually selected.
[e] Calculated with maximum potential selection differentials.

TABLE 11

SELECTION INDEXES IN RETROSPECT EXPRESSED IN STANDARD MEASURE FOR ACTUAL AND MAXIMUM POTENTIAL SELECTION β_{IP_k} FOR INDEX 2[a]

Line[b]	Parental type	Trait[c] BW	WDG	WG	WC	YDG	YG	YC	ΔI
		Actual sire or dam selection[d]							
WWL	Sire	.220	.962	-.276	.226	-.159	.043	-.023	1.352
	Dam	.204	.767	.110	.091	.147	.110	.060	.668
YWL	Sire	-.007	.382	.004	-.029	.519	.405	.024	1.626
	Dam	.340	.506	-.209	.094	.565	.066	.237	.619
PTL	Sire	.111	.948	.068	-.030	.317	-.249	-.045	1.882
	Dam	.006	.980	.007	-.036	.233	.101	-.104	.736
		Maximum potential sire or dam selection[e]							
WWL	Sire	.311	1.014	-.341	.180	-.142	-.123	.061	1.517
	Dam	.338	.800	.068	.050	-.028	-.006	-.075	.803
YWL	Sire	-.079	.572	.184	.102	.626	.160	.044	1.575
	Dam	.352	.683	-.012	.098	.525	-.059	.028	.812
PTL	Sire	.127	1.049	-.082	-.177	.021	-.036	.120	1.925
	Dam	.086	1.037	-.072	-.062	.043	.002	.008	.821

[a] β_{IP_k}=standard partial regression of the index on the k^{th} trait.
[b] WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line.
[c] BW=birth wt, WDG=preweaning daily gain, WW=weaning wt, WG=weaning conformation grade, WC=weaning condition score, YDG=weaning to yearling daily gain, YW=yearling wt, YG=yearling conformation grade, YC=yearling condition score.
[d] Calculated with selection differentials of parents actually selected.
[e] Calculated with maximum potential selection differentials.

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CHAPTER IV

DIRECT AND CORRELATED RESPONSES TO SELECTION FOR INCREASED WEANING AND YEARLING WEIGHTS IN ANGUS CATTLE. II. EVALUATION OF RESPONSE

D. K. Aaron, R. R. Frahm and D. S. Buchanan

Oklahoma State University, Stillwater 74078

Summary

Three lines of Angus cattle were selected for individual weaning weight (WWL), individual yearling weight (YWL) or a combination of individual and progeny weaning weights (PTL) from 1965 to 1979. Also, a contemporary Angus control line (CL) was maintained to monitor yearly environmental changes. Each line consisted of 50 cows with two bulls and 10 heifers being selected on line criteria within each line each year. Selected bulls were used for two years. Performance data through yearling age were collected on 694, 691, 666 and 698 calves in the WWL, YWL, PTL and CL, respectively. Traits analyzed were birth weight (BW), preweaning daily gain (WDG), weaning weight (WW), weaning conformation grade (WG), weaning condition score (WC), weaning to yearling daily gain (YDG), yearling weight (YW), yearling conformation grade (YG) and yearling condition score (YC). Estimated genetic responses in standard measure/generation in WWL, YWL and PTL, respectively, were: BW, .25, .49, .41; WDG, .29, .27, .52; WW, .32, .35, .57; WG, .12, .07, .17; WC,

.19, .02, .17; YDG, .11, .33, .42; YW, .27, .45, .61; YG, .12, .16, .09; YC, -.02, -.01, .00. Realized heritabilities were .29 for WW and .37 for YW and the realized genetic correlation between WW and YW was .81. The final group of bulls selected on line criteria (four bulls/line born in 1978) were randomly mated to a group of Angus cows to produce 201 calves in 1980. In general, growth and carcass performance of progeny from selection line sires significantly (P<.05) exceeded that of progeny from CL sires. Correlated responses in mature cow size and milk production traits were also evaluated.

(Key Words: Beef cattle, Selection response, Weaning weight, Yearling weight, Angus)

Introduction

Evaluation of selection response is complicated by the fact that observed phenotypic change is the result of both genetic and environmental factors. Thus, separation of observed change into its component parts is a primary concern in the analysis of selection experiments. Environmental trend can be eliminated from the observed change by use of an unselected control population, maintained and reproduced in the same environment as the selection lines. Assuming (1) the control population can be reproduced in such a way that the average expected genetic change is zero and (2) environmental changes have the same effect on all lines, the difference in change between control and select lines should represent genetic response (Falconer, 1960).

Control populations have often been used in selection experiments involving laboratory animals; however, few such studies have been conducted with livestock. The objective of this study was to evaluate direct and correlated responses, measured as deviations from an unselected control, after 14 years of selection for weaning or yearling weight in Angus cattle.

Materials and Methods

Three selection lines and an unselected control line were established from a common base of Angus cattle. Selection criteria were heaviest individual 205-d adjusted weaning weight (WWL), heaviest individual 365-d (bulls) or 425-d (heifers) adjusted yearling weight (YWL), and a combination of individual and progeny 205-d weaning weights (PTL). Replacement breeding animals in the control line (CL) were chosen to have minimum selection differentials for both weaning and yearling weight. First selections were made from the 1965 calf crop and continued through 1979 in all lines except the PTL which was terminated in 1978. Fifty cows were maintained in each line with two bulls and 10 heifers being selected on line criteria within each line each year. Selected bulls were used for two years. Performance traits analyzed were birth weight (BW), preweaning daily gain (WDG), weaning weight (WW), weaning conformation grade (WG), weaning condition score (WC), weaning to yearling daily gain (YDG), yearling weight (YW), yearling conformation grade (YG) and yearling condition score (YC). Complete descriptions of line formation, management, age of dam correction factors and selection applied were presented in the first paper of this series (Aaron et al., 1985).

Measurement of Response. Phenotypic trends for the nine traits were evaluated by regression of annual phenotypic means on years within each line and sex. Yearly means tend to fluctuate erratically; therefore, the best measure of average response per year is the slope of the regression line fitted to the appropriate line-yr-sex means (Falconer, 1981). Assuming genetic change was kept to a minimum in the CL, phenotypic trend in this line should reflect environmental trend. Annual genetic trend for each line and sex was calculated as the difference between the respective select and CL regression coefficients.

Genetic trend per year was averaged for bulls and heifers to estimate the average genetic trend for each trait in each selection line. Total genetic response was obtained by multiplying average genetic trend per year by the number of years of selection (14 in WWL and YWL, 13 in PTL). Genetic response per generation was then obtained by dividing total genetic response by the number of generations of selection that had occurred through the final calf crop (1979 in WWL and YWL, 1978 in PTL). An average of 3.87, 3.72 and 2.68 generations of selection had been practiced in the WWL, YWL and PTL, respectively (Aaron et al., 1985). Genetic responses per generation were converted to standard measure by dividing by the appropriate pooled within line-yr-sex standard deviation.

Realized heritabilities for WW in the WWL and YW in the YWL were calculated by dividing direct genetic response/yr by the average cumulative selection differential/yr. Also, the realized genetic correlation between the two traits was calculated as the square root of the product of symmetric correlated response: direct response ratios (Pirchner, 1983).

<u>Estimation of Population Parameters.</u> Estimates of heritabilities and genetic correlations (pooled over years - within lines) were obtained from paternal half-sib analyses of variance and covariance for bulls and heifers separately. Formulas presented by Falconer (1981)

were used to compute the estimates from variance components produced in these analyses. Parameter estimates obtained by this method do not include maternal effects, which may be an important source of variation for growth rate in cattle (Koch, 1972; Van Vleck et al., 1977).

Calves Sired by Final Group of Selected Bulls. Data utilized in this portion of the study were collected on calves sired by the final group of selection line and CL bulls. The four highest ranking bulls in WWL, YWL and PTL based on line criteria, and the four bulls in the CL having minimum selection differentials for both weaning and yearling weight were selected from the 1978 calf crop and randomly mated to a group of Angus cows to produce calves in 1980. Evaluation of progeny performance provides another comparision of genetic change among the selection lines.

To characterize the final set of 16 selected bulls, individual cumulative selection differentials were calculated as described in the first paper of this series (Aaron et al., 1985) for each bull and then averaged for each line. Also, inbreeding coefficients were obtained for each bull by pedigree analysis (Pirchner, 1983) and then averaged for each line.

Management procedures for cows and calves utilized in this portion of this study were the same as for the selection lines except bull calves were castrated. Traits evaluated included the nine primary traits evaluated on selection line calves plus yearling hip height (YH). Following weaning all calves were placed in the feedlot and fed ad libitum a corn based finishing ration. Calves were individually removed from the feedlot and slaughtered when an anticipated low choice carcass grade was reached.

Growth and carcass traits were analyzed by least-squares procedures assuming a statistical model that included fixed effects for sire line, sire within sire line, sex of calf and sire line by sex of calf interaction. Also, age of dam was included as a covariate for traits through a year of age. Least-squares means for each trait were calculated from reduced models in which nonsignificant ($P > .20$) sources of variation were eliminated.

Cow Weight Trends and Milk Production Traits. Mature cow size and milk production are two additional traits of economic importance that may undergo correlated changes as a result of selection for growth rate.

Each year cows were weighed in the spring, just prior to the breeding season, and in the fall at weaning. Cow weight for a given year was defined to be the average of the spring and fall weights. To evaluate mature cow size, mean cow weights were calculated by line and year for all cows 5 years old or older that produced a calf that year. Phenotypic trend was evaluated by regression of annual mature cow weight means on years within each line.

Milk production was evaluated on a random sample of mature cows (5 yr old or older) from the WWL, YWL and CL during the final year of the study. Lactational performance was measured monthly from April through September on 18 cows in the WWL and CL and 17 cows in the YWL. Because of time and labor requirements for milking cows by machine, it was necessary to do milking on two different days each month. One group of 27 cows (9 cows from each line) was milked on one day and the remaining group of 26 cows milked the following week. At the time of each monthly measurement, calves were separated from their dams for 6 hr, returned to their dams and allowed to suckle, and then separated again for an average of 12 hr. Cows were given an intramuscular injection of 10-20 mg of a tranquilizer, ace promazine, approximately 15 min prior to milking. Immediately prior to milking cows were injected with 1.5 mg of Sytocin, a synthetic oxytocin, in the jugular to induce milk letdown. Cows were milked with a portable vacuum pump milking unit. Milking time ranged from 5 to 10 min per cow. To assure a complete milkout was obtained, each teat was hand stripped after removal of the milking unit. Milk was weighed and two samples taken, one for butterfat analysis nd the other for protein and total solids analysis. Butterfat content was determined by a milk-o-tester at the University DHIA laboratory. Protein content was determined on duplicate samples by the UDY dye method and color computer (Udy, 1956, Ashworth et al., 1969) and total solids was determined by oven-drying samples in a 100° C oven for four hours.

Milk production data were analyzed by least-squares procedures assuming a statistical model that included fixed effects of line, sex of calf, week of milking, year of cow birth, line by sex of calf interaction and line by year of cow birth interaction. Also, calving date was included as a covariable. Least-squares means for each trait were calculated from reduced models in which nonsignificant ($P>.20$) sources of variation were eliminated.

Results and Discussion

Evaluation of Response. Annual phenotypic trends for each line are presented in table 1. A negative trend was observed for BW in all lines except YWL. Also, growth traits exhibited negative phenotypic trends with the exception of YDG and YW in the selection lines. Phenotypic trends for conformation grades and condition scores were positive in all lines. Frahm et al. (1985) analyzed data from two Hereford lines selected for WW and YW contemporary to the Angus lines evaluated in this study. In the Hereford lines, phenotypic trends were negative for all growth traits and similar to the Angus lines for conformation grades and condition scores.

Phenotypic trends are the result of both genetic and environmental factors; however, phenotypic trend in the CL should be a reflection of environmental trend. Thus, genetic trends in the selection lines were calculated as deviations from the CL. Annual genetic trends in each selection line are presented in table 2 by sex and averaged over sexes. In general, genetic trends followed a similar pattern for both sexes with genetic response tending to be larger in bulls. However, genetic responses for conformation grades and condition scores were higher in heifers. Similar results were reported by Frahm et al. (1985).

Genetic responses averaged over sexes for WW and YW, respectively, were 1.64 and 2.22 kg/yr in the WWL and 1.728 and 3.577 kg/yr in the YWL. Thus, the correlated response in WW from selection for YW was greater than the response obtained by selecting directly for WW. Conversely, the correlated response in YW from selection for WW was only 62% as effective as direct selection for YW. Unfortunately, positive correlated responses of .251 and .469 kg/yr were observed for BW in the WWL and YWL, respectively. In both lines, slight positive correlated responses were observed for WG, WC and YG with very little change observed for YC. Frahm et al. (1985) reported smaller genetic responses per year in Hereford lines for BW (.245 and .231 kg/yr in WWL and YWL), WW (1.076 and .93 kg/yr in WWL and YWL), and YW (.847 and 1.212 kg/yr in

WWL and YWL); however, genetic responses per year were similar for conformation grades and condition scores.

Annual genetic responses, averaged over sexes, were also evaluated in the PTL. Direct response for WW was 2.18 kg/yr and correlated response for YW was 3.776 kg/yr. Both values were larger than the respective genetic responses observed in the WWL and YWL. Birth weight showed a positive genetic response intermediate to responses observed in the WWL and YWL while responses in conformation grades and condition scores were similar in all lines.

Few other selection studies in beef cattle have utilized selection line-control line deviations to estimate genetic response; however, Newman et al. (1973) reported direct genetic responses of 4.4 and 2.8 kg/yr for YW in Shorthorn bulls and heifers, respectively. These estimates are higher than direct responses obtained for YW in the present study. Using other methods of estimating genetic response, Fahmy and Lalande (1973) reported correlated genetic responses of .11 and .48 kg/yr for BW and WW, respectively, from selection for WDG in Shorthorn cattle, and Brinks et al. (1965) reported genetic responses of .17 and .54 kg/yr for BW and WW in inbred Hereford lines selected for increased growth rate. Also, Willms et al. (1980), selecting for increased growth in Hereford, beef synthetic and dairy synthetic populations, estimated genetic responses for WW and YW of .10, .13; .90, 6.71; and 1.30, 6.80, respectively.

Direct and correlated genetic responses per generation, expressed in actual and standardized units, are presented in table 3 for the WWL, YWL and PTL. Genetic responses per generation for WW and YW, respectively, were .32 and .27 phenotypic standard deviation units (σ) in the WWL and

.35 and .45 σ in the YWL. Frahm et al. (1985) reported smaller genetic responses per generation for WW and YW in the Hereford WWL (.23 and .12σ) and YWL (.20 and .19σ). Using estimates of genetic parameters and selection indexes in retrospect to predict genetic response, Buchanan et al. (1982) reported genetic responses per generation for WW and YW, respectively, of .24 and .29σ in WWL and .24 and .39σ in YWL. These estimates were also smaller than in the present study. Brinks et al. (1965) reported a predicted genetic response of .33 σ/generation for WW, which was similar to genetic responses reported here. Also, Chevraux and Bailey (1977) reported a response in WW of .17 σ/generation as a correlated response to selection for WDG, which was smaller than correlated response for WW obtained in the present study.

Genetic responses per generation of selection in the PTL were .57σ for WW and .61σ for YW. These estimates are substantially larger than estimates obtained for WW or YW in the WWL and YWL in this study or other studies (Buchanan et al., 1982; Frahm et al., 1985). The larger genetic responses per generation in the PTL likely resulted from the increased accuracy of selection due to progeny test procedures. This increased response per generation was sufficiently large to more than compensate for the increased generation interval and result in more genetic response per year (table 2).

Birth weight increased at the rate of .25, .49 and .41 σ/generation in the WWL, YWL and PTL, respectively. With the exception of the estimate in the WWL, these correlated genetic responses for BW are larger than the .27 and .25 σ/generation increases in the Hereford WWL and YWL reported by Frahm et al. (1985) and the .26 and .27 σ/generation predicted in the WWL and YWL in the Nebraska study by Buchanan et al.

(1982). Such increases in BW are generally considered undesirable because of the potential for increased dystocia and calf death loss.

Realized heritabilities, calculated by dividing direct genetic response/yr by average cumulative selection differential/yr, were .29 for WW and .37 for YW. These realized heritabilities are in close agreement with the average heritability estimates of .31 for WW and .39 for YW obtained in other studies (Woldehawariat et al., 1977). Lower realized heritabilities of .23 for WW and .18 for YW were reported by Frahm et al. (1985) in Hereford lines. Newman et al. (1973) reported an average realized heritability of .45 for YW estimated from two selection lines. Realized heritabilities in the present study may have been slightly underestimated since a small amount of selection occurred for WW and YW in the CL in the early years of the experiment (Aaron et al., 1985).

Realized correlation between WW and YW was .81 which is slightly larger than the realized correlation of .74 reported by Frahm et al. (1985). Also, Woldehawariat et al. (1977) reported an average genetic correlation between WW and final feedlot weight of .73.

Estimates of Population Parameters. Heritabilities and genetic correlations obtained from pooled within line paternal half-sib analyses of variance and covariance are shown in table 4. In general, heritabilities were slightly lower than averages presented in the literature (Woldehawariat et al., 1977). Estimates of population parameters obtained by the paternal half-sib method are not free of selection bias; therefore, estimates obtained from these data may have been biased downward (Falconer, 1981; Ronningen, 1972). Heritability estimates (averaged over sexes) were .24 for WW and .34 for YW, which are in close agreement with estimates of .21 and .30 for WW and YW, respectively, reported by Buchanan et al. (1982) utilizing Hereford selection data. Also, heritibility estimates were similar to the realized heritabilities obtained from these same data.

Estimates of genetic correlations were generally higher than averages presented in the literature (Buchanan et al., 1982; Woldehawariat et al., 1977). However, the estimated genetic correlation between WW and YW of .86 is in close agreement with the realized genetic correlation of .81 obtained from these data.

Calves Sired by Final Group of Selected Bulls. To characterize the final set of 16 selected bulls, individual cumulative selection differentials (CSD) and inbreeding coefficients were calculated for each bull and then averaged for each line. Average CSD's for WW and YW, respectively were 91.3, 113.3; 58.1, 168.1; 88.3, 125.1; and 7.7, 14.9 kg for bulls in WWL, YWL, PTL and CL, respectively. Average inbreeding coefficients were 5.7, 5.1, 1.4 and 5.5% for the WWL, YWL, PTL and CL bulls, respectively.

Least-squares means for traits through a year of age of progeny sired by the final set of WWL, YWL, PTL and CL bulls are presented in table 5. Progeny from selection line sires significantly ($P<.05$) exceeded progeny from CL sires for all traits except BW and WG. Progeny from WWL sires performed similarly to progeny from YWL sires for all traits except YH. Progeny from YWL sires were 1.7 cm taller ($P<.05$) than progeny from WWL sires. Calves sired by PTL bulls gained 48 g/d faster and were 9 kg heavier ($P<.05$) at weaning than the average of calves sired by selected WWL and YWL bulls. Also, calves sired by PTL bulls had higher conformation grades at weaning than calves sired by WWL bulls (13.3 vs 13.0, P<.05). All other differences among sire lines were small and nonsignificant.

Least-squares means for feedlot and carcass traits of progeny sired by the final set of WWL, YWL, PTL and CL bulls are presented in table 6. Calves sired by CL bulls were 19.7 kg lighter upon entering the feedlot, remained in the feedlot 16 days longer, were 21 kg lighter at slaughter, had carcasses 15 kg lighter and had conformation scores .6 lower than the average of calves sired by selection line bulls (P<.05). Among progeny from selection line bulls, calves had similar weights entering the feedlot (182 kg) but calves sired by YWL bulls outgained calves sired by WWL bulls by 80 g/d (P<.05). Calves sired by WWL and PTL bulls were in the feedlot 9 days longer (P<.05) than calves sired by YWL bulls. Final weights were similar (436.4 kg) among calves sired by selection line bulls but calves sired by WWL bulls had lighter carcasses than calves sired by PTL bulls (273.3 vs 283.2 kg; P<.05) and less KHP fat than calves sired by YWL bulls (3.06 vs 3.30%; P<.05).

In general, calves sired by the final set of selected WWL, YWL and PTL bulls were similar in overall performance, and calves sired by selection line bulls outperformed calves sired by CL bulls. These results provide additional evidence that selection for growth rate was successful but that overall differences in response to selection for WW and YW were not large.

Cow Weight Trends and Milk Production Traits. Average mature cow weights for each line and year and the regression of mature cow weight on years are presented in table 7. Declining phenotypic trends were observed in all four lines. Genetic trends, obtained from comparing phenotypic trends of selection lines with CL, were .73, 1.23 and -.14 kg/yr for mature cow weight in the WWL, YWL and PTL, respectively.

The -.14 kg/yr genetic change in mature cow weight in the PTL was unexpected and probably does not represent a general biological phenomenon as the magnitude of this trend was small and nonsignificant. Frahm et al. (1985) also reported relatively small genetic changes in mature cow weight in Hereford lines selected for WW (.26 kg/yr) and YW (-.60 kg/yr). Relatively high positive genetic correlations among weights at different ages reported in other studies (Woldehawariat et al., 1977) would strongly suggest a positive genetic correlation between weight at early stages with mature weight as well. Thus, continued selection for weaning or yearling weight likely would result in more increase in mature weight as well.

Least-squares means for milk yield and composition traits of mature cows in the WWL, YWL and CL at the end of the selection period are presented in table 8. In general, milk yield and composition were similar for WWL and YWL cows; however, percent butterfat was .6% higher and percent total solids was .3% higher in milk from YWL cows ($P<.10$). Control line cows produced less milk than WWL cows (6.25 vs 7.02 kg; $P<.10$). Also, percent butterfat and percent total solids were .63 and .3% lower, respectively, ($P<.10$) in milk from CL cows than in milk from YWL cows. It is often assumed that selection for increased WW will result in a correlated increase in milk production; however, the similarity of milk yield and composition in cows from the WWL and YWL indicate that selection for WW or YW results in comparable genetic improvement in milk production. Similar results in milk yield and composition were reported by Frahm et al. (1985) in the Hereford WWL and YWL.

Conclusion. Results obtained from these data indicate that a well designed selection program for increased WW or YW should result in improved growth rate in beef cattle. Selection for YW appears to be the most effective for increasing both WW and YW; however, larger increases in BW result as well. Although selection for WW based on a combination of individual and progeny test information resulted in larger responses in WW and YW per year, the added expense of progeny testing may limit its practicality. The high genetic correlation between WW and YW (.81) will allow breeders to use WW as an effective early culling procedure even if the primary selection objective is to increase YW. In selection programs designed to increase growth rate some attention should be given to minimizing the correlated response of increased BW.

TABLE 1

REGRESSION OF PHENOTYPIC PERFORMANCE ON YEAR

	WWL[a]			YWL			PTL			CL			
Trait[b]	Bulls	Heifers	Average	Bulls	Heifers	Average	Bulls	Heifers	Average	Bulls	Heifers	Average	SE[c]
BW, kg	-.134	-.044	-.089	.139	.199	.129	-.041	-.031	-.036	-.380	-.299	-.340	.045
WDG, g/d	-2.36	.04	-1.16	-2.40	-1.13	-1.76	-.50	2.95	1.22	-10.48	-5.31	-7.90	1.08
WW, kg	-.610	-.035	-.322	-.355	-.114	-.234	-.141	.578	.218	-2.534	-1.391	-1.962	.254
WG[d]	.069	.078	.074	.074	.053	.064	.084	.068	.076	.058	.042	.050	.014
WC[e]	.098	.097	.098	.079	.056	.067	.098	.077	.088	.078	.051	.064	.010
YDG, g/d	2.99	1.95	2.47	15.87	3.72	9.80	13.56	5.67	9.62	-1.68	-1.41	-1.54	2.56
YW, kg	-.174	.174	0	2.189	.525	1.357	1.808	1.305	1.556	-2.732	-1.708	-2.22	.407
YG[d]	.077	.086	.082	.087	.094	.090	.056	.089	.072	.059	.059	.059	.011
YC[e]	.057	.067	.062	.055	.073	.064	.058	.075	.066	.064	.068	.066	.010

[a]WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line.
[b]BW=birth wt, WDG=preweaning daily gain, WW=weaning wt, WG=weaning conformation grade, WC=weaning condition score, YDG=weaning to yearling daily gain, YW=yearling wt, YG=yearling conformation grade, YC=yearling condition score.
[c]Standard error of regression coefficient averaged over line and sex.
[d]Conformation grade on a 17 point scale with 13=average choice.
[e]Condition score on a 9 point scale from 1=thin to 9=very fat.

TABLE 2

ESTIMATED GENETIC TREND PER YEAR MEASURED AS A DEVIATION FROM CONTROL LINE (CL)

	WWL[a]			YWL			PTL		
Trait[b]	Bulls	Heifers	Average	Bulls	Heifers	Average	Bulls	Heifers	Average
BW, kg	.246	.255	.251	.519	.418	.469	.339	.268	.304
WDG, g/d	8.12	5.35	6.74	8.08	4.18	6.14	9.98	8.26	9.12
WW, kg	1.924	1.356	1.640	2.179	1.277	1.728	2.393	1.969	2.180
WG[c]	.011	.036	.024	.016	.011	.014	.026	.026	.026
WC[d]	.020	.046	.034	.001	.005	.003	.020	.026	.023
YDG, g/d	4.67	3.36	4.01	17.55	5.13	11.34	15.24	7.08	11.16
YW, kg	2.558	1.882	2.220	4.921	2.233	3.577	4.540	3.013	3.776
YG[c]	.018	.027	.023	.028	.035	.031	-.003	.030	.013
YC[d]	-.007	-.001	-.004	-.009	.005	-.002	-.006	.007	.000

[a] WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line, CL=control line.
[b] BW=birth wt, WDG=preweaning daily gain, WW=weaning wt, WG=weaning conformation grade, WC=weaning condition score, YDG=weaning to yearling daily gain, YW=yearling wt, YG=yearling conformation grade, YC=yearling condition score.
[c] Conformation grade on a 17 point scale with 13=average choice.
[d] Condition score on a 9 point scale from 1=thin to 9=very fat.

TABLE 3

DIRECT AND CORRELATED GENETIC RESPONSES PER GENERATION

Trait[b]	WWL[a] Actual units[c]	WWL[a] Standard measure[d]	YWL Actual units	YWL Standard measure	PTL Actual units	PTL Standard measure
BW, kg	.908	.250	1.765	.486	1.475	.406
WDG, g/d	24.38	.287	23.12	.272	44.24	.520
WW, kg	5.933	.319	6.503	.349	10.575	.567
WG[e]	.087	.120	.053	.073	.126	.174
WC[f]	.123	.187	.011	.017	.112	.170
YDG, g/d	14.51	.111	42.68	.327	54.13	.415
YW, kg	8.031	.268	13.462	.450	18.316	.612
YG[e]	.083	.117	.117	.164	.063	.088
YC[f]	-.014	-.022	-.008	-.012	.000	.000

[a] WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line.
[b] BW=birth wt, WDG=preweaning daily gain, WW=weaning wt, WG=weaning conformation grade, WC=weaning condition score, YDG=weaning to yearling daily gain, YW=yearling wt, YG=yearling conformation grade, YC=yearling condition score.
[c] Units of measure as indicated by each trait.
[d] Standard measure is the response in actual units divided by the pooled within line-yr-sex phenotypic standard deviation.
[e] Conformation grade on a 17 point scale with 13=average choice.
[f] Condition score on a 9 point scale from 1=thin to 9=very fat.

TABLE 4

ESTIMATES OF HERITABILITIES AND GENETIC CORRELATIONS FROM POOLED WITHIN LINE PATERNAL HALF-SIB ANALYSES OF COVARIANCE[a]

Trait[b]	Sex	BW	WDG	WW	WG	WC	YDG	YW	YG	YC
BW	Bull	.28	.96	1.03	.15	.33	.14	.52	.18	.10
	Heifer	.28	.53	.72	.68	.23	.09	.63	.34	-.16
WDG	Bull		.22	.98	.61	0	.72	.91	.67	.10
	Heifer		.17	.97	.35	.22	-.18	.80	.50	-.28
WW	Bull			.27	.49	.04	.64	.86	.55	.10
	Heifer			.20	.44	.24	-.09	.85	.48	-.30
WG	Bull				.21	.91	.18	.33	.81	.69
	Heifer				.27	.52	-.42	.17	.68	-.01
WC	Bull					.17	.06	.04	.58	1.32
	Heifer					.29	-.07	.21	.83	.69
YDG	Bull						.40	.94	.91	.54
	Heifer						.19	.42	-.15	.18
YW	Bull							.43	.79	.38
	Heifer							.26	.33	-.20
YG	Bull								.06	.31
	Heifer								.32	.69
YC	Bull									.19
	Heifer									.37

[a]Heritabilities on diagonal and genetic correlations on off-diagonals.
[b]BW=birth wt, WDG=preweaning daily gain, WW=weaning wt, WG=weaning conformation grade, WC=weaning condition score, YDG=weaning to yearling daily gain, YW=yearling wt, YG=yearling conformation grade, YC=yearling condition score.

TABLE 5

LEAST-SQUARES MEANS AND STANDARD ERRORS FOR TRAITS THROUGH A YEAR OF AGE OF CALVES SIRED BY FINAL GROUP OF SELECTED BULLS

	Sire line[a]				
Trait[b]	WWL	YWL	PTL	CL	SE[c]
No. calves	51	47	53	50	
BW, kg	31.62[f]	30.88[fg]	30.39[fg]	29.34[g]	.58
WDG, g/d	693.8[g]	690.7[g]	740.4[f]	641.6[h]	12.7
WW, kg	173.8[g]	172.5[g]	182.2[f]	161.2[h]	2.8
WG[d]	13.1[gh]	13.2[fg]	13.3[f]	12.9[h]	.09
WC[e]	4.9[f]	5.0[f]	5.1[f]	4.6[g]	.08
YDG, g/d	1156.2[f]	1186.5[f]	1162.8[f]	1084.2[g]	24.0
YW, kg	359.2[f]	363.7[f]	369.4[f]	335.2[g]	5.0
YG[d]	13.1[f]	13.2[f]	13.2[f]	12.8[g]	.07
YC[e]	5.0[f]	5.1[f]	5.1[f]	4.6[g]	.10
YH, cm	111.9[g]	113.6[f]	113.0[fg]	109.6[h]	.60

[a]Four bulls/line from 1978 calf crop selected from weaning wt line (WWL), yearling wt line (YWL), progeny test line (PTL) and control line (CL).
[b]BW=birth wt, WDG=preweaning daily gain, WW=weaning wt, WG=weaning conformation grade, WC=weaning condition score, YDG=weaning to yearling daily gain, YW=yearling wt, YG=yearling conformation grade, YC=yearling condition score, YH=yearling hip ht.
[c]Standard error averaged over lines.
[d]Conformation grade on a 17 point scale with 13=average choice.
[e]Condition score on a 9 point scale from 1=thin to 9=very fat.
[f,g,h]Means in the same row not sharing a common superscript differ ($P<.05$).

TABLE 6

LEAST-SQUARES MEANS AND STANDARD ERRORS FOR FEEDLOT AND CARCASS TRAITS OF CALVES SIRED BY FINAL GROUP OF SELECTED BULLS

	Sire line[a]				
Trait	WWL	YWL	PTL	CL	SE[b]
No. calves	51	47	53	50	
Initial wt, kg	180.7^{f}	180.5^{f}	185.2^{f}	162.4^{g}	3.7
Final wt, kg	431.6^{f}	438.1^{f}	439.5^{f}	415.4^{g}	4.7
Average daily gain, g/d	1114.4^{gh}	1194.1^{f}	$1140.^{9fg}$	1056.1^{h}	23.4
Days on feed	228^{g}	219^{f}	226^{fg}	240^{h}	3
Feed efficiency, kg feed/kg gain	7.2	7.3	7.1	7.4	
Slaughter age, d	442^{fg}	433^{f}	439^{fg}	447^{g}	4
Hot carcass wt, kg	273.3^{g}	278.0^{fg}	283.2^{f}	263.2^{h}	7.7
Carcass wt/day of age, g/d	624.8^{f}	643.2^{f}	647.3^{f}	590.8^{g}	10.1
Dressing percent	63.3	63.3	64.3	63.2	.40
Average fat thickness, cm	2.04	2.23	2.09	2.16	.07
KHP fat, %	3.06^{g}	3.30^{f}	3.11^{fg}	3.11^{fg}	.08
Marbling score[c]	5.0^{g}	4.2^{f}	5.0^{g}	5.4^{f}	.10
Carcass grade[d]	10.0^{g}	10.2^{f}	10.0^{g}	10.4^{f}	.13
Carcass conformation[e]	11.3^{f}	11.6^{f}	11.6^{f}	10.9^{g}	.14
Rib eye area, cm^2	66.3^{g}	67.1^{g}	71.2^{f}	65.1^{g}	1.0
Carcass cutability, %	48.3	47.6	48.3	47.8	.24

[a]Four bulls/line from 1978 calf crop selected from weaning wt line (WWL), yearling wt line (YWL), progeny test line (PTL) and control line (CL).
[b]Standard error averaged over lines.
[c]Marbling score: 5=small.
[d]Carcass grade: 9=high good, 10=low choice.
[e]Carcass conformation: 1=low choice, 11=choice.
[f,g,h]Means in the same row not sharing a common superscript differ (P<.05).

TABLE 7

AVERAGE MATURE COW WEIGHTS BY YEAR[a,b]

Year	WWL[c]		YWL		PTL		CL	
	No. cows	Average wt, kg	No. cows	Average wt, kg	No. cows	Average wt, kg	No. cows	Average wt, kg
1964	6	472.2	7	482.6	4	454.5	6	482.2
1965	7	494.4	13	482.2	8	519.8	9	466.8
1966	19	449.5	21	433.6	16	455.9	13	464.5
1967	28	433.6	29	425.9	20	446.8	19	435.4
1968	20	445.4	27	432.2	20	449.5	18	442.7
1969	16	411.9	19	415.5	19	408.2	13	405.1
1970	17	420.9	18	414.1	16	435.4	19	426.8
1971	16	488.1	22	464.5	16	435.4	21	485.4
1972	21	479.9	23	482.6	20	484.4	28	477.2
1973	21	447.7	24	432.3	18	446.3	30	451.3
1974	23	447.2	25	419.6	24	448.2	28	463.1
1975	20	435.4	20	420.0	22	440.4	23	464.5
1976	20	441.4	24	449.1	25	429.1	27	447.2
1977	22	435.9	26	454.0	26	455.4	27	446.8
1978	22	429.6	25	434.6	25	429.1	20	420.0
1979	16	459.0	16	460.0	--	--	18	403.7
Regression on year	-1.38 ± 1.28		$-.78 \pm 1.35$		-2.15 ± 1.48		-2.01 ± 1.33	

[a]Mature cows were 5 yr old or older, and produced a calf in their respective line that yr.

[b]Average of spring wt prior to breeding season and fall wt after weaning.

[c]WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line, CL=control line.

TABLE 8

LEAST-SQUARES MEANS AND STANDARD ERRORS FOR MILK YIELD AND COMPOSITION TRAITS OF MATURE COWS IN 1979[a]

	Line[b]			
Trait	WWL	YWL	CL	SE[c]
No. cow-calf pairs	18	17	18	
Daily milk yield, kg	7.02[d]	6.45[de]	6.25[e]	.30
Butterfat, %	4.68[e]	5.42[d]	4.61[e]	.12
Daily butterfat yield, g	326[d]	323[d]	286[e]	.15
Protein, %	3.08	2.99	3.06	.04
Daily progein yield, g	215[d]	193[de]	191[e]	10
Total solids, %	13.3[e]	13.6[d]	13.3[e]	.13
Daily total solids, g	936[d]	880[de]	828[e]	39

[a]Cows were 5 yr or older at calving time.
[b]WWL=weaning wt line, YWL=yearling wt line, CL=control line.
[c]Standard error averaged over lines.
[d,e]Means in the same row not sharing a common superscript differ ($P<.10$).

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APPENDIX

APPENDIX A

COMPOSITION OF BULL TEST RATIONS

TABLE 1

COMPOSITION OF BULL TEST RATIONS[a]

Ingredient	Years ration used 1964-1965	1966-1969	1970-1973	1974-1979
	---	--- % ---	---	---
Ground whole ear corn (IFN 4-02-849)	35	--	--	--
Ground shell corn (IFN 4-02-861)	--	30	57	57
Cottonseed hulls (IFN 1-01-599)	20	15	23	22
Ground alfalfa hay (IFN 1-00-111)	10	10	--	6
Whole oats (IFN 4-03-309)	10	20	--	--
Wheat bran (IFN 4-05-190)	10	10	--	--
Protein supplement[b]	10	10	--	--
Molasses (IFN 4-00-668)	5	5	5	5
Supplemental pellets[c]	--	--	15	10

[a]As fed basis.
[b]Cottonseed meal (IFN 5-01-608) and soybean oil meal (IFN 5-04-604) were used interchangeabley depending on relative prices.
[c]Supplemental pellets consisted of 40% soybean oil meal (IFN 5-04-604), 33% dehydrated alfalfa (IFN 1-00-023), 16% wheat middlings (IFN 4-05-205), 3% urea (IFN 5-05-070), 3% salt (IFN 6-04-151), 2% dicalcium phosphate (IFN 2-07-988), 2% calcium carbonate (IFN 6-01-071), 3% Aurofac-10 (Cyanamid Auromycin), .1% trace mineral, .2% Vitamin A (10,000 I.U./gram).

APPENDIX B

ANNUAL MEANS AND STANDARD ERRORS FOR PRIMARY TRAITS

TABLE 2

ANNUAL MEANS AND STANDARD ERRORS FOR BIRTH WEIGHT[a] (KG)

	WWL[b]		YWL		PTL		CL	
Year	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers
1964	31.1± .7	30.5± .8	31.0± .7	27.8± .9	31.3±1.0	29.2± .7	33.2±1.4	29.7±1.2
1965	33.5± .8	31.3± .6	31.5± .7	31.0± .6	32.6± .7	31.1±1.0	32.3± .7	31.5± .5
1966	35.4± .8	31.2± .6	33.2± .7	31.6± .7	34.0± .6	30.1± .7	34.2± .8	30.6± .4
1967	33.2± .9	30.1± .7	33.5± .8	30.3± .7	32.2± .8	30.2± .7	31.8± .7	30.4± .6
1968	35.6± .7	33.8± .7	35.3± .6	32.6± .6	34.2± .6	31.7± .7	34.7± .8	31.8± .7
1969	31.3± .9	28.2± .8	31.5± .6	29.8± .9	33.1± .8	28.9± .8	30.8± .7	30.0± .8
1970	32.7± .7	29.5± .6	31.6± .9	29.0± .7	31.1± .7	28.9± .5	32.0± .8	27.8± .6
1971	33.3±1.2	31.0± .7	32.1± .8	31.3± .9	32.3± .8	30.2± .7	29.9± .9	28.8± .9
1972	34.7± .6	32.5±1.1	33.4± .7	31.8± .8	34.6± .8	31.7± .5	31.7± .8	28.6± .6
1973	32.0± .6	30.4± .9	34.3± .8	32.3± .8	32.8± .8	31.0± .6	30.9± .9	30.1± .7
1974	31.7± .6	30.0± .6	33.5± .5	31.2± .8	32.2± .7	29.3± .9	29.2± .7	26.5± .7
1975	32.7± .4	30.4± .7	32.9± .9	32.2±1.2	33.2± .8	30.6± .6	30.1± .8	29.3± .8
1976	30.4± .7	30.2± .8	30.8±1.0	29.7± .8	31.4± .8	28.2± .8	28.6± .7	26.1± .8
1977	31.8± .7	29.6± .7	34.5± .9	32.0± .9	32.1± .8	29.6± .7	27.5± .7	27.9±1.0
1978	32.0±1.0	30.1±1.1	35.0± .6	32.6± .9	32.5± .7	30.4± .6	28.8± .6	26.0± .7
1979	32.9±1.4	31.8±1.0	34.5±1.0	31.8±1.5			30.2± .8	27.6± .9

[a]Adjusted for age of dam.
[b]WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line, CL=control line.

TABLE 3

ANNUAL MEANS AND STANDARD ERRORS FOR PREWEANING DAILY GAIN[a] (G/D)

Year	WWL[b]		YWL		PTL		CL	
	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers
1964	872±23	779±19	803±20	777±17	838±19	775±21	870±22	775±14
1965	880±12	809±15	857±19	794±14	839±21	795±17	883±18	789±14
1966	844±17	795±14	852±18	777±11	840±17	760±13	860±18	777±12
1967	889±12	775±14	900±22	786±13	926±18	787±10	882±15	779±12
1968	873±18	814±16	911±18	812±13	921±27	825±16	906±15	829±16
1969	799±13	726±21	866±14	767±22	813±20	717±16	821±16	719±14
1970	836±19	758±18	828±20	759±15	819±21	760±16	834±15	715±15
1971	892±26	833±19	980±14	897±19	944±23	866±20	919±17	812±19
1972	935±19	843±22	942±21	856±16	979±21	859±15	925±18	795±12
1973	861±13	808±19	919±22	820±20	848±31	801±24	878±18	814±20
1974	900±18	840±20	922±20	857±17	911±30	862±22	866±11	779±13
1975	786±17	731±17	766±16	739±18	850±18	796±21	746±13	721±13
1976	854±22	766±21	817±35	734±24	869±19	801±22	733±18	671±19
1977	804±26	803±16	804±22	808±15	875±18	830±18	760±16	761±19
1978	835±18	748±14	815±14	740±16	809±13	762±15	735±12	672±14
1979	867±24	834±18	848±16	790±13			779±18	727±18

[a]Adjusted for age of dam.
[b]WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line, CL=control line.

TABLE 4

ANNUAL MEANS AND STANDARD ERRORS FOR 205-DAY WEANING WEIGHT[a] (KG)

Year	WWL[b] Bulls	WWL[b] Heifers	YWL Bulls	YWL Heifers	PTL Bulls	PTL Heifers	CL Bulls	CL Heifers
1964	210.2±5.1	190.0±4.1	195.9±4.4	188.0±4.1	203.4±4.1	187.7±4.8	211.8±5.3	188.4±2.9
1965	213.9±3.0	197.3±3.3	207.2±4.2	193.8±3.3	204.5±4.6	194.2±4.0	213.2±3.9	193.6±2.9
1966	208.5±3.9	194.3±3.0	208.1±4.0	190.9±2.7	206.4±3.6	185.9±2.9	210.8±4.2	190.0±2.6
1967	215.5±2.8	188.7±2.3	218.0±4.7	191.5±3.0	222.2±4.0	191.5±2.4	212.7±2.8	190.0±2.9
1968	214.5±4.0	200.6±3.7	221.4±3.8	199.1±3.0	223.2±5.7	200.9±3.4	220.7±3.5	201.8±3.6
1969	195.2±2.9	177.1±4.7	209.2±3.0	187.0±5.0	199.8±4.1	176.0±3.6	199.2±3.5	177.4±3.3
1970	204.3±3.9	184.9±4.1	201.2±4.6	184.4±3.4	198.4±4.8	184.7±3.3	203.0±3.4	174.4±3.4
1971	216.4±6.1	201.7±4.2	233.1±3.1	215.2±4.5	225.9±5.1	207.7±4.4	218.4±4.0	195.4±4.3
1972	226.5±4.0	205.3±5.0	226.8±4.6	207.2±3.5	235.4±4.5	207.7±3.3	221.3±3.8	191.7±2.7
1973	208.7±2.7	196.0±4.4	223.1±4.8	200.4±4.4	206.9±6.7	195.2±5.3	210.9±4.3	196.9±4.3
1974	216.4±3.9	202.1±4.3	222.7±4.0	206.8±3.9	219.2±6.2	205.9±5.1	206.8±2.6	186.2±2.8
1975	194.0±3.5	180.1±3.8	189.9±3.4	183.7±4.0	207.4±4.1	193.6±4.6	183.2±3.0	177.2±2.8
1976	205.5±4.5	187.1±4.4	198.4±7.3	180.1±5.0	209.6±4.0	192.3±4.7	179.0±4.0	163.7±4.0
1977	196.8±5.5	194.2±3.2	199.6±4.6	197.6±3.4	211.6±3.8	199.7±3.7	183.3±3.5	184.0±3.8
1978	203.2±3.9	183.4±3.2	202.1±3.0	184.4±3.4	198.6±2.8	186.6±2.9	179.7±2.6	163.7±2.9
1979	210.7±6.0	202.6±4.1	209.1±3.9	194.0±3.3			194.1±4.3	176.6±4.1

[a]Adjusted for age of dam.
[b]WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line, CL=control line.

TABLE 5

ANNUAL MEANS AND STANDARD ERRORS FOR WEANING CONFORMATION GRADE[a,b]

	WWL[c]		YWL		PTL		CL	
Year	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers
1964	13.0±.3	13.1±.3	12.5±.2	13.0±.2	13.0±.2	13.1±.2	12.9±.3	12.9±.2
1965	13.1±.1	12.6±.1	12.7±.2	12.8±.2	12.4±.2	12.7±.1	13.2±.2	12.6±.1
1966	12.3±.2	12.6±.1	12.6±.2	12.5±.2	11.9±.2	12.4±.2	12.5±.2	12.5±.1
1967	12.6±.1	12.5±.2	12.9±.1	13.0±.2	12.9±.1	13.0±.2	13.0±.2	13.0±.2
1968	12.3±.1	12.4±.1	12.5±.1	12.5±.1	12.4±.2	12.5±.1	12.5±.1	12.5±.1
1969	12.1±.1	12.3±.1	12.6±.1	12.7±.1	12.2±.1	12.2±.1	12.3±.1	12.3±.1
1970	13.2±.1	13.0±.1	13.2±.1	13.3±.1	13.2±.2	13.2±.1	13.3±.1	13.0±.1
1971	13.6±.2	13.3±.1	14.0±.1	13.5±.1	13.8±.1	13.6±.1	13.6±.2	13.2±.2
1972	13.0±.2	12.9±.2	13.0±.2	13.6±.1	13.4±.2	13.3±.1	13.1±.2	13.1±.1
1973	13.1±.1	13.0±.2	13.4±.2	13.1±.2	12.9±.2	12.8±.1	13.4±.1	12.9±.1
1974	13.1±.2	13.4±.2	13.4±.1	13.4±.2	13.1±.2	13.4±.2	13.3±.1	13.2±.1
1975	13.2±.2	13.1±.1	13.3±.1	13.4±.2	13.4±.1	13.5±.2	13.3±.2	13.3±.1
1976	13.7±.1	13.8±.2	13.7±.2	13.3±.2	13.9±.1	13.6±.1	13.6±.2	13.3±.2
1977	13.3±.2	13.5±.1	13.7±.1	13.5±.1	13.8±.1	13.4±.1	13.6±.1	13.4±.1
1978	13.1±.1	13.0±.1	13.0±.1	13.2±.1	12.8±.1	13.2±.1	12.7±.1	12.6±.1
1979	13.9±.2	13.8±.1	13.6±.2	13.6±.2			13.7±.2	13.3±.2

[a] Adjusted for age of dam.
[b] Conformation grade: 12=low choice, 13=average choice.
[c] WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line, CL=control line.

TABLE 6

ANNUAL MEANS AND STANDARD ERRORS FOR WEANING CONDITION SCORE[a,b]

Year	WWL[c]		YWL		PTL		CL	
	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers
1964	4.3±.3	4.9±.3	4.0±.1	4.8±.2	4.3±.1	5.0±.1	4.4±.2	4.8±.2
1965	4.3±.1	4.3±.2	4.3±.2	4.8±.2	3.8±.3	4.6±.1	4.6±.1	4.7±.2
1966	4.2±.2	4.3±.2	4.3±.1	4.4±.2	4.0±.2	4.3±.2	4.3±.2	4.6±.2
1967	4.2±.2	4.4±.2	4.4±.1	4.6±.2	4.4±.1	5.0±.2	4.3±.1	5.0±.2
1968	4.0±.1	4.2±.1	4.2±.1	4.3±.1	4.2±.1	4.5±.1	4.2±.1	4.4±.1
1969	4.0±.1	4.2±.1	4.4±.1	4.3±.1	4.1±.1	4.1±.1	4.3±.1	4.4±.1
1970	4.6±.1	4.7±.1	4.6±.1	4.8±.1	4.5±.1	4.7±.1	4.7±.1	4.7±.1
1971	5.7±.1	5.6±.1	5.7±.1	5.5±.1	5.6±.1	5.8±.1	5.7±.1	5.5±.1
1972	5.1±.1	5.1±.1	4.9±.1	5.2±.1	5.2±.1	5.1±.1	5.0±.1	5.0±.1
1973	4.3±.1	4.7±.2	4.2±.1	4.6±.2	3.8±.2	4.3±.2	4.7±.1	4.8±.2
1974	5.4±.1	5.6±.1	5.4±.1	5.4±.1	5.2±.2	5.4±.2	5.4±.1	5.4±.1
1975	5.3±.2	5.2±.2	4.9±.1	4.9±.2	5.0±.1	5.4±.2	5.2±.1	5.4±.2
1976	5.3±.1	5.8±.2	5.2±.2	5.1±.2	5.4±.1	5.7±.2	5.2±.1	5.3±.2
1977	5.1±.2	5.6±.1	5.2±.1	5.6±.1	5.5±.1	5.7±.1	5.5±.1	5.8±.2
1978	5.3±.1	5.0±.1	4.9±.1	5.1±.1	4.8±.1	5.0±.1	4.7±.1	4.8±.1
1979	5.6±.3	5.6±.1	5.2±.2	5.2±.2			5.4±.1	5.4±.1

[a]Adjusted for age of dam.
[b]Condition: 1=thin to 9=fat with 5=average fat.
[c]WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line, CL=control line.

TABLE 7

ANNUAL MEANS AND STANDARD ERRORS FOR WEANING TO YEARLING DAILY GAIN[a] (G/D)

Year	WWL[b] Bulls	WWL[b] Heifers	YWL Bulls	YWL Heifers	PTL Bulls	PTL Heifers	CL Bulls	CL Heifers
1964	1240±30	381±21	1104±29	383±16	1202±23	388±13	1168±48	419±13
1965	1163±26	226±11	1146±24	188± 6	1096±26	198±11	1201±37	217±.9
1966	1404±36	160±17	1319±46	168±13	1390±37	186±11	1337±32	141±16
1967	1272±32	350±11	1204±39	358±10	1308±10	359±12	1161±25	351±16
1968	1137±50	243± 8	1238±36	224±12	1167±39	226±11	1167±33	236±11
1969	1166±35	382±13	1077±34	353±14	1164±46	384±11	1211±30	372±17
1970	1352±41	612±14	1350±26	590±16	1408±41	587±18	1257±31	542±16
1971	1264±50	479±16	1249±34	492±16	1268±39	459±15	1118±29	462±13
1972	1118±39	269±11	1070±30	286±16	1115±38	318±11	1054±21	281± 9
1973	1312±30	313±32	1310±35	241±32	1439±34	304±24	1259±31	219±26
1974	1338±29	231±20	1309±38	238±14	1411±30	222±11	1215±33	199±15
1975	1375±29	416±15	1448±45	412±15	1368±36	378±16	1249±34	363±17
1976	1350±34	502±14	1381±41	542±14	1346±53	500±16	1193±36	438±18
1977	1163±48	342±16	1253±41	347±14	1350±32	354±17	1153±23	334±10
1978	1254±41	303±10	1472±50	327±13	1345±34	320±17	1165±28	277±12
1979	1217±98	241±18	1342±39	225±17			1185±34	156±24

[a]Adjusted for age of dam.
[b]WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line, CL=control line.

TABLE 8

ANNUAL MEANS AND STANDARD ERRORS FOR YEARLING WEIGHT[a,b] (KG)

Year	WWL[c] Bulls	WWL[c] Heifers	YWL Bulls	YWL Heifers	PTL Bulls	PTL Heifers	CL Bulls	CL Heifers
1964	410.3± 9.4	249.8±3.4	372.8± 7.6	246.5±5.1	397.4± 5.9	248.0±5.6	394.9±10.1	253.9±4.2
1965	400.5± 5.2	232.8±3.4	390.9± 5.5	223.2±3.3	340.4± 7.2	225.0±3.8	405.8± 7.0	227.6±3.3
1966	437.3± 8.2	227.4±3.9	422.4± 9.3	222.3±3.4	434.6± 8.5	221.5±3.3	424.7± 8.0	220.3±3.0
1967	419.2± 6.3	243.9±3.8	410.9±10.1	248.2±3.5	431.5± 7.3	253.5±3.4	398.6± 4.8	251.4±3.9
1968	396.5±10.8	238.8±3.8	420.8± 7.9	243.7±3.4	411.4±11.0	237.6±3.6	407.4± 6.9	239.0±3.4
1969	381.7± 6.2	239.5±5.4	381.2± 6.4	244.2±5.3	387.3±10.1	237.2±3.8	393.2± 5.8	236.2±4.8
1970	419.6± 8.3	282.1±4.8	418.3± 6.1	280.3±4.8	425.6±10.1	278.2±5.4	406.0± 6.8	260.8±4.4
1971	418.7±12.4	277.6±4.7	433.1± 6.0	293.5±5.8	428.8± 9.1	280.4±5.4	397.5± 6.8	268.5±4.9
1972	405.5± 7.5	247.6±4.5	398.9± 8.8	252.2±4.0	416.7± 7.0	258.1±3.6	390.2± 4.9	237.1±3.4
1973	419.3± 5.6	244.3±7.2	432.8± 8.5	238.7±5.9	436.8±10.9	243.0±6.2	411.2± 7.6	231.7±5.7
1974	432.2± 6.5	238.7±4.6	433.3± 9.2	244.8±4.3	447.5± 8.2	241.0±5.8	401.4± 5.8	217.5±4.1
1975	415.6± 6.0	245.9±4.2	421.4± 8.7	251.1±5.2	426.5± 8.1	253.3±5.2	384.6± 7.6	234.6±3.6
1976	421.7± 6.1	266.8±4.2	420.2±10.1	271.0±4.1	425.2±10.8	271.5±5.3	372.8± 7.6	235.2±4.5
1977	384.1±10.7	248.2±3.5	398.4± 6.6	252.8±3.8	427.1± 6.6	255.9±4.3	367.8± 6.1	236.9±4.1
1978	404.4± 8.8	231.6±3.7	437.3± 7.6	236.0±3.0	413.8± 6.1	237.3±3.8	366.3± 5.8	208.3±3.4
1979	405.6±19.4	240.3±5.1	423.7± 7.2	229.7±4.8			383.6± 8.6	200.9±6.2

[a]Adjusted for age of dam.
[b]365-day weight for bulls and 425-day weight for heifers.
[c]WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line, CL=control line.

TABLE 9

ANNUAL MEANS AND STANDARD ERRORS FOR YEARLING CONFORMATION GRADE[a,b]

Year	WWL[c]		YWL		PTL		CL	
	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers
1964	13.3±.2	12.0±.3	12.7±.1	11.9±.2	13.6±.2	12.0±.3	13.2±.4	11.9±.2
1965	12.0±.2	12.1±.2	12.1±.1	11.9±.2	11.9±.2	12.1±.2	12.4±.2	12.1±.2
1966	13.2±.2	12.7±.1	13.2±.2	12.8±.3	13.3±.2	12.8±.1	13.5±.2	12.8±.3
1967	12.8±.2	12.0±.1	13.0±.2	12.4±.1	13.0±.1	12.3±.1	12.5±.1	12.2±.1
1968	12.5±.1	12.1±.1	12.6±.2	12.1±.1	12.5±.1	12.0±.1	12.5±.1	12.2±.2
1969	12.7±.2	12.6±.2	12.8±.2	12.7±.1	12.8±.2	12.8±.1	13.0±.1	12.6±.2
1970	13.1±.2	13.5±.1	13.3±.2	13.5±.2	13.6±.3	13.2±.2	13.0±.2	13.0±.2
1971	13.8±.3	13.1±.1	14.0±.2	13.5±.1	13.6±.2	13.4±.2	13.4±.2	13.0±.1
1972	13.1±.1	12.9±.1	13.4±.1	13.2±.1	13.4±.1	13.4±.1	13.1±.1	12.9±.1
1973	13.3±.1	13.2±.2	13.5±.2	12.9±.1	13.2±.2	13.3±.2	12.8±.2	12.8±.1
1974	13.3±.1	12.0±.1	13.2±.1	12.1±.1	13.5±.2	12.1±.1	13.2±.1	11.8±.2
1975	13.5±.1	12.9±.1	13.6±.1	13.4±.1	13.5±.1	13.2±.2	13.0±.1	12.9±.1
1976	13.8±.1	13.4±.1	13.9±.2	13.6±.1	13.7±.1	13.6±.1	13.7±.1	12.8±.2
1977	13.5±.1	13.2±.1	13.3±.1	13.1±.1	13.2±.1	13.1±.1	13.5±.1	13.1±.1
1978	13.7±.2	13.4±.2	14.0±.1	13.8±.1	13.2±.1	13.4±.1	13.4±.1	13.2±.1
1979	13.6±.2	13.3±.1	13.7±.1	13.1±.2			13.5±.1	13.0±.2

[a] Adjusted for age of dam.
[b] Conformation grade: 12=low choice, 13=average choice.
[c] WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line, CL=control line.

TABLE 10

ANNUAL MEANS AND STANDARD ERRORS FOR YEARLING CONDITION SCORE[a,b]

	WWL[c]		YWL		PTL		CL	
Year	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers
1964	5.2±.2	4.1±.2	4.8±.1	3.9±.2	5.5±.2	4.2±.2	5.0±.3	4.0±.1
1965	5.1±.2	4.1±.2	5.1±.1	4.2±.2	4.6±.2	5.0±.1	5.1±.1	4.0±.1
1966	4.9±.1	4.9±.1	4.9±.2	5.1±.2	5.1±.2	4.9±.2	5.0±.2	4.7±.3
1967	4.9±.2	4.2±.1	5.3±.3	5.0±.1	5.4±.1	4.0±.1	5.0±.1	4.0±.1
1968	4.7±.2	3.9±.1	4.7±.1	3.8±.1	4.8±.1	4.1±.1	4.8±.1	4.0±.1
1969	5.1±.1	4.0±.1	5.1±.2	4.4±.1	5.0±.2	4.3±.1	5.6±.1	4.4±.1
1970	6.0±.2	6.7±.2	6.5±.1	6.6±.2	6.0±.2	6.4±.2	5.5±.2	6.4±.2
1971	5.8±.2	5.4±.2	5.8±.2	5.0±.1	6.2±.2	5.3±.1	5.9±.1	5.1±.1
1972	5.4±.1	5.1±.1	5.2±.1	5.0±.1	5.4±.1	5.1±.1	5.3±.1	5.0±.1
1973	5.2±.2	5.2±.1	5.3±.1	4.9±.1	5.2±.1	4.9±.1	5.2±.2	4.8±.1
1974	5.2±.1	4.1±.1	4.8±.1	4.2±.1	5.5±.1	4.9±.1	5.2±.1	4.9±.1
1975	5.6±.1	5.2±.1	5.5±.1	5.3±.1	5.7±.1	5.2±.1	5.5±.1	5.3±.1
1976	5.7±.1	5.3±.1	5.7±.1	5.2±.1	5.6±.1	5.4±.1	6.0±.1	5.3±.2
1977	6.0±.2	5.1±.1	5.9±.2	4.9±.1	6.1±.1	5.1±.1	6.1±.1	5.2±.1
1978	5.7±.1	5.2±.2	6.0±.2	5.7±.1	5.5±.1	5.3±.2	5.6±.1	5.3±.1
1979	5.6±.2	5.0±.1	5.7±.1	4.7±.2			5.8±.1	4.6±.2

[a]Adjusted for age of dam.
[b]Condition: 1=thin to 9=fat with 5=average fat.
[c]WWL=weaning wt line, YWL=yearling wt line, PTL=progeny test line, CL=control line.

APPENDIX C

PHENOTYPIC TRENDS FOR GROWTH TRAITS

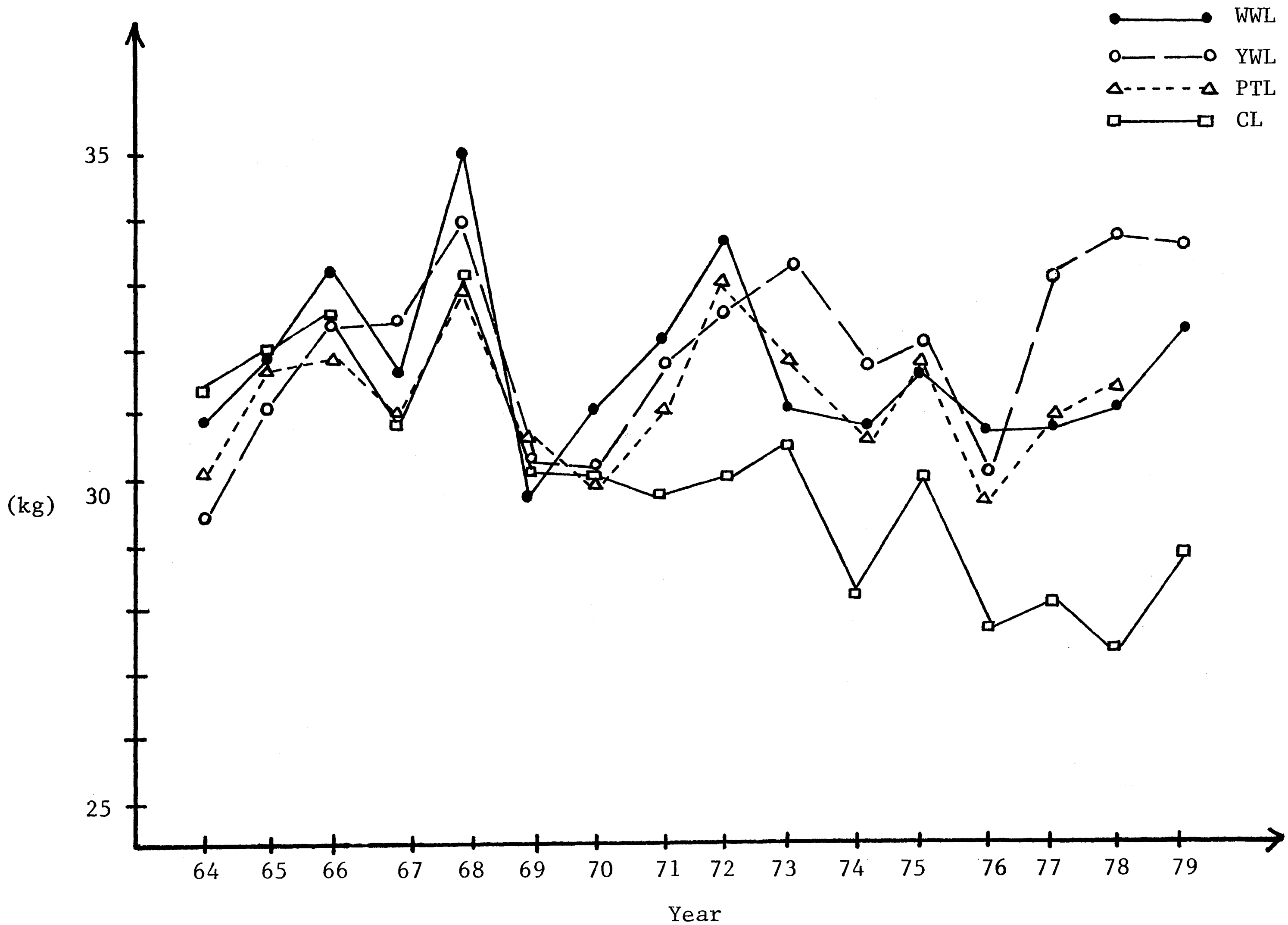

FIGURE 1. ANNUAL PHENOTYPIC MEANS FOR BIRTH WEIGHT AVERAGED OVER SEX

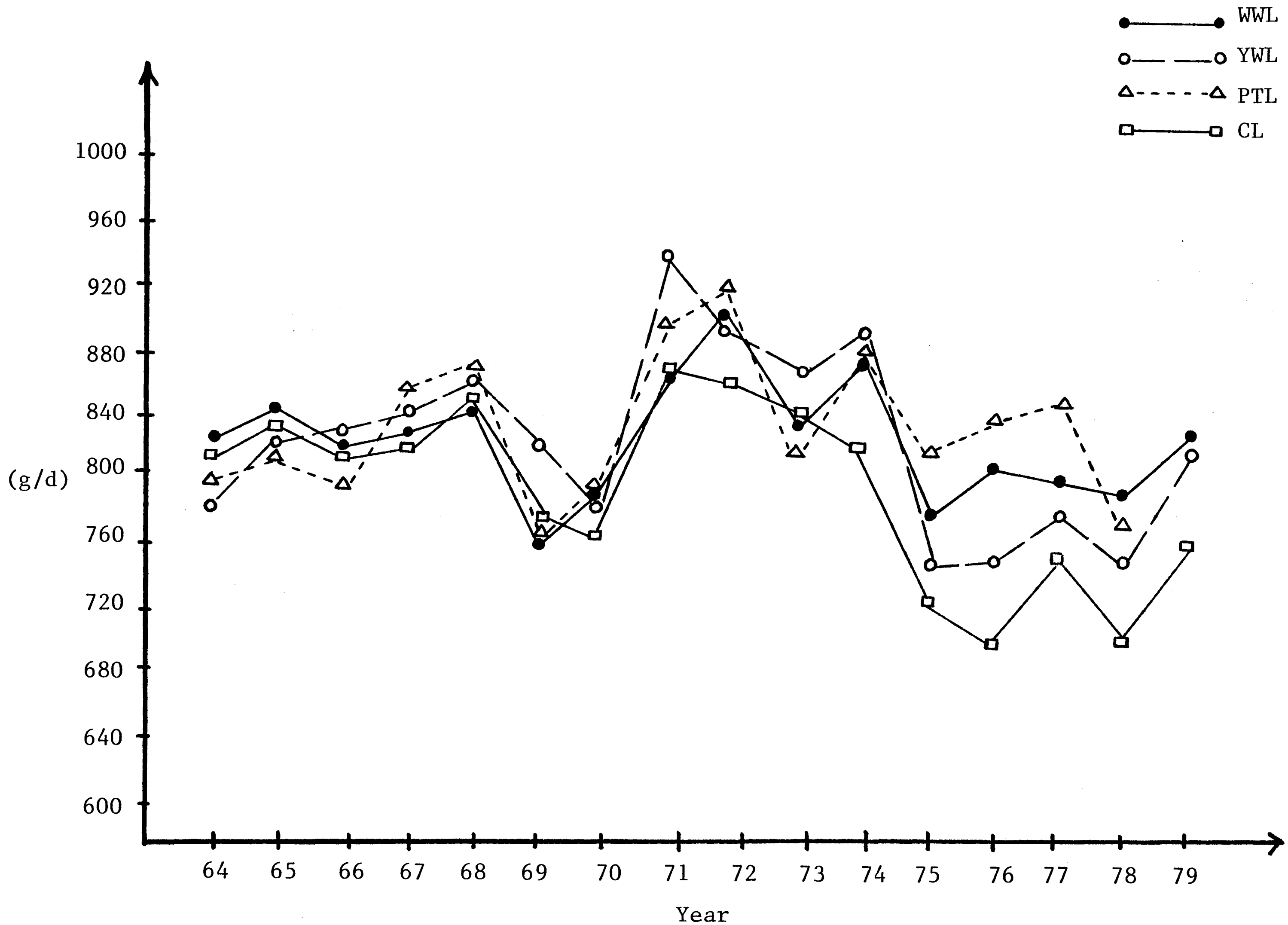

FIGURE 2. ANNUAL PHENOTYPIC MEANS FOR PREWEANING DAILY GAIN AVERAGED OVER SEX

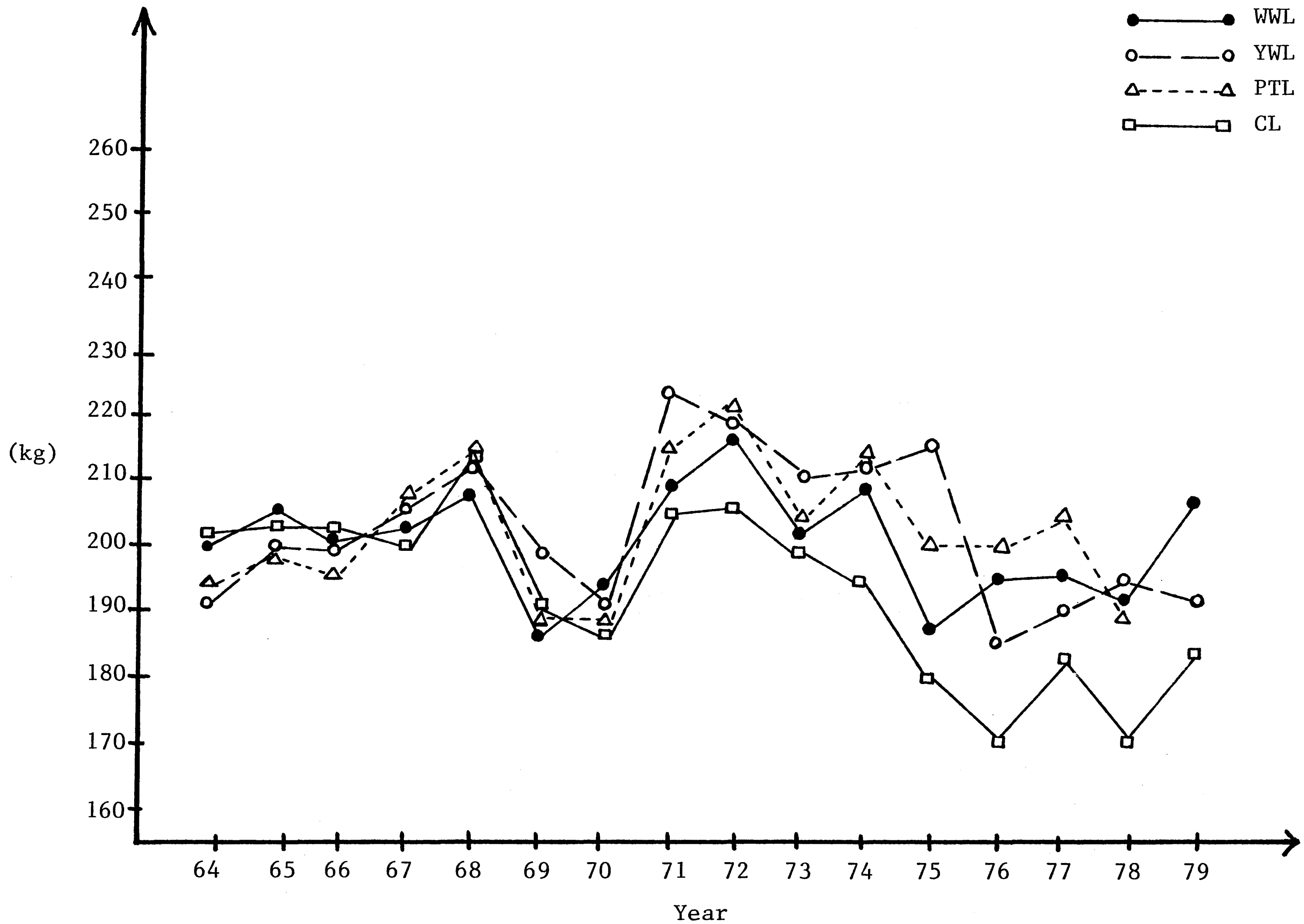

FIGURE 3. ANNUAL PHENOTYPIC MEANS FOR 205-DAY WEANING WEIGHT AVERAGED OVER SEX

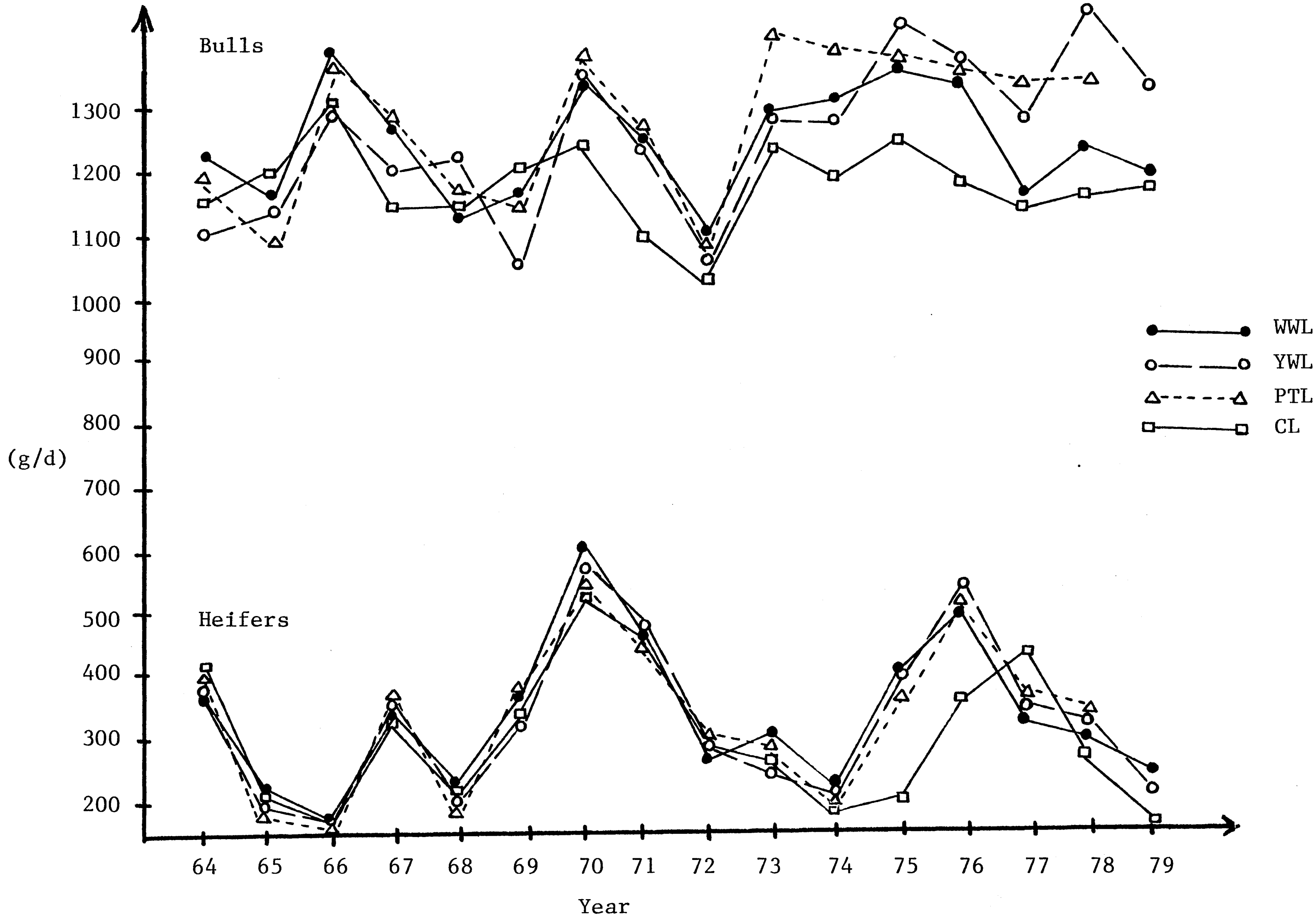

FIGURE 4. ANNUAL PHENOTYPIC MEANS FOR WEANING TO YEARLING DAILY GAIN FOR BULLS AND HEIFERS

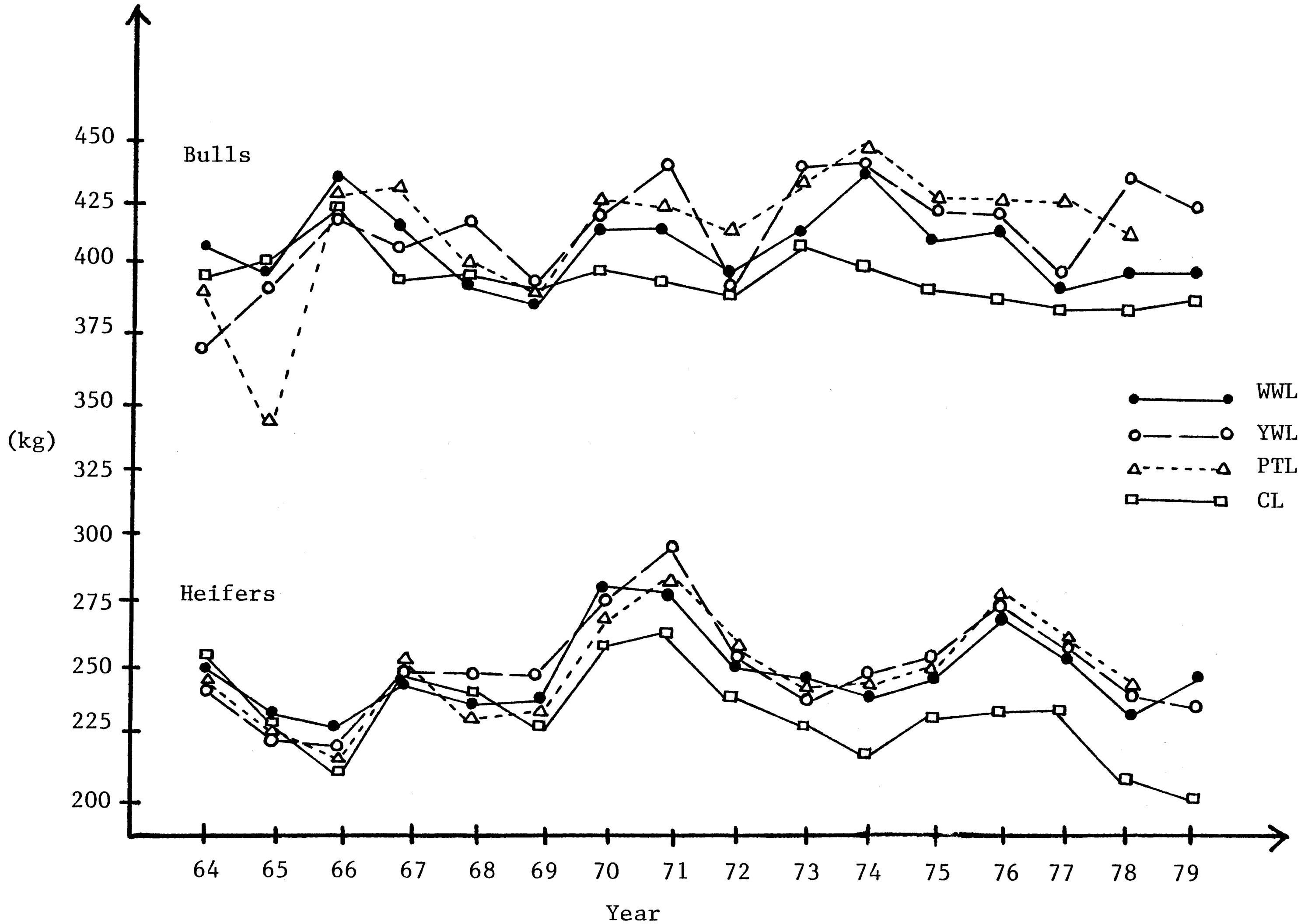

FIGURE 5. ANNUAL PHENOTYPIC MEANS FOR YEARLING WEIGHT FOR BULLS (365-DAY) AND HEIFERS (425-DAY)

APPENDIX D

GENETIC TRENDS FOR WEANING AND YEARLING

WEIGHTS

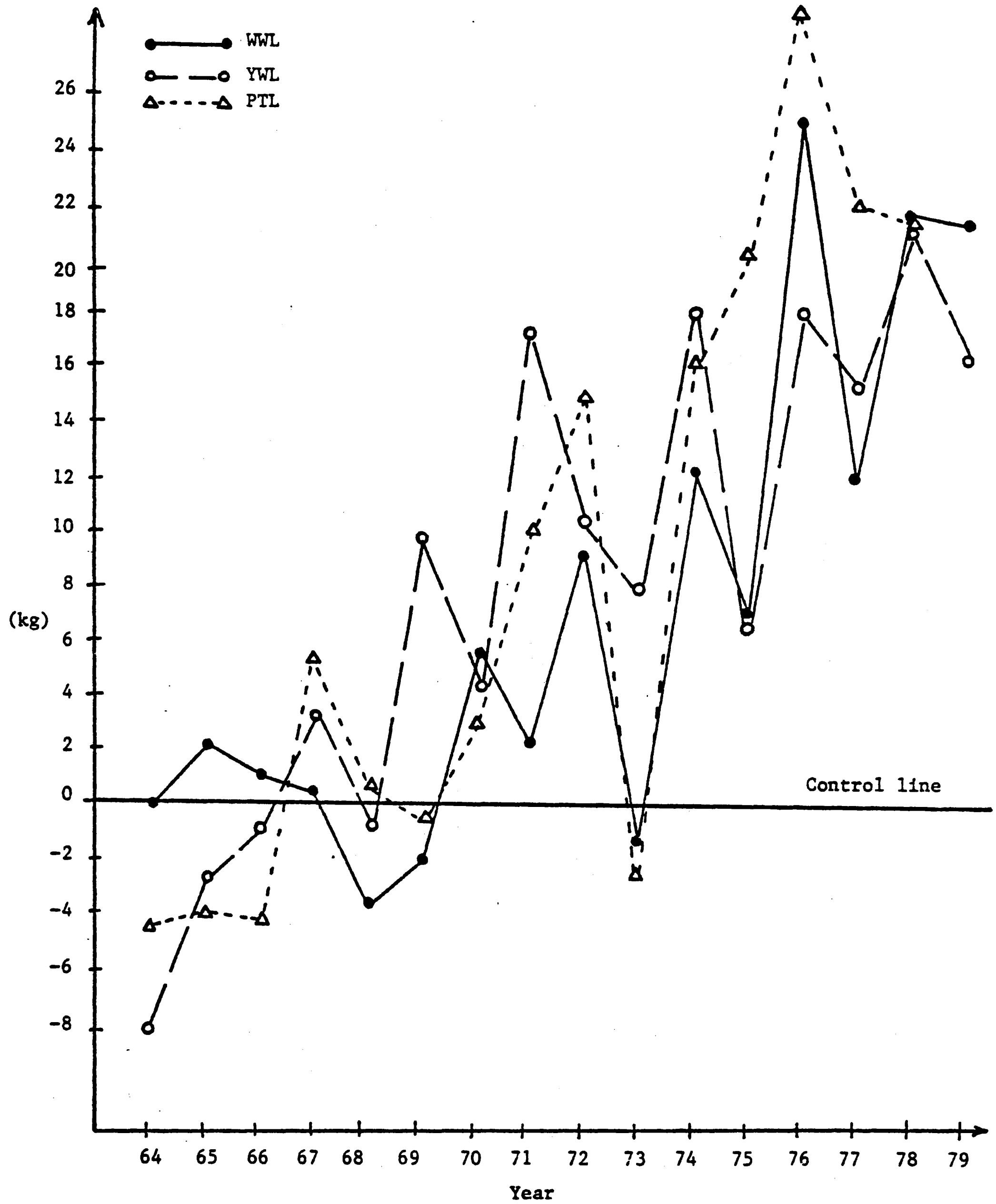

FIGURE 6. ANNUAL GENETIC TREND FOR 205-DAY WEANING WEIGHT AVERAGED OVER SEX AS DEVIATIONS FROM CONTROL

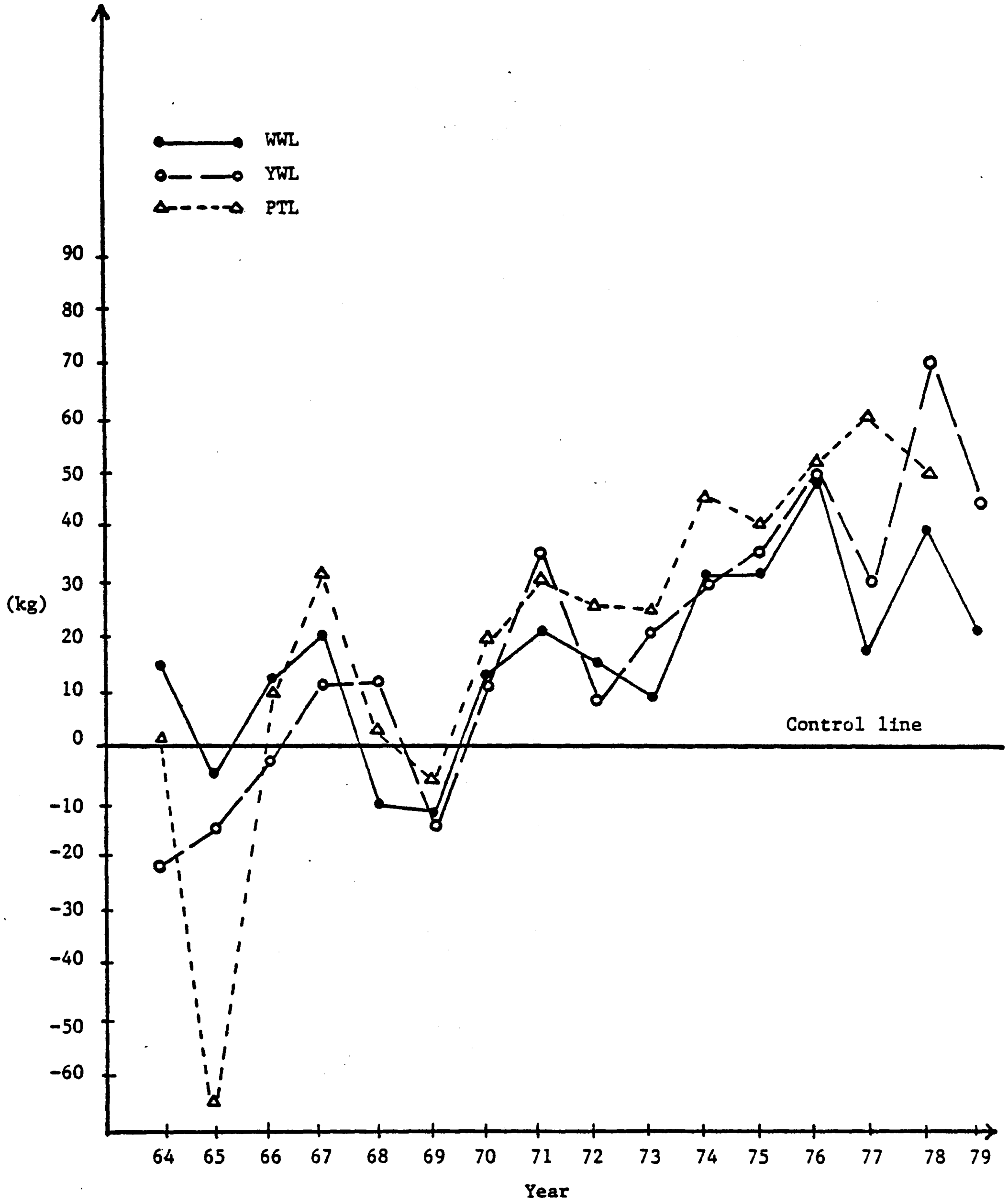

FIGURE 7. ANNUAL GENETIC TREND FOR 365-DAY YEARLING WEIGHT OF BULLS AS DEVIATIONS FROM CONTROL

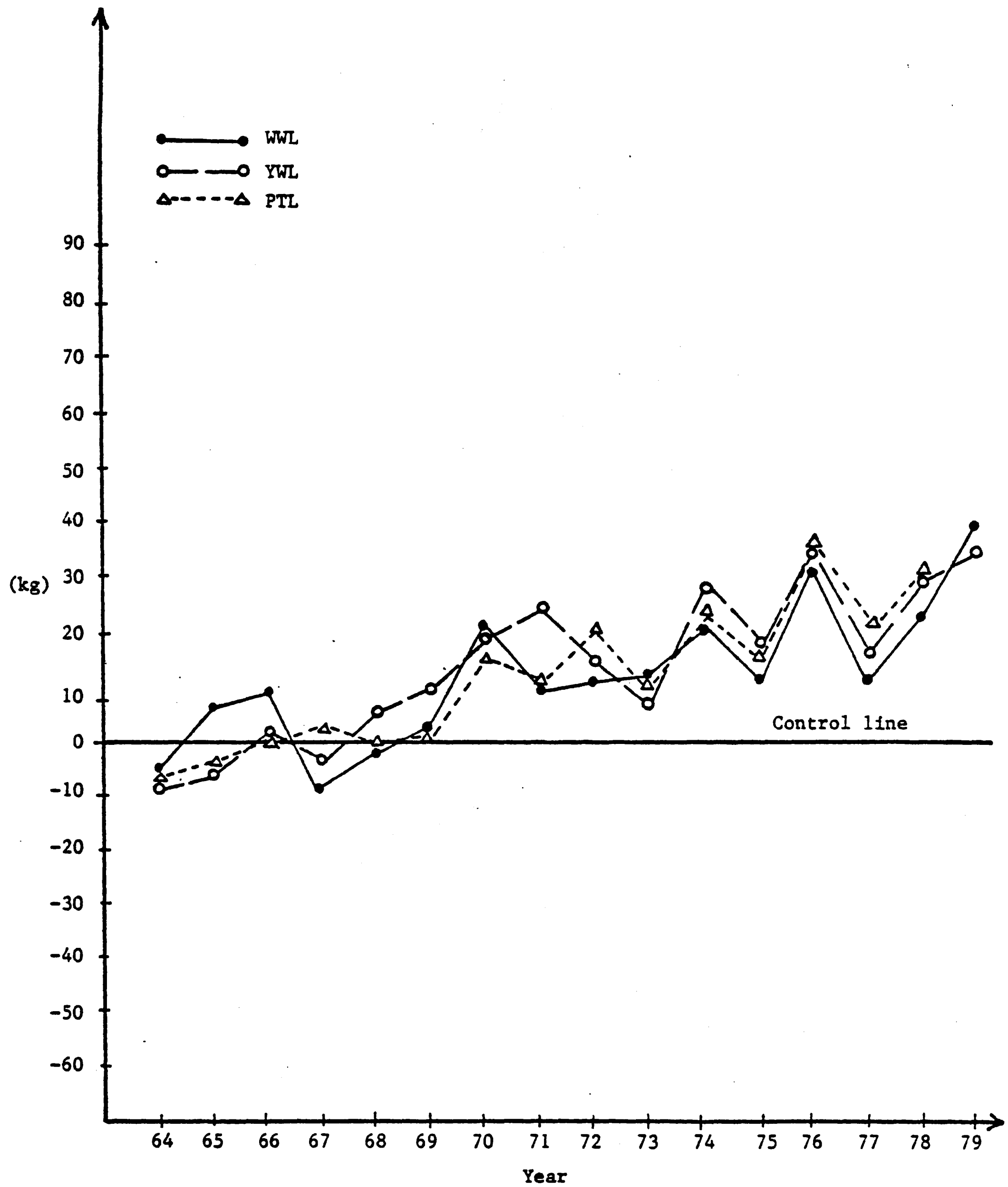

FIGURE 8. ANNUAL GENETIC TREND FOR 425-DAY YEARLING WEIGHT OF HEIFERS AS DEVIATIONS FROM CONTROL

APPENDIX E

STATISTICAL TABLES FOR GROWTH AND CARCASS TRAITS OF CALVES SIRED BY FINAL GROUP OF SELECTED BULLS

TABLE 11

MEAN SQUARES FOR TRAITS THROUGH A YEAR OF AGE OF CALVES SIRED
BY FINAL GROUP OF SELECTED BULLS
(FULL MODEL)

Source:	Sire line (L)	Sire within sire line (SL)	Sex of calf (S)	L*S	Age of dam[a]	Error
Trait[a] df:	3	12	1	3	1	180
BW, kg	44.9[+]	16.1	393.7**	3.4	13.8	17.1
WDG, g/d	77526**	8589	71846**	18725	180202**	7283
WW, kg	3590**	384.4	5711**	819[+]	8063**	356
WG[c]	1.466**	.558	.317	.563	13.542**	.389
WC[d]	1.701**	1.150**	1.338*	.456	10.764**	.337
YDG, g/d	73942*	30475	1234556**	3280	11763	27099
YW, kg	9321*	878	64883**	1231.3	4533[+]	1202
YG[c]	1.328**	.214	.124	.095	.657[+]	.230
YC[d]	1.905**	1.051**	1.289[+]	.390	6.415**	.417
YH, cm	111.3**	123.5	643.2**	10.5	90.6*	16.4

[+]P<.10, *P<.05, **P<.01.
[a]Covariate source of variation.
[b]BW=birth wt, WDG=preweaning daily gain, WW=weaning wt, WG=weaning conformation grade, WC=weaning condition score, YDG=weaning to yearling daily gain, YW=yearling wt, YG=yearling conformation grade, YC=yearling condition score, YH=yearling hip ht.
[c]Conformation grade on a 17 point scale with 13=average choice.
[d]Condition score on a 9 point scale from 1=thin to 9=very fat.

TABLE 12

SOURCES OF VARIATION FOR TRAITS THROUGH A YEAR OF AGE OF CALVES SIRED BY FINAL GROUP OF SELECTED BULLS (REDUCED MODELS)[a]

Trait[c] Source:	Sire line (L)	Sire within sire line (SL)	Sex of calf (S)	L*S	Age of dam[b]
BW, kg	X		X		
WDG, g/d	X		X	X	X
WW, kg	X		X	X	X
WG	X	X			X
WC	X	X	X		X
YDG, g/d	X		X		
YW, kg	X		X		X
YG	X				X
YC	X	X	X		X
YH, cm	X		X		X

[a]'X' indicates effect in reduced model for that particular trait.
[b]Covariate source of variation.
[c]BW=birth wt, WDG=preweaning daily gain, WW=weaning wt, WG=weaning conformation grade, WC=weaning condition score, YDG=weaning to yearling daily gain, YW=yearling wt, YG=yearling conformation grade, YC=yearling condition score, YH=yearling hip ht.

TABLE 13

MEAN SQUARES FOR FEEDLOT AND CARCASS TRAITS OF CALVES SIRED BY
FINAL GROUP OF SELECTED BULLS
(FULL MODEL)

Trait	Source: df:	Sire line (L) 3	Sire within sire line (SL) 12	Sex of calf (S) 1	L*S 3	Error 167
Initial wt on test, kg		4457**	279**	7733**	1355^{+}	631
Final wt, kg		4324**	852	105075**	689	1028
ADG on test, g/d		115174**	1497	1030398**	55256^{+}	23984
Days on feed		3416**	193	217	551	436
Age at slaughter, d		1578*	80	42	69	119
Hot carcass wt, kg		2624**	531	40977**	58	578
Carcass wt/d of age, g/d		28804**	4256	20757**	1672	4696
Dressing percent		10.2	14.5*	10.0	13.5	7.7
Average fat thickness, cm		.355	.591**	.105	.059	.227
KHP fat, %		.327	.224	.012	.018*	.312
Marbling score		1.71*	.31	.35	.20	.49
Carcass grade		2.42*	1.08	.01	.44	.85
Carcass conformation		4.40**	1.99*	3.64^{+}	.83	.95
Rib eye area, cm^2		327.9**	55.3	99.5	36.0	40.8
Cutability, %		5.60^{+}	6.70**	18.80**	1.65	2.52

$^{+}$P<.10, *P<.05, **P<.01.

TABLE 14

SOURCES OF VARIATION FOR FEEDLOT AND CARCASS TRAITS OF CALVES SIRED BY FINAL GROUP OF SELECTED BULLS (REDUCED MODELS)[a]

Trait / Source:	Sire line (L)	Sire within sire line (SL)	Sex of calf (S)	L*S
Initial wt on test, kg	X		X	X
Final wt, kg	X		X	
ADG on test, g/d	X		X	X
Days on feed	X			
Age at slaughter, d	X			
Hot carcass wt, kg	X		X	
Carcass wt/d of age, g/d	X		X	
Dressing percent	X	X	X	X
Average fat thickness, cm	X	X		
KHP fat, %	X			
Marbling score	X			
Carcass grade	X			
Carcass conformation	X	X	X	
Rib eye area, cm^2	X	X	X	
Cutability, %	X	X	X	

[a]'X' indicates effect in reduced model for that particular trait.

APPENDIX F

STATISTICAL TABLES FOR MILK PRODUCTION TRAITS

TABLE 15

MEAN SQUARES FOR MILK YIELD AND COMPOSITION TRAITS
(FULL MODEL)

Source:	Selection line (L)	Sex of calf (S)	Week of milking (W)	Cow age (CA)	L*S	L*CA	Calving date[a]	Error
Trait df:	2	1	1	4	2	7	1	34
Daily milk yield, kg	2.580	.151	.014	.204	.412	.955	.350	2.038
Butterfat, %	1.372**	.308	1.138*	.439+	.246	.400*	.752*	.172
Daily butterfat yield, g	10451+	2974	6083	3468	1770	3046	7580	440
Protein, %	.019	.023	.015	.002	.040	.031	.008	.034
Daily protein yield, g	3065	534	57	121	576	1272	252	2089
Total solids, %	1.430*	.513	.337	.454	.216	.337	1.692*	.304
Daily total solid yield, g	51258	8721	1052	8441	6909	18274	27134	34604

+P<.10, *P<.05, **P<.01.
[a]Covariate source of variation.

TABLE 16

SOURCES OF VARIATION FOR MILK YIELD AND COMPOSITION TRAITS (REDUCED MODELS)[a]

Trait Source:	Selection line (L)	Sex of calf (S)	Week of milking (W)	Cow age (CA)	L*S	L*CA	Calving date[b]
Daily milk yield, kg	X						
Butterfat, %	X		X	X		X	X
Daily butterfat yield, g	X						X
Protein, %	X						
Daily protein yield, g	X						X
Total solids, %	X						
Daily total solid yield, g	X						

[a] 'X' indicates effect in reduced model for that particular trait.
[b] Covariate source of variation.

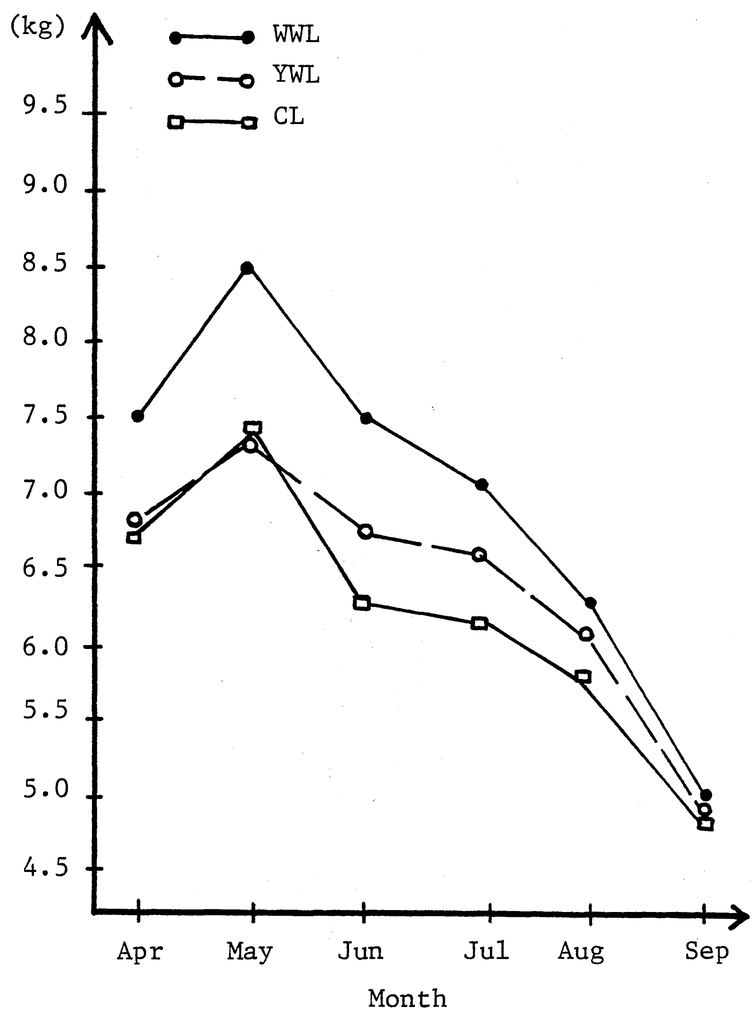

FIGURE 9. LEAST-SQUARES MEANS FOR 24-HOUR MILK YIELDS BY MONTH

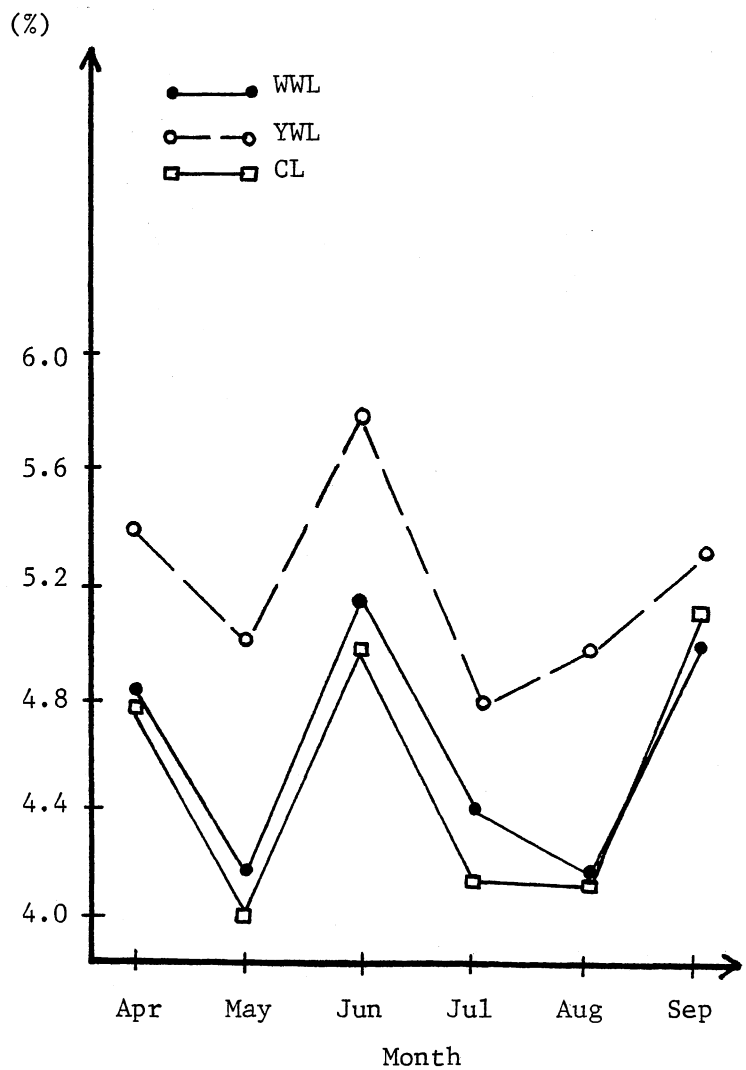

FIGURE 10. LEAST-SQUARES MEANS FOR BUTTERFAT PERCENTAGE BY MONTH

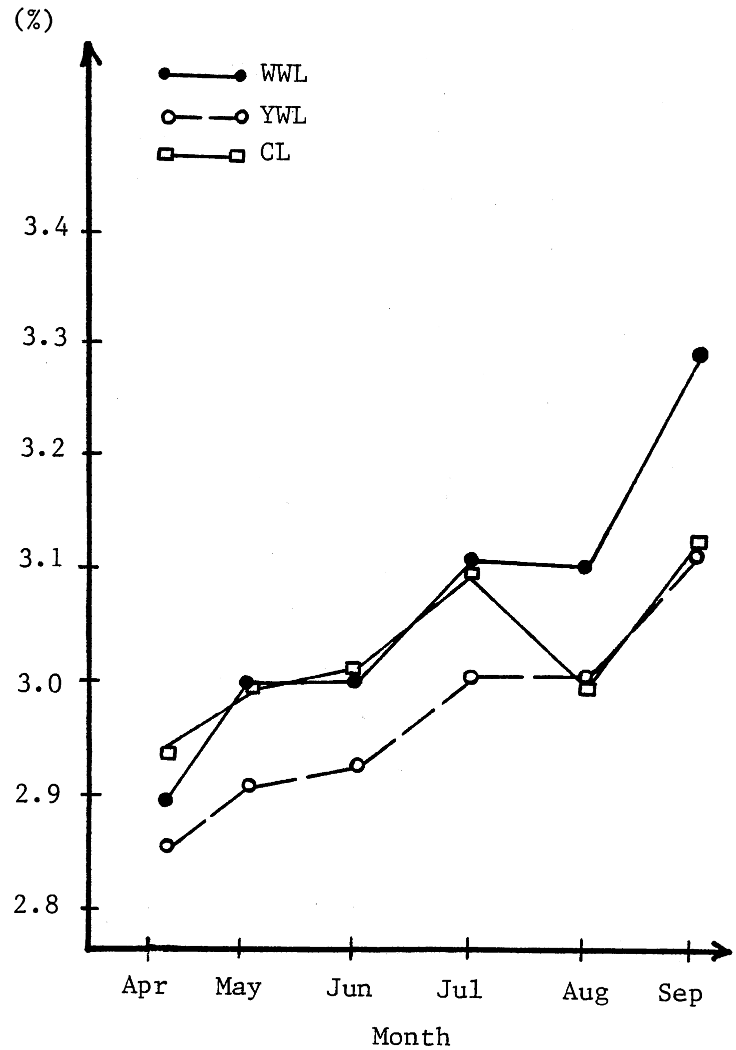

FIGURE 11. LEAST-SQUARES MEANS FOR PROTEIN PERCENTAGE BY MONTH

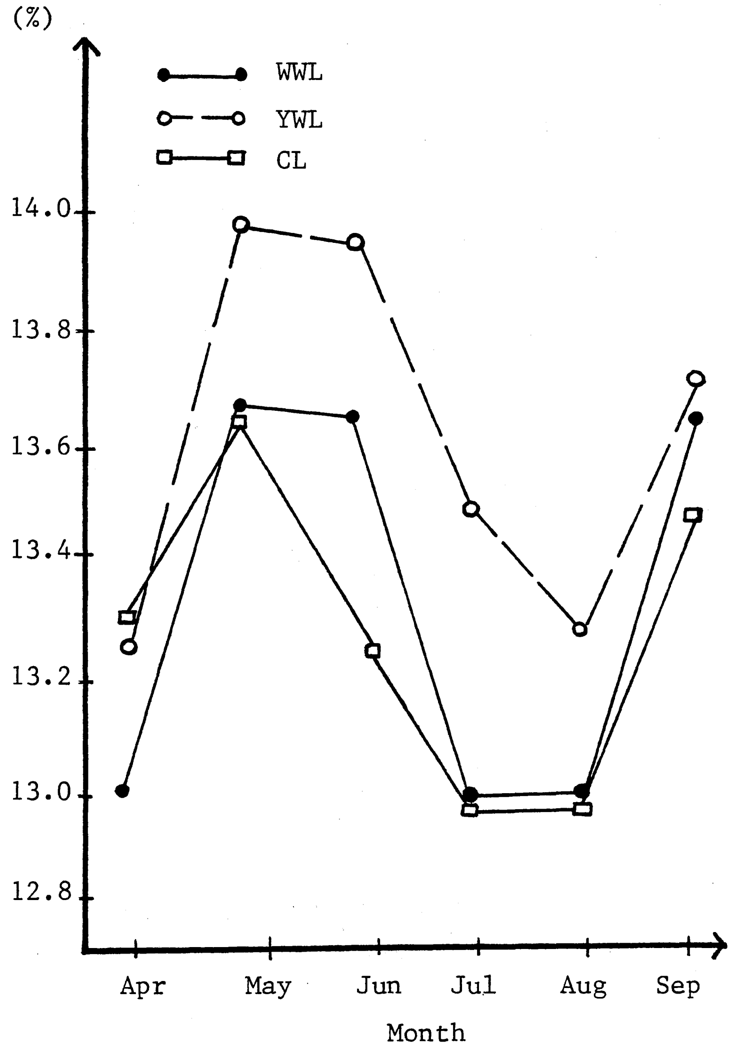

FIGURE 12. LEAST-SQUARES MEANS FOR TOTAL SOLIDS PERCENTAGE BY MONTH

VITA 2

Debra Kay Aaron

Candidate for the Degree of

Doctor of Philosophy

Thesis: DIRECT AND CORRELATED RESPONSES TO SELECTION FOR INCREASED WEANING AND YEARLING WEIGHTS IN ANGUS CATTLE

Major Field: Animal Breeding

Biographical:

Personal Data: Born in Somerset, Kentucky, June 12, 1956, the daughter of Mr. and Mrs. Keith A. Aaron.

Education: Graduated from Russell County High School, Russell Springs, Kentucky in May, 1974; received the Associate of Arts degree from Lindsey Wilson Junior College, Columbia, Kentucky in May, 1976; received the Bachelor of Science degree in December, 1978 and the Master of Science degree in May, 1981 from the University of Kentucky, Lexington, Kentucky; completed requirements for the Doctor of Philosophy degree at Oklahoma State University, Stillwater, Oklahoma in December, 1984.

Professional Experience: Summer Extension Intern, Cumberland County, Kentucky, summer, 1977; part-time student worker, Department of Animal Science, University of Kentucky, 1978; Research Assistant, Department of Animal Science, University of Kentucky, 1979-1981; Graduate Assistant, Animal Science Department, Oklahoma State University, 1981-1984.

Professional Organizations: American Society of Animal Science, Sigma Xi, Gamma Sigma Delta, Alpha Zeta, Phi Theta Kappa.