USE OF PHENOTYPIC TARGET OBJECTIVES IN BEEF CATTLE CROSSBREEDING STRATEGIES TO INCREASE UNIFORMITY IN PRODUCTION AND PRODUCT

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GARY ROBERT BROWN

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ABSTRACT

USE OF PHENOTYPIC TARGET OBJECTIVES IN BEEF CATTLE CROSSBREEDING STRATEGIES TO INCREASE UNIFORMITY IN PRODUCTION AND PRODUCT

Gary Robert Brown	Advisor
University of Guelph, 2000	Dr J. W. Wilton

The objective of this study was to compare a temporal 3-breed rotational crossbreeding strategy to a novel crossbreeding strategy. The novel uniformity crossbreeding strategy was devised to address phenotypic uniformity, targeted production, retained heterosis and a female replacement system. Data were simulated for 14 phenotypic traits and 16 additive genetic traits. Matings were selected and performed over a 10-year production cycle for 100 herds, with each herd containing 100 cows, and being randomly assigned to one of the two strategies. The female replacement system, for the uniformity strategy, successfully produced targeted replacement females at an economically optimum replacement rate. Maternal and individual heterosis was equivalent between strategies. The uniformity strategy produced significantly lower phenotypic variation for most traits studied. Phenotypic performance objectives were achieved in most traits throughout the 10 production years in the uniformity strategy. Composite bulls contributed to uniformity, retained heterosis, and target achievement in the uniformity strategy.

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Introduction

1.0 Introduction

Crossbreeding has been shown to produce economic benefits in beef production due primarily to capitalization on the effect of heterosis (Dickerson, 1974; Long, 1980; Gregory and Cundiff, 1980; Cundiff, 1986). Commercial beef cattle breeding strategies are typically characterized as structured crossbreeding schemes designed to improve performance, maximize heterosis and the use of complementarity. The most commonly discussed schemes are rotational or first cross-maternal (F1) to a terminal sire system. These strategies are generic and designed to maximize heterosis or retained heterosis and as such can be used by other livestock species. The problem with the above crossbreeding strategies, and others, in their application to beef cattle breeding has been the reproductive rate of cattle and the associated time period required to achieve the optimum breed contributions within the cow-herd. When the F1 terminal cross strategy is used in swine production systems, the F1 females can be produced on a large scale efficiently and quickly due to reproductive rates of the sows. In sheep production, F1's can be produced more efficiently, through a better progeny per female ratio than in beef cattle and there are currently initiatives taking place in the sheep industry attempting to capitalize on an F1 breeding system. Unfortunately, efforts to increase progeny output such as twinning and advanced reproductive techniques in beef cattle have proven to be problematic or too expensive for application at the commercial production level (Reid et al., 1986).

The use of generalized rotational crossbreeding systems for female production has been shown to be very effective once the system moves towards equilibrium for breed composition of the cow-herd (Fitzhugh et al., 1975; Wilton and Morris, 1976; Gregory and Cundiff, 1980; Long, 1980). The benefits are related to maximization of retained heterosis and accurate breed difference estimates allowing for effective breed choices and complementarity. The problem with implementing a rotational crossbreeding system in beef cattle lies mainly in the time required to reach equilibrium of the breed composition. Normal output from females is 1 calf per year, with age at first calving being as 2 year olds. Therefore it takes a minimum 3 years to have females from the first cross of the rotation to begin calving. As can be seen the period of time required reaching equilibrium for a 2-breed rotation is very long (approximately 7 years if a 20% replacement rate is assumed), with a 3-breed rotation being almost a lifetime project (approximately 20 years if a 20% replacement rate is assumed) for many commercial beef producers. A solution that is often suggested is to have a source of females that are at or close to the planned breed composition that could be purchased to accelerate the process. In general however, most commercial beef herds only purchase sire inputs from outside the herd mainly to avoid cash outlay or debt. Another issue is availability, because few producers are in the business of creating and selling F1 females. Therefore females are selected within the herd making the F1 purchase solution not very viable or probable.

Rotational or F1 based crossbreeding schemes can have less than desirable results because of other problems that may arise. If a producer opts to move to an F1 or rotational crossbreeding system an extremely high replacement rate must be implemented to move towards the desired breed composition. This results in low selection pressure on economically important traits. As well, a problem with maintaining an economically optimum age distribution occurs. An economically optimum age distribution can be defined as having a maximum percentage of females making it through the minimum number of calvings to be profitable (Melton and Colette, 1993). Another inherent problem of rotational crossbreeding systems that occurs is fluctuation in breed composition of the individual females within the herd (Gregory and Cundiff, 1980). This problem is mainly due to the use of purebred input sires, which causes fluctuation in breed composition in the females between 5/8 and 1/8 of any one of the breeds in a 3-breed rotation. The breed fluctuation problem usually has breed complementarity issues that are symptomatic of the breed composition of the individuals as well as obvious phenotypic uniformity issues. An example of this problem is that a portion (approximately 1/3) of the crossbred females in a 3-breed rotational crossbreeding herd may have mature weights that are 50 kg more than the rest of the herd due to a large maternal exotic breed being used in the rotation. This can cause nutritional and management problems and reduced efficiency of the herd. Many producers have abandoned rotational crossbreeding systems at a point part way through the scheme and have a cow-herd that has little phenotypic uniformity, a young average age, and a wide range of breed compositions and genetic merit present in the females, as well as reduced efficiency and profitability.

Beef producers have a large number of breeds available, which should be very beneficial in devising crossbreeding schemes. It would be expected that the desirable characteristics of different breeds could be blended in a crossbreeding program with excellent results. This expectation is complicated by the fact that breed development has tended to be for specific and very different purposes. Efforts to use the multitude of breeds available in crossbreeding systems and produce phenotypically superior offspring have not always considered all traits of economic importance. This can result in unexpected problems such as calving ease. It is also assumed that if wise breed selection occurs that uniformity of phenotypes will result. However this does not necessarily happen. Uniformity is critical for returns on a calf crop basis. Uniformity is desired because regardless of the age of the cattle the more similar they are, the easier they are to manage and the more valuable they are to sell. If cattle can be sold in large uniform groups, the carcasses will form a supply that can be sold as a branded product at a higher value. A survey of packers, processors and retailers in Ontario (Michelle Edwards, personal communications) indicated that specific markets do exist and that packers and processors do purchase product based on the specifications. Farmland Industries (Kansas City, Missouri) is a cooperative beef packer and pays producers for cattle based on a grid. The grid is based on a minimum lean meat yield and quality grade and provides the opportunity for as much as a $53 (US) premium per animal for achieving the highest quality and yield grade. Production of cattle that are uniform and capable of desired carcass characteristics could therefore receive higher returns. Most other competing meats have established market weights that are standard and consequently create uniformity while the beef market still allows a large range in carcass weights and qualities. The lack of specific market weight targets has been justified because of a perceived diverse market that will take all sizes and qualities of beef carcasses and will pay according to demand.

Complementarity is a term that is used to describe the situation where progeny (either as a calf or latter as a parent) have a more suitable and profitable phenotype than either parent, with the assumption that the parental phenotypes bracket the suitable phenotype (Cartwright, 1970; Fitzhugh et al., 1975). Utilization of complementarity for selecting breed contributions in a crossbreeding scheme has generally focused on selecting complementarity between trait pairs such as lean meat yield and finishing ability, or high milk production and easy keeping cows. The breeding schemes often do not account for the potential liabilities of other trait areas where complementarity was not considered. An example is where cows require nutritional resources that are greater than the farm environment produces, requiring supplementation. A further issue is that most breed choices are based on average known performance. Actual animal selection within breeds however is not based on choosing average animals within a breed but by selecting from individual animals. The performance results after selection are therefore often not precisely what were expected.

Payment for cow-herd production, in the form of calves, is generally linked to 3 marketing points depending on the degree of vertical integration of the operation. The key marketing points are weaning, yearling or slaughter. Many traditional cow-calf operations market calves at weaning where uniformity of the phenotypes of the calves is critical to their value along with certain breed and/or performance characteristics. Phenotypic uniformity is definable as a low or lower standard deviation in the weight, height, condition and muscling of the calves. Uniformity of the calf crop is directly related to uniformity of the cow-herd and the sires used in the individual matings. It also follows that uniformity at yearling age is improved by greater uniformity at weaning. Uniformity at slaughter has 3 important profit associations; performance, carcass size and carcass quality. Carcass size and quality defines the salability and premium or discount structure for payment. Therefore a sound commercial crossbreeding strategy needs to focus on performance relating to cost reduction, optimum carcass size, production premiums and avoidance of production discounting. Uniformity at slaughter is also directly related to uniformity at weaning and yearling. Employing a uniformity strategy designed to focus on the possible marketing points may enable a commercial cow-calf producer to achieve flexibility to maximize returns on any group of calves produced at any point they may wish to market them within the production system.

A current trend in the beef industry is the production of composite bulls that are composed of multiple breeds. A market for these bulls has developed in part due to carcass size and meat quality issues brought to the forefront by industry surveys and research on consumer acceptance of beef currently available for purchase. Phenotypic performance of composite bulls has also added to interest and demand due to the fact that they often produce optimal performance in part due to the complementarity considerations involved in the original breeding plans for the construction of the composite. Composites in this study were simulated and available for selection for the uniformity strategy.

Objectives

2.0 Objectives

The general objective of this research was to study a complete crossbreeding system for beef cattle, in which the primary goal is to produce phenotypic uniformity across a large number of traits while providing a system for generating replacements, maximizing heterosis, using complementarity and culling.

2.1 Specific Objectives

1) To investigate how complementarity and heterosis can be used in a crossbreeding strategy to achieve measurable phenotypic uniformity while optimizing performance using phenotypic performance targets.

2) To investigate a system of progressive improvement in mature cow phenotypic uniformity as part of the overall crossbreeding strategy while increasing cow utility within a semi-extensive production environment. Cow-herd utility traits are related to mature cow weight, height, body condition and reproductive performance. An optimum culling and replacement rate system for the cow-herd is incorporated to aid in producing uniformity of progeny phenotypic performance. A replacement female nucleus strategy is examined to minimize the portion of the cow-herd used for

replacements, and to use artificial insemination to provide a long term replacement female system.

Literature Review

3.0.0 Simulation

Stochastic simulation is a method that is utilized frequently to evaluate the potential value of new breeding strategies, or novel components of breeding strategies being incorporated into existing strategies, before actual application occurs. In a case where a novel strategy, such as the uniformity crossbreeding strategy that was being investigated in this study, is of interest and where accurate parameters were available, stochastic simulation can prove to be the only available method of investigation.

Elements of major crossbreeding strategies were incorporated if appropriate and of benefit in this study. Some desirable elements were to achieve a high level of retained maternal and direct heterosis and to utilize complementarity. Previous studies have included both simulated and experimental herds where components of a crossbreeding strategy were implemented and excellent estimates of effects as well as prediction information made available to provide the required parameters for a stochastic simulation (Dickerson, 1974; Fitzhugh, et al. 1975; Gregory and Cundiff, 1980; Long, 1980; Marshall, 1994; Koots et al., 1994; Gregory et al., 1995 a,b,c).

Stochastic simulation studies can be used to compare the results from a control or standard strategy to a proposed novel strategy. Deterministic simulations are designed to study changes in breeding objectives or procedural alternatives within a standard strategy.

Deterministic strategies also tend to simulate one standard production cycle, which represents the current production norms. Comparisons are made based on changes implemented for the replicate in comparison to standard replicates as Wilton and Morris (1976) did by comparing a purebred breeding system with various crossbreeding systems. The changes tend to be measured as cumulative change in output versus change in input, which was often placed on an economic scale and could be represented by gross margin. Fitzhugh et al. (1975) used deterministic simulation to examine the efficiency of beef production between straight breeding and crossbreeding systems. In the study by Fitzhugh et al. (1975) the production parameters remained constant while examining and quantifying efficiency of production as a function of heterosis and complementarity on a gross margin basis over one production cycle. Fitzhugh et al. (1975) simulated herds where the crossbreeding strategies were fully implemented and could not provide insight on efficiency during implementation of the crossbreeding strategy where the duration of implementation is often a problem. Several other researchers utilized the same simulation software as Fitzhugh et al. (1975) to explore cow size (Long et al., 1975) and mating plans or crossbreeding systems (Cartwright et al., 1975).

In this study the objective of phenotypic uniformity was an effect that accumulates over time and therefore investigation of change in uniformity over time was of interest and requires stochastic simulation. As well, the uniformity strategy contains a long-term female replacement strategy where uniformity was a key objective, which requires multiple production years to study. Of interest as well were the differences during the implementation period of the crossbreeding strategies, which is a problem with utilization of rotational crossbreeding strategies in industry. There have been no experimental herd or simulation studies performed with an objective of phenotypic uniformity.

3.1.0 Populations

As a review of population structure in the beef industry in Ontario there are two distinct types of producers. One group of producers can be considered seedstock producers specializing in producing and selling breeding stock. Another group consists of commercial producers who produce terminal calves for meat production as well as female replacements for within herd selection. In general, commercial producers do not test bulls from the calves born in their herds nor sell replacement female breeding stock. Therefore, it could be assumed that progeny from commercial herds were not for sale to other herds or for evaluation in the test bull population. This allows for the assumption, that there are two different populations of cattle, one that is commercial, and another that is seedstock. Commercial producers generally breed cows using natural service. It can be assumed that bulls selected for a herd in any given year were not related to the bulls selected in any of the other years for that herd. Therefore, selected bulls did not introduce inbreeding into commercial herds. This assumption was justified because of the structure of a temporal (Bourdon, 1997) rotational crossbreeding strategy where any breed of bull is chosen only once every fourth year by design. The uniformity strategy selected bulls in such a way that it was highly unlikely to pick bulls that were of the same breed, as detailed in chapter 4.

Sullivan et al. (1999) examined breed overlap and genetic trends for across breed genetic trend, which included commercial, purebred, and test bull records. Sullivan found that a genetic trend within breeds such that each breed appears to selecting towards a common average genetic ability. As such, a trend exists in low growth type breeds for a higher rate of genetic progress for growth, and for high growth breeds a trend for a lower rate of genetic progress. Since breeds appear to be selecting towards a common genetic ability, or maximum overlap, the across breed average genetic trend is very close to zero.

3.1.1 Parameters

The parameters for traits from birth to yearling were obtained from Beef Improvement Ontario (BIO) (Peter Sullivan, personal communication). These traits form the core multi-trait across breed genetic evaluation program offered by BIO. Many other across breed estimates were available which were in agreement with those used from BIO (Gregory et al., 1994; Koots et al., 1994; Marshall, 1994; Gregory et al., 1995a,b,c). The source of parameter estimates for the remaining traits were obtained from published results of the long-term composite breeding program at Roman L. Hruska Meat Animal Research Center (MARC) (Gregory et al., 1995 a,b,c). Estimates of covariances between traits were obtained from both BIO and MARC (Gregory et al., 1995 a,b,c; Peter Sullivan, personal communication).

Simulation of heterosis follows the explanations of Long (1980) where it was suggested that at lower levels of growth or rates of gain, heterotic effects are reduced or negligible.

Since some traits could have phenotypic performance that was negative or zero, the contribution due to heterosis in these instances was assumed to be zero. Long (1980) also expressed that heterosis probably was contributing to phenotypic performance at low levels of performance but was not detectable, which indicates a multiplicative heterotic effect was warranted. The available estimates from Gregory et al. (1995a,b,c) were transformed to be multiplicative so that varying the amount of heterotic contribution of crossbreeding was a function of phenotypic performance. The benefits of heterosis also vary as a percent of heterozygosity (Dickerson, 1970). Reduction in heterozygosity was estimated by breed overlap (Dickerson, 1970) which assumed that breed composition overlaps were linearly associated with heterozygosity and the percentage of retained heterosis.

Reciprocal back-cross information (Bailey et al., 1993; Newman et al., 1994) can be used to decide female and male breeds or breed combinations that provide the largest heterotic contribution, which is similar to the concept of nicking. Nicking in this case is defined as an advantage of a specific cross, which can be a breed combination or a sex within breed combination. An example would be using two breeds and determining that breed A will be contributed into the cross by females only and breed B by only males due to superiority over the reverse use of sexes for the cross. Reciprocal back-cross information was not utilized in this study because not all potential breed crossing patterns had information.

Complementarity involves breed and individual mate grouping in an attempt to achieve optimum performance, which implies performance from available individuals brackets the optimum or target performance level (Cundiff et al., 1986). Complementarity as well involves the cumulative interaction between animals and their environment, where animals were sires, dams, and progeny (Cartwright, 1970). Therefore, complementarity also requires knowledge of the production environment and information on the phenotypes best suited for each production environment (Cartwright, 1970; Cartwright et al., 1975; Fitzhugh et al., 1975; Long, 1980; Marshall, 1994). Complementarity can be either positive or negative. In this study, complementarity was considered as a function of individual or group performance combination. The interaction with environment have been assumed to be equal across all animals, herds, and replicates, in the studies by Cartwright et al. (1975), Fitzhugh et al. (1975), and Long (1980). Complementarity was utilized in forming the breeds involved in the 3-breed rotation and selection of mates for the uniformity crossbreeding strategy.

3.2.0 Crossbreeding and Composites

Beef cattle crossbreeding strategies have been studied and evaluated by many researchers under many different environmental conditions (Gregory and Cundiff, 1980; Long, 1980). It has been rigorously shown that crossbreeding produces economic efficiencies over straight breeding in almost any production or market situation (Cartwright et al., 1975; Wilton and Morris, 1976). Many studies have estimated heterosis, evaluated complementarity and looked at reciprocal back crossing. Many of the crossbreeding experiments deal with combining new genetics available as continental breed imports during the 1960's and 1970's and the production characteristics associated with these breeds. A main reason for characterizing these breeds in crossbreeding projects was due to the fact that semen became available and could then be utilized in commercial beef production.

Many studies have focused on actually utilizing rotational crossbreeding strategies such as those performed at Elora Beef Research Centre at the University of Guelph (McMorris et al., 1986; McMorris and Wilton, 1986; Fiss and Wilton, 1989; Fiss and Wilton, 1992). The Elora study was designed to evaluate and characterize 3-breed rotational crossbreeding for 3 different biological types of cattle. The biological types were a large rotational made up of large continental breeds, a small British breed-based rotational and a small continental and British breed-based rotational. These studies focused on utilization of the new breeds available and characterizing their performance in commercial conditions utilizing established crossbreeding systems. In particular the Elora studies examined cow size and output on an economic and productivity basis with actual cow feed intakes.

A second group of experimental herd studies utilized the new breeds in synthetic or composite breed formation. The MARC germplasm utilization project at the Roman L. Hruska Meat Animal Research Center is an example of a composite breed formation project that is still ongoing. Gregory et al. (1995a,b,c) have provided information on heterosis during formation of composites and retained heterosis levels from *inter se* mating after final breed composition had been achieved, which is estimable using breed composition overlap (Dickerson, 1969) as an estimate of heterozygosity and retained heterosis. Another benefit associated with the composite breed mixture can be to provide higher long-term heterosis values for progeny (Gregory and Cundiff, 1980). As well, breeds can be incorporated into the breeding plan that have a specific strength despite having some other attributes that are not beneficial, and could exclude their use on a commercial scale if only purebreds were available. An example could be a breed that has excellent carcass quality characteristics but has extremely poor growth performance. Another reason for composites in beef breeding is the large number of breeds available. The majority of breeds provide animals strong in specific traits based on their history of selection where a specific quality was emphasized such as draft animals, dual purpose or harsh environment adaptiveness. The specific niche qualities that some breeds exhibit attracts usage, however, in many cases at a cost in traits associated with profit. An example of a specific niche quality is extreme muscling. In the extreme muscling example, related traits such as mature size and mature condition score are at levels that are not beneficial in a low cost commercial cow-herd model if replacements are retained.

Estimates of breed mean phenotypic production levels have also been produced that provides (Gregory et al., 1995a,b,c) critical information on breed characteristics for economically important traits used for breed selection and complementarity planning in crossbreeding strategies. These studies have also highlighted the time required to implement 3-breed rotational crossbreeding strategies of seven generations (Gregory and Cundiff, 1980). As well, replacement female production issues and negative complementarity issues related to additive genetic variations in females through breed composition fluctuations (Gregory and Cundiff, 1980).

3.3.0 Breeds Simulated

A test bull population was simulated with purebred and composite bulls containing 10 different breeds in fixed proportions. The proportion of breeds in the test bull population was simulated to approximately equal their proportions in the Ontario test bull population.

Hereford, Black Angus, Red Angus, Shorthorn and South Devon breeds are typically assumed to be very hardy breeds that excel at easy fleshing and high fertility. The characteristic of easy fleshing provides a cow that typically can forage on lower quality feeds and still maintain her lower mature body weight and a high level of body condition. For terminal progeny the characteristic of easy fleshing would provide for a higher level of back-fat at a lighter slaughter weight and at a younger age. The characteristic of high fertility would generally be measured and characterized as a younger age at puberty, higher conception rates, and maintenance of a 365-day calving interval (Taylor, 1994).

The Charolais, Limousin, and Blonde D'Aquitaine breeds typically excel at muscling and growth, traits associated with terminal market progeny. Growth in the case of these breeds is very high for Charolais with the other two breeds being slower but typically achieving superior feed efficiency. Muscling in these breeds is characterized with larger rib-eye area and higher lean meat yield than in British breeds (Taylor, 1994).

The breeds Gelbvieh and Simmental are generally considered to have a higher level of milking ability then other beef breeds as characterized by their history as dual-purpose breeds. Historically as breeds were developed, selection was performed towards the needs of a region. In the regions where Gelbvieh and Simmental were developed the need was for cattle that produced a fairly large amount of milk for human consumption as well as for production of meat and work as draft animals. Therefore, these breeds are characterized as producing significantly higher milk yields, as well as a tendency towards high growth and heavy mature weight, especially with Simmental (Cundiff et al., 1986; Taylor, 1994).

3.4.0 Phenotypic Uniformity

Uniformity in beef cattle has been viewed as important (CCA, 1999) but not at the level of economic implications as with other meat producing industries. In the pork industry, the marketing and payment structure for pigs is principally designed around producing a specific live weight for slaughter and discounts are such that it is not as profitable to produce pigs that fall outside the market specifications (OP, 2000). Back-fat and muscling in the carcass grading system are subject to discounting if outside of specifications and reduce payment. As well, swine genetic improvement programs and production efficiency measures are all based on the established market weight specifications allowing for an intimate relationship between genetic improvement and profitability as with Ontario Swine Improvement Inc "Target Hog System" and Canadian Centre for Swine Improvement programs.

In poultry, the same type of market weight specifications exists providing the same type of advantages as pork, although more markets have been identified. A further benefit that has been capitalized on by these industries is the ability to concentrate their development and genetic improvement on enhancing the higher retail value components of the carcass and, more importantly, reducing the cost of production to improve efficiency. Both the swine and poultry industries also have an advantage in terms of portion sizes produced and meat quality. The swine industry produces carcasses at a certain weight and, correspondingly, there is some variation in portion size. However, portion size is rarely considered too large, which is of great concern in beef (CCA 1999). The same is true in poultry. Meat quality in the swine and poultry industries is primarily a function of age at slaughter. Both industries focus on extremely youthful slaughter animals, which contrasts with beef where a factor such as flavour is related to both age of the animal and marbling score. As a result, beef feeding programs are usually designed for a minimum of 100 days on high energy feed to help improve flavour and quality, which often forces animals to be older than other industries. As well, the youthful beef market has already been established as veal.

Cartwright et al. (1975) suggested that increasing uniformity of purebreds so that accurate means could be estimated with lower variances, would provide improved uniformity for commercial cattle breeders with respect to crossbreeding systems. He also suggest that breed associations choose to be either a paternal or a maternal line provider/specialists within the pure breeds to aid in combining breeds in crossbreeding programs (Cartwright, 1970).

Devising a crossbreeding strategy that has lower phenotypic variation in comparison to others is in contrast to Cartwright et al. (1975) who suggested lowering of the genetic variation within breed to reduce the variance of the population, and therefore reduce phenotypic variation when the breeds are utilized in crossbreeding. Lower genetic variation can only be accomplished through inbreeding and cloning, and can only marginally affect phenotypic variance within breed by reducing additive genetic variance within the breed (Falconer, 1981). It is also expected that crossing of inbred lines would rebound to at least the expected phenotypic variance and often higher phenotypic variance for both within breed inbred line crossing or crossbreeding of inbred breeds (Falconer, 1981). Selection for a higher mean as well results in higher variance and alternatively, selection for lower means produces lower variance. The reason for variance changes is as a function of selection differential, where selection is directional (Bulmer, 1971; Falconer, 1981). Therefore selection for changes in means will result in a change in variance which is dependent on direction of change and amount of change required. In this study selection for uniformity requires limiting any increases in variation. Increases in variation are associated with greater long term selection response (Falconer 1981) and, therefore, it is expected that genetic gain will be reduced in order to obtain greater uniformity.

Uniformity can be defined in many ways. However, for this study, uniformity was measured and evaluated as the phenotypic standard deviation of a trait. Beef cattle are marketed in groups where the grouping is defined as animals of the same sex and colour, and similar height and weight. With regards to weight, the market has defined for many years that animals should be grouped such that they are within 100 pounds or a CWT (hundred weight) from the heaviest to the lightest. In recent years, groups in a 50 pound range have been favored to further reduce variability and improve management and predictability of the cattle. Phenotypic uniformity was therefore of economic importance, which makes it critical to the economic viability for commercial cattle production. This study seeks to produce a lower phenotypic standard deviation within herd from a unique crossbreeding strategy in comparison to a 3-breed temporal rotational crossbreeding system which is known to often produce greater phenotypic variation when complementarity is considered in the design (Gregory and Cundiff, 1980; Cundiff et al., 1986).

The marketing points where phenotypic uniformity was important were established as points common in Ontario cattle marketing and will be discussed in conjunction with phenotypic uniformity. In Ontario, the most common marketing time for calves is weaning. At weaning, many factors outside of performance have an effect on the uniformity of the calf crop. In this study, the factors relating to calving dates within calving season and earlier or later weaning were not examined even though their effect on uniformity is great. The value of calves sold at weaning is attributed to having a weight that allows for a diversity of potential buyers. In this study, optimum weight was defined as the hundred weight midrange that had high gross revenue associated with it, which was 250 kg (OCA, 1999). This weaning weight provides a product that is marketable to a larger group of potential buyers. The potential for a wider range of sales exists because the calves can be used to feed to slaughter; or to approximately yearling age for resale to another buyer who will feed them to slaughter; or feed calves over winter and pasture them the following summer and then sell them to another buyer who feeds them to slaughter. For any of the potential buyers of calves, each must buy the calves and group them for feeding. The more uniform the initial groups of calves, the more uniform the buyer can expect they will be for their next market. As well, management and nutrition becomes simpler, more effective, and more profitable for a uniform group of calves. Buyers have traditionally had to purchase calves from more than one seller to fill their feeding and housing facilities. Therefore, calf groups with large numbers of uniform calves were of greater value because the potential buyers can then purchase from fewer sellers which reduces management and health issues thus reducing costs. Even for the integrated beef operation that finishes calves produced from their cows, economic benefits were received in terms of reduced costs when the calves were uniform as they pass through the production system mainly because of easier and more efficient management and feeding programs.

The packer purchases the slaughter cattle and is the link between producer and retailer. Uniformity for the packer is of economic importance as well. The beef industry is moving towards more branded products. The branded products can be retail (Beef Beyond Belief), packer (Sterling Silver) or alliance driven (Certified Angus Beef, Alberta

Premium Beef, Quality Angus Beef). Regardless of the type of branded product, all purveyors maintain specifications for their product which include quality, portion size, processing (i.e. hanging time for the carcass), and management (i.e. vitamin E feeding program or Ontario Corn Fed Beef). Some branded products from breed promotional societies include breed composition of the animals as well (Certified Angus Beef, Quality Angus Beef). All aspects of the branded product concept rely to varying degrees on uniformity of the phenotypes of the animals. Branded products, as expected, incur more costs for breeders, feeders, packers and retailers. The additional costs were recouped through the system by premiums paid and a higher retail price justified due to the extra measures taken to produce predictable quality in the product. Farmland Industries (Kansas City, Missouri) is a cooperative beef packer that pays for cattle based on a grid where a minimum yield and quality grade defines the base price. In the grid higher yielding and higher quality grades receive premiums up to $53 (US) per animal. Cattle grading in the premium part of the grid are marketed as a branded product.

The Canadian Cattlemen's Association (CCA) conducted a beef quality audit in 1995-96 and again in 1998-99 to quantify the effects of various issues and management factors affecting profitability and meat quality. Canadian Cattlemen Quality Starts Here: Beef Quality Audit (CCA, 1999) details the information discussed hereafter. Among the issues that were investigated were non-conformities. Non-conformities are defined as problems that are a direct result of carcasses outside the specified market norm. Therefore non-conformity issues are direct measures of the impact of uniformity at slaughter and indications of the need for production towards specific target means for various traits.

These problems include level of back-fat, marbling, carcass weight and muscling. The survey of carcass weights indicated average carcass weights of 365 kg for steers and 339 kg for heifers were occurring where the optimal weight range was reported to be 272kg-363kg with a mean of 315 kg. With regard to the optimal carcass weight range, 49% of steers had carcass weights in the desirable range and heifers were much better at 72%. These carcass weights were heavier than desired and it was estimated that the extra weight costs the producers of Canada $111 million per year, accounting for costs of producing the extra weight and carcass discounts. The rib-eye area means for these carcasses were 91cm^2 for steers and 90cm^2 for heifers. The rib-eye area had increased slightly between audits and was reported as being too large with respect to portion size. An actual cost was not calculated for rib-eye area because it was hard to quantify and overweight carcass losses were accounting for part of the costs. The Canadian grading system assigns grades based on an estimate of each animal's lean meat yield by measuring fat depth and rib-eye area from a carcass profile of a split between the 12th and 13th rib on the right side of the carcass. The fat depth or fatness score and rib-eye area or muscle score are used in combination to estimate lean meat yield from a grid. A carcass can be graded as A1 > 59% lean yield, A2 54-58% lean yield, and A3 49-53% lean yield. Another grade designation of yield is B1with <49% lean yield. As mentioned, rib-eye area had increased between the audits and was considered too large yet the audit reports an increase in the number of A3, which is a lower yield grade. The estimated cost for cattle not grading A1 was $62.7 million per year. Quality grading in Canada was based on appraisal of marbling, which is a visual estimate of the percentage of intramuscular fat. The audits have shown an increase in marbling, which was of benefit and a positive result for the industry.

3.5.0 Phenotypic Targets

Many of the reasons for utilization of phenotypic performance targets for carcass traits were quantified in the CCA Canadian Beef Quality Audits as previously discussed. Obvious economic advantages for specific carcass phenotypes were illustrated and discussed previously in section 3.4.0.

Reproductive traits in a beef herd can have an impact on efficiency and profitability. Having replacement females begin cycling 21 days younger, which is the length of an estrus cycle, results in a higher probability that all replacements are cycling at breeding time. With regard to gestation length, cows would benefit by the additional estrous cycle to ensure they are cycling before the breeding season starts. In addition, by having cows enter the breeding season 60 days post calving increases conception rate (OMAFRA Factsheet Breeding Season Management, 1997). Reproductive targets in this study were set with the objective of providing an additional estrous cycle of 21 days. Therefore, gestation length was targeted to decrease by 21 days, and age at puberty was also targeted to be 21 days younger than current population average.

Weight trait targets from birth to slaughter can be established based partly on economics and partly on management. The birth weight target was established to form a basis for weaning weight targets as well as providing a reasonable target for a high percentage of easy births. Although birth weight was simulated and targeted, the interactions between birth weight and calving ease was not simulated. It was assumed in this study that the range in birth weight was appropriate to the cows that were calving and that losses of progeny were not modeled due specifically to birth weight. The weaning weight target was established as a weight that fit in a high gross revenue range for weaned calves. The weaning weight target was established by average auction market prices for the various weight classes of calves (OCA, 1999). A further consideration that established a precise target was to consider female replacement development (OMAFRA Factsheet: Feeding and Management of Replacement Beef Heifers, 1991). The target for post weaning gain was set on the basis of accepted female replacement gain to breeding of 0.80 kg/day (OMAFRA Factsheet: Feeding and Management of Replacement Beef Heifers, 1991) in conjunction with establishing that the yearling weight was 70% of the targeted mature cow weight (OMAFRA Factsheet: Feeding and Management of Replacement Beef Heifers, 1991). The slaughter weight target was established as the live weight required for the targeted carcass weight (section 3.3) based on a dressing percentage of 60%. The yearling height target was established as a height that was just a little less than the population means (Gregory et al., 1995a,b,c).

Optimum cow size has been examined by many researchers with little consensus on what that size may be or what the appropriate measure(s) should be. Mature cow weight target (567 kg) was established based primarily on management targets or generally perceived optimums (Melton and Colette, 1993). Melton and Colette (1993) examined the age of a cow where profitability occurs for three different sizes of cows where the first type was Hereford-Angus cross, the second type was Brahman, and the third type was Pinzgauer. They found that, with increasing cow size, average age of profit increased and smaller cows returned a profit at a younger age. Cartwright et al. (1975) used deterministic simulation to examine crossbreeding systems where large, medium and small sized cows under both drylot and pasture based management system, on a fixed expense basis and found that small or medium sized crossbred cows were more profitable than large sized cows. Long et al. (1975) used the same deterministic simulation programs as Cartwright et al. (1975) but with an emphasis at specifically studying cow size and corresponding production effects under the 2 management systems, pasture and drylot. Long et al. (1975) found that under drylot management only large-sized crossbred cows returned a profit on a fixed expense basis. However, under pasture based management, small- and medium-sized crossbred cows returned greater profit. Armstrong et al. (1990b) used linear programming to examine economic returns for a 100 cow commercial beef operation with variation in cow weight, pricing ratios of beef return to feed cost, calving rates, and feed availability constraints. They found that all factors affected the ranking of the optimum cow size. Morris and Wilton (1976) as well found ranking for profitability based on cow sizes changed depending on the criteria of comparison. Wilton (1980) found that as cow weight increased in crossbred cows so too did feed intake increase at 0.55 kg dry matter per day per 100kg of cow weight added. McMorris et al. (1986) found that overall cow-calf enterprise profitability increased despite finding a relationship of increases in cost due to increasing cow weight which was slightly more than Wilton (1980) found. The increase in profit was attributed to gains in performance of progeny either directly or maternally. It should however be mentioned that the results of McMorris et al. (1986) and Armstrong et al. (1990b) were estimated under the previous Canadian Beef Grading System where quality grade estimated by marbling was not included and the current carcass weight problems were not issues.

It would appear that optimum cow size is a function of the management system employed and the production environment available. Cundiff et al. (1986) stated with regard to crossbreeding systems that 'genetic resources need to match nutritive resources' which implies that cow mature size and milking ability need to be in harmony with the production environment. In general, commercial cow-calf production tends to be located in more semi-extensive environments in Ontario which generally indicates that medium to small size crossbred cows are best suited. This also fits a least cost production model that was generally accepted to be the best long-term strategy for economic viability in commercial cow calf production (Melton and Colette, 1993).

The mature condition target was established as the optimum score, which was designed to score in the middle of the condition score scale. The optimum score was 5.5 based on a 10-point scale, which was associated with 91% of cows showing estrous within 60 days after calving (OMAFRA Factsheet Breeding Season Management, 1997) as compared to cows in a poor average condition (below 4.0) as low as 46%. Mature cow height target was established as slightly less than the populations mean (Gregory et al., 1995a,b,c).

3.6.0 Mean Age of Dam and Profit Association

Several deterministic simulation studies have utilized standard survival rates for different ages of dam over time. These simulation studies then simulated a distribution of ages, performed matings and produced simulated progeny while applying survival rates to the dams and progeny (Cartwright et al., 1975; Fitzhugh et al., 1975; Long et al., 1975). The cumulative effect produced an average age of dam that was in equilibrium over years (Cartwright et al., 1975) where the average remained constant and the number of dams in each age category remained constant as well.

In a study using data from the Roman R Hruska Meat Animal Research Center (MARC) research herd utilizing economic theories of optimum investment and asset replacement it was estimated that at 6 years of age profitability was achieved (Melton and Colette, 1993). Voluntary culling in this study for the uniformity strategy was designed to maintain a constant mean age of dam for a herd of 6 years, which was similar to the deterministic studies (Cartwright et al., 1975; Fitzhugh et al., 1975; Long et al., 1975). In contrast to the deterministic studies, however, the uniformity strategy does not require age of dam classes to remain at a constant frequency. This age of dam structure allows for dams to be of any age and remain in the herd if productive. It also allows for the potential of an older average age in the herd.

The average age of cows in a herd can be utilized to provide commercial cow calf operations a practical economic basis for establishing a voluntary culling rate. The voluntary culling rate in this study was the number of cows culled from the herd each year because of inferior phenotypic performance. In contrast, the involuntary culling rate in this study refers to the culling of cows where a calf did not survive to the end of the production cycle and consequently the dam was culled.

3.7.0 Female Replacement Nucleus

The uniformity strategy partitioned the cow-herd into two groups. The groups were a terminal natural service sire group and a replacement female artificial insemination group. The grouping of cows that were mated to produce replacement females using artificial insemination were called the female replacement nucleus in this study. The replacement female nucleus however was not an elite nucleus where advanced female reproductive technologies are utilized. It does however represent a within herd nucleus where the females selected were elite for the herd. It was expected that the average replacement female nucleus size was approximately 40 females out of the 100 cows available within herd in the uniformity crossbreeding strategy. The potential for genetic exchange between herds was not examined in this study although in practical production it would be expected that some exchange would occur. The bull population was generated from a standard seedstock breeding program where it was assumed an elite nucleus or nuclei were not utilized although well documented benefits would justify implementation of this concept (Gearheart et al., 1990). The 3-breed rotational crossbreeding herds utilized natural service sires only. Replacement females in either the rotational or uniformity crossbreeding strategy were selected from the female progeny produced within herd (Gregory and Cundiff, 1980).

3.8.0 Selection Index

Selection index weights have been developed for various selection objectives. Koots and Gibson (1997) developed index weights for some key production traits under an intensive beef production model. The weights calculated (Koots and Gibson, 1997) did not include all the traits modeled in this study, as well, the grading system modeled did not account for the economic benefits for higher marbling score that currently exist. Economic weights were developed by Lazenby et al. (1996), where marbling score increases produced higher returns, however, many of the cow-herd and fertility traits were not accounted for. Given that there were no studies producing weighting on all the traits of interest for this study, an alternative was devised of equal weighting of all traits within a selection objective. The equal ranks were designed to place equal emphasis in obtaining targets across all traits. This implies, unlike the economic based selection indexes, that it was important for each trait to obtain its target.

3.9.0 Areas for Study

Generally, crossbreeding strategies have focused on heterosis. However, achieving high levels of heterosis in crossbreeding programs, where all aspects of implementation and ongoing production have been considered have encountered problems. Investigation of a strategy that has heterosis as an objective and plans for immediate production benefits such as uniformity at a desirable level of production could be of value. As well, investigation of potential long-term benefits such as a female replacement strategy where culling was a function of average replacement profitability, cow-herd traits emphasis, and replacement generation from within the herd was of interest.

Methods

4.0.0 Strategies

Two commercial beef breeding strategies were examined. The strategies were a novel uniformity-based crossbreeding strategy and a 3-breed rotational crossbreeding strategy, both of which were designed for commercial beef production with an objective of optimal utilization of the beneficial effects of heterosis and complementarity. The strategies differed in breeding objectives, breed of sire usage, artificial insemination utilization, replacement female strategies, and culling.

The uniformity breeding strategy encompassed all aspects of selection and culling within an integrated birth to slaughter commercial beef operation with an emphasis on uniformity of calf crop phenotypes at weaning, yearling, slaughter and carcass traits, as well as a uniform cow-herd. Replacement females were selected from the female progeny generated from the herd. Sires utilized to produce potential replacement females were selected from a list of artificial insemination (AI) sires in an individual mating scheme. Potential dams for the production of replacement females were selected as a proportion of the cow-herd, with the remaining cows being mated using natural service in a group mating system for terminal production. The use of natural service sires was intended to mirror current commercial production. Selected sires for the uniformity strategy can be of any breed or breed combination, therefore not limiting potential candidates.

The rotational strategy, in contrast, was a 3-breed rotational cross designed to produce a high level of retained heterosis, approximately 86% of maximum. The specific type of rotational cross, as described by Bourdon (1997), is temporal or a rotation in time, where breeds were utilized sequentially over time. Another type of rotation is spatial where breeds are used concurrently within a breeding season, however this type of rotation was not examined.

The rotational strategy models a typical Ontario cow-calf operation where calves are sold at weaning. The calves are purchased, fed a grower ration until approximately a year of age and then a finishing ration and slaughtered. Calves are often resold during the growing and finishing phases. It was assumed that calf performance can be tracked and was available from birth to slaughter, so that even though the cow-calf breeder has a selection objective that only involves traits to weaning when the calves are sold, complete information was available. Replacement females were selected from the female progeny generated in the herd. All matings were to natural services in a group mating system. Sires selected for the rotational strategy were purebred and the breed order for the rotation was preset for each herd. The 3-breed rotation as defined for this study is typical in Ontario, where the breed composition would be 2/3 continental (Charolais (CH), Simmental (SM), Gelbvieh (GV), Blonde D'aquitaine (BD) or Limousin (LM)) and 1/3 British breeds (Hereford (HE), Black Angus (AN), Red Angus (AR), South Devon (DS) or Shorthorn (SS)). In a more extensive environment, a typical 3-breed rotational would be 1/3 continental and 2/3 British breed. The breeds chosen for the rotation in this study were determined using general characteristics of the breed with an objective of complementarity and an optimum final product of the rotation.

The replications in this stochastic simulation study were accomplished by producing 10 herds of 100 cows per strategy per replicate. There were 5 replicates run. This produced 100 (10 herds for 2 strategies by 5 replicates) total replications and producing 95000 progeny records in total over 10 production years.

4.0.1 Culling

Involuntary culling, regardless of the strategy was set at 5% of the cows per year. Voluntary culling was performed differently for each strategy. The rotational strategy was set to voluntarily cull 15% of the cows each year. The culling criterion was weaning weight. The uniformity strategy had a floating culling rate, which is described in detail latter. The floating culling rate was a function of the average age of the cows of the herd and was tied to an optimum age average of 6. The optimum age of 6 represents the age at which a cow has returned enough profit to cover the development expenses associated with raising her from weaning to first calving and loss of income as a result of not selling her as a feeder calf (Melton and Colette, 1993). The range of voluntary culling for the uniformity strategy was expected to vary between 8 and 15 percent.

4.0.2 Test Bull Simulation

A computer simulation was developed to produce yearly crops of test bulls. The simulation was designed to produce true breeding values for the yearly crop of test bulls assumed to come from a separate population of animals that were considered seedstock. The across breed genetic trend of the test bull population was assumed to be zero (Sullivan et al., 1999) and bulls regardless of breed were assumed to potentially have additive genetic ability over the entire across breed distribution. No progeny from the commercial cows were evaluated as tested bulls. A current trend in the beef industry is the production of composite bulls that were composed of multiple breeds. Composites in this study were simulated for 50% of the test bull population.

An AI stud was produced by selection from the test bull population each year. The bulls selected from the test bull population for Artificial Insemination (AI) were selected with an equal number of purebreds and composites.

4.0.3 Sire Breeds

The test bull population was simulated with purebred and composite bulls containing 10 different breeds in fixed proportions without the presence of specific breed effects. The proportion of breeds in the test bull population was simulated to approximately equal their proportions in the Ontario test bull population. Composite bulls were simulated such that all breeds in the purebreds were present in the composites and that F1 (2 breed) bulls were 84% of the composites, F2 (4 breed) were 12%, and F3 (8 breed) were 4%. The percentage of composites as 2, 4 and 8 breed combinations was determined as an estimate of overall ease of producing the breed composition by seedstock producers.

4.0.4 Cow-herd Simulation

The cow-herds were simulated similarly to test bulls with the base generation having across breed true breeding values, a starting age, and random assignment to the 20 herds per replicate, with each herd containing 100 cows. The cows were considered to be commercial with recording of traits beginning with the progeny produced from the first mating. None of the male progeny become test bulls, thus maintaining a separate test bull population.

Progeny phenotypes were simulated as the additive sum of the across breed breeding values plus a random residual value, random Mendelian sampling value, random uncorrelated permanent environment effect, fixed sex of calf effects, fixed age of dam effects, and multiplicative heterosis values for both maternal and individual level of heterozygosity as detailed later. Breed effects were not simulated in assuming that animals from any breed could be found with across breed breeding values within the additive genetic distribution. Random herd phenotypic means for each trait were simulated for year one in each replicate and adjusted for changes in herd performance each year and will be detailed later.

In this study, the factors relating to calving dates within calving season and earlier or later weaning were not examined even though their effect on uniformity is great. It was assumed for this project that cows calve on the same date or close to it each year and that all economically viable management techniques for reducing the length of the calving season were implemented and do not change over the 10 years simulated for a replicate.

4.1.0 Parameters

Across breed true breeding values were simulated for the base generation for cows and each year for test bulls for the traits:

BW = birth weight, the weight of the calf at birth adjusted for age of dam by sex of calf,

BWM = birth weight maternal, the maternal effect estimated from BW,

WW = weaning gain, the weight of the calf at weaning adjusted for age of dam, sex of calf, BW, and age of calf,

WWM = weaning gain maternal, the maternal effect estimated from WW,

PWG = post weaning gain, gain from weaning to yearling, adjusted to 165 days,

YHT = yearling height, hip height taken as a mean of measurements at 368 and 522 days of age,

SW = slaughter weight, weight at slaughter, adjusted to 438 days of age,

CW = carcass weight, weight of hot carcass with kidney, heart and pelvic fat removed, and adjusted to 438 days of age,

BF = carcass back-fat, measured on carcass after 24 hour chill, adjusted to 438 days and for carcass weight,

MS = carcass marbling score, scored after 24 hour chill, adjusted to 438 days and for carcass weight,

REA = rib-eye area, size of the longisimus dorsi muscle between the 13th and 14th ribs on the right side of the carcass after 24 hour chill, adjusted for carcass weight and to 438 days of age,

MATWT = mature cow weight, weight at 5 years of age as a mean of 3 weights in that year pre-calving, start of breeding season, and pregnancy check,

MATHT = mature cow height, hip height at 5 years of age as a mean of 3 measurements in that year pre-calving, start of breeding season, and pregnancy check,

MCON = mature cow condition score, scoring of cows at least 5 years of age on a 10 point scale, with 1 being emaciated and 10 being obese,

GEL = gestation length, and

AP = age at puberty, age at first observed estrous starting observation at approximately 7 months of age.

The simulation technique utilized a full variance covariance matrix (GVCV) (Table 4.1). The estimates for the traits BW, BWM, WW, WWM and PWG were obtained from Beef Improvement Ontario (BIO) (Peter Sullivan, personal communications). The remaining estimates were from the crossbreeding program at Roman L. Hruska U.S. Meat Animal Research Center (MARC) at Clay Center Nebraska by Gregory et al. (1995a,b,c). Heritabilities and genetic correlations are illustrated in Table 4.2.

The phenotypic traits simulated were:

BWp = birth weight, measured within 24 hours of birth,

WWp = weaning weight, measured between 120 and 280 days of age,

PWGp = post weaning gain, measured at least 90 after WWp and <430 days age,

YHTp = yearling height, measured at the same time as PWGp,

SWp= slaughter weight, measured at slaughter,

CWp = carcass weight, measure after 24 hr chill,

BFp = back-fat, measured after 24 hr chill,

MSp = marbling score, measured after 24 hr chill,

REAp = rib-eye area, measured after 24 hr chill,

MATWTp = mature cow weight, measured at 5 years of age as a mean of 3 weights in that year pre-calving, start of breeding season, and pregnancy check,

MATHTp = mature cow height, hip height at 5 years of age as a mean of 3 measurements in that year pre-calving, start of breeding season, and pregnancy check,

MCONp = mature condition score, scoring of cows at least 5 years of age on a 10 point scale,

GELp = gestation length, difference between breeding date and calving date, and

APp = Age At Puberty, recorded first observed estrous.

Simulation of the herd phenotypic means and progeny phenotypes required a full phenotypic variance covariance matrix (PVCV) (Table 4.3), residual variance covariance matrix (RVCV) (Table 4.4) and phenotypic means (Table 4.5). The trait estimates for

BWp, WWp and PWGp were obtained from BIO (Peter Sullivan, personal communication). The remaining trait estimates were from the crossbreeding program at MARC (Gregory et al., 1995a,b,c).

4.1.1 Base Population - True Breeding Values

The base population consists of 2,000 cows per replicate. The cows were assumed to be unrelated. The across breed true breeding values were generated by creating a vector (W) of pseudo-random deviates generated from a normal distribution with a mean of zero and a variance of one (N (0,1)). The deviates were generated by SAS using a Box-Muller transformation of a random univariate such that a deviate called X was calculated as:

$$X = \hat{\mu} + (\hat{\sigma} * n)$$

where n was the random normal number, $\hat{\mu}$ was 0 and $\hat{\sigma}$ was 1.

The length of the vector W was 16 (16X1) for the genotype simulation (Table 4.1). The variance covariance matrix (GVCV) was then decomposed such that:

$$GVCV = TT'$$

T was a lower triangular matrix where the elements were computed using Cholesky decomposition (Goult et al., 1974).

$$t_{ii} = \left(v_{ii} - \sum_{k=1}^{j-1} t^2{}_{ik} \right)^{0.5} \text{ for i=j and}$$

$$t_{ij} = \left(v_{ij} - \sum_{k=1}^{j-1} t_{ik} t_{ij} \right) / t_{jj} \text{ for i>j}$$

where t was elements of T and v were elements of GVCV.

Across breed true breeding values (TBV) were then generated as the product of W*T. The TBV then have the properties of being generated simultaneously with all covariances included (Van Vleck, 1994).

4.1.2 Age and Breed of Dam

Cows were randomly assigned an age by generating a random deviate for each cow from a poisson distribution where the mean was set at 6.0, which is in keeping with an average cow in Ontario. The cows were randomly assigned to 20 herds with all cows initially assigned a composition breed of 100% Hereford with all across breed true breeding values (TBV) generated from across breed variances and means. It was assumed that Hereford cows could have across breed TBV within the full distribution of the across breed population.

4.1.3 Phenotypic Means of Traits

A herd phenotypic mean for each trait in the base year was simulated for each herd similar to TBV, the phenotypic means were generated by creating a vector P using a pseudo-random deviate such that N (0,1). The vector P has 14 elements to match the number of traits in PVCV (Table 4.2). As detailed earlier (section 4.1.1) PVCV was decomposed using Cholesky decomposition such that:

PVCV=TT'

This formed the lower triangular matrix such that P*T generates deviated phenotypic means with the properties of being generated simultaneously with all covariances included. A vector of length 14, which contains the population means (Table 4.5), was then added to P*T to change the deviated means from 0 to that of the population $N(\hat{\mu}_p, \hat{\sigma}^2{}_p)$.

4.1.4 Test Bull True Breeding Values

In general, commercial producers do not test bulls from the calves born in their herds nor sell replacement female breeding stock. Therefore, for the purpose of this study it was assumed that no progeny from commercial herds were available for sale to other herds or for evaluation in the test bull population. This allowed for the assumption in this study, that two different populations of cattle exist, one that is commercial, and a separate seedstock population that provides the bulls for a test bull population. Because of this assumption, the test bulls were simulated with only across breed true breeding values.

The test bulls across breed TBV were simulated yearly for selection and were simulated identically to the base cows. A different seed was used to simulate each year. A unique seed produces a new sample of deviates although all seeds produce normal deviates such that N (0,1). By maintaining a mean of 0 for TBV for the test bull population it was assumed that the across breed genetic progress each year was zero. It was also assumed that bulls simulated and assigned any breed(s) could be found equally within the across breed TBV. Therefore, specific breed effects were not simulated, although breed(s) were assigned randomly to bulls and heterosis could be estimated from the degree of heterozygosity.

4.1.5 Progeny

Progeny phenotypic records for all traits were simulated after each round of selection and mating. Progeny phenotypes were generated using the generalized model:

$$Y_{ij} = \left(\bar{Y}_{herd} + \left(0.5 * EBV_{dam} + 0.5 * EBV_{sire}\right) + EBV_{maternal} + AOD * Sex + R_e + MS + Pe\right) * \left(1 + \left(H_{direct} + H_{mate}\right.\right.$$

where

AOD*Sex = the fixed effect age of dam by sex of calf for birth weight and weaning gain,

$\bar{Y}_{herd}$ = a herd mean for the trait,

R_e = random residual for each progeny,

MS = random mendelian sampling for each progeny,

Pe = permanent environment when maternal effect present,

H_{direct} = direct multiplicative effect for heterosis, and

$H_{maternal}$ = maternal multiplicative effect for heterosis when maternal effect present.

All the above effects in the generalized model are described in detail latter.

4.1.6 Continuous Age of Dam by Sex of Calf Effects

The age of dam by sex of calf effects were calculated as a quartic function based on defined class solutions provided by BIO from the 1997 evaluation run. The data were analyzed by sex using the GLM procedure in SAS with the weighting option. The model analyzed class solutions with age as the dependent variable up to the quartic power in a regression analysis. The quartic function of age produced an R^2 value of 0.99 indicating a very good fit for the function. The quartic function was also found to be preferable by Nelson et al. (1992) and Bertrand et al. (1994). Each element of the equation was significant (P>. 01). The equations were:

Birth Weight

$$AOD_{heifer} = -18.11710241 + age * 6.93872954 - age^2 * 0.96347242 + age^3 * 0.05481561 - age^4 * 0.001$$

$$AOD_{bull} = -13.84799806 + age * 7.31767704 - age^2 * 1.03692006 + age^3 * 0.06026783 - age^4 * 0.001$$

where age was the age of the cow in years.

Weaning Gain

$$AOD_{heifer} = -138.1403807 + age * 51.8330046 - age^2 * 6.8561079 + age^3 * 0.3585080 - age^4 * 0.0064$$

$$AOD_{steer} = -136.1267549 + age * 62.3980473 - age^2 * 8.5518948 + age^3 * 0.4723863 - age^4 * 0.00917$$

where age was the age of the cow in years.

4.1.7 Expectations of Direct and Maternal Additive Traits

To calculate the residual variance covariance matrix requires the genotypic variance covariance (GVCV) matrix to have the same order as the phenotypic variance covariance matrix (PVCV). To accomplish this maternal variances and covariances of GVCV must be added back into their direct trait. The traits requiring the addition were BW and WW. By using expectations the required additions were:

$$E(V(BW)) = V(BW_{direct}) + V(BW_{maternal}) + 2 * COV(BW_{direct}, BW_{maternal})$$

$$E(V(WW)) = V(WW_{direct}) + V(WW_{maternal}) + 2 * COV(WW_{direct}, WW_{maternal})$$

$$= V(WW_{direct}) + V(WW_{maternal})$$

since $COV(WW_{maternal}, WW_{direct})=0$, as in Table 4.2.

$$
\begin{aligned}
E(COV(BW,WW)) &= COV(BW_{direct}, WW_{direct}) + COV(BW_{maternal}, WW_{maternal}) + 2*COV(BW_{direct}, WW_{mater} \\
&\quad + 2*(COVBW_{maternal}, WW_{direct}) \\
&= COV(BW_{direct}, WW_{direct}) + COV(BW_{maternal}, WW_{maternal})
\end{aligned}
$$

since $COV(BW_{direct}, WW_{maternal}) = 0$ and $COV(BW_{maternal}, WW_{direct})=0$ as in Table 4.2.

4.1.8 Residual Variances and Covariances

The residual variance covariance matrix (RVCV) was then calculated as outlined by Dickerson (1969). The computational method requires calculation of the difference of the diagonals between the matrices PVCV and GVCV. Off diagonals were calculated as follows:

$$R_{Eij} = \frac{R_{Pij} - R_{Gij} * g_i * g_j}{e_i * e_j}$$

where

R_{Eij} = residual correlation,

R_{Pij} = phenotypic correlation,

R_{Gij} = genotypic correlation,

g_i = square root of the heritability for trait i,

g_j = square root of the heritability of trait j, and

$e_i = \sqrt{1 - g_i^2}$.

Calculation of the random residual was performed by the creation of a vector R of pseudo random deviates N (0,1) of the same number of traits (14) as in the residual variance covariance matrix (RVCV). The matrix RVCV was then decomposed using Cholesky decomposition to form the lower triangular matrix T, as described in section 4.1.1. The product of R*T produces the random residuals for each trait. The random residuals have the properties of being simultaneously generated with covariances taken into account with a mean of 0 and a variance equal to the trait residual variance ($N\left(0,\hat{\sigma}^2_e\right)$).

4.1.9 Mendelian Sampling

The Mendelian sampling variance was equal to half of the genetic variance because the simulation design produced an inbreeding coefficient of zero (Bulmer, 1971). To ensure the inbreeding requirement was accomplished, mating rules were designed to guarantee an inbreeding coefficient of zero as detailed later. To compute the Mendelian sampling terms, the matrix GVCV diagonal variances were halved and the off diagonals calculated to maintain the genetic correlation found in GVCV, therefore ensuring Mendelian sampling variances and covariances were equal to 1/2 of the genetic variance covariance matrix. The procedure for calculation of the actual random values was performed as described previously (section 4.1.1) using Cholesky decomposition. A vector M of pseudo-random deviates was generated for 16 traits. The Mendelian sampling matrix was decomposed using Cholesky decomposition into a lower triangular matrix (section 4.1.1). The product M*T produces the random Mendelian sampling value for each trait with a mean of zero and variance equal to the Mendelian sampling variance covariance matrix.

4.1.10 Permanent Environment

When cows had correlated repeated records, the uncorrelated random effect of permanent environment was computed. The traits with an associated permanent environment effect were birth weight maternal (BWM) and weaning weight maternal (WWM). The permanent environment variances are shown in Table 4.6. The permanent environment effects were computed as previously described in section 4.1.1 using the pseudo-random deviates and Cholesky decomposition. Permanent environment effects were simulated for a cow for her first calving or year 1 for base generation cows, and were maintained constant for all her future calvings.

4.1.11 Direct and Maternal Heterosis

Heterosis was included as a multiplicative factor. Heterosis can be a direct effect due to the calf being heterozygous or a maternal effect due to the dam being heterozygous. The multiplicative factors for heterosis (Table 4.7) (Gregory et al., 1994) were scaled to the percent of retained heterosis expected from the crossing of breeds. All breed crosses where the breed composition of the parents was unique were given the maximum heterosis amount. When breed composition overlaps, the percentage of retained heterosis was calculated as follows (Dickerson, 1969):

$$H = \left(1 - \sum_{1}^{n} q_s * q_d\right) * h,$$

where

q_d = percentage of a breed in the dam,

q_s = percentage of a breed in the sire,

h = multiplicative heterosis factor for a trait.

4.1.12 Bull Breed Composition

Bulls were designed to be the source of alternate breeds for crossbreeding and thus were the source of introduction of heterosis into the cow-herd. Breed assignment was simulated to maintain a frequency of a breed in the test bulls at a set level both in the purebreds and the composites. The 10 breeds found in the purebreds and composites and their frequencies are in Table 4.8. There were 1500 bulls simulated for selection each year with 750 randomly assigned to be purebred (100% of a breed) and 750 randomly assigned to be composite. The composite bull in this study was defined as a bull that was not purebred. The bull breed compositions and population sizes simulated in this study are illustrated in Table 4.9. The ratio of purebreds to composites was chosen due to the increasing trend in the beef industry towards the production and use of composites. Composite bulls were available for use in the uniformity strategy. The rotational strategy uses only purebred bulls of specific breeds in a specific sequence.

4.1.13 AI Stud

The AI stud was generated by selecting bulls from the crop of test bulls. Each year individuals were selected from the crop of test bulls for the AI stud, as well as for natural service for the uniformity strategy, and natural service for the rotational strategy. Bulls were selected for only one task and consequently an overall selection order was established where AI stud selection was performed first, natural service bull selection for the uniformity strategy second and natural service bull selection for the rotational strategy third. The selection order was chosen to reflect the ability of the purchaser to pay and establish their need. In this simulation, the AI stud chooses first, assuming precise knowledge of what bulls were desired, and was assumed to have the economic resources to guarantee acquisition. The uniformity strategy herds were assumed to be more precise in their bull needs and chose second while the rotational strategy chose third. The impact of the selection order was minimal because it produced no overlap in potential bull prospects for the three groups, because of the variations in selection objective as will be discussed later. A selection order was still performed to ensure bull selections could not overlap and as a realistic representation of sire selection when various groups are selecting from a population of test bulls.

4.1.14 AI Bull Selection

The AI stud contained 32 bulls. AI was used only in the uniformity strategy. Bulls were maintained in the stud for 4 breeding seasons and then discarded. The rate of replacement was therefore 8 bulls per year. The AI stud maintains 16 purebred bulls and 16 composite bulls, which corresponds to the test bull population ratio. The AI stud has 4 categories of bulls. The selection procedure picks 1 composite and 1 purebred bull for each category from each crop of test bulls. The 4 categories were:

1) Maternal/Calving Ease Bulls

2) Terminal Growth Bulls

3) Carcass Bulls

4) Multipurpose/General Use Bulls.

Each category selects bulls based on different criteria. The method of selection was to rank the across breed TBV for the traits and then combine the ranks additively with equal weighting. Weighting the ranks equally was chosen as the method of selection because published selection index weights (MacNeil and Newman, 1994; Lazenby et al., 1996; Koots and Gibson, 1997) were not available for all the traits simulated in this study. The traits and direction of ranking for each category were:

Maternal / Calving Ease

BW - birth weight direct, negative is better,
BWM - birth weight maternal, average is better,
WW - weaning gain direct, positive is better,
WWM - weaning gain maternal, positive is better,
MCON - mature condition score, average is better,
GEL - gestation length, negative is better,
AP - age at puberty, negative is better.

Terminal Growth

BW - birth weight direct, negative is better,
WW - weaning gain direct, average is better,
PWG - post weaning gain, positive is better,
YHT - yearling height, average is better,
SW - slaughter weight, average is better,
CW - carcass weight, average is better,
REA - rib-eye area, positive is better.

Carcass

CW - carcass weight, average is better,
BF - back-fat, average is better,
MS - marbling score, positive is better,
REA - rib-eye area, positive is better.

Multipurpose / General Use

BW - birth weight direct, negative is better,
BWM - birth weight maternal, average is better,
WW - weaning gain direct, positive is better,
WWM - weaning gain maternal, positive is better,

PWG - post weaning gain home, positive is better,

YHT - yearling height, average is better,

SW - slaughter weight, average is better,

CW - carcass weight, average is better,

BF - back-fat, average is better,

MS - marbling score, positive is better,

REA - rib-eye area, positive is better,

MATWT - mature cow weight, average is better,

MATHT - mature cow height, average is better,

MCON - mature condition score, average is better,

GEL - gestation length, negative is better,

AP - age at puberty, negative is better.

After the ranks were determined for all the available bulls, selection was performed and the selected bulls were added to the AI stud.

4.2.0 Crossbreeding Strategies

The crossbreeding strategies modeled in this study were a 3-breed rotational system using purebred sires only and a unique phenotypic uniformity system. The 3-breed rotational crossbreeding strategy was considered the comparison strategy in this study. The uniformity strategy was proposed as a phenotypic target based crossbreeding strategy that allows for utilization of composites and AI sire usage.

4.2.1 The 3-Breed Rotational Strategy

The simulation program assigned 10 of the 20 herds per replicate randomly into a 3-breed temporal rotational crossbreeding strategy. A temporal rotation is a rotational use of breeds over time. There were 5 different temporal rotations modeled and thus each rotation occurs twice within a replicate to total 10 herds. The potential rotations were:

1) Hereford X Charolais X Gelbvieh
2) Hereford X Charolais X Simmental
3) Hereford X Blonde D'Aquitaine X Simmental
4) Hereford X Limousin X Simmental
5) Hereford X Limousin X Gelbvieh

The 3-breed rotations as defined for this study would be typical of Ontario (semi-intensive) where the breed composition would be 2/3 continental (CH, SM, GV, BD, LM) and 1/3 British breeds (HE, AN, AR, DS, SS). All herds in this study regardless of strategy, started with the base breed of Hereford and thus the other British breeds simulated were not utilized for the rotational strategy, but could be chosen for the uniformity strategy.

The breeds chosen for the rotation in this study were determined using general characteristics of the breed with an objective of complementarity and an optimum final product of the rotation. The optimum final product was defined as occurring at the point where the average breed composition for each breed within the herd is equal to 1/3. The average expected retained level of heterosis at equilibrium is 86%, with an individual animal range at equilibrium of 94-75%. Although specific crosses were simulated, breed effects in the bulls were not simulated under the assumption that bulls from any breed could range in across breed TBV over the entire additive across breed distribution. Therefore, the characteristics of specific crosses were not examined as a component of the study.

4.2.2 Cow Grouping for Rotational Strategy

Only natural service purebred sires were used for the 3-breed rotational crossbreeding herds. Therefore, cows were placed in breeding groups prior to selecting bulls. The size of the breeding groups was set at 20 primarily because yearling bulls were simulated and selected and this falls into the range of an appropriate cow to bull ratio (OMAFRA Factsheet: Breeding Season Management, 1997). To set up groups of cows the criterion chosen was to group the cows by weight and height, which would correspond to a commercial cow-calf system for cow grouping. Each herd contained 100 cows and, therefore, had 5 breeding groups. To assign cows to one of the five breeding groups the rank procedure of SAS was used. Cows were ranked for weight and height within herd and then these ranks were averaged. The cows were then ranked on the averaged value, which created a 50:50 or equal weighting for weight and height. The cows were then placed in breeding groups of 20 cows per group by dividing the rank out of 100 by 5. The resulting within herd breeding groups on average contained 20 cows depending on ties which caused some groups to contain a few more or less cows.

4.2.3 Bull Selection for Rotational Strategy

The bulls were selected and used for one mating season and then discarded. The selection criterion established for the rotational crossbreeding herds was maximum across breed total maternal weaning gain where:

$$Total\ Maternal\ Weaning\ Gain = EBV_{WW_{direct}} / 2 + EBV_{WW_{maternal}}$$

Total maternal weaning gain (TMWG) was chosen as the criterion for selection to typify the situation in Ontario commercial cow-calf operations where calves were marketed at weaning and larger weaning weights were desired.

Each breeding group of cows across herds was randomly assigned to a selection order. The random selection order was calculated by assigning a random number to each breeding group and then sorting by the random number to establish selection order. Then each breeding group, in order, selected a bull such that:

1) The bull is of the breed that pertains to the herd and its temporal rotation at that time.
2) The bull ranked highest for TMWG.

As bulls were selected, they were removed from the available bull list so that each selected bull was chosen only once.

4.2.4 Rotational Strategy Culling and Replacement

The simulation was designed to produce an involuntary culling rate of 5% per year for each herd regardless of the strategy. Involuntary culling was performed randomly by assigning a random number to each progeny as they were simulated and then assigning the 5 progeny with the highest random number to the involuntary cull list and removing their phenotypic records. All cows with progeny that were missing phenotypic records were culled. The rotational strategy utilizes a fixed voluntary culling rate of 15% per year resulting in an overall culling of 20% per year. Ranking the cows within herd for Total Maternal Weaning Gain (TMWG) and then culling the 15 poorest cows performs voluntary culling. Replacement selection was based on the same criterion. Female progeny were ranked for TMWG and the best 20 were chosen and added to the herd to maintain a constant herd size of 100.

4.2.5 Uniformity Strategy

The uniformity strategy utilizes natural service of yearling test bulls for cows that were selected to be bred for terminal calf production and a portion of the cows, the nucleus, were selected to produce herd replacements where Artificial Insemination (AI) was used. There were 10 of the 20 herds assigned to this strategy for each replication.

4.2.6 Replacement Female Nucleus Selection and Herd Culling for Uniformity Strategy

The uniformity crossbreeding strategy selects a group of cows to form a replacement female nucleus. To calculate the size of the nucleus the voluntary culling rate must be estimated and combined with other factor as follows.

The simulation was designed to create an involuntary culling rate of 5% for each herd per year regardless of the strategy. The involuntary culling was performed after all phenotypic records had been estimated, by creating a missing record for all traits for the randomly chosen calves, as described in section 4.2.4. All cows failing to have a calf with a phenotypic record for all traits were automatically culled. All culled cows were replaced to maintain a cow-herd size of 100 cows per herd.

The proportion of the cows voluntarily culled was defined in this study as the number of cows that will be culled because of poor performance. Poor cow performance for the uniformity strategy was established based on the same ranks as were used to select bulls for terminal production, which is described in detail in the next section. The traits associated with terminal production were:

BW - birth weight direct,
WW - weaning gain direct,
PWG - post weaning gain,
YHT - yearling height,

SW - slaughter weight,

CW - carcass weight,

BF - back-fat,

MS - marbling score, and

REA - rib-eye area.

The voluntary culling proportion of the cow-herd for the uniformity strategy was calculated based on the payback time required for the development costs of a replacement female (Melton and Colette, 1993). The profit required for payback is approximately equal to 5 calves. Since one calf per year is produced and females are 2 years old at first calving, the age of the female when costs have been covered is 6 years. This parameter was utilized to calculate a voluntary culling rate designed to maintain the herd in a situation where, on average, replacements were covering their cost of development. Equivalently, the average cow age for the herd was 6. The primary equation used to calculate voluntary culling rate for the uniformity strategy was:

$$Voluntary\,Culling\,Age\,In\,Total\,Years = \left(\left(\overline{AOD} - 6\right) * n\right)$$

where $\overline{AOD}$ was the average age of the dams in the herd for the following year, n was the number of cows (100) in the herd that was desired for the following year, 6 represents average age for profit achievement for a cow. To use the voluntary culling age in total years result, the cows were ranked within herd, by across breed EBV, in descending order for the traits associated with terminal progeny production (section 4.2.7) and the lowest ranking cows considered for culling. The age of a selected cull cow was deducted from the voluntary culling age in total years result until all the voluntary culling age years were used and the result was less than or equal to zero. The number of cows culled therefore was a function of the age of the poorest cows in the herd and varied from 8-14% per year.

The voluntary culling procedure was used in estimation of the female nucleus size prior to each production year and again at the end of each production year for actual culling. The nucleus size was calculated as the sum of the estimated voluntary and involuntary culling, adjusted for sex ratio and potential calf loss due to involuntary culling. Replacement progeny losses could occur, however, if nucleus cows and their progeny were randomly voluntarily culled. As well, involuntary culling could impact the mean age of the cow-herd and could affect how many cows were culled compared to the estimated voluntary culling rate. The impact of these two problems was solved by adding 5 more cows to the estimated nucleus size as a buffer to the calculated nucleus size. The additional cows added to the nucleus also provided some selection of potential replacement females assuming a few more females were produced than needed. Each uniformity strategy herd therefore had a unique female replacement nucleus size, which varied from year to year.

4.2.7 Target Bulls for the Uniformity Strategy

As described earlier the uniformity strategy utilizes natural service sires as well as AI. The natural service sires were only used for one calf crop and then discarded as with the rotational strategy. To use natural service, cows were assembled into breeding groups, with group size limited to a suitable cow to yearling bull ratio of 20:1, as described for the rotational strategy (Section 4.2.2).

The uniformity strategy has the objective of lowering the phenotypic variability of the calf crop. To obtain this objective, a phenotypic performance goal was set for each trait (Table 4.10). The phenotypic targets were set on the basis of optimum performance levels where profitability was perceived to be at a maximum. The targets relating to terminal production were utilized for natural service sire selection and the targets relating to cow traits for AI service selection. The use of targets has the effect of selecting for a non-linear selection objective where maximum progress for any trait(s) was not most profitable but a combination across traits of intermediate output was most profitable. An economic analysis was not performed to derive the targets in this study. The targets were set to values generally perceived within the industry as potential maximum profit points (Table 4.10).

To group cows and assign cows to the nucleus, an individual target bull was estimated. The first step in the process was to calculate the difference between the herd phenotypic mean of each trait and the target. This difference represents the amount the herd mean must change to achieve the goal. The herd difference was then adjusted for each cow's across breed expected progeny difference (EPD) for direct traits or across breed estimated breeding value (EBV) for maternal traits, her following year's age of dam effects, direct heterosis (H) effects estimated as the maximum amount, and her maternal heterosis value.

Sex effects were added in with a probability of 50:50 to represent the probability of a heifer or bull calf being born.

$$Herd\ Difference(HD) = Trait\ Goal - Herd\ Mean(\overline{Y}_{i\ herd})$$

$$Target\ Sire = HD - AOD - (EBV_{direct}/2) - EBV_{maternal} - Sex - ((H_{direct} + H_{maternal}) * \overline{Y}_{i\ herd})$$

Cows were then ranked for target sire values for each trait in the terminal progeny objective (section 4.2.6). Cows that have a target sire of low merit, which means they were close to the phenotypic performance objective, were assigned to the nucleus until it was filled. Bull selection for the nucleus was discussed in Section 4.2.8. The remaining cows were then ranked again and were divided into 3 breeding groups per herd. The number of breeding groups was preset assuming approximately 40 cows per herd would be bred AI for replacement female production, which will leave 60 cows or approximately 3 natural service breeding groups. Within each breeding group the individual cow target sires were averaged to produce a group target sire which represents the ideal bull for the breeding group. The mean breed composition for the breeding group was also calculated for maximization of heterosis for the breeding group during sire selection. The mean breed composition was used in Dickerson's equation (Section 4.1.3) for estimating retained heterosis.

4.2.8 Artificial Insemination Bull Selection for the Uniformity Strategy

With the nucleus size determined, cows assigned and their target sire calculated, AI mate selection was performed. Selection of sires for the nucleus cows involved using the target sire values as outlined in section 4.2.7. Cows that were designated as part of the nucleus were the cows that were closest to the terminal production target values as previously discussed. Different traits were considered for selection of bulls to produce replacements. The nucleus only selects from AI bulls and thus no servicing ratios or restrictions were implemented as with the selection of natural service sires, as previously discussed. As well, a randomized selection order was not required. The relaxation of mate allocation rules means a single AI sire could be used to mate every nucleus cow in all herds. This, however, did not occur due to the diversity of individual target sires represented by the nucleus females. In order to ensure an inbreeding coefficient of 0 (section 4.1.8), mating rules were imposed on AI mate selection because stud bulls were the only potential source for the introduction of inbreeding. The rules excluded mating of cows to their sire, dam-sire, grand dam-sire, or the great grand dam-sire, which functionally covered the maximum period of time an AI sire would be available in the AI stud for selection.

The traits involved in selection for replacement female production for the nucleus cows were:

BW - birth weight direct,

WW - weaning gain direct,

PWG - post weaning gain,

YHT - yearling height,

MATWT -mature cow weight,

MATHT - mature cow height,

MCON - mature condition score,

GEL - gestation length, and

AP - age at puberty.

The rank procedure from SAS was used to select AI mates. The steps were:

1) Each AI bull's across breed expected progeny difference was subtracted from each nucleus cow's individual target bull values for each trait to calculate a difference.

2) The absolute value of the difference was calculated.

3) The bulls were then ranked for each trait for each cow in ascending order.

4) A second ranking for the bull's heterotic contribution utilizing Dickerson's equation was then calculated (section 4.1.3).

5) The rank for performance and heterotic contribution were then averaged.

6) A final rank was then calculated and the highest rank AI bull was selected.

4.2.9 Natural Service Bull Selection for the Uniformity Strategy

Cows involved with terminal progeny production from the uniformity strategy were bred using natural service. The bulls for natural service were selected from the simulated annual group of test bulls, used for a breeding season and then discarded. In order to ensure a bull was selected for only one breeding group a selection process was required. A randomized selection order provided an equal opportunity of selecting the bull that matches the group target sire best. This was accomplished by assigning a random number to each group target sire and then sorting the random number in ascending order to assign the selection order.

The group target sires were created for the cows that were to be mated for terminal progeny production. Therefore, the traits that were being selected for relate to the terminal production traits. The traits involved in this selection were:

BW - birth weight direct,
WW - weaning gain direct,
PWG - post weaning gain,
YHT - yearling height,
SW - slaughter weight,
CW - carcass weight,
BF - back-fat,
MS - marbling score, and
REA - rib-eye area.

The difference between the group target sire and the appropriate across breed EPD(s) for each bull for each trait was estimated. The absolute differences were then ranked in ascending order such that the bulls ranking at the top were closest to a value of 0 for the difference, which corresponds to being closest to the group target sire. A rank across traits was then performed which equally weights each trait difference and ranks the bulls with closest overall fit to the group target sire. Equal weighting of ranks was previously discussed in Section 4.14. The bulls were then ranked for contribution to heterosis as a percentage of retained heterosis estimated using Dickerson's equation from section 4.1.3. Adding the ranks between performance and contribution to heterosis performed the final selection process for the bulls and then a final rank was calculated and a bull was selected.

4.3.0 Mating

Once each cow has a mate selected the progeny can be simulated as previously discussed (4.1.7). The sex of each calf was simulated by randomly assigning a uniform deviate to each calf. The uniform deviate was then divided into the two sexes. If the value was less than or equal to 0.5 the calf was a male and if greater than 0.5 a female. With the sexes assigned, phenotypes were then simulated as previously discussed.

Once the phenotypes have been simulated the final step was to randomly cull 5% (involuntary loss) of the calves and their performance records as described earlier in section 4.2.4.

4.4.0 Estimated Breeding Values

The EBVs were calculated after each round of phenotypic record simulation. The program chosen after testing many of the packages available was Multiple Trait Derivative Free Restricted Maximum Likelihood (MTDFREML) program (Boldman, Kriese, Van Vleck, Van Tassell and Kachman, 1995). The main criterion for package selection was the maximum number of traits that could be computed. A further requirement was the computation of maternal genetic effects as well as random uncorrelated permanent environment effects. Another important component of selecting the package was computational speed of the package although a major component of the speed was whether variances and covariances could be inputed and only Best Linear Unbiased Prediction (BLUP) solutions calculated. Other packages either did not offer maternal trait calculation or were not able to just calculate the BLUP solutions without calculating variance components.

4.4.1 Data Preparation

Data were prepared as outlined in the MTDFREML manual (Boldman et al., 1995). Animal identification was converted from alphanumeric to age sequential integers utilizing SAS data routines. This was required to correctly set up the inverse of the animal relationship matrix (A^{-1}). Manipulation of data to create performance and pedigree files was performed using SAS data functions.

4.4.2 Trait Grouping for Evaluation

A problem that occurred was the inability to run a multiple trait BLUP for 14 traits with 2 traits having a maternal genetic effect. The problem simply was the size of the matrices required and the computational space required for storing and solving them.

The maximum number of traits that could be run simultaneously in this study was 7 under option 2 of MTDFREML. This 7-trait block included the traits with the maternal genetic effects. After reviewing traits and the covariances between them an 8-trait block and a 6-trait block were chosen. The 8-trait BLUP required alterations to the PARAM.DAT file which sets space and memory requirements. Originally MTDFREML allocated memory at the maximum potential requirements based on traits and the presence of maternal effects. A major change was made to the method of memory allocation for maternal genetic effects such that only 2 maternal genetic effects were solved for instead of 1 maternal genetic effect for each trait. Another change was to allocate fixed effect space by the average number of fixed effect levels versus the maximum number. As well the matrix EXPMAT was set to (1,1) as suggested in the manual for MTDFREML (pg 52) (Boldman et al., 1995) to conserve memory.

The alterations to conserve memory in PARAM.DAT were successful such that an 8-trait design with all the desired effects and levels could be compiled and successfully run. A few additional changes were required in the programs MTDFRUN and MTDFLIK were the original structural in PARAM.DAT was utilized to calculate heritablities and check the matrices to ensure that they were positive definite. The changes required were small and involved adding the maternal genetic variances and covariances back into the direct variance and covariances so phenotypic variances and covariances could be calculated and checked to ensure they were positive definite. The expectations used for the maternal genetic variance addition to the direct genetic variance were previously discussed (Section 4.1.2).

The traits were grouped as follows:

8-Trait Group

1) Birth Weight - direct and maternal,
2 Weaning Gain - direct and maternal,
3) Post Weaning Gain,
4) Yearling Height,
5) Slaughter Weight,
6) Carcass Weight,
7) Mature Cow Weight,
8) Mature Cow Height.

6-Trait Group

1) Back-fat,

2) Marbling Score,

3) Rib-eye Area,

4) Mature Cow Condition,

5) Gestation Length,

6) Age at Puberty.

Traits were grouped so that all the moderate to highly correlated growth traits were grouped together in the 8-trait runs. The 6-trait runs included the carcass and reproductive traits.

4.4.3 Evaluation Models

MTDFREML allows for a unique model for each trait in the multiple trait BLUP. The traits and model were as follows:

Birth Weight and Weaning Gain

$$y_{ij} = \mu + Herd * Year + AOD + Sex + Pe + b_1 H_d + b_2 H_m + a_{ij} + m_{ij} + e_{ij}$$

where:

Herd*Year was a fixed effect,

AOD was the age of dam fixed effect,

Sex was the sex of calf fixed effect,

Pe was the permanent environment effect,

b_1H_d was the covariate of direct heterosis,

b_2H_m was the covariate of maternal heterosis,

a_{ij} was direct genetic effect,

m_{ij} was the maternal genetic effect, and

e_{ij} was the residual.

The (co)variances for the direct and maternal animal effects are in Table 4.1. The residual (co)variances are in Table 4.4. The permanent environment variances are in Table 4.6.

Remaining Traits

$$y_{ij} = \mu + Herd * Year + Sex + b_1 H_d + a_{ij} + e_{ij}$$

where:

Herd*Year was a fixed effect,

Sex was a fixed effect,

b_1H_d was the covariate of direct heterosis,

a_{ij} was direct genetic effect, and

e_{ij} was the residual.

The (co)variances for the direct animal effects are in Table 4.1 and residuals in Table 4.4.

4.5.0 Analysis of Strategies

The analysis of the strategies examines the areas of interest as defined in the objectives. The major areas of interest were uniformity, phenotypic target adherence, genetic improvement and level of retained heterosis.

4.5.1 Overall Uniformity across Traits

Uniformity was defined for this study as a lower phenotypic standard deviation of the uniformity strategy in comparison to the rotational strategy. To determine differences between the uniformity strategy in comparison to the rotational strategy the phenotypic standard deviation for each trait were calculated using the MEANS procedure in SAS. The standard deviation of each trait, within year, for each herd (1000 observations per trait calculated from 95000 progeny records) were then analyzed using a repeated measures analysis using the GLM procedure in SAS. Repeated measures analysis utilizes orthogonal polynomial contrasts of the standard deviations for each trait over time. The contrasts were analyzed using the model:

$$X_{ij} = Strategy_i + e_{ij}$$

where X_{ij} is a contrast which was either linear, quadratic or the mean for a trait. The objective of the analysis was to compare the average effect of strategy on the standard deviation of each trait as well as examine the trend over years. This method of analysis does not require the assumption that correlations between all pairs of yearly time points be equal. The correlation between year 1 and year 2 was likely to be different than the correlation between year 1 and year 10. A repeated measures analysis allows for inference that is unbiased by unequal correlations between the yearly time points (Snedecor and Cochran, 1989).

Testing of the mean standard deviation from the repeated measures analysis provided information that was valuable as an overall strategy difference measure. However, for this study, significant differences in later years were also important. To test for strategy standard deviation differences for each trait by year a univariate analysis was performed.

Phenotypic standard deviations for both the rotational and uniformity strategies were calculated across replicates and plotted over time for a visual representation of the trends.

4.5.2 Uniformity of Phenotypic Means with Target Objectives for Uniformity Strategy

The Phenotypic Targets were established and used to create the mechanism to allow for the objective of uniformity of phenotypic production at a desired level to occur. An error in the simulation was discovered upon analysis of the means over years. The rotational strategy mean phenotypic performance levels had increased at an overwhelming rate over the 10 years of production simulated. The error and method of adjustment are described in detail in Appendix I.

Phenotypic means for both the rotational and uniformity strategies were calculated across replicates and plotted over time along with a plot of the phenotypic target incorporated for a visual representation of the trends.

4.5.3 Comparison of Retained Heterosis between Rotational and Uniformity Strategies

A primary objective of rotational crossbreeding strategies was to capitalize on heterosis and maintain a high level of retained heterosis over time. For the uniformity strategy to be effective it must also achieve a high level of retained heterosis. Means for heterosis, both direct and maternal, were calculated across replicates within strategy and plotted to illustrate trends and amounts achieved over time.

Table 4.1: Genetic Variance Covariance Matrix (GVCV)

Traits	**BW[a]** (kg^2)	**MBW[a]** (kg^2)	**WW[a]** (kg^2)	**MWW[a]** (kg^2)	**PWG[a]** (kg^2)	**YHT[b]** (cm^2)	**SW[b]** (kg^2)	**CW[b]** (kg^2)	**BF[b]** (mm^2)	**MS[b]** (score^2)	**REA[b]** (cm^4)	**MATWT[b]** (kg^2)	**MATHT[b]** (cm^2)	**MCON[b]** (units^2)	**GEL[b]** (days^2)	**AP[b]** (days^2)
BW[a]	**7.01**	-0.47	3.82	0.0	4.73	2.12	15.36	6.53	-0.24	0.0	1.195	6.68	1.17	-0.21	0.0	1.20
MBW[a]	-0.47	**3.11**	0.0	2.32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WW[a]	3.82	0.0	**208.14**	0.0	90.18	15.17	134.0	82.99	2.71	0.0	34.01	209.77	11.29	-0.11	0.0	-30.6
MWW[a]	0.0	2.32	0.0	**173.45**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PWG[a]	4.73	0.0	90.18	0.0	**318.94**	18.37	311.01	183.45	3.21	0.0	34.38	225.81	9.58	1.39	0.0	-13.53
YHT[b]	2.12	0.0	15.17	0.0	18.37	**5.23**	21.23	12.52	0.0	0.0	-1.12	29.63	3.16	-0.12	0.0	-3.81
SW[b]	15.36	0.0	134.0	0.0	311.01	21.23	**539.17**	270.32	4.53	0.0	49.04	293.6	16.51	1.81	0.0	-17.59
CW[b]	6.53	0.0	82.99	0.0	183.45	12.52	270.32	**187.58**	2.67	0.0	43.06	173.17	9.74	1.07	0.0	-10.37
BF[b]	-0.24	0.0	2.71	0.0	3.21	0.0	4.53	2.67	**2.25**	0.0	-0.22	0.73	0.0	0.0878	0.0	0.0
MS[b]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.16**	0.0	0.0	0.0	0.0	0.0	0.0
REA[b]	1.195	0.0	34.01	0.0	34.38	-1.12	49.04	43.06	-0.22	0.0	**24.13**	46.58	-0.87	-0.038	0.0	0.0
MATWT[b]	6.68	0.0	209.77	0.0	225.81	29.63	293.6	173.17	0.73	0.0	46.58	**999.19**	26.41	4.93	0.0	-23.94
MATHT[b]	1.17	0.0	11.29	0.0	9.58	3.16	16.51	9.74	0.0	0.0	-0.87	26.41	**3.16**	-0.07	0.0	0.54
MCON[b]	-0.21	0.0	-0.11	0.0	1.39	-0.12	1.81	1.07	0.0878	0.0	-0.038	4.93	-0.07	**0.152**	0.0	-1.0
GEL[b]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**7.29**	0.0
AP[b]	1.20	0.0	-30.6	0.0	-13.53	-3.81	-17.59	-10.37	0.0	0.0	0.0	-23.94	0.54	-1.0	0.0	**229.52**

[a] obtained from BIO
[b] obtained from MARC

Table 4.2: Heritabilities and Genetic and Phenotypic Correlations[a]

Traits	BW[b]	MBW[b]	WW[b]	MWW[b]	PWG[b]	YHT[c]	SW[c]	CW[c]	BF[c]	MS[c]	REA[c]	MATWT[c]	MATHT[c]	MCON[c]	GEL[c]	AP[c]
BW[b]	**0.54**	-0.10	0.10	0.0	0.10	0.35	0.25	0.18	-0.06	0.0	0.15	0.08	0.25	-0.20	0.0	0.03
MBW[b]		**0.21**	0.0	0.10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WW[b]	0.23		**0.33**	0.0	0.35	0.46	0.40	0.42	0.12	0.0	0.48	0.46	0.44	-0.02	0.0	-0.14
MWW[b]				**0.25**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PWG[b]	0.12		0.07		**0.35**	0.45	0.75	0.75	0.12	0.0	0.39	0.40	0.30	0.20	0.0	-0.05
YHT[c]	0.31		0.37		0.43	**0.45**	0.40	0.40	0.0	0.0	-0.10	0.41	0.78	-0.14	0.0	-0.11
SW[c]	0.30		0.41		0.51	0.34	**0.28**	0.85	0.13	0.0	0.43	0.40	0.40	0.20	0.0	-0.05
CW[c]	0.26		0.42		0.50	0.33	0.60	**0.23**	0.13	0.0	0.64	0.40	0.40	0.20	0.0	-0.05
BF[c]	-0.04		0.12		0.19	0.0	0.20	0.22	**0.24**	0.0	-0.03	0.015	0.0	0.15	0.0	0.0
MS[c]	0.0		0.0		0.0	0.0	0.0	0.0	0.0	**0.46**	0.0	0.0	0.0	0.0	0.0	0.0
REA[c]	0.14		0.24		0.29	-0.05	0.28	0.30	0.10	0.0	**0.37**	0.30	-0.10	-0.02	0.0	0.0
MATWT[c]	0.18		0.34		0.41	0.35	0.41	0.40	0.08	0.0	0.22	**0.48**	0.47	0.40	0.0	-0.05
MATHT[c]	0.28		0.31		0.31	0.55	0.31	0.31	0.0	0.0	-0.04	0.54	**0.31**	-0.10	0.0	0.02
MCON[c]	-0.08		0.03		0.12	-0.10	0.11	0.10	0.16	0.0	-0.03	0.32	-0.025	**0.40**	0.0	-0.17
GEL[c]	0.11		0.03		0.02	0.04	0.02	0.02	0.0	0.0	-0.01	0.009	0.02	0.0	**0.39**	0.0
AP[c]	0.03		-0.10		-0.08	-0.05	-0.05	-0.12	0.0	0.0	0.0	0.0008	0.02	-0.02	0.06	**0.31**

[a] heritabilities are on the diagonals, genetic correlations are above the diagonal and phenotypic correlations below the diagonal

[b] obtained from BIO

[c] obtained from MARC

Table 4.3: Phenotypic Variance Covariance Matrix (PVCV)

Traits	BWp[a] (kg^2)	WWp[a] (kg^2)	PWGp[a] (kg^2)	YHTp[b] (cm^2)	SWp[b] (kg^2)	CWp[b] (kg^2)	BFp[b] (mm^2)	MSp[b] (score^2)	REAp[b] (cm^4)	MATWTp[b] (kg^2)	MATHTp[b] (cm^2)	MCONp[b] (units^2)	GELp[b] (days^2)	APp[b] (days^2)
BWp[a]	**14.64**	21.0	13.25	3.79	46.74	26.73	-0.41	0.0	4.06	29.81	3.26	-0.18	1.65	3.29
WWp[a]	21.0	**693.81**	52.79	31.87	450.18	301.27	9.04	0.0	47.53	388.38	24.48	0.51	3.20	-64.35
PWGp[a]	13.25	52.79	**911.57**	43.90	676.69	428.68	17.31	0.0	69.39	562.39	30.33	2.18	2.50	-62.51
YHTp[b]	3.79	31.87	43.90	**11.68**	50.75	32.51	0.0	0.0	-1.26	54.48	6.07	-0.20	0.57	-5.01
SWp[b]	46.74	450.18	676.69	50.75	**1909.69**	746.69	26.61	0.0	97.39	809.99	43.82	2.85	4.01	-63.90
CWp[b]	26.73	301.27	428.68	32.51	746.69	**812.25**	19.29	0.0	67.67	519.42	28.26	1.81	2.63	-92.80
BFp[b]	-0.41	9.04	17.31	0.0	26.61	19.29	**9.42**	0.0	2.39	10.81	0.0	0.31	0.0	0.0
MSp[b]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.348**	0.0	0.0	0.0	0.0	0.0	0.0
REAp[b]	4.06	47.53	69.39	-1.26	97.39	67.67	2.39	0.0	**64.47**	79.16	-1.15	-0.14	-0.49	0.0
MATWTp[b]	29.81	388.38	562.39	54.48	809.99	519.42	10.81	0.0	79.16	**2069.34**	78.70	8.94	1.76	0.99
MATHTp[b]	3.26	24.48	30.33	6.07	43.82	28.26	0.0	0.0	-1.15	78.70	**10.26**	-0.05	0.33	1.96
MCONp[b]	-0.18	0.51	2.18	-0.20	2.85	1.81	0.31	0.0	-0.14	8.94	-0.05	**0.38**	0.0	-0.31
GELp[b]	1.65	3.20	2.50	0.57	4.01	2.63	0.0	0.0	-0.49	1.76	0.33	0.0	**18.72**	6.67
APp[b]	3.29	-64.35	-62.51	-5.01	-63.90	-92.80	0.0	0.0	0.0	0.99	1.96	-0.31	6.67	**734.41**

[a] indicates obtained from BIO

[b] indicates obtained form MARC studies

Table 4.4: Residual Variance Covariance Matrix (RVCV)

Traits	**BWp[a]** (kg^2)	**WWp[a]** (kg^2)	**PWGp[a]** (kg^2)	**YHTp[b]** (cm^2)	**SWp[b]** (kg^2)	**CWp[b]** (kg^2)	**BFp[b]** (mm^2)	**MSp[b]** ($points^2$)	**REAp[b]** (cm^4)	**MATWTp[b]** (kg^2)	**MATHTp[b]** (cm^2)	**MCONp[b]** ($units^2$)	**GELp[b]** ($days^2$)	**APp[b]** ($days^2$)
BWp[a]	**3.89**	11.07	7.20	1.41	26.50	17.07	-0.14	0.0	1.78	19.53	1.76	0.02	1.39	1.76
WWp[a]	11.07	**242.84**	-32.97	14.73	278.85	192.51	5.59	0.0	11.91	157.52	11.64	0.54	2.82	-29.77
PWGp[a]	7.20	-32.97	**592.63**	25.53	365.68	245.23	14.09	0.0	35.17	336.59	20.80	0.79	2.50	-48.99
YHTp[b]	1.41	14.73	25.53	**6.45**	29.52	19.98	0.0	0.0	-0.14	24.85	2.91	-0.09	0.57	-1.20
SWp[b]	26.50	278.85	365.68	29.52	**1370.52**	476.37	22.09	0.0	48.35	516.40	27.31	1.03	4.01	-46.31
CWp[b]	17.07	192.51	245.23	19.98	476.37	**225.75**	16.62	0.0	24.61	346.24	18.52	0.74	2.63	-82.42
BFp[b]	-0.14	5.59	14.09	0.0	22.09	16.62	**7.17**	0.0	2.61	10.07	0.0	0.22	0.0	0.0
MSp[b]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.19**	0.0	0.0	0.0	0.0	0.0	0.0
REAp[b]	1.78	11.91	35.17	-0.14	48.35	24.61	2.61	0.0	**40.34**	32.58	-0.28	-0.10	-0.49	0.0
MATWTp[b]	19.53	157.52	336.59	24.85	516.40	346.24	10.07	0.0	32.58	**1070.15**	52.29	4.01	1.76	24.94
MATHTp[b]	1.76	11.64	20.80	2.91	27.31	18.52	0.0	0.0	-0.28	52.29	**7.10**	0.02	0.33	1.42
MCONp[b]	0.02	0.54	0.79	-0.09	1.03	0.74	0.22	0.0	-0.10	4.01	0.02	**0.23**	0.0	0.69
GELp[b]	1.39	2.82	2.50	0.57	4.01	2.63	0.0	0.0	-0.49	1.76	0.33	0.0	**11.43**	6.67
APp[b]	1.76	-29.77	-48.99	-1.20	-46.31	-82.42	0.0	0.0	0.0	24.94	1.42	0.69	6.67	**504.89**

[a] obtained from BIO
[b] obtained from MARC

Table 4.5 Phenotypic Population Means

Trait	Mean
Birth Weight[a] (kg)	38.01
Weaning Gain[a] (kg)	186.58
Post Weaning Gain[a] (kg)	113.46
Yearling Height[b] (cm)	124.00
Slaughter Weight[b] (kg)	550.00
Carcass Weight[b] (kg)	334.00
Carcass Back-Fat[b] (mm)	7.50
Marbling Score[b] (score)	4.97
Rib-Eye Area[b] (cm^2)	82.26
Mature Cow Weight[b] (kg)	592.00
Mature Cow Height[b] (cm)	135.00
Mature Condition Score[b] (units)	5.55
Gestation Length[b] (days)	283
Age at Puberty[b] (days)	371

[a] trait means from BIO
[b] trait means from MARC

Table 4.6 Variance Matrix for Permanent Environment Effects

Traits	**MBW**[a] (kg^2)	**MWW**[a] (kg^2)
MBW[a] (kg^2)	**1.56**	0.0
MWW[a] (kg^2)	0.0	**69.37**

[a] obtained from BIO

Table 4.7 Maximum Multiplicative Heterosis Estimates[b]

Traits	**Multiplicative Heterosis Value** (proportion)
Birth Weight Heifer[b]	0.046
Birth Weight Bull[b]	0.033
Birth Weight Maternal[b]	0.070
Weaning Weight Heifer[b]	0.081
Weaning Weight Steer[b]	0.086
Weaning Weight Maternal[b]	0.066
Yearling Height Heifer[b]	0.017
Yearling Height Steer[b]	0.018
Post Weaning Gain[b]	0.030
Slaughter Weight[b]	0.042
Carcass Weight[b]	0.044
Carcass Back-Fat[b]	0.077
Marbling Score[b]	0.010
Rib-Eye Area[b]	0.040
Mature Cow Weight[b]	0.035
Mature Cow Height[b]	0.006
Mature Cow Condition[b]	0.054
Gestation Length[b]	0.000
Age at Puberty[b]	-0.057

[b] obtained from MARC

Table 4.8 Breed Frequencies for Test Bull Population

Breed (abbreviation)	**Frequency**[a]
Hereford (HE)	0.10
Black Aberdeen Angus (AN)	0.15
Red Aberdeen Angus (AR)	0.15
Charolais (CH)	0.15
Simmental (SM)	0.20
Gelbvieh (GV)	0.05
Blonde D'Aquitaine (BD)	0.05
Limousin (LM)	0.10
South Devon (DS)	0.025
Shorthorn (SS)	0.025

[a] The breed frequency were chosen to reflect approximately those found in Ontario

Table 4.9 Numbers of Test Bull Breed Types per Year

Purebred[a] and F1[b] Bulls

Breed	HE[c]	AN[c]	AR[c]	CH[c]	SM[c]	GV[c]	BD[c]	LM[c]	DS[c]	SS[c]
HE[d]	**75**	22	21	22	29	7	7	15	4	4
AN[d]	22	**113**	33	33	44	11	11	22	5	5
AR[d]	21	33	**113**	33	44	11	11	22	5	5
CH[d]	22	33	33	**113**	44	11	11	22	5	5
SM[d]	29	44	44	44	**150**	15	15	29	7	7
GV[d]	7	11	11	11	15	**37**	4	7	2	2
BD[d]	7	11	11	11	15	4	**37**	7	2	2
LM[d]	15	22	22	22	29	7	7	**75**	4	3
DS[d]	4	5	5	5	7	2	2	4	**19**	0
SS[d]	4	5	5	5	7	2	2	3	0	**18**

[a] purebred bulls (750 in total) along the diagonal
[b] 84% of composite bulls (630 in total)
[c] 1st breed in an F1 (1/2 of breed composition)
[d] 2nd breed in an F1 (1/2 of breed composition)

F2[a] Bulls

Breeds	CH[b]	SM[b]	GV[b]	BD[b]	LM[b]	DS[b]	SS[b]
HE,AN,AR[c]	18	24	6	7	12	3	3
CH,SM,GV[c]				4	8	2	2
BD,LM,DS[c]							1

[a] 12% of composite bulls (90 in total)
[b] 4th breed in an F2 (1/4 of breed composition)
[c] 1st 3 breeds in an F2 (3/4 of breed composition, 1/4 of each breed)

F3[a] Bulls

Breeds[b]	Number of Bulls
HE,AN,AR,CH,SM,GV,BD,LM	20
HE,AN,AR,CH,SM,GV,BD,DS	5
HE,AN,AR,CH,SM,GV,BD,SS	5

[a] 4% of composite bulls (30 in total)
[b] 1/8 of breed composition for each breed

Table 4.10 Phenotypic Performance Goals

Traits	Performance Goal
Birth Weight (kg)[a]	40.82
Weaning Weight (kg)[b]	249.43
Post Weaning Gain (kg)[c]	136.05
Yearling Height (cm)[d]	119.38
Slaughter Weight (kg)[e]	548.75
Carcass Weight (kg)[f]	328.80
Carcass Back-Fat (mm)[g]	7.0
Marbling Score (score)[h]	5.5
Rib Eye-Area (cm^2)[i]	87.10
Mature Cow Weight (kg)[j]	566.89
Mature Cow Height (cm)[k]	132.08
Mature Cow Condition (units)[l]	5.5
Gestation Length (days)[m]	278
Age at Puberty (days)[n]	355

[a] Birth weight goal often used by industry.

[b] Weaning Weight that is midway between 227kg and 272kg which produces the high gross dollars at auction.

[c] Weight required after weaning to produce optimum sized yearling heifer for target cow weight.

[d] Yearling height was target to be slightly less that population average.

[e] Slaughter weight that corresponds to carcass weight.

[f] Optimum carcass weight located in Canadian Quality Audit ideal range.

[g] Back-fat level was set as mid A1 level

[h] Marbling Score was targeted as mid AAA.

[i] Rib-Eye Area estimated to be an ideal portion size for a boneless striploin (8-oz).

[j] Mature cow weight considered ideal by industry.

[k] Mature cow height targeted to remain unchanged.

[l] Mature cow condition was targeted for optimal score.

[m] Gestation length estimated to produce 1 more estrous cycle before rebreeding which is beneficial for maintaining a tight calving season.

[n] Age at puberty was targeted to achieve an additional estrous cycle before 1st breeding.

Results and Discussion

5.0.0 Validation of Simulation

In all simulation studies validation of the simulated population must be performed to ensure that results are usable for inference. The primary method of validation was to verify that genetic and phenotypic means and correlations were close to the starting values used in the simulation. Genotypic correlations, as calculated using the correlation procedure in SAS, are reported in Table 5.1 with the starting parameters reported in Table 4.2. The statistics for the simulated values were calculated using SAS procedure CORR using the base cows across replications which totals 10,000 cows. It was evident that all traits were simulated such that correlations are close to the expected value, therefore validating the simulation methodology for genetic correlations. The expectation for the genetic means was that they are zero for all traits which was similar to those calculated and reported in Table 5.1.

The phenotypic means and correlations are reported in Table 5.2 and were also calculated using the CORR procedure in SAS. The data used to calculate the statistics were the herd means simulated for each herd in the base generation across replication, which totals 100 herds. The starting phenotypic parameters were reported in Table 4.2 for the phenotypic correlations and Table 4.5 for the phenotypic means. The phenotypic mean results were very similar between the parameters and the simulation. The phenotypic correlations were also very similar given that only 100 values were used for the calculation. During the process of creating the simulation programs for this study, each step of the simulation was checked against the starting parameters to ensure correctness. This testing process involved simulating large groups of 100,000 animals for true breeding values and 100,000 herds for phenotypic values over several different seed starting values. The variances, correlations and means were calculated to validate the programs for the values, which were simulated across seeds. This testing of the simulation programs was completed before the programs were incorporated into the study.

5.1.0 Phenotypic Uniformity

The first objective of this study was to investigate a complete crossbreeding strategy with the objective of phenotypic uniformity in comparison with a 3-breed rotational crossbreeding strategy. Although several different rotations were simulated for the 3-breed rotational strategy, the differences relate only to breed, for which no breed specific effects were simulated. Therefore, all rotational crosses were grouped together under the premise that all rotations were of the same design (temporal), had the same selection objective and bull availability. Comparisons of the uniformity and rotational strategy were based on average within herd phenotypic standard deviations. The phenotypic standard deviations for both strategies are illustrated graphically in Figures 5.1 to 5.15. Estimates of the significance of the mean differences in standard deviation between the uniformity and rotational strategies, from repeated measure analysis, are contained in Table 5.3. Table 5.4 reports univariate analysis results of the significance of the differences between the strategies at each year.

5.1.1 Phenotypic Uniformity from Birth to Slaughter

Phenotypic standard deviations were plotted over time for the 2 crossbreeding strategies in Figures 5.1 through 5.6. In general, the graphs illustrate that during the first 3 years of selection the phenotypic standard deviations were reduced somewhat regardless of strategy. This pattern was expected due to the fact that selection was taking place and that a low level of replacement and culling had taken place relative to herd size.

The graphs illustrate quite effectively that for the traits from birth to slaughter the uniformity strategy always had a lower phenotypic standard deviation than the rotational strategy. As well, the standard deviations for the uniformity strategy remained fairly close to the starting values. It was expected that the uniformity strategy would produce a pattern of maintaining variation close to the starting values in contrast to the rotational strategy having a trend of increasing variation. Gregory and Cundiff (1980) reported increasing variation as the rotational strategy progresses. A recommendation given by Cundiff et al. (1986) for preventing the problem of increasing phenotypic variation in rotational crossbreeding strategies from occurring was to select breeds for the rotational strategy that are comparable in performance characteristic. However, an unfortunate result of choosing comparable breeds was that the power of complementarity was diminished (Gregory et al., 1986).

With respect to the first objective of this study, the marketing points of weaning (Figure 5.2), yearling (Figure 5.4) and slaughter (Figure 5.6) results all show an improvement in phenotypic variation with the uniformity strategy. The trait of weaning weight was the most common marketing point for commercial cow-calf producers in Ontario. It has often been suggested that commercial cow-calf producers only have breeding objectives to weaning (Melton and Colette, 1993). Therefore, a comparison of the strategies at weaning, because of the rotational strategy breeding objective focused, was very important. In terms of phenotypic uniformity, Figure 5.2 illustrates an obvious superiority for the uniformity strategy both in terms of the pattern of uniformity over time and the difference of 33% more uniformity in later years. The results from repeated measures analysis in Table 5.3, show that the trend for weaning weight had a significant linear and quadratic component. As well an interaction between strategy and both the linear and quadratic trends exists. Individual year differences between the strategies in Table 5.4 show a pattern of early significance and late significance while the middle years are not significant. Table 5.3 contains the results for mean strategy differences from repeated measure analysis. These results significantly ($p<.05$) infer that the uniformity strategy provided a lower phenotypic standard deviation compared to the rotational strategy. Weaning weight was a composite trait genetically and phenotypically. Genetically, weaning weight changes can be selected for in terms of birth weight and weaning gain in both direct and maternal components. In phenotypic terms weaning weight was the additive result of birth weight and weaning gain. The complexity of creating uniformity at weaning was, therefore, considerable but possible according to the results of this study.

Marketing of cattle at yearling age is another common marketing point for cattle in Ontario. Yearling cattle are those that would correspond to cattle in the terminal production cycle where they are placed on finishing diets after being raised on growing diet(s) since weaning. At yearling age, cattle to be marketed are evaluated with respect to uniformity in terms of both weight and height. The addition of height to the evaluation process occurs due to an association between height and finishing ability that buyers believe exists. Figure 5.4 graphically illustrates the results for yearling weight and Figure 5.5 the results for yearling height. The repeated measure results are reported in Table 5.3. Yearling weight phenotypic variation was greatly affected by the variation that existed at weaning. Therefore, as expected, the results for yearling weight was very similar in both the pattern of variation over time the magnitude of difference between the strategies (approximately 45% less variation) in later years, and the actual amount of variation. This was expected given the correlations that exist as well as intuitive association given the production systems as they exist. Yearling height however is highly correlated with mature height but only moderately correlated with other weight traits. The pattern of phenotypic variation over time for yearling height was quite similar between the 2 strategies overall with both a linear and quadratic trend being significant (Table 5.3). However, the magnitude of the difference between strategies was very large and more dramatically different than the other traits from birth to slaughter. This mean difference was significant (Table 5.3) between strategies. A reason for this distinctive difference compared to traits discussed earlier, was that the phenotypic target was set very close to the population mean. Close proximity of the target to the mean requires little selection and therefore minimizes the increases in phenotypic variation. Therefore, differences in uniformity of height at yearling were dramatic and would produce significant visual and economic advantages for the cattle produced from the uniformity strategy immediately and would be sustained over the first 10 years of utilization.

Slaughter weight phenotypic variation as plotted over time (Figure 5.6) shows a pattern that was quite different than the traits discussed previously. The slaughter weight pattern of variation illustrates a slight increase in variation over time for both strategies however a definite advantage in the magnitude of the difference in phenotypic variation exists that favors the uniformity strategy (approximately 15% in year 10). The results in Table 5.3 also illustrate the significant mean difference between the strategies as well as confirming a significant overall quadratic trend. It is important to note from Table 4.2 that slaughter weight has moderately high correlations phenotypically and genetically with a great number of other traits. Correlations that are moderate and associated with traits where selection for those traits was for a general increase in genetic merit, and consequently phenotype, can result in increases in variation of the phenotypes of the correlated traits. This pattern also occurs for several other phenotypic traits, including carcass weight and rib-eye area, which will be discussed latter.

5.1.2 Phenotypic Uniformity for Carcass Traits

The plots of phenotypic standard deviations over time for carcass traits are presented in Figure 5.7 to 5.10. The trait carcass weight follows the pattern of slaughter weight where the plot illustrates an increasing level of phenotypic variation over time with a decided and significant advantage for the uniformity strategy in terms of magnitude of the difference being significant between strategies (Table 5.3) with a difference in variation of approximately 25% in year 10. Back-fat produced a very similar pattern of phenotypic variation over time to carcass weight and slaughter weight and also produced a significant mean difference (Table 5.3).

The marbling score phenotypic variation plot over time (Figure 5.9) shows a pattern that was typical of weaning and yearling weight as previously discussed in section 5.2.1. The plot although visually illustrating differences in the magnitude of phenotypic variation did not produce a significant difference between strategies for the means (Table 5.3). A likely reason for the lack of significance was due to the fact that marbling score was influenced by the target (Table 4.10) being set significantly higher than the phenotypic population average (Table 4.5) which resulted in selection for higher genetic merit bulls for natural service usage. The result of choosing bulls with high genetic merit in a random selection order would have this effect of increasing variation simply because the number of high merit bulls does not match the need, consequently some cows were mated to lower merit bulls, adding variation within herds. If bull genetic merit was near the mean many more bulls are available which therefore increases the chances of supplying all the bulls needed even under the random bull selection system (section 4.2.9).

In Figure 5.10 the pattern for rib-eye are phenotypic variation over time appears to favor uniformity during the years 3 through 7 but then the plots converge such that no difference would appear to exist in the last few years. Significant strategy differences for years 1 and 3 are reported in Table 5.4. The result in Table 5.3 shows there was no significant mean difference between the rotational and uniformity strategies. A reason was that rib-eye area, although not desired, was selected for in a positive direction through the female replacement nucleus. This result is illustrated in terms of phenotypic variation is Figure 5.10 and in terms of strategy means in Figure 5.25 for rib-eye area. The female replacement nucleus utilized the AI stud bulls in an individual mating system as described in section 4.2.8. The true source of the rib-eye area problem occurred as a result of bull selection for the AI stud where the bulls across breed true breeding values were utilized (section 4.2.9). The relation between AI bull selection process and the uniformity strategy individual herd needs was not complete as illustrated in Table 5.5 where the average across breed estimated breeding values for the natural and AI service bulls are presented. In the case of natural service sire selection, bulls were chosen from the test bull population where the distribution of across breed true breeding values was large and contained bulls that matched the herd needs better. For replacement female nucleus selection of AI sires, the bulls available represented only those bulls that were ranked at the top of the population (section 4.1.4). The result of utilizing the AI stud was that although the best bulls were chosen for the stud according to the selection criteria and the bulls chosen to mate to the nucleus cows was such that best suited mates were mated, the resulting progeny were not precisely what was desired. In the case of rib-eye area the result was larger than desired size and contributed to increased variation phenotypically. As well any traits moderate to highly correlated with rib-eye area, such as carcass weight and slaughter weight as previously discussed, illustrated a correlated response. The correlated response produced a quadratic trend in both carcass weight and slaughter weight in latter years (Figure 5.6 and 5.7) as well as reducing the percentage of variation reduction to 15-20% compared to traits like yearling weight that produced approximately a 45% reduction. In terms of variation reduction, it is important to note that the uniformity strategy did not reduce variation, but maintained the initial variation present in comparison to the pattern of increasing variation illustrated by the rotational strategy. Slaughter weight, carcass weight and rib-eye area all exhibited slight increase in variation over time and consequently less overall variation reduction. In comparison, weaning weight and yearling weight exhibited little or no increase in variation over time and a higher overall reduction in variation.

5.1.3 Phenotypic Uniformity for Mature Cow Traits

The results for mature cow traits are illustrated graphically in Figure 5.11 to 5.13 with repeated measurement results reported in Table 5.3. The plot of phenotypic variation over time for mature cow weight shows that variation was greater in magnitude for the rotational than the uniformity strategy with both a linear and quadratic component to the pattern (Table 5.3). As well, little change in mature weight variation occurred in the uniformity strategy where the rotational strategy increased over time (Figure 5.11). The results in Table 5.3 illustrate a significant difference in variation between the strategies as well. It was expected that this would occur mainly because of the results of traits like weaning and yearling weight, which are moderately correlated with mature cow weight.

Mature cow height and yearling height are highly correlated both genetically and phenotypically and produced almost identical results graphically (Figures 5.12 and 5.5) however mature height mean differences were not significant (Table 5.4). As well both traits were set with targets close to the phenotypic population means which as well helps to produce very similar results.

The trait mature cow condition in Figure 5.13 shows a pattern where phenotypic variation is increasing for both strategies and very little advantage in terms of variation reduction occurs in the uniformity strategy. Table 5.3 shows a non-significant mean difference between the uniformity strategies. Mature cow condition does have a moderately high genetic correlation with mature cow weight and moderate genetic correlations with some other growth traits such as carcass weight and slaughter weight. The genetic correlations with slaughter and carcass weight were previously discussed along with the interactions with the trait rib-eye area in the selected AI sires. The pattern of increasing variation in the later years also was indicative that the real source of the variation was entering through the female replacement system, which utilizes the AI sires. The method of selecting sires for the AI stud had a very important and large effect in this study with relation to phenotypic variation. If AI sire selection had specifically matched the needs of the uniformity strategy cow-herds, then it was likely that the results for the herds would have been lower standard deviations. A method of ensuring the match between AI sires and herd needs would have been to use the commercial herd means to select AI sires. This system would mimic an alliance or cooperative program for AI sire selection. Since the AI selection process was simulated to replicate current industry norms it should also signal that perhaps a component of low AI usage in the Ontario beef industry is also associated with the types of AI sires available. These results illustrate that a great deal of consideration needs to be taken in matching the commercial customers' needs with the bulls selected and offered through AI.

5.1.4 Phenotypic Uniformity of Reproductive Traits

The trait gestation length appears to produce a reduced phenotypic variation over time (Figure 5.14) however, the repeated measures results (Table 5.3) indicated differences in mean phenotypic variation between strategies was not significant. The univariate result in Table 5.4 indicates that there were no significant differences between the strategies at any of the time points. Gestation length did produce a trend that had a significant linear component (Table 5.3) although it would appear to be close to zero (Figure 5.14). It would appear from Figure 5.14 that the strategies were diverging over time and if more than 10 years of production were simulated perhaps a significant difference would be achieved in latter years.

Age at puberty is a trait that is fairly highly correlated with weight traits from birth to yearling age. Age at puberty was determined phenotypically by age and weight such that a minimum threshold of weight must be achieved for estrous cycles to begin and a minimum age must also be achieved (Williams, 1999). In Figure 5.15 it appears that phenotypic variation decreases quickly in both strategies and then appears to produce very little difference over time. Table 5.3 shows that an overall linear trend occurred and that there was a strategy interaction. The results in Table 5.4 show that the pattern of significant differences between years occurred early and late with non-significant differences between which explains the interaction. The trend for the uniformity strategy was expected because of selection for reduced age at puberty. Thus the uniformity strategy produced a response to selection. The rotational strategy selected for increased weaning weight, which produced higher weights and therefore produced an early age of puberty as a correlated response (Table 4.2). Thus the rotational strategy decreased age at puberty through increasing weight while the uniformity strategy did it by direct selection. The repeated measure results indicate that the mean differences between the strategies for phenotypic variation are significant (Table 5.3).

5.2.0 Phenotypic Targets

Phenotypic targets are commonly discussed and quoted at producer and industry meetings. In section 5.2 the phenotypic uniformity results of the progeny and cows are discussed in detail however a key component of the uniformity strategy was the use of phenotypic targets to anchor the mate selection process. The phenotypic target objectives as set for this study were reported in Table 4.10 in chapter 4. The results for herd means and the targets were plotted by strategy over time and are reported in Figure 5.16-5.30.

5.2.1 Phenotypic Targets and Mean Performance from Birth to Slaughter

The phenotypic target objectives were utilized only in the uniformity strategy. Herd means over time for the rotational strategy were plotted to provide a comparison. The rotational strategy selection was based on maximum total maternal weaning weight.

The birth weight means trend over time (Figure 5.16) for the uniformity strategy illustrates that birth weight approached and remained close to the target, but did deviate in the later years. The deviation to an upward trend occurred due to the effect of AI sire selection as previously mentioned in Section 5.1.2.

Figure 5.17 presents the plot for weaning weight over time. The rotational strategy regardless of the trait examined from birth to slaughter produce the trend of increasing herd means over time. The main reason for the increasing character of the rotational strategy is the positive genetic correlations between weaning weight and the other traits, which produced a positive correlated response, as illustrated in Table 4.2. As expected the trend for weaning weight over time for the rotational strategy increased at a high rate which corresponded to the breeding objective of increased weaning weight for this strategy. The uniformity strategy plot illustrates that the mean weaning weight was almost constant over time as was desired and it was almost exactly the same as the target weaning weight. For the uniformity strategy, therefore, this study illustrates that the mean production of the herds was achieved and that significant improvement in uniformity compared to the rotational strategy was also achieved. This finding corresponds to objective 1 of this study.

Yearling time is critical both for the profitability of the terminal calves and for female replacement development. Figure 5.19 illustrates the trend for yearling weight over time for the uniformity strategy. The trend, as expected, was that very little change occurs in the mean yearling weight over the 10 years of production modeled. The target weight versus the uniformity trend does indicate that yearling weight appears to be a little lower than desired. In Figure 5.18 which was the graph for post weaning gain over time illustrates that the main reason for yearling weight means not matching as well with the targets as desired was post weaning gain. The reason was that post weaning gain was substantially lower than the target relates to a problem encountered with fixed effect addition errors as detailed in Appendix I. The fixed effects error had an effect on post weaning because the target objective for the study was yearling weight from which weaning weight and birth weight are subtracted each year to create a post weaning gain objective. Therefore, the post weaning gain objective was estimated to be smaller than was needed in order to account for the fixed effect error. An alternative system that could have been implemented would have been to fix the target for post weaning gain and not account for the levels of birth weight and weaning weight. The disadvantage of the alternative, however, was that any potential fluctuations in birth weight or weaning weight would automatically show up in the yearling weight. Traits with minimal fixed effects other than post weaning were not affected by the adjustment procedure discussed in Appendix I.

The yearling height plot is contained in Figures 5.20. The graph shows that the uniformity strategy does not achieve its target objective and that the herd means are actually moving away from the objective over time. This pattern however has more to do with the scale of the graph than the actual means. The target and means are within a few centimeters. Yearling height also has correlations that are moderate with early growth (Table 4.2), therefore, part of the difference is associated with a correlated response. As well, the method of selecting mates by ranking across a large number of traits would produce very little emphasis on yearling weight because the phenotypic means were close to the target throughout the 10 production years.

The trend for slaughter weight (Figure 5.21) given selection for increasing weaning weights in the rotational strategy is important as it illustrates what has occurred in beef production in Ontario over the last 20 years. With the increasing trend in weaning weight a corresponding increase in slaughter weight has occurred at a rate that was quite similar validating the general belief that increasing weaning weight has contributed to increasing slaughter and carcass weight. Slaughter weight means of the uniformity herds over time produces a pattern where the means diverge from the target and the target phenotype was not achieved in any year. This pattern occurs due to genetic and phenotypic correlations (Table 4.2) with rib-eye area, which increased over time due to the AI sire selection system and utilization of the selected bulls in female replacement nucleus as previously discussed in Section 5.1.2.

5.2.2 Phenotypic Targets and Mean Performance for Carcass Traits

The traits of carcass weight (Figure 5.22) and back-fat (Figure 5.23) produced results similar to slaughter weight as previously discussed. Carcass weight has a high correlation with rib-eye area, which would be expected to produce the correlated response due to the AI sire selection (Section 5.2.1). Back-fat has a moderate positive correlation with carcass weight and slaughter weight (Table 4.2) which produced a correlated response.

Marbling score (Figure 5.24) and rib-eye area (Figure 5.25) show a characteristic increasing mean level of performance over time, due to accumulation of higher genetic merit within the herds. AI sires utilized in the female replacement nucleus system of the uniformity strategy were selected for high genetic merit through the rank system (Section 4.1.14). Therefore, both traits were expected to have an increase in mean phenotypic performance over time especially towards the later years. A further influence on marbling score was that the target was set well above the average population phenotypic mean and, therefore, the terminally bred progeny contribute to the increase. Marbling score does not have genetic correlations with other traits (Table 4.2) in comparison to rib-eye area and thus did not produce the same correlated result effects as previously discussed.

5.2.3 Phenotypic Targets and Mean Performance for Mature Cow Traits

Mature cow weight for the uniformity strategy produced a constant mean weight over time with a slope that appears to be close to zero (Figure 5.26). This indicated that, as with yearling weight, the target weight was not achieved at any point over the 10 production years the difference remained small with very little selection pressure developed using the rank selection method. It is very important to note the difference between the rotational and uniformity strategy where a large amount of cow weight accumulated over time in the rotational strategy. This weight accumulation was expected due to correlated response and is also illustrative of a situation were cow weights increase as a function of selection for higher weaning weight.

Mature cow height (Figure 5.27) illustrates the pattern over time for the uniformity strategy that was expected for mature cow traits in general. It was expected that the movement of cow-herd traits towards the target would be slow and gradual in early years and then increase in later years as the herds accumulate replacements.

The results for mature cow condition are illustrated graphically in Figure 5.28. The means for both strategies are almost identical over time and diverge from the target mean. The pattern of change over time for the rotational strategy is explained by correlations with growth traits and mature weight as illustrated in Table 4.2. The reason for the pattern for the uniformity strategy was due to the AI sire selection issues as previously discussed.

5.2.4 Phenotypic Targets and Mean Performance for Reproductive Traits

Figure 5.29 graphically illustrates the means of the herd results for gestation length over time. The pattern illustrates that for the uniformity strategy the means move towards the target and achieve the target in the middle years and then closely parallels the target. It is interesting that the rotational strategy means remain close to the population mean throughout the 10-year production cycle. In Table 4.2 the genetic and phenotypic correlations for this trait are zero with almost all other traits and therefore a breeding objective of total maternal weaning gain would have no correlated response as illustrated. Further, due to the lack of correlations, gestation length across breed expected progeny differences of the selected sires are basically a random sample of potential values and would be expected to on average produce no phenotypic change (Table 5.5).

Age at puberty is highly correlated with weight traits, which provides a correlated response for the rotational strategy and the uniformity as illustrated in Figure 5.30. The rotational strategy pattern was simply due to selection for total maternal weaning gain, where as the uniformity strategy was a function of selection.

5.3.0 Retained Heterosis

A primary consideration in the development of crossbreeding strategies was to take advantage of the effect of heterosis. Many researchers have quantified the effect of heterosis both for individual and maternal heterosis and both strategies in this study were designed to maintain a high level although by very different methods.

5.3.1 Retained Individual Heterosis

The 3-breed rotational crossbreeding strategy was designed to allow for continuous crossbreeding with the utilization of purebred input sires. The expected level of retained individual heterosis at the equilibrium breed composition of on average 1/3 is 86% of the maximum. Maximum heterosis values for the traits involved in this study are reported in Table 4.7. The uniformity crossbreeding strategy was also designed to maintain a high level of retained individual heterosis without the requirement of purebred sire inputs, however, purebreds were not restricted from use. Figure 5.31 illustrates the proportion of retained heterosis over time for both strategies. The rotational strategy had not reached equilibrium by the tenth year, due to the temporal design, and therefore maximum retained heterosis had not been achieved. The uniformity strategy pattern for retained individual heterosis after year 2 was at least equal to or slightly greater that the rotational strategy. Gregory and Cundiff (1980) presented results that illustrated that as the number of breeds in a composite increase so does the percentage of retained heterosis, and that the maximum level of retained heterosis approaches that of a 3-breed rotation, as the results from this study also indicate.

The rotational pattern has drops in retained heterosis in years 3, 6, and 9. These years correspond to the years when the original parent breed Hereford was the sire breed in the temporal rotation.

5.3.2 Retained Maternal Heterosis

The results for retained maternal heterosis over time are illustrated graphically in Figure 5.32. The expected level for average retained maternal heterosis at equilibrium for the rotational strategy is 86% of maximum, which is the same as retained individual heterosis. As with individual heterosis, both strategies appear to have equivalent average levels of heterosis that indicates that the uniformity strategy is at least equivalent to a 3-breed rotational crossbreeding strategy in this study.

The rotational pattern has drops in retained heterosis, although smaller that individual retained heterosis, in years 4, 7, and 10. These years correspond to the years when females from the matings using the original parent breed of Hereford as the sire breed occurred in the temporal rotation.

5.4.0 Replacement Female Systems

The female replacement system in both strategies is quite different. The uniformity strategy utilizes a variable portion of the cow-herd as the nucleus and these cows are bred using AI sires. Previously, the impact of the AI sires and the selection process has been discussed relative to their impact for several traits both for phenotypic uniformity and phenotypic target achievement. The average number of cows bred AI as replacement nucleus females, across replicates, for the uniformity strategy, was 47%. Therefore, on average a large portion of the uniformity phenotypic means and variation was affected the genetic merit of the selected AI sires. In contrast, the rotational strategy simply chose replacement females from the total progeny produced from the herd. As well, the selection pressure for female replacements for the uniformity herds was half of that in the rotational strategy herds due to the nucleus structure producing half the number of females that could be selected.

The uniformity strategy utilized a fluctuating voluntary culling rate which was tied to the average age of dam in the herd and the optimum age of dam that was desired (section 4.2.6). The average age of dam for the uniformity strategy across replicates was 5.97 compared to 5.33 for the rotational strategy. Therefore, the methodology used to maintain the optimum age of dam was effective. The rotational strategy did not utilize the average age of the cows in the herd and illustrates the average age resulting from a fixed 20% replacement rate. This fixed rate produced an average age of dam that was lower than optimum as defined by Melton and Colette (1993). The average replacement rate for the uniformity strategy over all replicates and years was 15.85% in comparison to the 20% rate for the rotational strategy. The differences in replacement rates should produce a greater rate of genetic change in the rotational strategy which was illustrated in Figures 5.15 - 5.30 in comparison to the uniformity strategy. As well, the lower replacement rate for the uniformity strategy would be expected to delay phenotypic uniformity improvement and phenotypic target achievement for mature cow traits which is also illustrated in Figures 5.26 - 5.29. If the genetic merit of the AI sires had precisely matched the needs of the uniformity the rate of genetic change for mature cow traits would have been greater although not enough to equal the replacement rate differences.

5.5.0 Characteristic of Cows and Bulls

Table 5.5 details the average genetic merit of cows and bulls in both strategies across replicates. The rotational strategy selects replacement females and sires in an effort to maximize total maternal weaning gain which is illustrated in the average across breed estimated breeding values (EBV). Traits with genetic and phenotypic correlations with weaning gain produced a correlated response as expected as illustrated in Table 5.5. Cows in the uniformity strategy have average EBV as expected given the results previously discussed for phenotypic variation and mean phenotypic performance. Included in the average EBV for cows is the pattern discussed previously of increasing variation and poor target achievement with traits such as rib-eye area, slaughter weight, and carcass weight where the EBV are higher than expected. Table 5.5 illustrates a contrast of average EBV for natural service and AI sires used for the uniformity strategy. In general, there was very poor agreement between the 2 sire groups as previously discussed, which leads to the conclusion that the method of selecting AI sires did not match the needs of the herds in the uniformity strategy.

The relative selection pressure for replacement females was approximately double for the rotational strategy in comparison to the uniformity strategy. The selection intensity for sires favors the uniformity strategy due to the use of composite or purebred bulls, compared to the rotational strategy, which was limited to purebreds. The selection pressure of the uniformity strategy for natural service selection of bulls was 0.02 or 2% in any given year compared to the rotational strategy which on average was 11%. This would most certainly provide advantages for the uniformity strategy. However, it is important to note that the strategies did not choose bulls with similar EBV (Table 5.5). Therefore, the advantage of selection intensity for bull selection was negligible for the uniformity strategy. In terms of AI sire selection for nucleus mating, the effect of selection intensity is potentially greater because four purebred bulls that potentially could have been used for the rotational strategy are selected out of each test groups as detailed in section 4.2.8. The average total maternal weaning gain genetic merit for the AI sires was quite high (Table 5.5) and comparable to the natural service sires used in the rotational strategy. However, only five purebred AI sires were selected for mating to the nucleus cows, although the bulls utilized were from the breeds involved in the rotational strategy. Therefore, the rate of improvement for total maternal weaning gain was likely slightly lower due to the loss of the five purebred bulls to the AI stud. The effect, however, would have been quite small considering the number of females exposed to a bull being only 20.

The uniformity strategy was not limited to selecting only composite bulls and thus purebred bulls were sometimes selected and used. The number of composite bulls utilized totaled 913 out of a total of 1664 for the uniformity strategy across replicates. There were 203 composite AI sires and 710 natural service utilized. The remaining 751 bulls were purebreds, of which 5 were AI sires and 746 natural service. The selection allowed herds in the uniformity strategy to select before the rotational strategy, which therefore reduced the number of purebred bulls available for the rotational strategy herds. Although the effective selection pressure was reduced there was a distinct difference in the genetic merit of the bulls chosen by either strategy (Table 5.5). This difference in bull merit indicates that there is no likelihood that bulls selected by the uniformity strategy would have been candidates for the rotational strategy. As well, the selection order was established as a component of each strategy and formed part of the differences between the strategies. Thus, differences because of selection order were considered to be part of the strategy.

Table 5.1: Estimated Genetic Means[a] and Correlations[b] for Simulated Base Cows

Traits	BW (kg)	MBW (kg)	WW (kg)	MWW (kg)	PWG (kg)	YHT (cm)	SW (kg)	CW (kg)	BF (mm)	MS (score)	REA (cm^2)	MATWT (kg)	MATHT (cm)	MCON (units)	GEL (days)	AP (days)
BW	**-0.07**	-0.10	0.09	-0.02^c	0.10	0.35	0.25	0.18	-0.07	0.02^c	0.14	0.07	0.24	-0.20	0.0	0.02
MBW		**0.012**	0.0	0.11	0.0	0.0	0.01^c	0.0	0.0	0.01^c	0.0	0.0	0.0	0.0	0.0	0.02^c
WW			**-0.04**	0.0	0.35	0.46	0.40	0.43	0.14	0.01^c	0.49	0.47	0.44	-0.03	0.0	-0.13
MWW				**0.31**	0.0	-0.02^c	0.0	0.0	0.02^c	0.01^c	0.02^c	0.0	-0.02^c	0.0	-0.01^c	0.0
PWG					**-0.23**	0.44	0.74	0.74	0.12	0.0	0.39	0.40	0.30	0.21	0.0	-0.03
YHT						**-0.03**	0.39	0.39	0.01^c	0.0	-0.10	0.41	0.78	-0.13	0.0	-0.09
SW							**-0.46**	0.85	0.12	0.0	0.44	0.41	0.40	0.20	0.0	-0.03
CW								**-0.26**	0.14	0.0	0.64	0.41	0.40	0.20	0.0	-0.03
BF									**0.0**	-0.01^c	-0.02^c	0.02^c	0.02	0.15	-0.01^c	0.0
MS										**0.0**	0.0	0.0	0.01^c	0.01^c	0.0	0.01^c
REA											**-0.06**	0.30	-0.10	-0.02	-0.01^c	0.0
MATWT												**-0.13**	0.47	0.41	0.01^c	-0.04
MATHT													**-0.02**	-0.10	0.01^c	0.04
MCON														**0.0**	0.01^c	-0.16
GEL															**-0.01**	0.0
AP																**-0.08**

[a] genetic means are on the diagonals
[b] genetic correlations are above the diagonal
[c] not significant at $P <(0.05)$ level

Table 5.2: Estimated Phenotypic Means[a] and Correlations[b] for Simulated Base Herds

Traits	BWp (kg)	WWp (kg)	PWGp (kg)	YHTp (cm)	SWp (kg)	CWp (kg)	BFp (mm)	MSp (score)	REAp (cm^2)	MATWTp (kg)	MATHTp (cm)	MCONp (unit)	GELp (days)	APp (day)
BWp	**37.5**	0.34	0.15^c	0.46	0.35	0.33	-0.1^c	0.1^c	0.16^c	0.3	0.4	-0.08^c	0.1^c	0.09^c
WWp		**189.02**	-0.12^c	0.41	0.35	0.36	0.01^c	-0.18^c	0.13^c	0.32	0.4	-0.08^c	0.1^c	-0.07^c
PWGp			**107.01**	0.41	0.45	0.46	0.06^c	-0.02^c	0.25	0.20	0.26	0.05^c	0.1^c	-0.06^c
YHTp				**123**	0.39	0.39	-0.2	-0.06^c	0.02^c	0.23	0.54	-0.27	0.06^c	-0.15^c
SWp					**546.53**	0.57	0.09^c	-0.17^c	0.22	0.39	0.31	-0.07^c	0.11^c	0.02^c
CWp						**331.06**	0.21	-0.07^c	0.18^c	0.37	0.26	-0.02^c	0.05^c	0.0^c
BFp							**7.4**	-0.07^c	-0.09^c	-0.09^c	-0.13^c	0.09^c	0.12^c	0.14^c
MSp								**4.94**	0.09^c	0.02^c	0.0^c	-0.06^c	0.13^c	0.07^c
REAp									**82.07**	0.21	-0.04^c	-0.06^c	-0.01^c	0.13^c
MATWTp										**588**	0.42	0.2	0.2	0.1^c
MATHTp											**135**	-0.17^c	-0.17^c	0.0^c
MCONp												**5.5**	-0.14^c	-0.15^c
GELp													**283**	0.18^c
APp														**371**

[a] phenotypic means are on the diagonals
[b] phenotypic correlations are above the diagonal
[c] not significant at P <(0.05) level

Table 5.3 Significance Testing of Mean, Linear, and Quadratic Contrasts from Repeated Measures Analysis

Phenotypic Trait	**Mean**	**Linear**		**Quadratic**	
		Overall[a]	**Strategy**[b]	**Overall**[a]	**Strategy**[b]
Birth Weight	*	*		*	
Weaning Weight	*	*	*	*	*
Post Weaning Gain	*	*		*	
Yearling Weight	*	*		*	*
Yearling Height	*	*		*	
Slaughter Weight	*			*	*
Carcass Weight	*				
Back Fat	*				*
Marbling Score				*	
Rib Eye Area				*	
Mature Cow Weight	*	*		*	
Mature Cow Height		*		*	
Mature Cow Condition Score		*		*	
Gestation Length		*			
Age at Puberty	*	*	*		

* significant at $P < (0.05)$

[a] overall trait trend

[b] strategy interaction with trend

Table 5.4 Significance of Differences in Standard Deviation between Uniformity and 3-Breed Rotational Strategies by Trait at Yearly Time Points

Trait[a]	Yr1	Yr2	Yr3	Yr4	Yr5	Yr6	Yr7	Yr8	Yr9	Yr10
BWp	*	*	*	*	*	*	*	*	*	*
WWp	*		*						*	*
PWGp										
YWTp	*		*						*	*
YHTp			*			*			*	
SW p									*	*
CW p										*
BF p			*			*				
MS p										
REAp	*		*							
MATWTp								*	*	
MATHTp										
MCONp				*						
GELp										
APp	*		*					*	*	

* significant at $P<0.05$)

[a] abbreviations from section 4.1.1

Table 5.5 Mean Across Breed Estimated Breeding Values (EBV)

Trait	Rotational Cow[a]	Uniformity Cow[b]	Natural Service Sires Rotational[c]	Natural Service Sires Uniformity[d]	AI Service Sires Uniformity[e]
BW (kg)	-0.44	0.24	1.1	-0.28	1.31
MBW (kg)	0.69	0.4	0.47	0.02	0.52
WW (kg)	2.1	4.81	11.13	-3.34	10.79
MWW (kg)	12.88	-9.19	8.79	0.0	-8.04
PWG (kg)	2.52	1.25	6.67	-3.26	7.76
YHT (cm)	0.35	-0.06	1.44	-0.28	0.92
SW (kg)	2.85	5.53	12.58	-4.81	16.06
CW (kg)	1.82	3.71	7.51	-3.08	10.55
BF (mm)	0.05	0.61	0.29	-0.18	0.81
MS (score)	0.0	0.09	0.05	0.06	0.29
REA (cm^2)	0.45	3.15	2.26	0.07	5.83
MATWT (kg)	5.62	-6.4	19.18	-1.73	10.17
MATHT (cm)	0.28	-0.78	0.86	-0.33	-0.34
MCON (units)	-0.02	-0.09	0.16	0.14	0.10
GEL (days)	0.02	-1.08	0.01	-0.22	-1.51
AP (days)	0.61	-1.7	-6.84	-4.46	-13.61

[a] number of rotational cows across replications was 6837

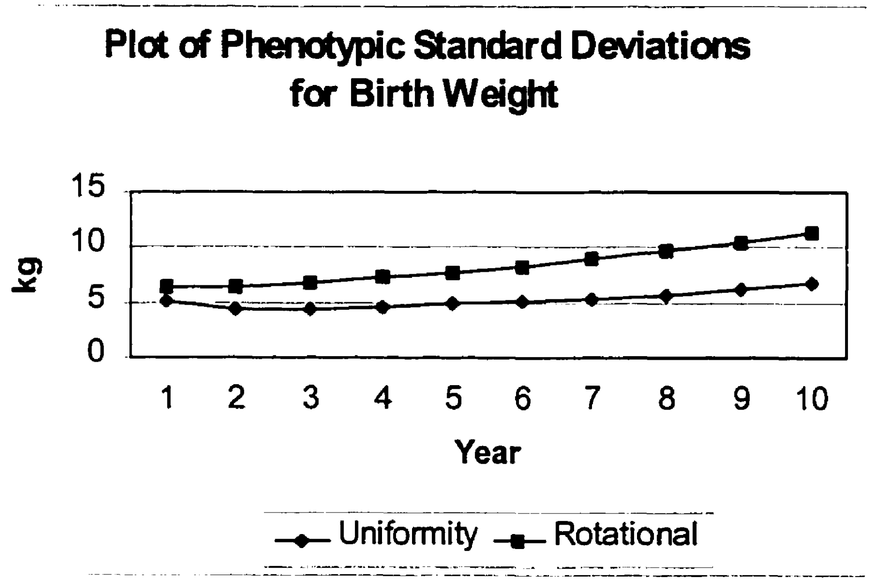
[b] number of uniformity cows across replications was 6018

[c] number of natural service rotational strategy bulls was 1630

[d] number of natural service uniformity strategy bulls was 1456

[e] number of AI service uniformity strategy bulls was 208

Figure 5.1



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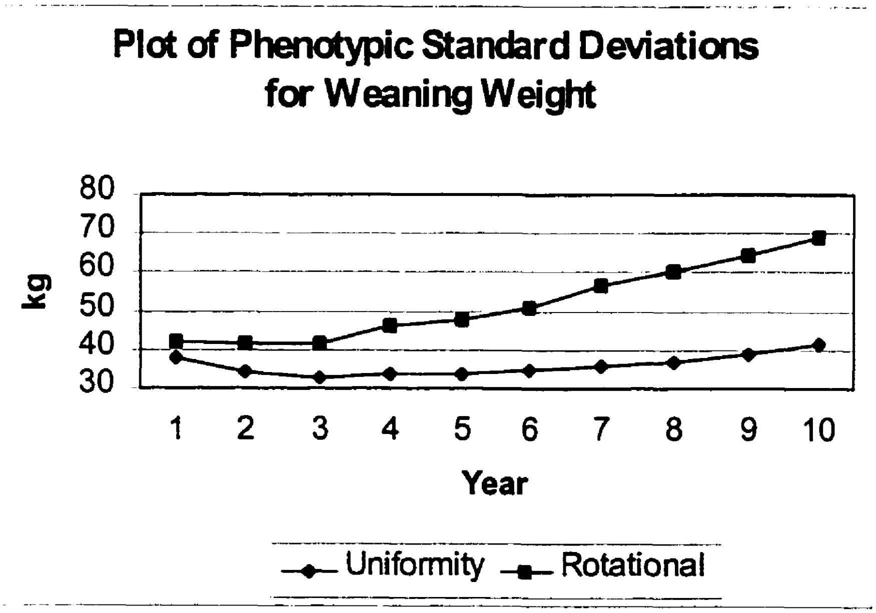

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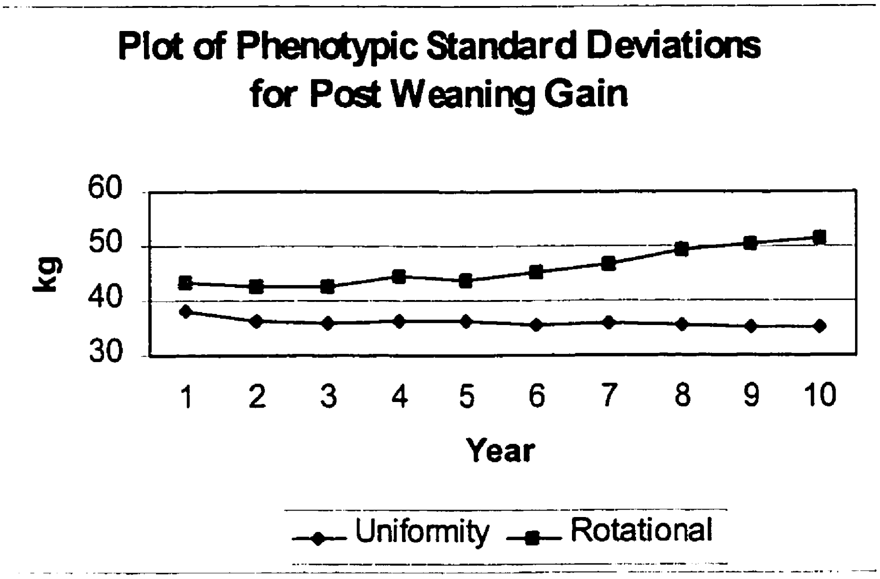

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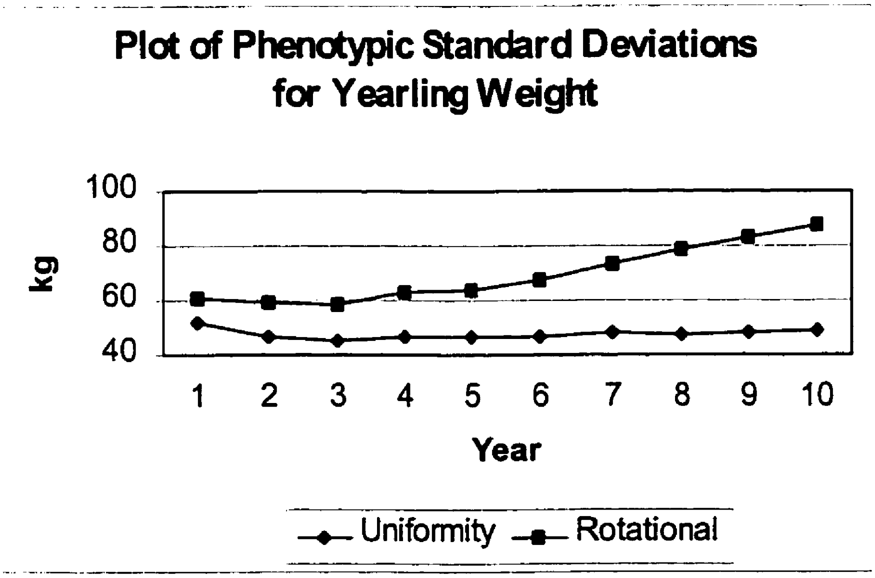

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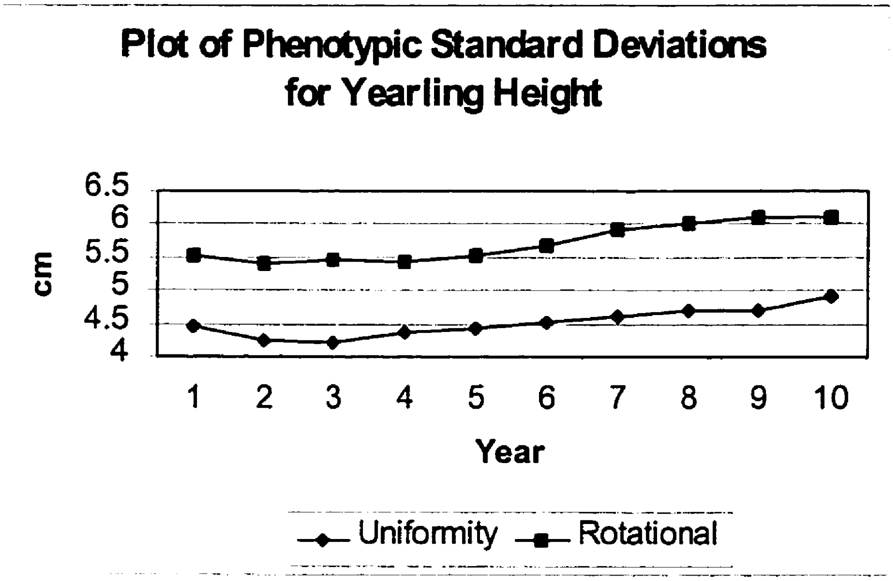

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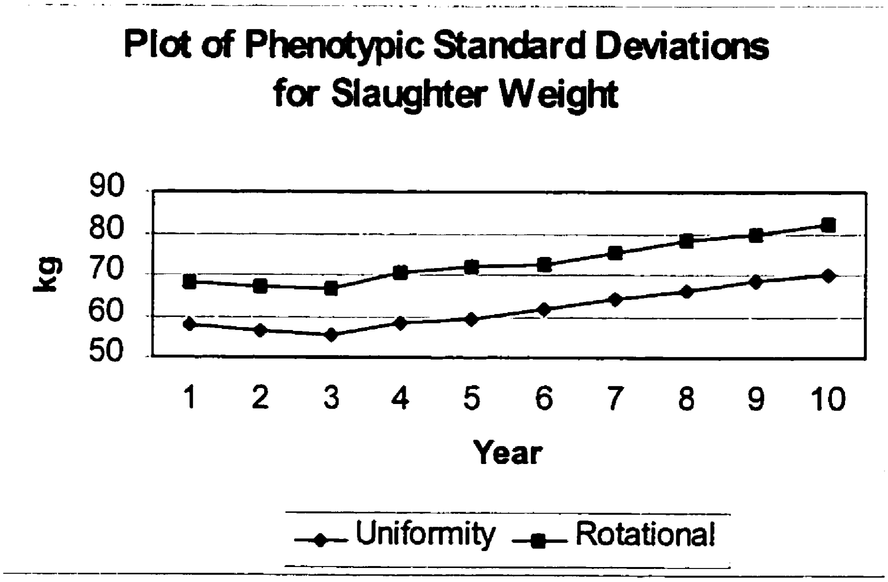

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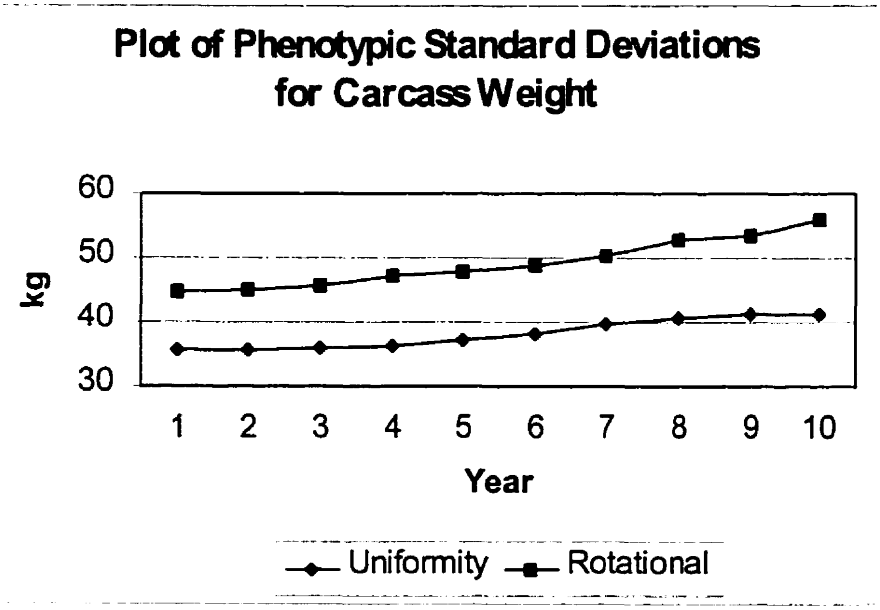

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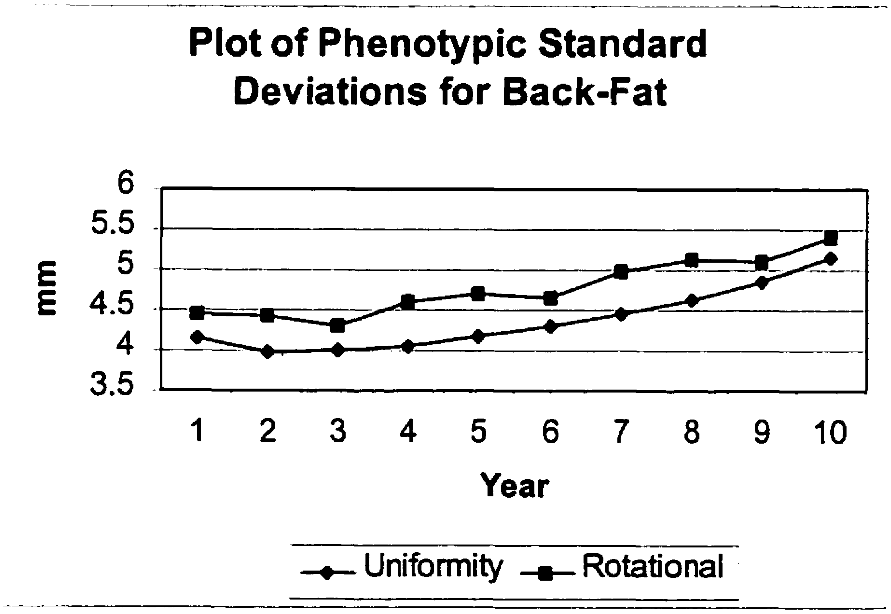

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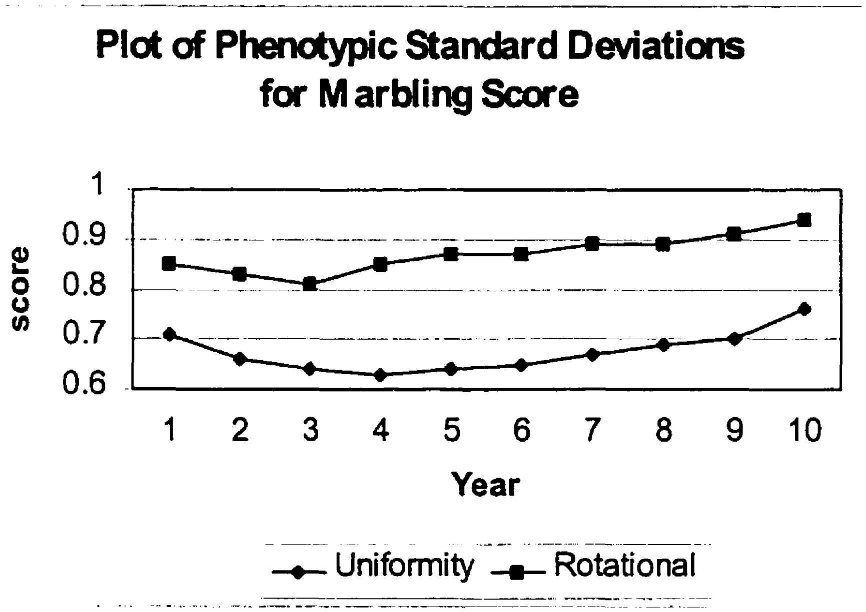

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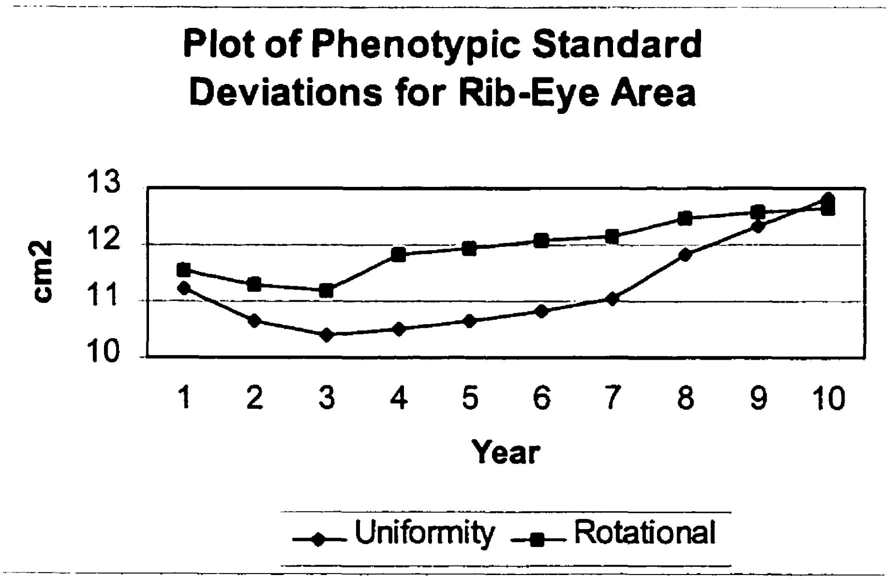

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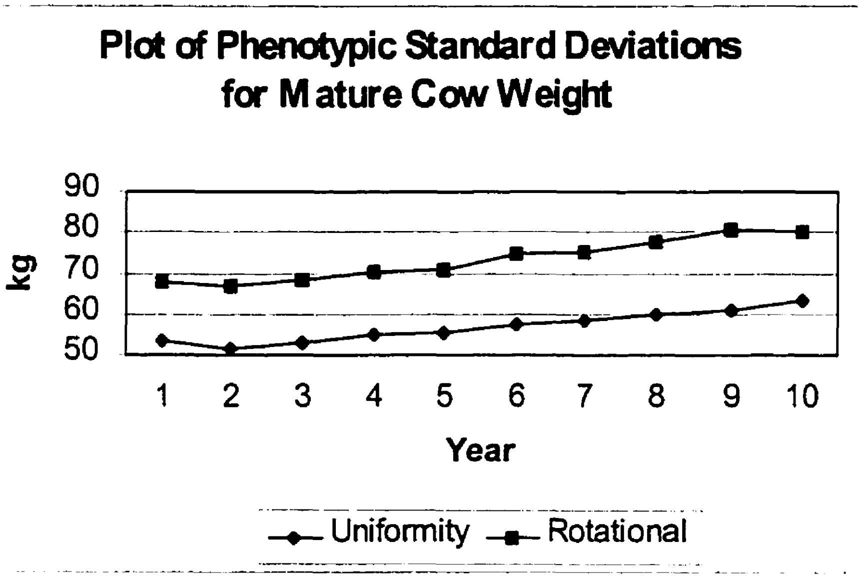

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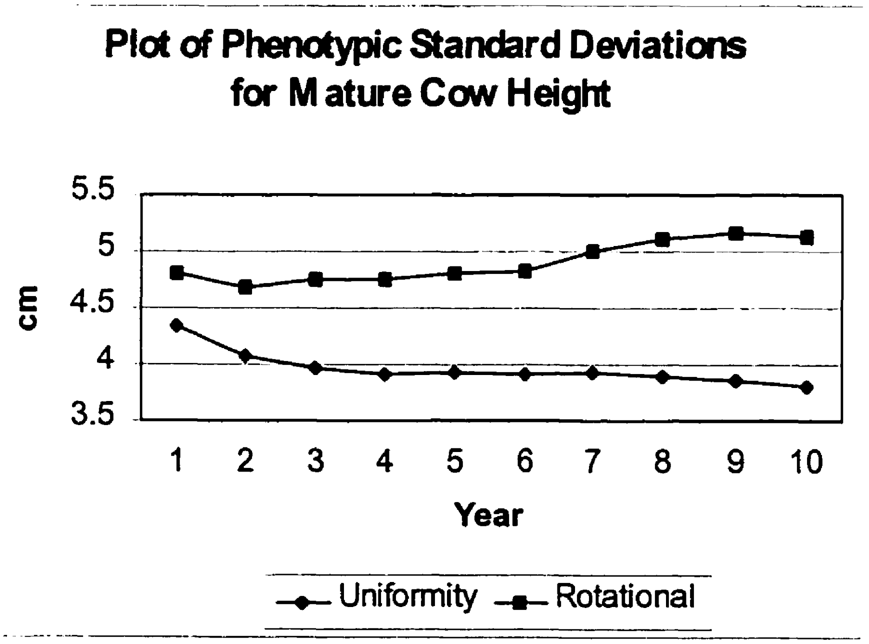

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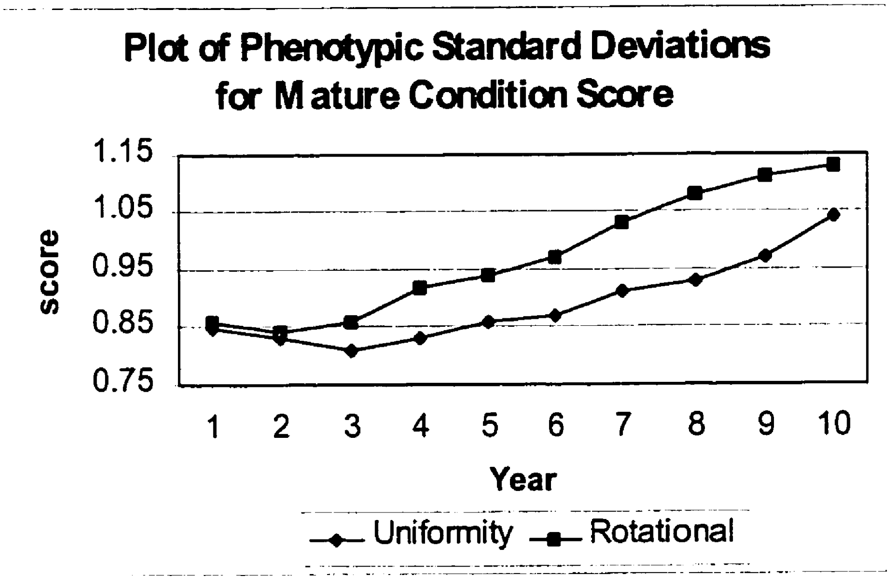

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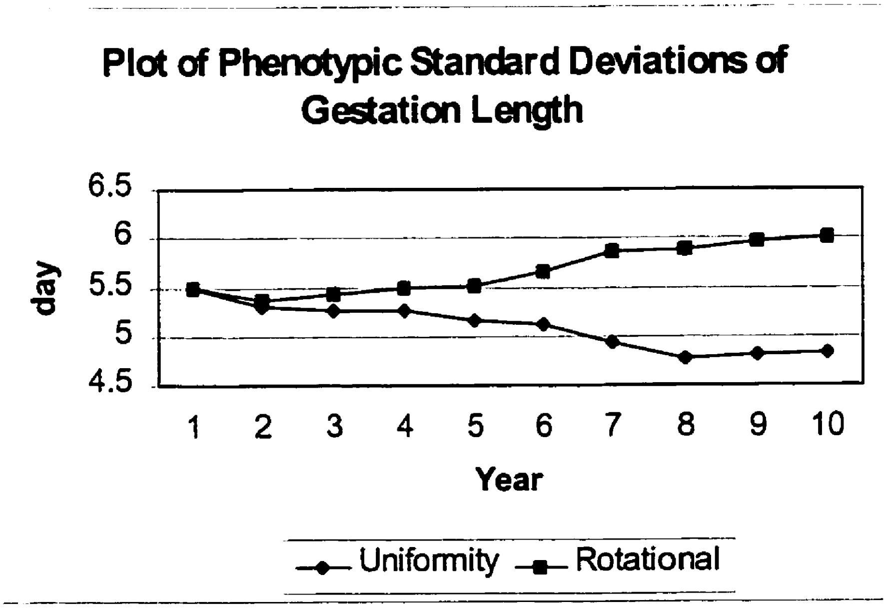

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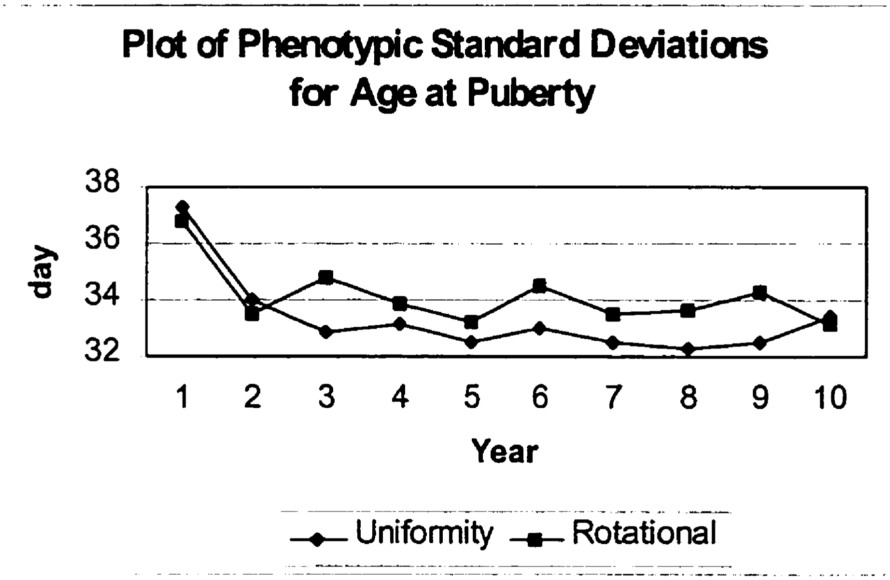
Plot of Phenotypic Standard Deviations for Age at Puberty
38
36
34
32
day
1
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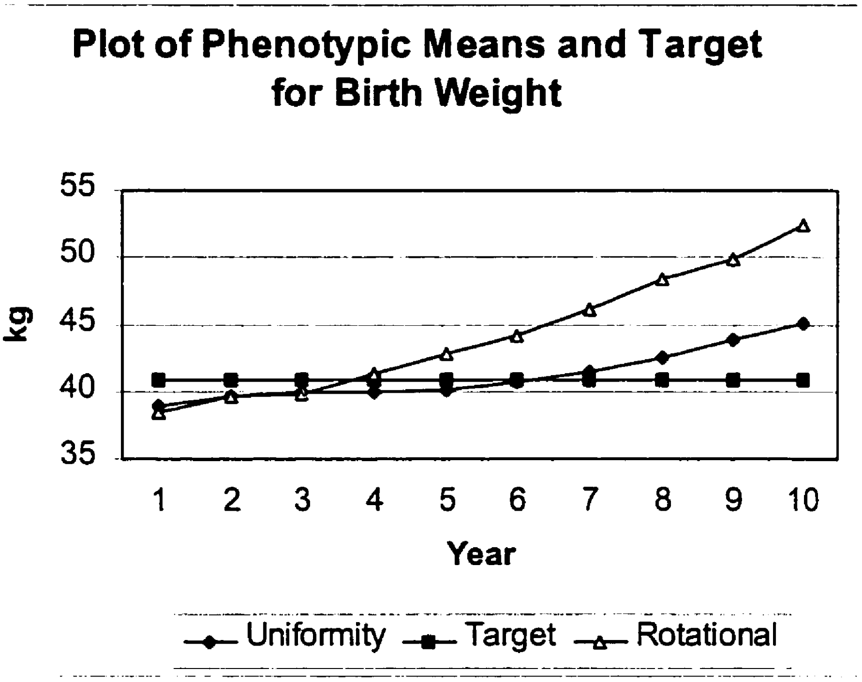
3
4
5
6
7
8
9
10
Year
Uniformity
Rotational

Figure 5.16



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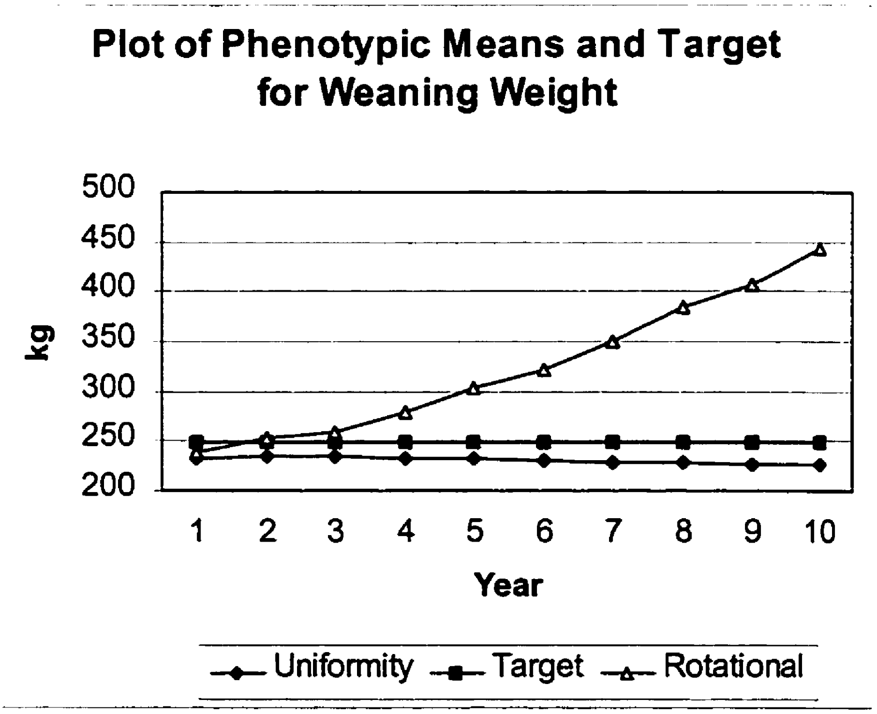

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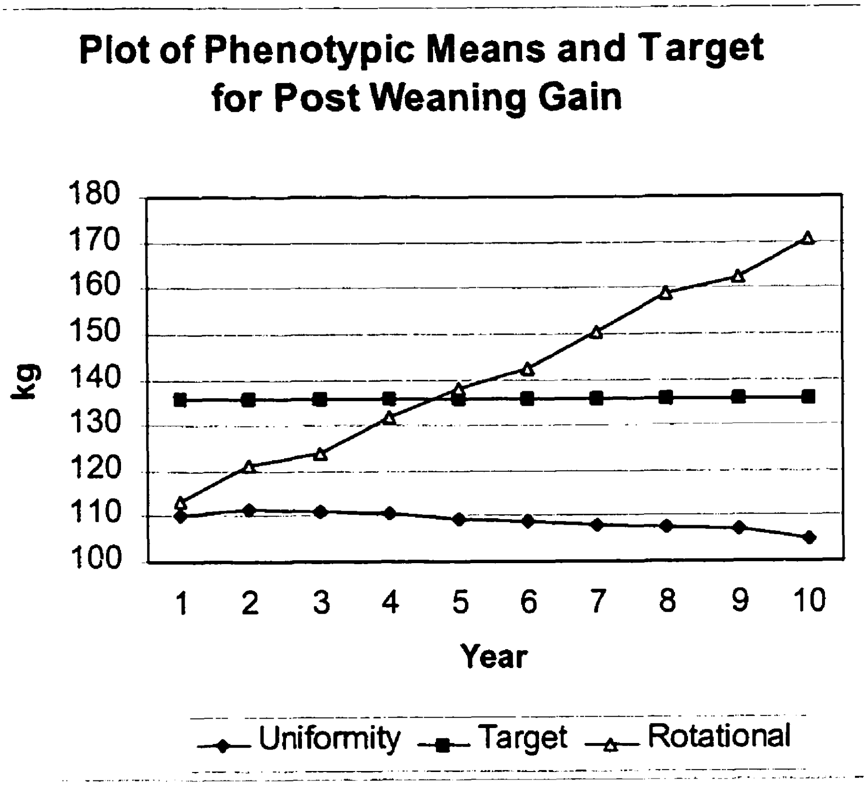

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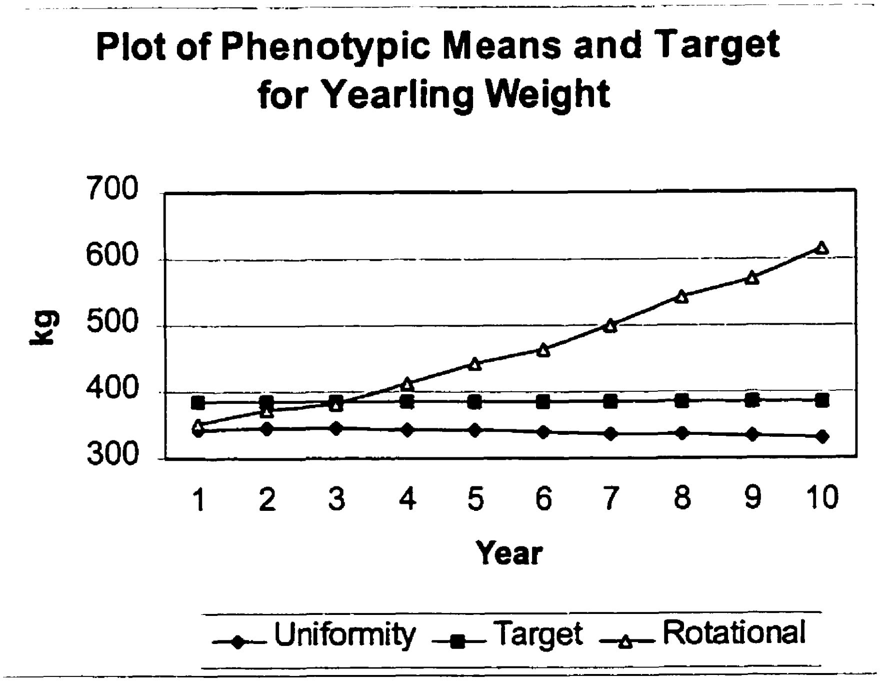

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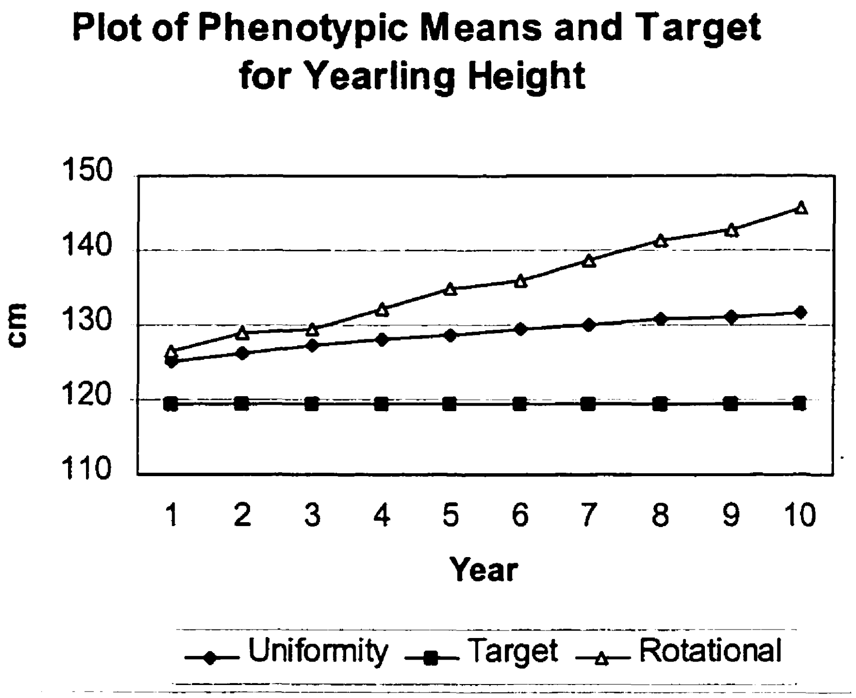

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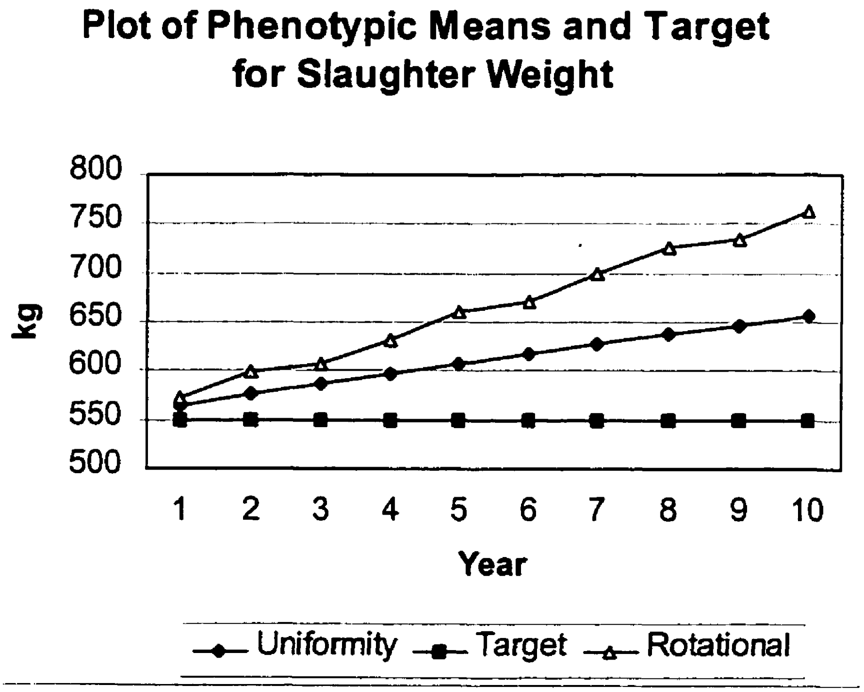

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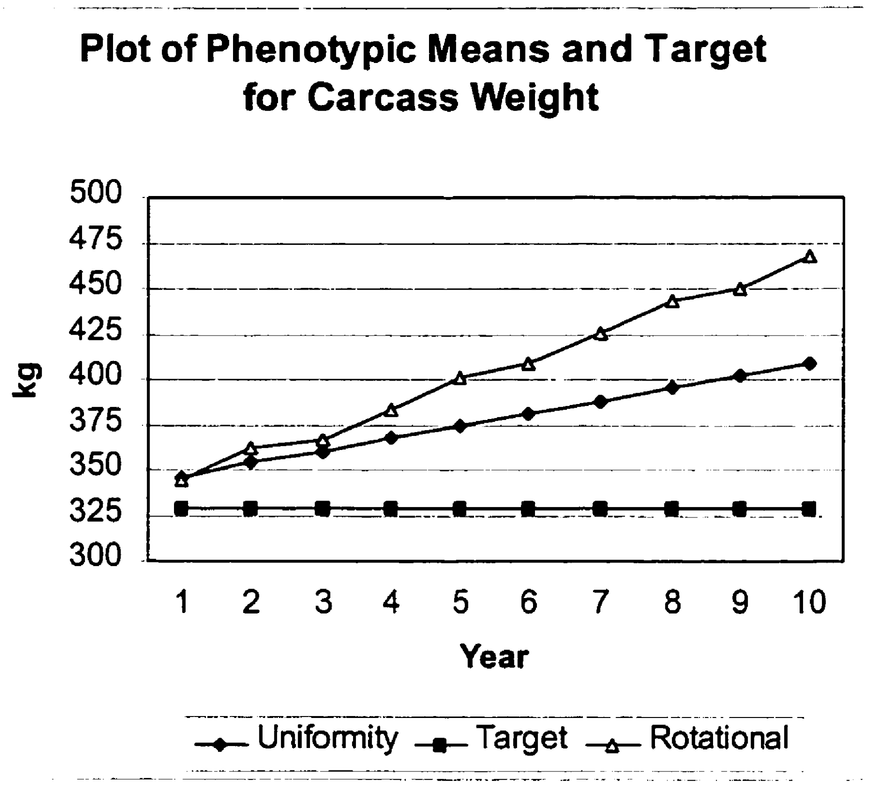

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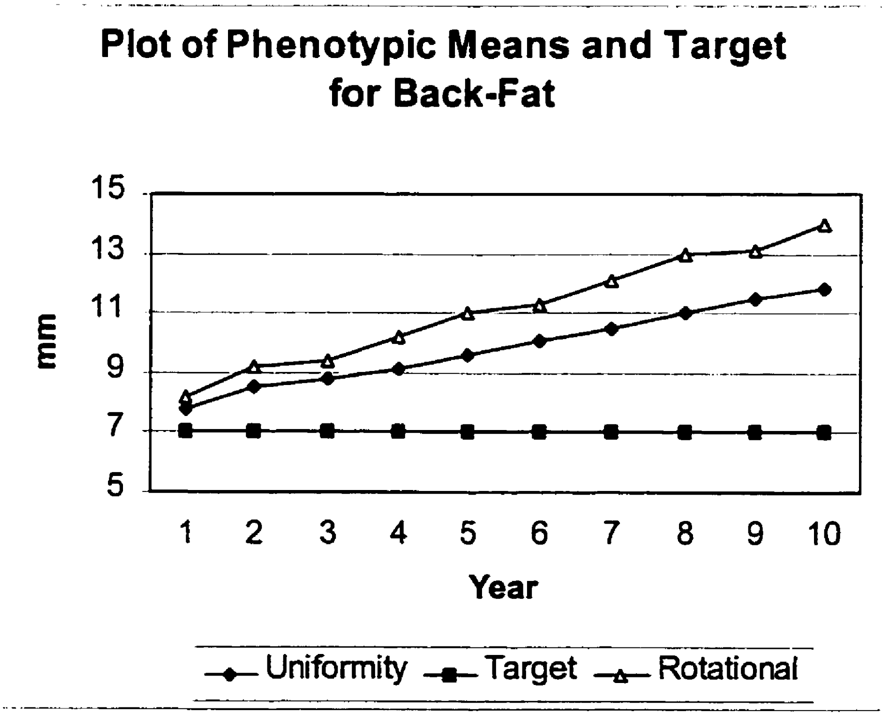

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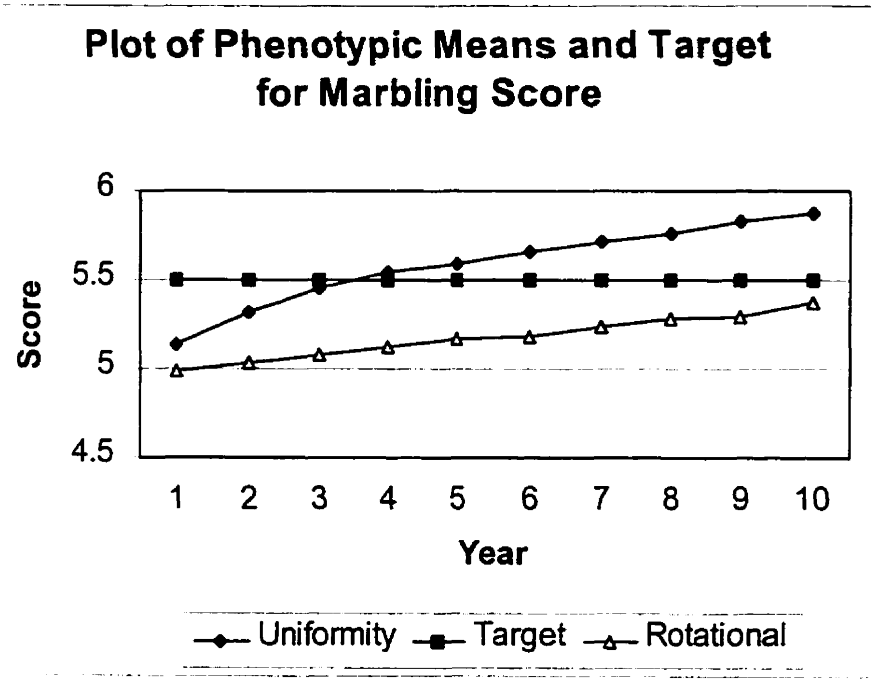

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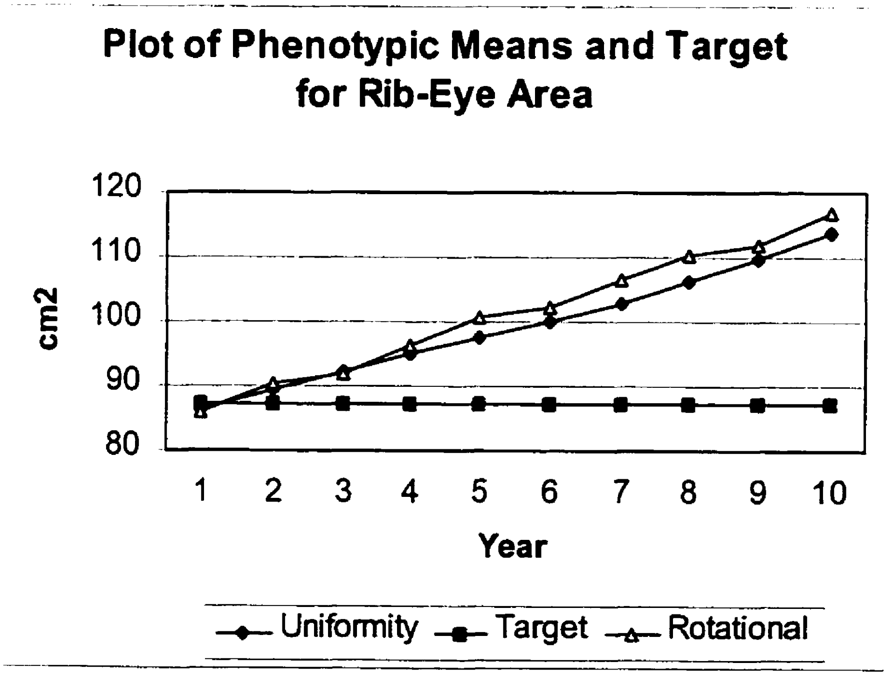

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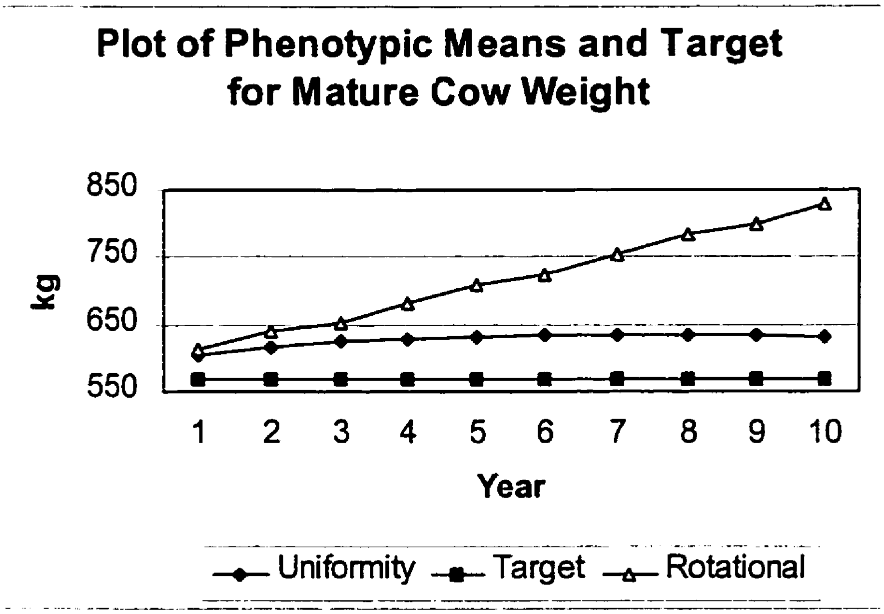

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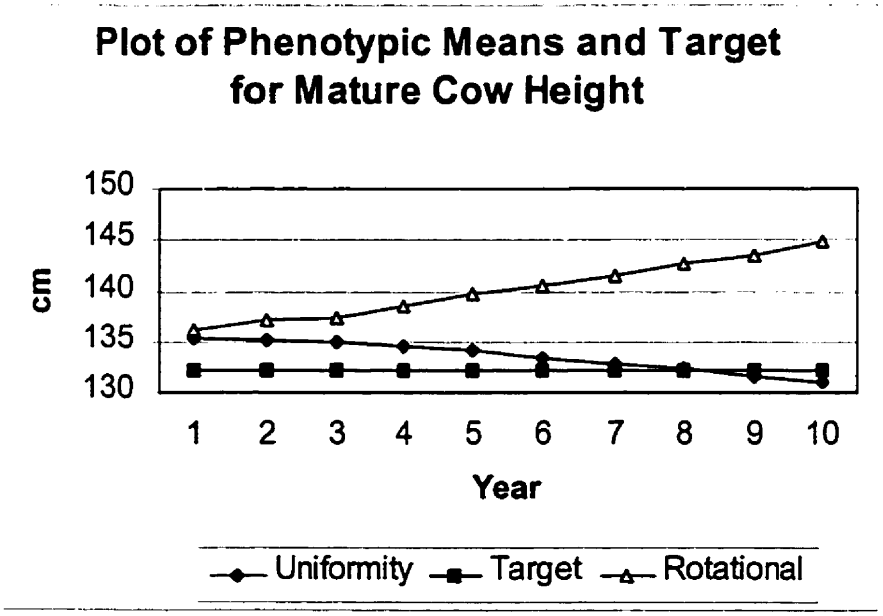

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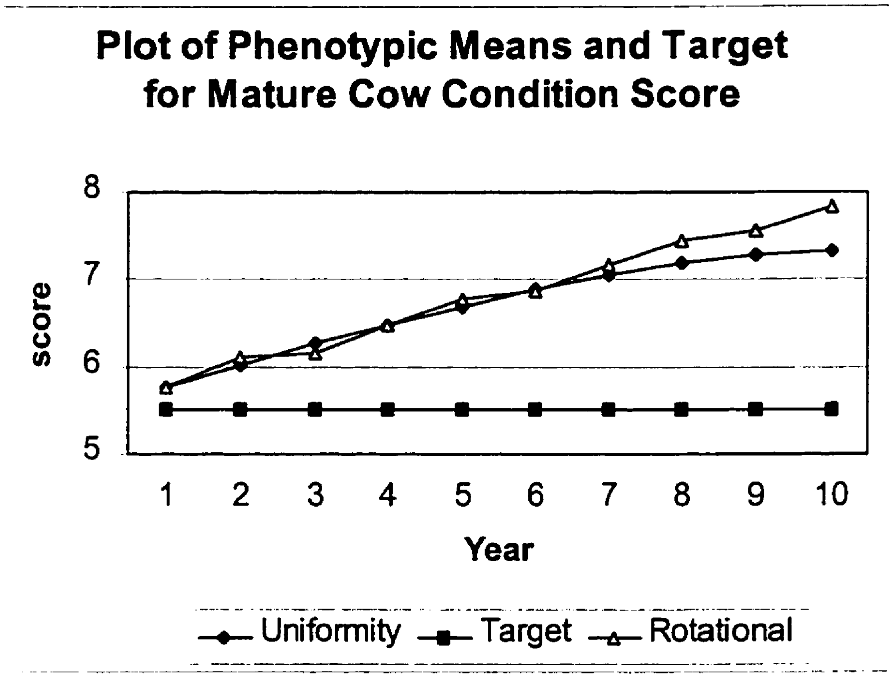

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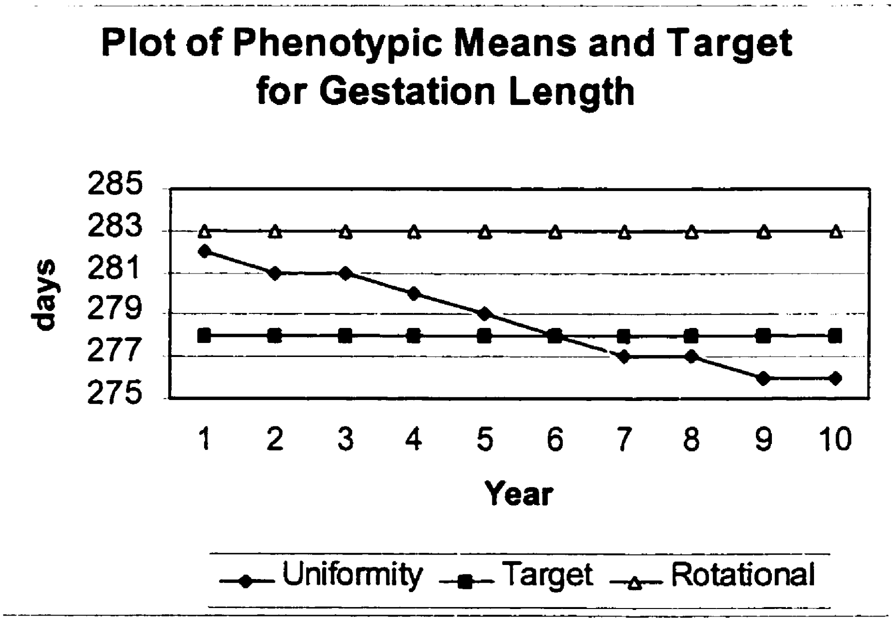

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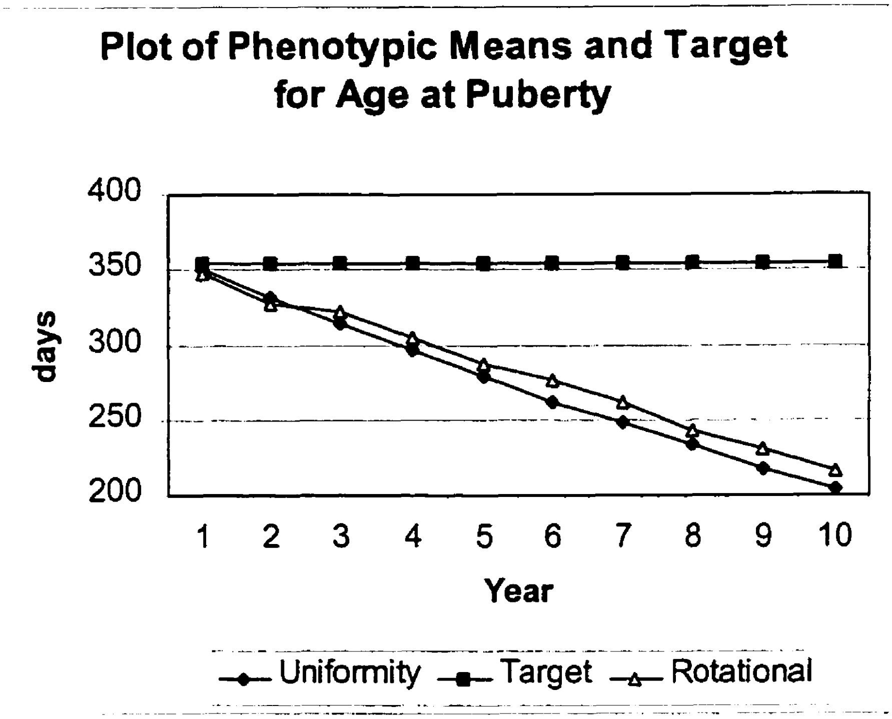
Plot of Phenotypic Means and Target for Age at Puberty
400
350
300
250
200
days
1
2
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5
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7
8
9
10
Year
Uniformity
Target
Rotational

Figure 5.31

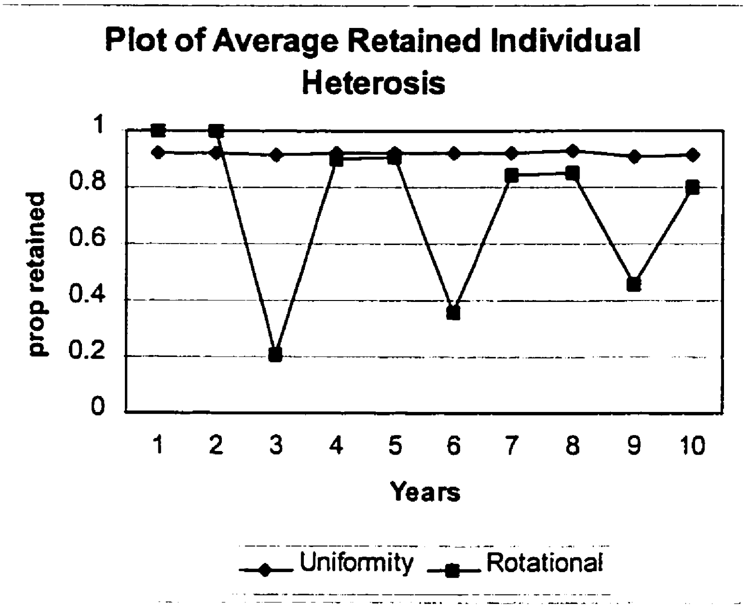
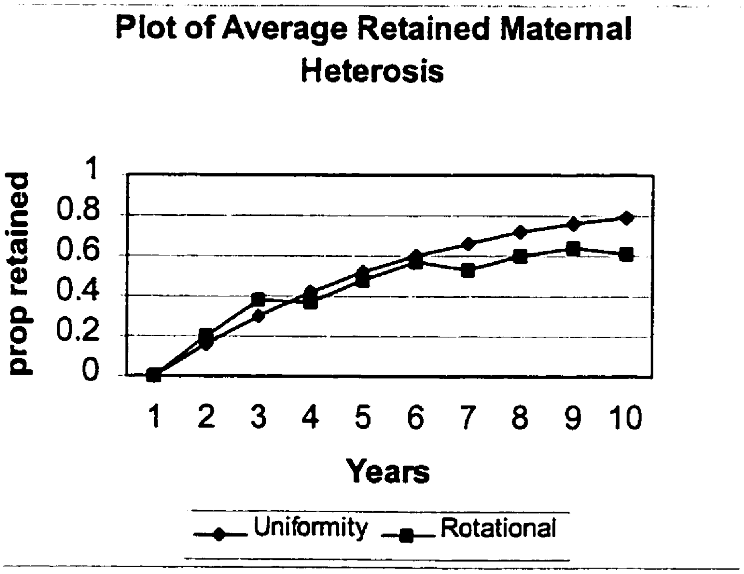


Figure 5.32



Conclusions

6.0 General

In general the uniformity strategy produced improved phenotypic uniformity as well as a viable culling and replacement system in comparison to a 3-breed rotational crossbreeding system. The uniformity strategy was also designed to deal with current trends in seedstock production, where composite bulls are being produced. As such, composite bulls were targeted for utilization and were proven to be effective in achieving uniformity and meeting targets.

The stochastic simulation was effective in investigation of the differences between the strategies. Replicates, although randomized, produced additional comparison power but actual replicate effect was not significant in analysis of the results.

6.1 Terminal Calf Production

The first objective of this study related specifically to studying the uniformity strategy in comparison to the rotational strategy for terminal calf production. Complementarity was utilized in an attempt to achieve phenotypic performance targets. The results for the phenotypic performance targets compared to means obtained illustrated conclusively that targets for terminal calf performance could be successfully achieved.

Phenotypic uniformity as measured by the standard deviation of phenotypic production was shown to be better (lower) increasingly over time for most traits in the uniformity strategy compared to the rotational strategy.

Individual retained heterosis in progeny produced from the uniformity strategy was at least equal to the level produced from the rotational strategy.

In general, the uniformity strategy was able to match the 3-breed rotational strategy in terms of the key components of retained heterosis and utilization of complementarity. The uniformity strategy produced significant improvement in areas where problems with 3-breed rotational strategies have been identified which are phenotypic uniformity and precise targeted production.

6.2 Cow Herd

The second objective of the study related to improving the uniformity of the cow-herd as well as improving reproduction and utility by creating smaller and better-conditioned cows than the 3-breed rotational strategy. Although a slightly smaller cow size was targeted in the uniformity strategy, the strategy was not designed specifically to model an F1 terminal cross system (Cartwright, 1970; Gregory and Cundiff, 1980) where maternal F1's are selected to be small and large terminal sires selected as mates to produce terminal progeny. The similarities between these strategies is only related to smaller cow size, which for the uniformity strategy was part of the selection objective for the association between cow size with annual cow costs

A criticism of rotational strategies is that the female replacement system is slow to achieve breed composition equilibrium and, therefore, implementation time is long. Breed composition fluctuations in individual cow breed composition can result in poor phenotypic uniformity. The female replacement system of the uniformity strategy was designed to create a difference between the breeding objective of female replacement and terminal production. This system was intended to overcome the issue of implementation time by providing immediate terminal progeny uniformity benefits as shown previously (section 6.1). The splitting of the breeding objective into replacement and terminal production was accomplished by creating a nucleus group of cows to be bred to AI sires and natural service terminal sires. The replacement female nucleus produced favorable results for uniformity for most traits and was therefore an improvement over the rotational strategy female replacement system. Phenotypic mean target achievement was less successful than planned. The main source of the problem with target achievement did not relate to the uniformity strategy specifically, but occurred due to the AI sire selection method.

The results of the nucleus system indicated that the level of maintained maternal heterosis was at least equal to the rotational strategy.

A component of the female replacement strategy was to utilize an economically optimum voluntary culling rate, tied to the ability of retained females on average to produce a profit, which was 6 years of age. The optimum age was achieved by the uniformity strategy while the rotational strategy produced an average age of dam of 5.3 years according to Melton and Colette (1993) criterion. On average, replacement females from the uniformity strategy returned a profit, while replacement females from the rotational strategy did not. In order to achieve the optimum average age of dam, the uniformity strategy ended up with a much lower voluntary culling rate, which affected the rate of genetic change.

6.3 Future Research and Implementation Requirements

An area where future research is required, is the selection method for choosing AI sires if commercial cow calf producers are targeted as potential clients. The current industry process of selecting bulls high in percentile rank and genetic merit for growth traits was demonstrated to be less than ideal for targeted phenotypic production. If commercial clients are considered an area of growth for AI semen usage, efforts to understand their precise genetic needs must be developed and implemented.

Another potential solution for matching AI sire genetics to commercial herd needs would be the creation of commercial cow-calf alliances or cooperatives, where the purchase and distribution of genetics that is precisely suited for members. Many logistic problems could potentially exist, however, uniformity of production and product at highly desired phenotypic levels are possible as shown in this study.

The precision of selecting and mating in this study would be improved if economic weights and selection indexes were developed instead of the method of ranking with equal weight as utilized in this study. However, the index weights would need to be customized for individual herds and account for the non-linear target optimums that are part of the beef industry economic production environment. Indexes that assume linearity with unrestricted genetic gain for any trait or group of traits will provide inferior long term economic performance unless the production and marketing system are changed to accommodate the linear assumptions of the index.

Implementation of the uniformity strategy will rely on continued investment and development of data recording and genetic evaluation systems. A critical component of the uniformity strategy was knowledge of herd phenotypic production, individual animal identification and across breed genetic evaluation.

The current trend for composite bull production would need to continue to increase if the uniformity strategy was implemented. As with AI sire selection, designing composite programs that specifically match commercial production needs would be required.

Purebred breeding objectives will need to maintain and embellish breed specific characteristics to provide the genetic resources to produce desirable composites or purebreds as required. Purebred breeders will need to position their breed as leaders in providing genetic resources for composite production, and subsequently, success will be determined by the percentage of commercial cattle containing their breed.

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Appendix I

8.0 Adjustment of Herd Means

An error in the simulation programs was discovered during analysis of herd means compared to phenotypic performance targets. The error occurred because after each mating new progeny were created and the fixed effects of age of dam and heterosis were correctly added to the phenotype, however the phenotypic means from the previous year's progeny were not adjusted back for the mean levels of these fixed effects before addition. This created an effect were the average fixed effect levels for age of dam and heterosis were added to the mean herd performance for each calf crop every year concurrently. The amount incorrectly added was systematic each year throughout the simulation. To adjust for the error the means were adjusted by removing the proportion of the mean differences between years that was calculated incorrectly. This generally produced adjusted means that were not very different for the uniformity strategy because of the target sire estimation (section 4.2.7) as utilization. The rotational strategy means however were at much more appropriate level of progress.

The problem was limited to the phenotypic means for the herds and because it was systematic had no effect on the phenotypic variation about the means. The BLUP evaluations absorbed the inflated means, again because they were systematic, into the herd-year fixed effect solution. Therefore there were no across breed genetic evaluation issues due to the error. In terms of mate selection, the rotational strategy was unaffected by the error because the objective was for maximum total maternal weaning gain and thus no use was made of the phenotypic means. The uniformity strategy did however utilize the herd means to create the target sire (section 4.2.7). The only trait for the uniformity strategy where the adjustment procedure for the means had an effect was for post weaning gain. Post weaning was affected because the target objective for the study was yearling weight from which weaning weight and birth weight are subtracted each year to create a post weaning gain objective. Consequently errors in age of dam by sex of calf adjustments and heterosis both maternal and individual associated with birth and weaning were removed from the post weaning gain target each year. The result was that the post weaning gain objective was estimated to be smaller than was needed due to the fixed effect error.