GENETIC AND ECONOMIC SIMULATION MODELS DEVELOPING SPECIALIZED TERMINAL AND MATERNAL LINES OF BEEF CATTLE IN A NUCLEUS BREEDING PROGRAM IMPLEMENTING EMBRYO TECHNOLOGIES

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ABSTRACT

GENETIC AND ECONOMIC SIMULATION MODELS
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A genetic simulation model was developed to compare rates of genetic improvement attained by selection within specialized sire and dam lines and selection in a single line for both terminal and maternal traits. An economic simulation model was used to compare the economic impact of genetic response attained in the specialized sire and dam lines, the single multi-purpose line, and a commercial beef herd bred by artificial insemination (A.I.). A Novel breeding scheme was also defined, in which embryos from a terminal line were implanted in recipient cows from a dam line. A Non-specialized (NS)

breeding scheme, in contrast, was defined as one in which embryos from a single line were implanted in recipient cows from the same single line.

Genetic responses in terminal and maternal traits in specialized sire and dam lines, respectively, were significantly higher than in single line selection. The rates of genetic improvement in both specialized and single lines of beef cattle in a nucleus breeding scheme implementing multiple ovulation and embryo transfer (MOET) were significantly higher ($P<0.01$) than in an *in vitro* embryo production (IVEP) nucleus.

Comparison of MOET schemes with commercial A.I. showed that embryo costs must be reduced 9%, 34%, 31% and 32% for the Novel, and Non-specialized (NS) schemes (with 80/20, 70/30 and 60/40 relative emphasis on terminal and maternal traits, respectively) from 1998 costs to be economically competitive with a commercial A.I. program. It was concluded that, in spite of the genetic superiority of embryos and recipient cows from specialized and non-specialized breeding schemes, current high costs were a limiting factor for producing market animals. Production costs may be decreased in the future as technology advances.

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My PhD program will end a long term of self development, learning process and growth. It started with some undergraduate courses, being followed by my Master degree. It is time for closing this door and opening another one, where I can be of use to society and put in practice what I have been learning and investigating.

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CHAPTER 1

1.0 GENERAL INTRODUCTION

The beef cattle industry has been evolving and changing over centuries. Its scope includes the various segments that make up an overall management program, ranging from breeding, feeding, and marketing cattle with the eventual processing and merchandising of retail products to consumers (Taylor,1994).

Market animals returning maximum profit over time is the goal of commercial meat production. This goal is concerned with rate and efficiency of production as well as quality of product, since long-term consumer demand is determined by price and desirability. From the standpoint of animal expression, individual productivity and quality are paramount.

Most commonly, specialized seed stock herds, usually with pure breeds, provide sires used in commercial herds. Commercial herds normally produce their own replacement heifers required for market-animal production and to this extent perform part of the seed stock function. Under this production system, the genetic content of a commercial herd is determined by the succession of sires used, implying that seed stock producers become the primary source of genetic improvement. The genetic improvement of beef cattle, at this upper level of the industry, is essential for beef cattle commercial operators to produce the cattle preferred by the consumer the most profitably.

This thesis looks at using specific breeding systems with specialized breeding objectives to develop specialized lines and assesses the use of various reproductive technologies within these systems.

1.1. Breeding system

The choice of breeds and breeding system has traditionally been made independently of the choice of individuals within breeds. Thus, promising breeds are first identified based on additive genetic merit for important traits.

Many different breeds are available to the commercial beef producer. These breeds represent a wide variety of genetic types. Each breed has strengths and weaknesses, as well as superior and inferior individuals.

The diversity of breeds and emphasis on different traits in selection programs has generated several biological types which can interactively be used in meeting commercial breeding objectives.

Some breeds have been selected more intensively for traits like lean growth and carcass quality. Breeds of that class are identified as terminal breeds. On the other hand, maternal breeds are recognized to have strengths in cow fertility, mature size, milk yield and longevity. Taking as an example, the Charolais breed is widely acknowledged to excel in the areas of lean growth and carcass quality. Therefore it is proposed that the breeding goal for the Charolais breed include only those traits affecting lean growth efficiency, carcass and meat quality; growth rate, backfat thickness, feed efficiency, etc. This is very logical since the Charolais breed, under this strategy, would not contribute any genetics to the maternal side of the production equation. On the other hand, the Hereford breed, is recognized to have strengths in cow fertility, mature size and longevity areas and is an ideal breed in which to select for the maternal aspects of beef production.

Breeding systems are designed to optimize the additive contribution of the component breeds and the realized contribution of heterosis and complementarity (Hamilton and Wilton, 1987). A vast amount of research has shown that planned crossbreeding can produce more pounds of beef from the same number of brood cows, at a lower cost per pound (Gregory and Cundiff, 1980; Lamb et al. 1992).

Basic systems of utilizing crossbreeding in beef cattle are known as rotational crossing systems. They utilize hybrid vigor but largely sacrifice benefits of complementarity. A system of crossing F_1 cows to a third breed utilizes both hybrid vigor and complementarity, but it is a more complicated system because it has some inefficiencies associated with producing the F_1's (Peters, 1969). Selection of purebreds for use in crossbreeding should stress traits desired in the crossbred and may include some attention to general and specific combining ability. For different systems of crossbreeding, different breeds and different selection goals should be considered or there may be conflict in desirability of traits.

Selection programs are developed to allow continued genetic progress toward some predefined breeding objective within the resulting populations. Cartwright (1969) argued that selection for general purpose cattle is on a decreasing rate. Limitations are placed on mature size and milk production.

Emphasis was given on development of specialized dam lines and/or breeds with focus on relatively small size, early maturity, desired milking qualities, freedom from calving difficulties, female fertility (perhaps twinning) and general soundness and adaptability (Cartwright, 1969). Selection on specialized sire lines and/ or breeds focuses on high rate of gain, efficient feed conversion, high cutout percent, tender and palatable beef (Cartwright, 1969). These traits are those desired in a feedlot steer.

Trends towards special purpose beef cattle indicate the feasibility of considering coordinated or integrated production systems. Both vertical and horizontal integration or cooperation of beef production has the effect of shifting emphasis from the production of individual cows, bulls or steers to production on a herd output/input basis, and consequently changing selection criteria.

1.2 Breeding Objectives

The objective of beef cattle improvement programs is to determine which individuals within a herd are of superior genetic value. In order to attain this goal, it is necessary to define breeding objectives, and determine which traits are economically important to achieve maximum profit at enterprise level. Maximizing profitability involves multiple inputs and outputs and achieving a balance among them. The traits included in the breeding objective should be selected by their importance, independently of their difficulty and cost (Ponzoni and Newman, 1989).

Cartwright (1970) stressed the need to use variation among breeds for maternal and terminal traits, recognizing the possibility of antagonisms between sire and dam. Recently, simulation models have been developed to analyze the economic importance of 21 traits on the whole production system (Koots, 1994). There is, however, still a need for a simulation model that accounts for differences among biological traits on sire and dam lines and analyzes their genetic and economic feasibility in a nucleus breeding herd implementing reproductive technologies.

1.3. Reproductive Technologies

The goal of producers using reproductive technologies is to increase reproductive potential. The use of artificial insemination (AI) and multiple ovulation and embryo transfer (MOET) has proved that these new technologies can be used to create substantial increases in the rate of genetic improvement of a population (Land and Hill, 1975; Smith, 1988). A drawback of the use of these technologies is that they have the potential to increase the rate of inbreeding. Among the approaches devised to prevent inbreeding, one has to consider the selection for an index that takes account of inbreeding as well as genetic merit. Woolliams and Thompson (1994) viewed selection and inbreeding as two different aspects of a process that can be described in terms of the matrix of relationships among all members of a population.

1.4. General Objectives

The objectives of this thesis were:

1) To develop and study beef breeding programs that take advantage of the difference among breeds/lines including separating maternal and terminal characteristics.

2)To study genetic improvement structures that make use of recently developed reproductive technologies as a tool for accelerating genetic progress.

3)To evaluate the economic feasibility of these breeding systems and reproductive technologies.

Chapter 2 presents a review of the literature on (1) development of specialized lines; (2) embryo transfer and related techniques; and (3) nucleus breeding programs. The objective of chapter 3 was to comparatively study the implementation of a beef nucleus breeding program for selection in a single line versus specialized lines implementing MOET or in vitro embryo production (IVEP).

Chapter 4 describes a computer model of commercial and specialized beef production systems and compares scenarios representing specialized production systems versus a commercial A.I. beef herd using terminal crossing. This study also determined if market animals could be produced economically considering embryo costs. A general discussion of the results and implications of the studies is presented in the final chapter.

CHAPTER 2

LITERATURE REVIEW

2.1. NOVEL BEEF BREEDING PROGRAM

The genetic improvement of commercial livestock involves selection among available breeds, choice of a breeding system, and ongoing selection of individuals within breeds or crossbred types. Breeds can be considered as lines within a species that differ in gene frequencies (Miller, 1996). These differences in frequency are usually a result of emphasis on different traits in selection, either human influenced or natural selection if the breeds originated from different geographical locations. Breeds are recognized for their contribution to the overall profitability of the commercial beef enterprise. Some breeds have been selected more intensively for traits like lean growth and carcass quality. Breeds of that class are identified as terminal breeds. On the other hand, maternal breeds are recognized to have strengths in the areas of cow fertility, mature size, milk yield and longevity. Crossbreeding programs involving a terminal sire in the commercial (maternal) herds are a common practice in beef production. A problem occurs on the maternal side when lean growth, carcass and meat quality aspects enter into the picture. Since the slaughter calf produced by the maternal line cow carries one-half of her genetics, the maternal line then has a large influence on lean growth efficiency, carcass and meat quality genetic potential of the calf and hence the final product and the success of this system. The emphasis of selection goals for either sire lines or dam lines, in different herds, shifts the beef industry from a general purpose to specialized strategy for both breeds/lines and breeders (Cartwright, 1970).

2.2. NEW REPRODUCTIVE TECHNOLOGIES

New reproductive technologies, such as multiple ovulation and embryo transfer (MOET), in vitro embryo production (IVEP), embryo splitting, cloning, sexing of semen and embryos, as well as other technological procedures, are being developed to study biological embryo development and are consequently opening new opportunities for genetic improvement programs (Smith, 1984; Smith, 1989; Barnes et al. 1991; Dekkers, 1992; Betterigde, 1992; Betteridge and Rieger, 1993; Wilmut and Campbell, 1994; Hasler et al. 1995; Lohuis, 1995; Thibier and Nibart, 1995; Rutledge, 1996).

2.2.1. EMBRYO TRANSFER FOR GENETIC IMPROVEMENT

Embryo transfer and related techniques have been the focus of work on the development of breeding strategies to accelerate genetic progress in cattle and sheep, by decreasing the constraints imposed by a rather low female reproduction rate. Early studies on the use of MOET in cattle nucleus breeding schemes (Land and Hill, 1975; Nicholas, 1979; Nicholas and Smith, 1983; Colleau, 1986; Juga and Maki-Tanila, 1987; Smith, 1988; Ruane, 1988; Woolliams, 1989; Keller and Teepker, 1990; Dekkers, 1991; Betteridge and Rieger, 1993; Lohuis et al. 1993; Villanueva et al. 1994) demonstrated the potential of reproductive techniques for cattle genetic improvement. The principles of multiple ovulation and embryo transfer (MOET)are for most simple procedures and enable a valuable cow to have more genetic offspring than nature intended. MOET can add to the response rates with current breeding systems by allowing for more intense and accurate selection, since there are more records per elite animal for genetic evaluation. Embryo transfer also affects generation intervals, since there are more replacement females available which can raise the culling rate and lower the generation interval. Smith (1988) reviewed and discussed the literature on MOET in the genetic improvement of sheep and cattle, and pointed out advantages that would occur if different breeding schemes were adopted. The highest genetic response rates were cited to be obtained with nucleus breeding-selection units bred by MOET. Adult MOET allowed for moderate gains in genetic response, while juvenile MOET yielded higher gains. Smith (1988) concluded that effective MOET using juveniles was required to fully implement the possible advantages of MOET in genetic improvement. Wooliams and Smith (1988) gave an example of an adult scheme in which cows had 8 progeny by 3 years of age, and a herd with only

512 recorded cows could achieve a rate of improvement of 2.4% of the mean per year, compared with 2.0% per year in a large conventional progeny testing scheme.

Although MOET produces extra genetic gain by increasing the reproductive capacity of females, the details of its implementation (selection on pedigree or sib information versus progeny testing, closed versus open schemes, centralized versus dispersed nucleus) in practical breeding programs are still unclear. Teepker (1990) indicated that some flexibility on operational parameters (i.e., embryo recovery and transfer techniques, sire and dam usage, etc.) is needed before practical recommendations of breeding system structure can be made. Further theoretical work is needed to fully understand the potential of MOET, and the relationship between genetic gain and breeding schemes, especially in beef cattle breeding.

2.2.2. IN VITRO EMBRYO PRODUCTION (IVEP)

Scientific advances in embryo transfer have shifted this procedure from technical development to commercial potential in the *in vitro* maturation and fertilization of oocytes (IVEP)(Betteridge, 1992). This technology opens the possibility of producing large numbers of embryos, with substantial advantages in the rate of genetic improvement. IVEP can be an alternative to MOET schemes by decreasing generation interval, and therefore offering the potential to increase the rate of genetic improvement. With IVEP, time constraints disappear, since matings are done in the laboratory. Lohuis (1995) investigated the genetic implications of IVEP in a dairy nucleus and suggested benefits higher than those expected for MOET programs: a 20%-25% faster rate of genetic improvement than with a progeny testing scheme. It is essential that before MOET or IVEP is adopted, potential benefits and risks, both genetic and economic, are considered. To be able to make this decision it is necessary to obtain realistic views on both technologies and determine their effectiveness, both now and in the future.

2.3. NUCLEUS BREEDING PROGRAM

Nucleus breeding schemes have been advocated to capitalize on embryo transfer technology. Nucleus breeding schemes are breeding programs involving elite groups, the best males and females combined in a nucleus (Bourdon, 1997). In a closed nucleus scheme germ plasm flows in only one direction. Animals produced in the nucleus are used in cooperating herds. In an open nucleus scheme a comparison is made of the stock in the nucleus to the best animals available from populations being tested and ranked on the basis of BLUP. This approach reduces risk of inbreeding (Burnside and Smith, 1994).

Studies focusing on the consequences of opening dairy nucleus on the male side by selecting sires across those available within and outside the nucleus showed to be advantageous in relation to a closed nucleus (Colleau, 1986; Dekkers and Shook, 1990). The benefit of opening a dairy nucleus on the female side to cows from the commercial population is, however, less clear. Opening the nucleus resulted in a reduction in genetic variance because of increased female intensity and accuracy of selection (Dekkers, 1992). This resulted in a substantial decrease in accuracy in the nucleus and a large decrease in genetic selection differential for males, which dominated the increase in selection differential for females. Lower genetic gains for open nucleus schemes are a result of the effects of prior selection on genetic variance and accuracy (Dekkers, 1992).

A nucleus breeding scheme can be defined logistically according to physical allocation of the breeding females as a centralized or dispersed nucleus. In a centralized nucleus herd, elite animals are managed in a group within a single location. Centralized nucleus schemes have the advantage over dispersed nucleus since environment is controlled and female selection is more accurate, but the size of the nucleus limits selection intensity and can lead to inbreeding problems (Lohuis, 1995). A centralized nucleus offers the opportunity to record important economic traits, such as feed efficiency, and include them in a breeding objective. Although centralized nucleus schemes can exercise greater control and provide improvement for more traits, the associated costs can be quite high.

Dispersed schemes are strategies in which MOET is performed on elite females to produce large full and half-sib families, which are then dispersed in the general cow population. Dispersed nucleus schemes can also allow for larger population sizes and resulting lower inbreeding rates. Dekkers (1992) considered dispersal of the nucleus in dairy breeding programs. Meuwissen (1989) demonstrated that a centralized nucleus herd does not have advantages over use of MOET on bull-dams in a progeny test, because the latter leads to development of a dispersed nucleus. Nevertheless, there are several advantages to utilization of a centralized nucleus scheme. Lohuis (1995) argued that in countries with well established and unbiased national recording programs, dispersed schemes offer comparable rates of genetic improvement and are easier to finance. The benefits from recording animals outside the nucleus are often marginal when secondary traits are included in the breeding goal (Meuwissen, 1991).

2.4. SYNTHESIS

Practical techniques for embryo transfer in farm animals were developed about 20 years ago and since then they have been applied increasingly in animal breeding, specially in cattle. The methods so far have been based on superovualtion of selected donor animals by administration of gonadotrophic hormones, fertilization *in vivo* by artificial insemination, collection of embryos by flushing the reproductive tract, and transfer to recipients at an appropriate stage of the reproductive cycle. Both collection and transfer of embryos in cattle can be carried out repeatedly by non-surgical procedures and the average number of embryos collected at one time is about six.

New technologies have been established for large-scale production of embryos by *in vitro* and culture to the blastocyst before freezing on implanting on recipient females.

Embryo transfer and related reproductive technologies enable more rapid multiplication of breeds or genetically elite animals. Recently multiple ovulation and embryo transfer is being applied to increase the rate of genetic progress in cattle improvement schemes. Determining how to gain genetic advantage from these technologies, while at the same time minimizing their genetic disadvantages, has provided a major challenge for geneticists. With artificial insemination (A.I) and (MOET), the conclusions are now fairly clear: these technologies can be used to create substantial increase in the rate of genetic improvement with acceptable rates of inbreeding. With *in vitro* embryo production, the answers are not yet fully worked out, although it is clear that these technologies, may also have substantial genetic advantage.

Embryo technologies have been well accepted in the dairy industy, which has made effective use of AI and ET in such a way that large numbers of siblings and progeny have been accumulated in a shorter period of time than normal conditions would have allowed . Application of AI and ET has never been as successful in the beef industry as it has been in dairy. Therefore, it generally takes time to get large numbers of records on a group of related individuals or progeny.

Simulation studies have been used to comparatively study different breeding strategies in the dairy, sheep, poultry and beef industries. Through simulations a framework can be develped to study different scenarios before field implementation. This thesis investigates the use of new reproductive technologies through the simulation of specialized and non-specialized beef lines within a closed breeding nucleus. A further step is also attempted which is to study the economic feasibility of producing market beef animals implementing multiple ovulation and embryo transfer.

CHAPTER 3

SPECIALIZED TERMINAL AND MATERNAL BEEF LINES VERSUS SINGLE LINE SELECTION IN A NUCLEUS BREEDING PROGRAM IMPLEMENTING MOET OR IVEP

3.1 Abstract

A simulation model was developed to investigate rates of genetic improvement in specialized maternal and paternal lines to compare with single line selection. Specialized and Non-specialized breeding schemes were comparatively studied in a closed nucleus herd framework implementing MOET or IVEP.

Rates of genetic gain in specialized sire and dam lines were significantly higher than genetic improvement achieved in non-specialized schemes. Efficiency of selection in Non-specialized lines was greater when genetic correlations between terminal and maternal traits were favourable. Efficiency of selecting in Non-specialized lines was also dependent on the ratio of heritabilities and relative economic weights between maternal and terminal traits. Efficiency of selecting in Non-specialized lines increased as the ratio of heritabilities of terminal to maternal traits increased. Efficiency of selecting in Non-specialized beef lines increased as the ratio of economic emphasis between terminal and maternal traits decreased.

3.2 Introduction

Rather than disperse breeding and selection over many breeders and A.I. nucleus units, it may be better to concentrate effort in dedicated selection stocks and units. These are usually called nucleus units and stocks. Most of the advantages of nucleus units are derived from the genetic gain achieved when the elite nucleus population is formed, being referred to as genetic lift (Gearheart, 1990). Furthermore, nucleus schemes allow for increased accuracy in selection, and an increased selection intensity. Nicholas (1979) and Nicholas and Smith (1983) outlined dairy cattle breeding schemes using nucleus units of elite sires and dams chosen from the breed population and allocated within a nucleus for further study the implications of MOET on genetic improvement of dairy population. The general conclusion was that MOET could produce substantial increases in the rate of genetic improvement in any species in which natural reproductive rate is low; and that if high rates of embryo transfer could be achieved, the rate of genetic improvement could even be doubled.

Nucleus breeding schemes with MOET have been proposed as a way to further increase the rate of genetic progress in dairy cattle (Ruane and Thompson, 1991; Dekkers, 1992) beef cattle (Land and Hill, 1975; Gearheart et al. 1989; Keller et al. 1990; Wray and Simm, 1990) and sheep (Smith, 1986; Wray and Goddard, 1994).

Villanueva et al. (1995) reviewed the literature and stated that early studies concentrated on extra genetic progress expected with MOET, while more recent studies have also considered possible risks associated with the use of MOET techniques. These authors stressed that by greatly increasing the number of progeny to be produced by single individuals, genetic progress can be improved due to increased intensity of selection. However, the extra gains can be accompanied by increased inbreeding since fewer parents contribute to the next generation.

Several authors (Smith, 1964; Moav, 1966; Moav and Hill, 1966; Cartwright et al., 1975; Gregory and Cundiff, 1980; Bennett et al., 1983; MacNeil et al., 1988) have studied the development of specialized genetic lines in specific roles within crossbreeding systems in order to improve the profitability of commercial beef production. It is, however, not known whether there are immediate gains from selecting for overall performance of a single line or selecting in specialized sire and dam lines for producing commercial embryos.

3.3 OBJECTIVES

The specific objectives of this study were:

1) To develop a computer model simulating a beef nucleus breeding program implementing either multiple ovulation and embryo transfer (MOET) or in vitro embryo production (IVEP) in development of

single and specialized lines.

2) To study rates of genetic improvement attained in specialized and single line beef selection within a beef nucleus scheme using MOET and IVEP.

3) To compare relative rates of improvement attained by selecting within a single line (non-specialized) with selecting within specialized maternal/terminal beef lines.

3.4. METHODS

3.4.1 Description of simulations

A deterministic simulation model was used to predict genetic response in a closed nucleus herd of beef cattle implementing either MOET or IVEP. Selection was assumed to be for two traits representing a terminal and a maternal trait. Genetic improvement attained in specialized sire and dam lines was compared to selection for the same maternal and terminal traits on a single multiple purpose line. Accumulated genetic response over 10 generations of selection was the basis for comparison of MOET and IVEP breeding schemes.

Selection in a single line, combined overall performance of two component traits, M representing the trait maternal performance and T representing performance of the market progeny. These can represent either a single major trait or an index of several traits involved in each component. Maternal and terminal traits are both expressed in standard deviation units so that their phenotypic variances are unity. Let h^2_T and h^2_M be the respective heritabilities of the terminal and maternal traits, and *rp* and *rg* represent the phenotypic and genetic correlations between the two traits. The difference in importance of the maternal to terminal traits, was taken into account by defining the relative economic value, (*a*), as the value of one standard deviation change in M relative to the value of a change of one standard deviation unit in T. The various parameters are combined in a selection index (Hazel, 1943) which will maximize the overall genetic improvement towards some specific selection goal. The selection goal for a terminal line differs from that for maternal line. Breeding for fast growth rate, feed efficiency and carcass traits is the main selection goal for a sire (terminal) line. Selection in maternal lines focuses on maternal ability (milk yield, protectiveness, mature cow weight) and reproductive traits. Selection objective in a single line was defined by an aggregate breeding value (*H*), as a linear function of the breeding values M and T for the two component traits.

The genetic improvement realized in sires and dams from specialized lines is expressed in a specialized breeding program, defined as a "Novel" breeding program. In the Novel breeding program, terminal embryos are implanted in recipient cows originally from the specialized maternal line. In contrast, in a

Non-specialized breeding program, embryos from a single line were implanted in recipient cows also from that single line selection.

The aims of selection varied in the different lines. In selecting within a single line for overall performance the aim is to maximize the change in aM + aT, while in terminal and maternal lines the selection goals are to improve M and T respectively. Whatever the aim of selection, a selection index combining information on both traits will provide maximum genetic gain due to the correlated response on indexed traits if the parameters are well estimated (Sivanadian, 1995).

In order to calculate relative rates of improvement by the different breeding schemes, rather than the absolute rates, only the heritabilities and the relative economic values of the two traits were considered. A range of values was specified for these parameters and the relative rates of improvement in overall performance and specialized lines were calculated. The range of parameters chosen to represent the two sets of traits were:

1) levels of heritabilities = 0.1 (low), 0.25 (medium), 0.5 (high).

2) economic values = 0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0.

3) genetic correlation = -0.8, -0.4,-0.2,0.0,0.2,0.4,0.8.

4) phenotypic correlation = -0.7,-0.3,-0.16,0.0,0.16,0.3,0.7.

Certain combinations of the parameters h^2_T, h^2_M, *g and r* were not possible because the matrix is not positive definite(Searle, 1961).

In those cases, combinations that were not possible were excluded from the data set.

3.4.2 Type of selection

Selection was assumed to be on an index of economic merit with records available at 15 months of age on males and females, sire, dam and a group of half and full sibs for the MOET scheme. For the IVEP program, information on dam and sire was used to calculate the index for selecting female donors. Dams which had been used in aspiration were assumed to have made a record for both the maternal and terminal traits by the time of selection for the next generation. Sire selection in the IVEP program was based on a full family index as described for the MOET program.

3.4.3 Parameters used for MOET and IVEP

The number of viable embryos per flush, rate of conception on a fresh implant basis (MOET scheme) represents the current rates obtained in Ontario (Hall, 1998). In the IVEP program the number of oocytes, rates of fertility and age of females at aspiration are described by Earl et al. (1994). The parameters used for developing a MOET/IVEP nucleus program are described in Table 3.1.. They include nucleus size, embryo transfer per donor, conception rates, rate of survival to selection, age at flush or oocyte aspiration, generation interval, number of donors, number of sires, mating ratio, progeny size and selected proportion of males and females.

A single flush was assumed in MOET schemes and potential donors were also used as recipients cows, after being flushed. In IVEP breeding schemes embryos were implanted into different recipients cows, since oocyte aspiration was performed at 2 months of age.

3.4.4 Simulation structure and associated standard selection differential, inbreeding and genetic response.

Selected sires and dams were used only once. The number of recipient cows used each generation defined the herd size and was set at 510 recipients, according to a small nucleus size described by Keller et al. (1990). The progeny generation was produced as a single cohort. A distinct generation was used assuming that average breeding values of selected group and next generation were higher than the present generation. A second assumption for using a distinct generation is based on the fact that the nucleus size studied was small and the amount of information available for selection in the nucleus did not allow for higher accuracy. For schemes relying on one flush per donor (MOET), the generation interval was assumed to be 2 yrs. Oocyte aspiration started on female calves at 2 months of age and female generation interval was 1.3 years.

3.4.4.1 Selection differentials

Hill (1976) showed that standardized selection differentials are affected by population structure as well as size. Hill's equation was derived for selection in a population of unrelated families each of equal size.

Standardized selection differential was adjusted for population size and structure according to Hill (1976):

$$I_1 = I - (1 - p)/\{2Ip[ns(1 - \rho) + s\rho + 1]\} \qquad [1]$$

I_1 = realized standardized selection differential adjusted for population size and structure,

I = standardized selection differential for an infinite population of unrelated individuals,

p = proportion selected,

n = family size,

s = number of groups and

ρ = intraclass correlation among observations in a family.

Keller et al. (1989) modified Hill's equation to account for hierarchical mating used in closed nucleus breeding schemes. In a closed nucleus breeding scheme with hierarchical mating, there is a mixture of full-sib and paternal half-sib families that become related over time. Realized standardized selection differentials were computed for selection among full-sib families (I_{fs}) and selection among paternal half-sibs (I_{phs}) separately, according to Keller et al. (1989). The intraclass correlation among full-sib families was estimated as the variance of an index based on full-sib, paternal half-sib, dam and sire records divided by the variance of an index based on own, full-sib and paternal half sib, dam and sire records (full index) Hill (1976). The intraclass correlation among paternal half-sibs was estimated as the variance of an index based on paternal half-sib records only divided by the variance of the full index. The full sib family size was defined for the current breeding program by 1/x times the number of paternal half sibs, where x is the number of donors per sire. The overall realized differential (I_t) was approximated as the weighted sum of I_{phs} and I_{fs} as follows;

$$I_t = (1 - 1/x) I_{phs} + (1/x) I_{fs} \quad [2]$$

3.4.4.2 Effective population size

Robertson (1961) found that for a population consisting of unrelated families of equal size, the ratio of actual number of breeding animals (N) to the effective number (Ne) could be found as a function of the standardized selection differential (I_t) and the intraclass correlation among groups (ρ). Therefore, the effective breeding population size in generation t was predicted as:

$$Ne^{t} = (N + I_{t}^{t})/(1 + I_{t}^{t}\rho^{t}) \quad [3]$$

Equation [3] was used to predict the effective number of sires and dams separately because N and I_{t} differed between sires and dams in the different mating structures examined. Average intraclass correlation among full-sibs and paternal half-sibs was used in equation [3].

3.4.4.3 Inbreeding

Having the effective numbers of sires (Ne_s) and dams (Ne_d) from [3], the rate of inbreeding in generation t (ΔF^t) was predicted as follows (Falconer and Mackay, 1996):

$$\Delta F^{t} = (1/Ne_s^{t-1} + 1/Ne_d^{t-1})/8 \quad [4]$$

The level of inbreeding in generation t (F^t) follows a procedure described by Falconer and Mackay, (1996), and it ranges from 0 for noninbred animals to 1 for completely inbred animals. The level of inbreeding at generation t was predicted as:

$$F^{t} = \Delta F^{t} + (1 - \Delta F^{t})F^{t-1} \quad [5]$$

3.4.4.4 Genetic response

The expected response to selection for each trait in generation n

+ 1 will be:

$$\Delta_{n+1} = \frac{G_n b I_d}{\sqrt{b' P_n b}}$$

where $\Delta' = (\Delta G_1 \Delta G_2)$, ΔG_1 and ΔG_2 represents genetic gain per generation for terminal and maternal traits, G and P are the genetic and phenotypic variance-covariance matrices in generation n; $b' = (1\ 1)$ represents a scaler of index coefficients assigned to each trait, and I_d is realized standardized selection differential adjusted for population size and structure (Hill, 1976; Rawling, 1976). The recurrence relationship of the genetic variance matrix, taking into account the effect of selection (Bulmer, 1971), is, according to Tallis and Leppard (1988):

$$G_{n+1} = (0.5G_n + 0.5K(b'P_nb)^{-1}G_nbb'G_n) + 0.5G = G_{n+1}^{\text{[illegible]}} + G_{n+1}^{\text{[illegible]}}$$

where $K = -I_d(I_d - x)$ is the change in variance as a result of selection, x is the point of truncation. The change in the phenotypic variance matrix is equal to that of the genetic variance matrix ($P_n - P_1 = G_n - G_1$). To take into account the joint effects of drift (sampling effects and inbreeding) and selection, the between family genetic variance matrix becomes $(1 - 1/f)G^{between}$, where f is the number of selected parents (Keightly and Hill, 1987); the within full sib family genetic variance matrix becomes: $(1 - F_t)G^{within}$ (Langlois, 1990).

Accuracy of selection was obtained as the square root to the heritability of index. Heritability of index was defined as:

$$h^2_I = (b'Gb/b'Pb)$$

3.5 Statistical analysis

The mean difference of Novel and Non-specialized breeding programs was tested within each breeding scheme and across breeding schemes (MOET and IVEP) using a two-tailed paired t-test (Snedecor and Cochran, 1989) at different levels of heritabilities and phenotypic correlations among the two traits. The paired t-test was performed within each level of genetic correlation and relative economic weights. In order to test if treatments were statistically significant within a deterministic framework, since no replicates were generated, the approximate mean square error for the statistical test was based on the assumption that interactions among the different levels of heritabilities and phenotypic correlations were not statistically significant. The initial assumption of testing differences on genetic progress was questioned by Crow (1998), who suggested characterizing the importance of main effects and interactions using sums of squares instead of testing, and then determining the variation in the outcome expressed in proportional terms. The two different approaches are discussed interchangeably in the results and discussion of this chapter.

3.6 RESULTS

3.6.1 Genetic gain on MOET versus IVEP

Comparing nucleus implementation based on accumulated genetic response over ten generations of selection, averaged over all levels of the genetic parameters, response of the MOET nucleus herd was significantly (P<0.001) higher to a nucleus herd implementing IVEP,(Table 3.2). Genetic improvement attained in the Novel breeding program (specialized sire/dam lines) was 35% higher in MOET compared to IVEP over 10 generations.

Genetic response on non-specialized schemes in the IVEP nucleus was also significantly lower (P<0.001) than genetic gain attained in MOET nucleus (Table 3.2),averaging approximately 20% less.

The significantly lower rates of genetic improvement achieved on IVEP nucleus breeding scheme were limited by the rates of success attained currently on that technology. Lower reproductive rates affected the number of donors available for selection and number of oocyte aspirations required to maintain a constant nucleus size. The smaller number of female donors in the IVEP nucleus led to a lower opportunity for maintaining the same selection intensity used in the MOET nucleus scheme. In order to maintain constant herd size for both nuclei (MOET and IVEP), an optimum number of oocyte aspirations in the IVEP nucleus was used leading to higher rates of inbreeding.

The lower selection pressure in addition to higher levels of inbreeding, did not overcome the gain from reduction of generation interval in the IVEP nucleus, because the generation interval for IVEP was 82% of that for MOET. Consequently, IVEP had a lower annual genetic gain than the genetic gain observed in the MOET nucleus. These findings agreed with those described by Dekkers (1992) and Lohuis (1995).

3.6.2 Effect of genetic and phenotypic correlation on efficiency of selection of specialized lines in relation to single line selection.

The efficiency of selecting within specialised sire and dam lines, relative to selection in a single line, is tabulated in Table 3.3 and Table 3.4 for MOET and IVEP respectively.

When the genetic correlation between terminal and maternal traits was favourable, fairly substantial gains in efficiency were obtained by selecting specialized lines in MOET and IVEP breeding schemes (Tables 3.3 and 3.4). Smith (1964) described similar results to this research when he compared rates of improvement by selecting for overall performance in a single line with selection on specialized dam and sire lines and subsequently crossing them. In the research of this chapter, specialized embryos were implanted in recipient cows from a maternal line. The benefits of having specialized lines were, therefore, even larger than in the study of Smith (1964).

The efficiency of selecting within specialized lines, compared to selecting in a single line, decreased substantially going from a favourable genetic correlation between traits to an unfavourable one.

Average efficiency across all levels of relative economic weights, heritabilities, and genetic correlations was 72% with MOET (Table 3.3) and 70 % with IVEP (Table 3.4).

Decreasing rates of efficiency were larger at high levels of positive genetic correlations compared to negative correlations, with an average decrease of 12% from -0.8 to -0.4 and 22% from 0.4 to 0.8 in MOET (Table 3.3). Smaller losses in efficiency were found in IVEP breeding scheme, 18% for genetic correlations ranging from -0.8 to -0.4 and 10% from 0.4 to 0.8.

3.6.3 Effect of heritability and relative economic weights on efficiency of selection of specialized lines in relation to single line selection.

Loss of efficiency was dependent on the level of heritabilities of terminal and maternal traits and the relative economic weights attributed to each trait.

High levels of heritability and relative economic weights for the terminal trait led to a dominance of this trait over the maternal trait. The efficiency of Novel breeding scheme over non-specialized breeding scheme was higher at low levels of heritability and relative economic weights on the maternal trait

In order to fully express the genetic potential of terminal embryos, recipient cows from a dam line would have to provide an adequate environment to sustain offspring performance at an optimum level. Therefore, reduction in genetic response due to the combined effect of heritability and relative economic weights for the maternal trait decreased the efficiency of non-specialized herds in comparison to Novel breeding scheme. This conclusion agrees with the findings of Smith (1964), who described in the context of a single line, the quantity ap (a=relative economic weight, $p=h^2_M/h^2_T$) which measures the economic improvement by selecting for one character relative to the improvement by selecting for others. Smith (1964) concluded that if ap is large or very small, all selection in the specialized lines will favour one of the traits and effectively ignore the other.

The advantage of selecting specialized lines was significantly higher on the average across all genetic correlations and all economic weights, when the proportion of heritabilities for the terminal and maternal trait was 1 to 1, compared to 2 to 1 and 5 to 1, on MOET and IVEP (Tables 3.3 and 3.4).

The decreasing rates of efficiency of specialized lines over single line selection for different proportions of heritabilities (1:1,2:1,5:1) were significantly higher when the ratio of relative economic weights of terminal to maternal trait decreased from 90:10 and 60:40 (Tables 3.3 and 3.4). If the ratio of economic weights decreased from 60:40 to 50:50,the efficiency of selecting specialized lines was significantly less for ratios of heritabilities (2:1 and 5:1) compared to dissimilar heritabilities(1:1) (Tables 3.3 and 3.4).

The increase in rates of efficiency due to relative economic weights showed a similar pattern for the MOET and IVEP nuclei (Table 3.3 and 3.4). Efficiency increased at a different rate according to the ratio of heritabilities between the two traits. When the heritabilities of the two traits was of the same level (1:1), the increase in efficiency due to a decrease in the ratio of relative economic weighting of the two traits, was 17%. If the heritability of the terminal trait was twice the maternal trait, efficiency decreased by 9%, as the economic weight ratio decreased.

3.6.4 Main effect and interactions of different levels of heritabilities, phenotypic correlations, genetic correlations, and relative economic weights.

The main effect and interactions of different levels of heritabilities, phenotypic correlations, genetic correlations and relative economic weights are presented in Table 3.5.

The analysis of sums of squares of main effects and interactions expressed as a percentage of the total sum of squares, showed that relative economic weights explained 40 % of the total variation, followed by heritability at 23 % and genetic correlations at 14 %. The relative importance of two-way interactions was minor compared to the main effects (Table 3.5);the interaction of heritability by relative economic weights explained 6.19 % of the total sum of squares.

The advantage of Novel over non-specialized breeding schemes became evident, since in the Novel scheme economic emphasis was given in full to the terminal and maternal traits in specialized beef lines. The efficiency of the Novel breeding scheme over non-specialized became more evident as the heritability of one trait decreased while the other was kept constant, or maintained at a higher level.

3.6.5 Inbreeding

The annual rate of inbreeding, ΔF, was 2.2% in the MOET scheme and 2.4% in the IVEP scheme for a constant mating ratio of 1 male to 6 females. Gearheart (1989) described higher rates of inbreeding (3.9%)for a similar mating ratio (1:8) for selection based on family information.

Inbreeding can be a problem with a small MOET/IVEP nucleus. Inbreeding accumulated faster for the MOET and IVEP schemes outlined, indicating that it can be difficult to interpret ΔF alone. A ratio of ΔF per unit of response may be a more meaningful expression for interpreting ΔF for a comparison of breeding schemes (Gibson, 1989). The ratio of ΔF to genetic response per generation in the MOET scheme was considerably smaller than in the IVEP nucleus program (Figure 3.1). On average, over 10 generations of selection, the ratio of ΔF to genetic response was 19% superior for IVEP than for MOET.

3.6.6 Genetic variance

Reduction in genetic variance over 10 generations was 5% (22 to 27%) higher in the IVEP nucleus than in the MOET nucleus (Figure 3.2). Accounting for selection disequilibrium, inbreeding, finite population size and relationship structure, selection response for MOET and IVEP was 69 and 71% in generation 10 of the response in the first generation. Keller, et al. (1990), reported for a similar nucleus size, over 20 generations of selection, that the combined effect of all factors described led to selection response of only 59%, as large as the response in generation 1.

3.6.7 Selection differential

Advantages from MOET/IVEP breeding schemes are largely due to higher selection intensities that can be applied to females. Shorter generation intervals are possible for IVEP versus MOET (Table 3.6). Theoretical response rates estimated for MOET and IVEP are shown in Table 3.6. In order to maintain the same family structure and also due to lower fertility and pregnancy rates in IVEP, selection intensity in males and females was decreased compared to MOET (Table 3.6). Accuracy of selection was also lower in IVEP because selection was based on pedigree information, since female calves started on oocyte aspiration at two months of age. By starting female gamete aspiration at an early stage, a significant reduction in generation interval was obtained in the IVEP scheme, 1.65 to 2 years in MOET scheme. In spite of the gain in generation interval with the IVEP scheme, the loss of selection intensity and accuracy of selection compromised the IVEP scheme's competitiveness. Average genetic response per year in the IVEP nucleus beef herd was approximately 10% less than the MOET breeding program (Figure 3.3 and Table 3.6).

3.7 DISCUSSION

The results of the research in this chapter pointed to a highly specialized beef production system. Although this study concluded that there was an advantage in developing specialized beef lines, it did not study the effect of using existing breed differences for terminal and maternal traits for the implementation of nucleus beef herds. Amer et al.(1992) conducted an analysis of published genetic differences among the predominant beef cattle breeds in Canada. The authors found important genetic differences for many traits. Breeds with larger mature size tended to be larger and leaner at a constant age and better for maternal calving ease and maternal calf survival. In contrast, smaller breeds were superior in their direct genetic contribution for calving ease and calf survival. Angus were more fertile and Simmental less fertile than the other breeds.

The development of new lines by selection depends on planned selection efforts while utilization of available breeds capitalises on breed resources for maternal and terminal lines. Gearheart (1989) proposed the use of elite nucleus units in beef breeding strategies in general terms. The author indicated that in the initial stages of nucleus formation the greatest immediate gains were likely to come from selecting among lines (breeds). Formation of elite nucleus populations would result in an initial one-time genetic improvement, or genetic lift, due to selection of elite population sires and dams.

This study used the concept of nucleus breeding schemes in a deterministic framework, without considering different approaches to nucleus formation and continuation, and demonstrated significant levels of genetic improvement for specialized and single line selection, but at the expense of rapidly increasing inbreeding . It is suggested for future research that the effects of size of nucleus and structure of matings be studied. Dekkers (1992) reviewed the literature, discussed the advantages and disadvantages of centralized versus dispersed nucleus herds and concluded that a centralized nucleus in practice would have advantages over the dispersed nucleus. The advantages were mainly related to the increased ability to control and manage the breeding stock. Application of MOET and new technologies such as IVEP, could lead to better and less variable results or, alternatively, measures could be taken to ensure that donors are flushed or aspirated until sufficient male and female siblings are obtained. Centralized nucleus herds are more ideal because the environment is controlled and female selection can be more accurate, but the size of the nucleus limits selection intensity and can lead to inbreeding problems (Lohuis,1995). The research presented in this chapter did not compare IVEP and MOET nuclei of different sizes, but focussed on their rate of genetic gain with a constant nucleus size.

The present results are of most value in indicating that in a highly specialized nucleus breeding system, the use of reproductive technologies such as MOET or IVEP in selecting specialized lines leads to a greater rate of improvement than selecting for overall performance in a single line.

3.8. CONCLUSIONS

In conclusion, selection of specialized sire and dam beef lines, and the use of reproductive technologies, like MOET and IVEP, yielded new challenges for future investigation. At the present rates of success for multiple ovulation and embryo transfer and for the framework simulated in this study, MOET nucleus implementation had larger benefits than IVEP.

Progress by selecting in a single line for overall merit was compared to progress attained by selecting specialized sire and dam lines and subsequently implanting terminal embryos into maternal recipient dams. The rate of improvement through specialized lines was considerably higher, and was even better if there was an unfavourable genetic correlation and large ratio of relative economic weights between the terminal and maternal traits

Table 3.1: Parameters used for multiple ovulation and embryo transfer (MOET) and in vitro embryo production (IVEP) breeding programs.

	Scheme	
Parameter	MOET	IVEP
Nucleus size [1]	510	510
Embryos transfers per donor	6	6
Conception rate fresh embryos %	76	53
Rate of survival to selection	75	70
Age at flush/aspiration (month)	15	2
Generation interval males (years)	2	2
females (years)	2	1.3
Number of donors	85	85
Number of sires	14	14
Mating ratio(# of females per male)	6	6
Number of progeny	290	189
Proportion selected males (%)	5	7.5
females (%)	29	90

[1] Nucleus size was denoted by number of recipient cows (implants)

Table 3.2: Accumulated genetic response (δ_E) for terminal and maternal trait for MOET and IVEP nucleus breeding programmes over 10 generations of selection

Breeding scheme		MOET	IVEP
NOVEL	- terminal	2.23	1.62
	- maternal	2.23	1.62
NS 90/-10	- terminal	2.19	1.61
	- maternal	0.21	0.16
NS 80/-20	- terminal	2.11	1.59
	- maternal	0.47	0.35
NS 70/-30	- terminal	2.02	1.50
	- maternal	0.84	0.61
NS 60/-40	- terminal	1.83	1.55
	- maternal	1.19	0.88
NS 50/-50	- terminal	1.53	1.41
	- maternal	1.53	1.41

Novel - 100% relative economic weight on a terminal trait and 100% on a maternal trait.

NS80/-20 - non-specialized 80% relative economic weight on terminal traits and 20% on maternal traits.

NS70/-30 - non-specialized 70% relative economic weight on terminal traits and 30% on maternal traits.

NS60/-40 - non-specialized 60% relative economic weight on terminal traits and 40% on maternal traits.

Table 3.3. Efficiency[*] of selecting within specialized sire and dam lines versus selection within a single line at similar and different levels of heritabilities for two traits in a MOET nucleus breeding scheme

Selection Scheme	h^2_T	h^2_M	Genetic correlation -0.8	-0.4	-0.2	0.0	0.2	0.4	0.8
NOVEL	0.50	0.50	100	100	100	100	100	100	100
NS 90/-10	0.50	0.50	96	78	65	55	40	30	6
NS 80/-20	0.50	0.50	96	81	71	60	46	35	8
NS 70/-30	0.50	0.50	97	84	73	65	55	43	11
NS 60/-40	0.50	0.50	97	85	76	68	57	49	17
NS 50/-50	0.50	0.50	97	86	77	70	58	50	22
NOVEL	0.50	0.25	100	100	100	100	100	100	100
NS 90/-10	0.50	0.25	96	81	71	59	56	44	24
NS 80/-20	0.50	0.25	97	83	73	61	58	47	25
NS 70/-30	0.50	0.25	97	84	76	64	61	50	26
NS 60/-40	0.50	0.25	97	85	77	65	62	51	27
NS 50/-50	0.50	0.25	97	86	78	66	63	53	29
NOVEL	0.50	0.10	100	100	100	100	100	100	100
NS 90/-10	0.50	0.10	97	86	79	74	67	60	44
NS 80/-20	0.50	0.10	97	87	80	75	68	61	45
NS 70/-30	0.50	0.10	97	88	81	76	70	62	45
NS 60/-40	0.50	0.10	97	88	82	77	71	63	46
NS 50/-50	0.50	0.10	98	89	84	78	73	64	47

[*] Efficiency was defined as accumulated genetic response over 10 generations for the non-specialized line divided by response for the specialized line (Novel) (x 100)

Novel - 100% relative economic weight on a terminal trait and 100% on a maternal trait.

NS80/20 - 80% relative economic weight on terminal traits and 20% on maternal traits.

NS70/30 - 70% relative economic weight on terminal traits and 30% on maternal traits.

NS60/40 - 60% relative economic weight on terminal traits and 40% on maternal traits.

Table 3.4. Efficiency* of selecting within specialized sire and dam lines versus selection within a single line at similar and different levels of heritabilities for two traits in a IVEP nucleus breeding scheme

Selection Program	h^2_T	h^2_M	Genetic correlation -0.8	-0.4	-0.2	0.0	0.2	0.4	0.6
NOVEL	0.50	0.50	100	100	100	100	100	100	100
NS 90/10	0.50	0.50	96	79	69	55	40	29	5
NS 80/20	0.50	0.50	97	82	69	57	46	34	7
NS 70/30	0.50	0.50	97	84	75	63	52	41	10
NS 60/40	0.50	0.50	98	86	78	68	57	47	15
NS 50/50	0.50	0.50	96	89	79	70	59	49	18
NOVEL	0.50	0.25	100	100	100	100	100	100	100
NS 90/10	0.50	0.25	97	82	71	64	55	44	24
NS 80/20	0.50	0.25	97	84	73	67	58	47	24
NS 70/30	0.50	0.25	97	85	75	69	61	49	25
NS 60/40	0.50	0.25	98	86	77	72	62	52	27
NS 50/50	0.50	0.25	97	87	78	74	65	53	29
NOVEL	0.50	0.10	100	100	100	100	100	100	100
NS 90/10	0.50	0.10	98	87	80	76	68	60	45
NS 80/20	0.50	0.10	98	88	81	81	69	61	45
NS 70/30	0.50	0.10	98	89	82	81	72	62	45
NS 60/40	0.50	0.10	98	89	83	79	71	63	46
NS 50/50	0.50	0.10	98	90	84	81	73	64	48

* Efficiency was defined as accumulated genetic response over 10 generations for non-specialized line divided by response for the specialized line (Novel) (x 100)

Novel - 100% relative economic weight on a terminal trait and 100% on a maternal trait.
NS80/20 - 80% relative economic weight on terminal traits and 20% on maternal traits.
NS70/30 - 70% relative economic weight on terminal traits and 30% on maternal traits.
NS60/40 - 60% relative economic weight on terminal traits and 40% on maternal traits.

Table 3.5. Analysis of the variance of accumulated genetic response over 10 generations of selection.

Source of variation	Degrees of freedom	Sum of squares	Proportion from total sum of squares (%)
Heritability (h)	2	16268.25	23.10
Phenotypic Corr.(rp)[1]	6	410.15	0.56
Genetic Corr. (rg)[2]	6	9744.55	13.84
Relative Ec. Wt. (a)[3]	10	28225.59	40.09
h x rp	12	296.05	0.42
h x rg	12	542.68	0.77
h x a	20	4363.13	6.19
rp x rg	36	209.64	0.29
rp x a	60	460.59	0.65
rg x a	60	9888.02	0.14
Total sum of squares	224	70408.65	

[1] Phenotypic correlation

[2] Genetic correlation

[3] Relative economic weights

[4] Significant at $p<0.001$

Table 3.6. Rates of genetic gain on MOET and IVEP breeding programs.

Parameters	MOET	IVEP
Proportion selected (%) ♂	5	7.5
Proportion selected (%) ♀	29	45
Generation interval (yrs) ♂	2	2
Generation interval (yrs) ♀	2	1.3
Accuracy ♂	0.73	0.73
Accuracy ♀	0.73	0.38
Genetic gain (SD/yr)	0.261	0.232

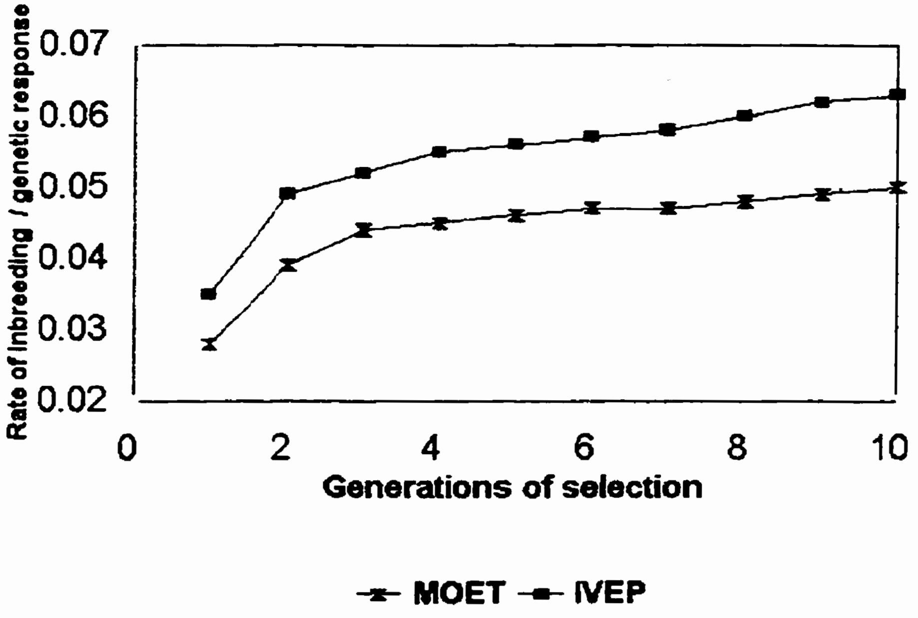


Figure 3.1 Ratio inbreeding /genetic response for MOET and IVEP nucleus

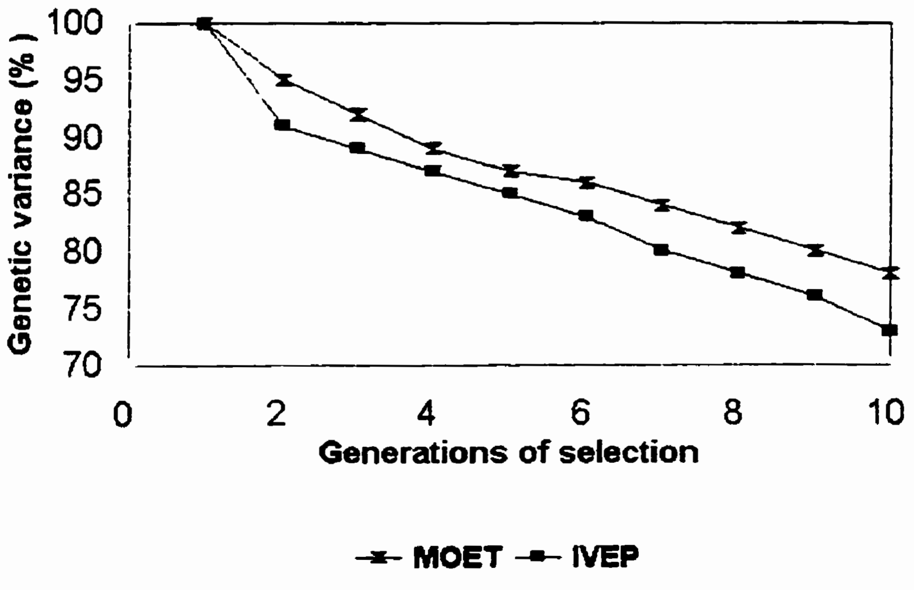
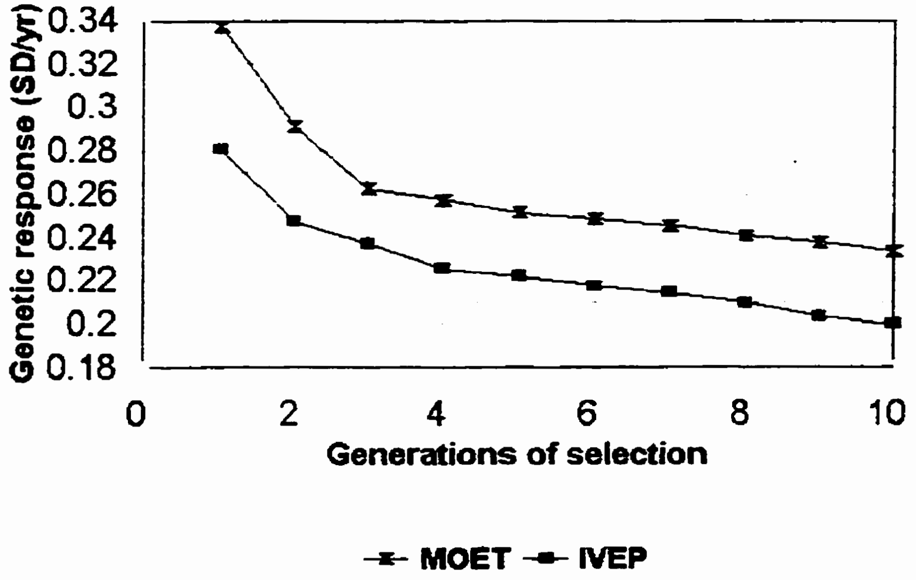


Figure3.2 Reduction genetic variance on MOET and IVEP breeding schemes

Figure 3.3 Genetic response over 10 generations selection on MOET and IVEP



CHAPTER 4.

Economic feasibility of embryo transfer for commercial beef production at various genetic levels of performance

4.1 Abstract

A computer model of specialized, non-specialized and commercial beef production systems was developed to assess the economic feasibility of embryo transfer for producing market animals. A Novel breeding program was defined by implanting specialized embryos in specialized maternal recipients. In a Non-specialized breeding scheme, embryos from a single line were implanted into recipient cows also from that single line. Specialized and Non-specialized breeding schemes were compared economically to a commercial beef herd bred by A.I. in a terminal crossbreeding system.

The Novel breeding program was economically more feasible than Non-specialized breeding schemes. The comparison of Non-specialized breeding schemes with different economic emphasis on terminal and maternal traits pointed out that selection on mature cow weight, from 20 to 30%, increased embryo value by 6%. A further emphasis on reducing mature cow weight (30 to 40%) had the negative effect of reducing embryo value. A ratio of 70 to 30% for selection on terminal to maternal trait showed the highest gross margin and consequently the higher price that could be paid for embryos from that breeding system.

4.2 Introduction

Previous studies on the use of embryo transfer (Land and Hill, 1975; Nicholas and Smith, 1983; Smith, 1988; Villanueva et al., 1994) have demonstrated the potential of these techniques for genetic improvement of cattle. Only a few studies have investigated the feasibility of embryo transfer as a tool to produce market animals, because of the high cost involved in flushing donors and implanting embryos in recipient cows (Ferris and Troyer, 1987).

Recent improvements in the efficiency of embryo transfer and related techniques (Betteridge and Rieger, 1993), along with the advancements made in the areas of genetic evaluation, statistical techniques and computing resources (Kemp and Wilton, 1992), have opened the opportunity for maximizing the productivity of specialized beef production systems.

The present study investigates the economic feasibility of embryo transfer for commercial beef production. The economic feasibility of embryo transfer is addressed in this chapter based on the following objectives;

1)To develop a computer model of commercial and specialized beef production systems; and to compare specialized production systems using embryo transfer versus a commercial beef herd using A.I..

2) To compare gross margins obtained in specialized sire and dam

breeding schemes versus gross margins attained in maternal and terminal traits within single line selection.

3) To investigate if market animal production using embryo technology is economically.

4.3 Material and Methods

4.3.1 Economic analysis of specialized and non-specialized lines of beef cattle.

Maximization of profits usually is the fundamental goal of commercial beef producers. A producer must decide whether to select for animals that produce calves with large weaning weights (outputs) or select for animals with low feed intakes (inputs) or some combination of inputs and outputs. Determining optimal strategies for combining inputs and selecting among breeding systems is necessary to be competitive in the beef industry.

With the advance of reproductive technology such as multiple ovulation and embryo transfer, beef producers are facing a new possibility of increasing revenues over costs.

A cost-benefit analysis of embryo technology compared to a conventional A.I. breeding scheme is essential for beef producers to make an accurate decision of whether or not to adopt MOET or A.I (Figure 4.2).

In the present research, simulated beef herds implementing MOET or A.I. were studied to determine the economic feasibility of a beef production system based on embryo transfer or artificial insemination.

4.3.2 Description of biological information for simulated beef herds

The model is deterministic, static and has a one-year planning horizon. The model described an integrated beef production system, including a cow-calf operation and a feedlot. The following classes of animals were simulated: breeding cows/recipients, calves, feedlot steers and heifers.

Herd size was set to 100 pregnant females at time of pregnancy checking at weaning (Figure 4.1). Herd size was maintained by culling open cows after the pregnancy check. Calves were born in the spring (March and April) and weaned in the fall (end of October) (Figure 4.1).

4.3.3 Feeding programs

Spring and summer feeding programs for beef cows were based on pasture which was set in the model as being available for 184 days (May to end of October). During the summer, metabolizable energy (ME) requirements of cows were supplied entirely from pasture. The energy content of pasture was described by Marshall et al. (1998) (Table 4.1). In fall and winter, cows were assumed to be housed and fed a ration of corn silage and haylage during the dry period (November to end of April), with a duration of 181 days (Table 4.1).

Simulated feedlot steers and heifers were fed a diet of haylage (30%) and high moisture corn (70%) until they reached a market weight (Table 4.1).

The calf feeding programs were based initially on milk nursing, and gradually forage and milk nursing during the grazing period.

Net energy requirements (Mcal ME/day) for maintenance and daily gain were estimated based on NRC (1996) equations

Maintenance:

$$Nem = 0.077 * LW^{.75}$$

Which is:

LW = live weight of calf (Kg)

Daily gain:

$$Neg = 0.0635 * LW^{[illegible]} * EBG^{[illegible]}$$

Which is:

EBG = empty body gain, (Kg/day)

Energy content of milk and pasture (Mcal ME /Kg DM) are presented on table 4.1.

Milk yield and its contribution to suckled calf gains were based on experimental findings from the East of Scotland College of Agriculture and the Institute for Grassland and Animal Production described by Allan(1990) (Table 4.2).

Some authors (Gleet and Berg, 1968; Clutter and Nielsen, 1987; Fiss, 1989; Lewis et al., 1990; Miller, 1996) described a positive association between milk yield and weaning weight,and concluded that higher milk producing cows weaned heavier calves compared to lower milk producing cows. Based on that finding, differences in simulated pre-weaning gains were considered a direct effect of growth,where maternal environment did not limit calf's performance.

4.3.4 Metabolizable energy requirements

4.3.4.1 Cow requirements

Energy requirements for the cow/calf sector were based on NRC (1996) equations. Feed requirements were calculated on a daily basis per age class group and accumulated over the entire period. Cow requirements were divided into 3 groups: replacement heifers, dry cows, and lactating cows.

The dry feeding program began November 1st until pasture turn out on May 1st.

Maintenance requirements Nem, were:

$$Ne_m \text{ (Mcal/day)} = [\ 0.077\ SBW^{0.75}\ (L)(COMP)] + a_2$$

SBW = shrunk body weight, kg;

L = lactation effect on Ne_m requirements (1 if dry or 1.2 if lactating);

COMP = effect of previous plane of nutrition on Ne_m requirements is reflected by body condition score. A constant average condition score of 5, on a scale of 1 (very thin) to 9 (very fat), is assumed.

a_2 = adjustment for previous temperature,

$a_2 = 0.0007(20 - T_p)$, where T_p is previous average daily temperature, °C.

Adjustment for previous temperature was based on the average temperatures of five environmental stations in Ontario published by Environment Canada (1996). Average temperature during the lactation period was 15.3 °C and during the dry feeding program period was -5.64 °C.

Pregnancy requirements were based on expected average calf birth weight and day of gestation NRC (1996).

$Ne_{(preg)}$ Mcal/day = $CBW*(k_m/0.13)*(0.05855-0.000096t)*e^{[illegible]}$

Where;

CBW = Calf birth weight;

Km = Values for efficiency of utilization of ME for maintenance, $K_m = Ne_m/ME$. Relationships for converting ME values to Ne_m (Mcal/Kg DM) NRC (1996).

$Ne_m = 1.37\ ME - 0.138ME^2 + 0.0105ME^3 - 1.12,$

ME = Metabolizable energy (Mcal/Kg DM) for spring/summer and dry period feeding programs,

t = day of pregnancy,

e = base of natural logarithms.

Lactation requirements were calculated using day of lactation, milk fat composition %, milk solids non-fat composition %, NRC (1996).

Ne_l = milk yield(kg/day)* E;

in which:

$E = 0.092*MF + 0.049*SNF - 0.0569$, Mcal($Ne_m$)/Kg,

MF = fat percent per Kg of milk,

SNF = milk solids not fat composition percent per kg of milk.

Milk fat composition (3.16%) and solids (8.63%) were average values obtained at Elora Beef Research Station (Watson, 1997 personal communication).

4.3.4.2 Feedlot requirements

Energy requirements for steers and heifers in feedlot were predicted with the following three steps.

Net energy required per day for maintenance of steers and heifers (NERm) was computed using equations of Lofgreen and Garret (1968).

$$NERm\ (Mcal/day) = 0.077\ LW^{0.75}$$

In which:

LW = live weight (Kg).

Net energy required per day for live weight gain (NERg) of medium frame bull calves (NRC, 1996) in megacalories of ME/day was calculated from LW and daily weight gain (LWG, kg/day) as follows:

$$NERg\ (Mcal/day) = 0.0635\ EQSBW^{0.75}\ EBG^{1.097}$$

in which:

EQSBW = equivalent shrunk body weight, kg;

EBG = empty body gain, kg.

Derivation following NRC (1996).

$$EQSBW = SBW * (SRW / FSBW)$$

in which:

SBW = shrunk body weight, kg

SRW = standard reference weight for expected final body fat (Table 4.3)

FSBW = final shrunk body weight at the expected final body fat,

NRC (1996) equations for predicting energy and protein requirements for growing cattle assume that cattle have a similar body composition at the same degree of maturity. The NRC (1984) medium frame steer equation was used as the standard reference base to compute energy content of gain at various stages of growth and rates of gain. This was accomplished by adjusting the body weights of cattle of various body sizes and sexes to a weight at which they were equivalent in body composition to medium frame steers described by Tylutki et al. (1994). The weight equivalent to the NRC (1984) medium frame-size steer, was obtained by knowing the standard reference weight (SRW) and final shrunk body weight (FSBW) at the expected final body fat. These values were determined by averaging the percent body fat within all cattle in each of the three marbling categories in the energy and protein retained validation data NRC (1996) (Harpster, 1978; Danner et al., 1980; Lomas et al., 1982; Woody et al., 1983). Body fat percent averaged 27.8, 26.6, and 25.2 in the small, slight, or trace marbling categories, respectively. This variable SRW allows adapting the system to both U.S. and Canadian grading systems and determining SRW for marketing cattle at different end points (Table 4.3).

A survey designed to determine the preferences of Ontario packers on weight, marbling and yield class (Edwards 1997) and statiscs published on Agriculture and Agri-Food Canada (AAFC) indicated that the majority of carcasses in Ontario were A marbling followed by AA and AAA marbling. In the same survey, retailers indicated preference for AA marbling; therefore in this study an AA grade marbling was the target average marbling score.

The NRC (1996) equations required an accurate estimation of FSBW for adjusting different cattle weights to a medium-frame steer. Therefore, the final slaughter weight adopted in this study was based on average carcass weight and yield described by AAFC. The final predicted average slaughter weight for steers was 534 kg. A similar value was described on NRC (1996) for an average steer in the United States(533 Kg).

Sex differences affect conformation, particularly body composition. Taylor (1994) indicated that heifers achieve the same body composition, on a live weight basis, 46 to 68 kg lighter than steers of the same breed and under the same nutritional regime. In this study, sex was adjusted by decreasing FSW by 57 kg, the average of the values mentioned by Taylor (1994).

Daily ME requirements for maintenance (MERm) in megacalories of ME/day were calculated following description of Garrett (1980).

MERm (Mcal/day) = NERm/(NEm/AME)

in which:

NEm = net energy (Mcal ME/Kg DM) available in feed for maintenance,

AME = average metabolizable energy values for the diet.

Daily ME requirements of steers and heifers for growth (MERg) in megacolories of ME/day were calculated as follows:

$$MERg = NERg/(NEg/AME)$$

in which:

NEg = net energy (Mcal ME/Kg DM) available in the feed for gain,

Requirements for maintenance and growth (MER) in megacalories of ME/day were calculated as follows:

$$MER = MERm + MERg$$

4.3.4.3 Nutrient requirements for replacement heifers

The nutritional program for replacement heifers included the period from breeding to calving. Heifers were on a grazing feeding program from May 1 to October 31. During fall and winter heifers had access to the same diet as dry cows (Table 4.1). Heifers at breeding time had 65% of mature cow weight as recommended by Taylor (1994). Growth rate from breeding to calving was defined as the predicted weight at calving determined by Brody's growth equations minus weight at breeding divided by number of days from breeding to first calving. Energy requirements for growing heifers were determined using NRC (1996) equations.

4.3.5 Replacement Rate

A replacement rate was defined by the number of first calving cows needed to maintain a constant herd size, dependent on herd fertility, rates of death, and voluntary culling. The proportion of cows that conceived after a breeding season was assumed to be 80% for the commercial beef herd (Amer et al., 1992).

The mortality rate of 2 percent assumed in the present study was taken from a survey of beef herds in Colorado (Wittum et al., 1990). Voluntary culling was simulated to allow for a beef producer to cull heifers/cows that did not meet minimum requirements in the herd; for example, poor maternal ability. A rate of 4% was set for cows culled voluntarily.

In the modeling, a replacement rate for a commercial beef herd was set to 26%, (20% due to reproductive problems, 4% to voluntary culling and 2% to death). A large number of heifers was needed in specialized herds, because of lower rates of pregnancy with fresh embryo transplantation. The pregnancy rate for fresh embryos was taken to be 76% (H. Hall 1997, Gencor genetic services, personal communication), which represents average Ontario rates of pregnancy for fresh embryo implantation. The same death rate and voluntary culling was assumed for the commercial herd. The replacement rate in specialized herds was therefore set to 30%.

4.3.6 Cow age distribution

In order to calculate feed requirements for different age groups in the cow/calf portion of the simulation, the age distribution across the herd was required. Age distributions within the cowherd were defined according to Azzam et al. (1990). The proportions of cows in each age class in the present study were calculated employing Markov chain theory. Culling probabilities for commercial and specialized herds were calculated based on fertility rates, death and voluntary culling. Equal probability of culling for different age groups was assumed. The culling probability was calculated as the difference between 1 and the probability of a cow calving the following year.

In this study, cows at 8 years of age after weaning a calf were culled, as described by Bourdon and Brinks (1987) who examined culling at 8 or 10 years of age. The authors concluded that although optimal biological efficiency occurred with a younger herd, economic efficiency occurred when cows were culled at 8 years the younger herd of the two ages examined in the study.

4.3.7 Growth parameters

Cow body weights at calving for various ages were calculated using Brody's growth equation (Brody, 1945). The Brody growth curve was described as:

$$LW = A\ (1 - Be^{-Kt}).$$

In which:

A = mature weight (Kg),
B = time scale parameter (Kg),
K = maturing rate parameter (Kg),
t = age in days from birth.

Mature weights of cows (A) were obtained from analysis of published results on genetic differences among the predominant beef cattle breeds in Canada (Amer et al.,1992). The value for B was determined by taking the difference between A and the mean birth weight expressed as a proportion of mature cow size (as an example for the Hereford breed B = 561 - 27.7 / 561 = 0.951). The range of B values in this study (0.915 to 0.937) were similar to the values of 0.921 to 0.933 obtained for Angus cross cows by Montaño-Burmudez and Nielsen (1990). Koots (1994), using data from the Elora Beef Research Center (EBRC) described by Fiss and Wilton (1992) defined maturity (K) parameters of 0.0027, which was larger than that described by Sanders and Cartwright (1979) (0.0022) for similar mature cow weights. Koots (1994) suggested that a larger K value indicates a faster maturing genotype which is contrary to expectations based on the positive genetic trend generally observed for mature size of British cattle breeds (Taylor, 1989; Agriculture Canada 1992). Koots (1994) argued that the higher K value, therefore, might be due to the feeding regime at EBRC, since cows at EBRC had high body condition scores. Comparable values of K for cows in high body condition were not found in the literature. A K value of 0.0022 was therefore used in this model.

The commercial herd was composed of medium frame cows similar in weight to the Angus/Hereford breeds described by Amer et al. (1992). For specialized beef herds, various cow body weights were simulated as explained in the description of the specialized herd. The weights from the Brody equations were used to estimate feed consumption at various age classes.

Calf birth weigths in the model were estimated as 6 percent of mature weight. This percentage was based on average mature cow weights and calf birth weight for five beef breeds described by Amer et al. (1992). This value was similar to those described by Fiss and Wilton (1993). Birth weight of heifers was assumed to be 0.97 that of steers based on the review by Woldehawariat et al. (1977).

4.3.8 Pre-weaning and post-weaning gain

The rates of growth from birth to weaning and from weaning to slaughter for the commercial beef herd were average values over five beef breeds described by Amer et al. (1992) (Table 4.5). Weaning weights of heifers were set to 95 % of the weaning weight of male calves (Taylor, 1994).

4.3.9 Dystocia

The degree of calving difficulty was calculated per age class and averaged over the cow herd. In the current model, calves have different birth weights since they were from different sire lines. Because sire and dam genotypes differ, the probability of calving difficulty may change, due to fetal-pelvis interaction (Meijering, 1984). Bourdon and Brinks (1987) derived regression equations to predict calving difficulty as a function of birth weight and heifer weight in first calf heifers, and as a function of calf birth weight alone in two older age classes using expected mean values.

In the current model, mean calving ease was predicted using equations derived from Bourdon and Brinks (1987).

$$DYS = -0.2038 + 0.0564\ BW - 0.0032\ WM \qquad (\text{Cow age} = 2)$$

$$DYS = -0.7227 + 0.02154\ BW \qquad (\text{Cow age} = 3 \text{ or } 13+)$$

$$Dys = -0.223 + 0.00608\ BW \qquad (3 < \text{Cow age} < 13)$$

where DYS is the proportion of cows experiencing dystocia, BW represents calf birth weight expected for the genotype simulated and WM is growth curve weight.

Calving difficulty costs were based on degree of calving difficulty calculated in each herd simulated. Calving difficulty was classified as unassisted (U), easy pull (E), hard pull (H), or surgical (S). Costs associated with each category were obtained from Koots (1994). The incidence of each category was based on data obtained from Elora Beef Research Center (1981-1992), as presented by Koots (1994) (Table 4.5).

4.3.10 Feed costs

Feed costs for different animal classes were expressed as $/Mcal ME and obtained from Lazenby et al. (1997). Pasture costs were obtained by Dubon (1997) and represented average costs from Elora pasture for 1996 (Table 4.1).

4.3.11 Overhead costs other than feed costs

Overhead costs were obtained from the Ontario Farm Management Analysis Project publication 69 (OFMAP) for 1995. Overhead costs were defined on a per cow basis for the cow-calf sector, based on an average Ontario beef farm. Feedlot overhead expenses were expressed on a per kilogram basis (Table 4.6).

4.3.12 Price data

Cattle prices were based on averages obtained from the Ontario Cattlemen's Association (1997). Prices paid for replacement heifers were obtained from Edwards (1997), (Table 4.7).

In a survey described by Edwards (1997), a determination of weight, marbling and yield class were defined by packers in Ontario. Agriculture and Agri-Food Canada (AAFC) statistics and packer survey results described the Ontario beef cattle population. Seventy-two percent of reported cattle purchases were carcasses weighing 315 kg or more, and over 60% of the cattle yielded 59% or better. In this simulation study average target carcass weight was set to be 315 Kg. Under the current Ontario carcass weight discount-pricing scheme (Table 4.8) no discounts were applied to a carcass between 251 and 340 kg, a range that covers the target carcass weight simulated in this study.

4.3.13 Economics aspects of simulation

Commercial and specialized beef systems were compared based on gross margins. Gross margin was defined as net return above the variable costs over one production cycle. Variable costs included feed, overhead and replacement costs. The production cycle started at calving and ended at slaughter of that offspring, (Figure 4.1). Fixed costs did not affect profitability of the beef enterprise in the short term and were therefore ignored in the comparative economic analysis of commercial A.I. and specialized MOET schemes.

The revenue generated in the commercial and specialized beef herds was based on selling cull cows and feedlot steers and heifers. Cull cows were sold based on live weight and steers and heifers on a carcass weight basis. Cow revenue was defined as:

Cow revenue($) = cow weight at weaning (kg) x cow price ($/kg)

Steer/heifers revenue = carcass weight (kg) x price ($ / kg carcass)

The effect of changes of expenses or revenue was based on costs and prices described in this study. No sensitivity analysis was conducted to determine a single or combined effect of different prices or costs on the results, due to the fact that rates of inflation were low in the last five years. Therefore, cattle prices and production costs simulated were accurately representative of costs and prices for a beef production system in Ontario.

4.3.14 Semen Price

Semen price was obtained from a commercial A.I. company and represents what is currently charged to Ontario beef producers. Semen prices averaged 15.00 (CAN$) per dose of semen, with a standard deviation of $8.00 (CAN$) (L. Smith, 1997, Gencor - genetic and services, personal communication). The number of doses of semen per pregnancy of 1.8 was obtained from Gencor, and represents an average for Ontario.

4.3.15 Embryo costs

Embryo costs were split into cost of production and cost of their genetic value. Commercial costs of flushing a donor cow, preparation and implantation of embryos in a recipient were obtained from Gencor. The prices used represented current charges to producers in Ontario (Table 4.9).

The genetic value attributed to embryos was derived from opportunity costs. The opportunity cost of an input was defined as the return earned in its best alternative use. Purebred breeders were considered specialized beef breeders producing seedstock for commercial producers. These breeders' goals are to produce offspring of superior quality, increasing the chance of higher profit at the commercial level. In practice, a purebred animal could have been sold in one of the following situations. In the first situation, a steer/heifer was sold to market with a probability of 25%. In the second category, the animal could have been sold as a bull or purebred heifer at an Ontario average price of $2500.00 (CDN$) (BIO - Beef Improvement Ontario 1997), with a probability of 50%. A third category assumed that an elite animal would be sold at a price of $5000.00 (CDN$) (BIO - Beef Improvement Ontario 1997) with a probability of 25% (Appendix 4.1).

Embryo costs per unit were then obtained by subtracting returns from expenses for each simulated scenario, divided by the product of the average number of viable embryos per flush by number of flushes per donor per year. In that calculation, embryo costs due to veterinarian services were added to genetic value of embryos.

4.3.16 Embryo Value

The embryo value indicates the price that a breeder could paid per embryo, if a breeding scheme similar to those described in this study were adopted. Embryo value was defined as the difference between gross margin in the specialized herd minus gross margin at commercial terminal herd (Appendix 4.2).

4.3.17 Description of beef herds

Two hypothetical beef herds were simulated in order to investigate the proposed objectives. The simulated herds mimicked a commercial/terminal crossbreeding system bred by A.I. and a specialized herd bred by MOET.

4.3.17.1 Commercial Herd

In the commercial beef herd cows were bred artificially to a terminal sire with a mature size similar to the Charolais breed (Amer et al., 1992). The mature weight of commercial cows represented an approximate mean of five major breeds (Charolais, Hereford, Aberdeen Angus, Limousin, Simmental) described by Amer et al. (1992) (Table 4.11). Steers were market at a constant live weight of 533 kg, which represents average weight for steers slaughtered in Canada, Agriculture and AgriFood Canada (AAFC). Heifers were slaughtered at 96% of steers weights Taylor (1994). All replacement heifers were bred at approximately 15 months old to calve at two years of age. Replacement heifers were purchased just before the start of breeding season and were bred artificially. Steers and heifers from the terminal crossbreeding system were all sent to market.

4.3.17.2 Specialized Herd

The specialized beef herd was simulated with a production system based on implanting embryos from a terminal line into recipient cows from a maternal line. In Chapter 3, genetic progress was compared in specialized sire and dam lines versus selection within a single line. Differences in relative economic weights were attributed to terminal and maternal traits within single line selection.

The rates of genetic improvement obtained in the MOET nucleus breeding programs, after applying the described genetic correlations between preweaning gain and cow mature weight (Table 4.10), in the simulation in chapter 3, were used in this research to compare the economic feasibility of specialized versus non-specialized selection lines. The terminal trait was defined as pre-weaning gain and the cow trait as mature cow weight. Birth weight and post-weaning gain were also studied as correlated traits. Correlated response to selection on pre-weaning gain was used to predict rates of improvements on those traits, Falconer and Mackay (1996). Phenotypic mean values and standard deviations were obtained from Amer et al. (1992) (Table 4.5). Genetic correlations between traits were obtained from Koots (1994) (Table 4.10).

Genetic responses attained on individual traits in specialized selection program were obtained for pre-weaning gain and mature cow weight as directly measured traits, and indirectly to birth weight and post-weaning gain. The phenotypic mean values of these traits after ten generations of selection are shown in Table 4.11.

4.4 Results and Discussion

The results are presented initially based on the biological effect of traits and then the economic implications of different breeding schemes are described and discussed. Embryo value was reported for two levels of genetic correlation between terminal and maternal traits (-0.17 and 0.57).

From the four economic traits considered in this study, mature cow weight had a large effect on economic viability of different breeding systems. Over 20 years of selection implemented in a closed nucleus scheme bred by MOET, mature cow weight in a specialized maternal herd was reduced to 70% of that in a commercial cow herd. In a single selection line, with economic emphasis on cow size of 20, 30 and 40%, mature cow weight was reduced by 15%, 19%, and 23%, when genetic correlation was -0.17, respectively compared to the commercial cow herd scenario (Table 4.11).

The positive genetic correlation between pre-weaning gain and mature cow weight(0.57) combined with favorable economic weights in pre-weaning gain and unfavorable economic weights in cow weight led to different rates of gross margin according to the breeding scheme studied. At 20% of economic weight and 80% in pre-weaning gain (NS 80/-20), cow mature weight was 5% higher than commercial cow herd weight (Table 4.12). The increment of relative economic weights by 10% and 20% in cow mature weight (20 to 30 and 20 to 40) decreased cow mature weight by 23 and 83 kg respectively, compared to commercial cow weight(Table 4.12).

4.4.1 Energy intake in the cow-calf phase

Annual energy intake for maintenance, growth, lactation and gestation were lower for the commercial herd compared to the Novel and Non-specialized herds, at the two levels of genetic correlations studied. A similar energy intake was found for cows in the commercial herd and Novel breeding scheme, in spite of the difference in mature size (Table 4.13). The higher energy intake for cows at Novel was due in part to a higher milk yield. 699 kg above the milk production in the commercial herd (Table 4.14). Energy intake in NS80/20, NS70/30 and NS60/40 was 18, 13 and 6% higher than in commercial cows.

A positive relationship between energy intake and milk yield was also reported by Miller (1996). Milk yield in single selection breeding programs NS80/20, NS70/30 and NS60/40 was for the two levels of genetic correlation studied ,56, 52, and 43% higher than milk production of commercial cows (Table 4.14).

4.4.2 Weaning weight for different breeding schemes.

Weaning weight was significantly higher in the specialized single line selection herds compared to the commercial beef herd (Table 4.14). Weaning weight in the novel scheme was 56 kg higher than weaning weight of commercial calves.

Decreasing progression of weaning weight in the Non-specialized breeding schemes were dependent on the genetic association between pre-weaning gain and mature cow weight and the relative economic weights attributed to those traits. At a genetic correlation of 0.57 between WWG and MCW, weaning weight decreased twice the amount obtained when genetic correlation was -0.17 (8 to 4 kg) (Table 4.14). Comparing NS 70/30 to NS 60/40, weaning weight at a genetic correlation 0.57 decreased by 5 times compared to NS 70/30 and NS 60/40 at a genetic correlation -0.17.

4.4.3 Feedlot phase

Heavier weights at the beginning of the feedlot phase in addition to higher rates of post-weaning gain significantly reduced days on feed and total energy intake for specialized and non-specialized herds in comparison to the commercial herd (Table 4.15).

Feedlot steers and heifers from the Novel breeding program spent 98 fewer days on feed compared to commercial steers and heifers. Energy intake for steers and heifers from the Novel breeding program represented 21.7 % less energy consumption than steers and heifers finishing to the same end-point in the commercial herds (Table 4.15).

4.4.4 Costs associated with the cow-calf phase

Annual costs in the cow-calf phase, excluding embryo costs in specialized and semen costs in commercial herds, were lower in Novel and Non-specialized breeding programs compared to a commercial herd (Table 4.16).

Notter et al. (1979) examined biological and economic efficiency of mature cow size across several breed types and concluded that breed size effects on economic efficiency were expected and were a function of management, pricing schemes and their interaction with breed size rather than a biological effect.

The results of the current study agree with the literature. The larger cow tends to decrease revenue due to greater mature size and higher maintenance costs. Taylor (1994) indicated that feed costs in the cow-calf phase represent 40 to 70% of the total cow-calf costs.

4.4.5 Costs related to replacement heifers

Costs associated with replacement heifers were lower for the Novel scheme compared to NS80/20, NS70/30, NS60/40 and the commercial herd (Table 4.17). Replacement heifers were purchased at 14 months of age based on live weight (as 65% of cow mature weight). Since Novel mature cow weight was the smallest of all breeding schemes studied, the purchase price for replacement heifers was proportionally lower compared to the other breeding schemes. Overhead costs were also lower for replacement heifers in a Novel scheme compared to NS80/20, NS70/30, NS60/40 and commercial, since energy for maintenance and growth from breeding to parturition was considerably less. Embryo cost represented 16% of the overall costs for replacement heifers on Novel schemes. For a Non-specialized herd, on average embryo costs made up 14% of the total costs (Table 4.17).

4.4.6 Costs for the feedlot phase

Feedlot costs were significantly higher for commercial herds compared to herds implementing MOET (Table 4.17). Differences in feedlot costs decreased at different rates for Novel and Non-specialized breeding schemes compared to the commercial herd; $34, $31, $26, and $17 (CDN$), respectively.

4.4.7 Economic comparison between specialized and non-specialized breeding schemes.

Comparing economic feasibility, selection for specialized maternal and terminal traits versus selection in single line, or non-specialized herds, gross margin favored the Novel breeding strategy (Table 4.18).

A similar gross margin was found between NS 60/40 and NS 70/30, and NS 80/20, for the average of the two genetic correlation levels between WWG and MCW. Costs were lower at NS 60/40 but gross income was higher. The difference in gross income was due to the extra cow weight sold.

By increasing relative economic emphasis from 20 to 30% in the maternal trait, gross margin was 10% higher in NS70/30 than gross margin in NS80/20.

The gross margin generated for the five breeding schemes in this study, excluding costs related to embryos, was higher in the Novel and Non-specialized than commercial herd gross margin(Table 4.18).

The current cost of embryo transfer (an average of $151.35 CDN$), for producing market animals was too high to make specialized and non-specialized breeding schemes economically viable (Table 4.18). Embryo cost in the Novel breeding scheme should be reduced by 5.6% ($151.35 to $142.81 CDN$) and 12.7% ($151.35 to $132.04 CDN$) to be economically feasible at genetic correlations of -0.17 and 0.57, respectively.

In Non-specialized breeding schemes embryo costs should be reduced even further than in the Novel scheme. Reducing embryo costs by 34% in NS 80/20, 31% in NS 70/30, and 32% in NS 60/40, for the average of two genetic correlation levels, would make embryo transfer economically feasible in those breeding schemes.

4.5 Conclusions

Comparing net returns over variable costs showed that implanting embryos from highly selected lines for growth traits into cows that were selected for small body size was more economically viable than embryos from a single line implanted in cows from the same breeding scheme.

If a multi-trait selection objective was used to maximize profit, within breeding schemes similar to those studied in this simulation, caution should be exercised when setting relative economic emphasis of terminal to maternal traits. A maternal trait, represented in this study as mature cow weight, had a major economic effect on the breeding schemes simulated and should be included in a multi-trait breeding objective.

Within the range of relative economic emphasis given to a terminal trait in relation to a maternal trait in single line selection, a slight increase in gross margin was found by increasing economic emphasis on mature cow weight.

At the current costs of embryo transfer, producing market animals by ET is not economically viable. Embryo price has to be reduced in order to be implemented in highly specialized breeding strategy.

Table 4.1: Diet formulations and feed stuff costs

Ingredient	Dry matter[1] (%)	Mcal ME kg/DM	Price[2] ($/tonne/As fed)	Percent diet (%)	Price ($/Mcal ME)
<u>Dry cow diet</u>					
Corn silage	33	2.2	25.00[3]	30	0.0344
Haylage	38	2.0	30.00	70	0.0395
Diet	36.5	2.1	28.50	100	0.0381
<u>Feedlot</u>					
Haylage	38	2.0	30.00	30	0.0395
HM corn	72	3.3	101.00	70	0.0401
Diet	62	2.9	63.64	100	0.0400
Pasture		2.35		100	0.0291[4]
Milk	12	5.29		*	

[1] Source: NRC (1996)

[2] Source:Lazenby et al.(1997)

[3] Source: Dubon (1997)

[4] Source: Miller (1996)

* Percent of milk in calf's diet presented in Table 4.2

Table 4.2: Proportion of the calf's diet that is from milk.

Month of age	% of calf gain from milk
1	100
2	100
3	75
4	61
5	51
6	45
7	35

[1]Source: Allen (1990).

Table 4.3: Standard reference weights for different final body compositions[1].

	Average marbling score		
	Traces	Slight	Small
Body fat %	25.2± 2.9	26.8± 3.0	27.8±3.4
Standard reference weight, kg	435	462	478

[1] Source: NRC (1996).

Table 4.4: Means, phenotypic standard deviations and heritability[1] of traits simulated.

Traits	Parameters		
	Mean	SD	h^2
Cow mature weight (kg)	580	45	0.50
Direct birth weight (kg)	34	4	0.31
Birth to weaning gain (kg/day)	0.970	0.100	0.29
Postweanig growth (kg/day)	1.200	0.115	0.31

[1] Source: Koots (1994)

Table 4.5: Costs and incidences of calving difficulty in commercial and specialized herds, prices based on Elora Beef Research Centre values (1981-1992)[1].

Category	Incidence(%)	Cost ($)
Unassisted	59.0	0.00
Easy Pull	17.2	6.67
Hard Pull	20.4	20.00
Malpresentation	0.0	78.00
Surgical	3.4	218.00

[1] Source: Koots (1994)

Table 4.6: Variable expenses for cow-calf sector expressed per cow basis, and for feedlot per 100 kg basis.

Variables	Cow-calf	Feedlot
Animal health & breeding	30.20	5.56
Other (Stabilization, Supplies)	8.96	1.78
Marketing, transportation	11.82	7.19
Custom work, equipment rent	6.71	2.82
Hired labor	2.59	2.79
Machinery & equip. fuel & oil	13.45	1.58
Machinery & equip. Repair	18.36	2.64
Motor vehicle expenses	10.96	2.18
Building, fence repairs	17.85	6.53
Heating fuel	2.23	0.18
Electricity & telephone	17.69	2.86
Accounting, office expenses	6.48	1.27
Interest - operating	11.51	5.17
Other cash variable expenses	19.61	0.79
Total variable expenses other than feed costs	178.42	43.34

Source: Ontario Farm Management Analysis Project

Table 4.7: Average cattle prices[1] (January to July), and replacement heifers purchase price (per kg).

Cows - all weights(live cow price)	1.09
Steer rail price (carcass)	3.38
Heifer rail price (carcass)	3.37
Replacement heifers[2]	2.24

[1] Ontario Cattlemen's Association (1997)

[2] Edwards (1997)

Table 4.8: Ontario carcass weight discount prices scheme.

Carcass weight (kg)	Discount($/100kg)
204-267	5.29
268-250	2.65
251-340	0.00
341-363	2.65
364-408	5.29
409-498	10.58
499-499	13.23

Source: Ontario Packers as supplied by Edwards (1997)

Table 4.9: Costs associated with multiple ovulation and embryo transfer[1] (CDN$)

Variables	Cost
Semen	15.00/dose[2]
Drugs	150.00
Medium	50.00
Labour	175.00/hr[3]
Fee	40.00
Price per embryo[4]	106.43

[1] Source: Hall, E (1997) - Gencor
[2] Average doses of semen per flush 1.8
[3] Time spent from flushing to implantation of embryos 2 hrs
[4] Average of six viable embryos per flush

Table 4.10. Genetic correlations[1] between traits simulated.

Traits	Genetic correlations
WWD - BWD	0.26
WWD - PWG	0.47
WWD - MCW	-0.17 , 0.57[2]

[1] Source: Koots (1994)
WWD - Weaning gain direct
BWD - Birth weight direct
PWG - Post-weaning gain
MCW - Mature cow weight
Source: Koots (1994)

Table 4.11: Mean values (kg) of simulated traits after 20 years of selection for specialized and non specialized line selection[1]

Selection				Traits		
line		WWD	BWD	PWG	MCW	MWT
Sire line	(100/0)	1.132	43	1.441	---	534
Dam line	(0/100)	---	----	---	403	534
Single line	(80/20	1.119	42	1.426	494	534
Single line	(70/30)	1.102	42	1.410	468	534
Single line	(60/40)	1.080	41	1.387	446	534
Commercial		0.900	34	1.200	580	534

[1] Genetic correlation between weaning gain direct and mature cow weight (-0.17)

WWD - Weaning gain direct
BWD - Birth weight direct
PWG - Post-weaning gain
MCW - Mature cow weight
MWT - Market weight

Table 4.12: Mean values (kg) of simulated traits after 20 years of selection for specialized and non specialized line selection[1]

Selection				Traits		
line		WWD	BWD	PWG	MCW	MWT
Sire line	(100/0)	1.132	43	1.441	---	534
Dam line	(0/100)	---	----	---	403	534
Single line	(80/20)	1.118	43	1.424	609	534
Single line	(70/30)	1.084	42	1.393	557	534
Single line	(60/40)	1.023	39	1.330	497	534
Commercial		0.900	34	1.200	580	534

[1] Genetic correlation between weaning gain direct and mature cow (0.57)

WWG - Weaning gain direct
BWD - Birth weight direct
PWG - Post-weaning gain
MCW - Mature cow weight
MWT - Market weight

Table 4.13: Live weight and energy intake of breeding females for specialized and non specialized beef herds.

Variable	Novel (dam line)	NS80/20	NS70/30	NS60/40	COMM
MCW(-0.17)[1]	374	457	433	413	535
MCW(0.57)[2]	373	563	515	459	535
AEI(-0.17)[3]	7122	7839	7579	7268	6993
AEI(0.57)[4]	7104	8735	8263	7632	6993

[1,2] Mature cow weight at calving using genetic correlations of -0.17[1] and 0.57[2] between mature cow weight and weaning gain direct

[3,4] Weighted annual cow energy intake using genetic correlation of -0.17[3] and 0.57[4] between cow mature weight and weaning gain direct.

Novel - 100% on a maternal trait.
NS80/20 - 80% relative economic weight on terminal traits and 20% on maternal traits.
NS70/30 - 70% relative economic weight on terminal traits and 30% on maternal traits.
NS60/40 - 60% relative economic weight on terminal traits and 40% on maternal trait.

Table 4.14: Calf milk consumption and weaning weight for different breeding schemes.

Variables	Novel	NS80/20	NS70/30	NS60/40	COMM
Milk[1] (kg)	1876	1845	1810	1759	1519
Milk[2] (Kg)	1885	1847	1777	1638	1519
WW[3] (Kg)	268	265	261	256	213
WW[4] (Kg)	270	266	258	243	213

[1] Milk yield on breeding scheme when genetic correlation between pre-weaning gain and mature cow weight was -0.17.

[2] Milk yield on breeding scheme when genetic correlation between pre-weaning gain and mature cow weight was 0.57.

[3] Weaning weight when genetic correlation between pre-weaning gain and mature cow weight -0.17.

[4] Weaning weight when genetic correlation between pre-weaning gain and mature cow weight 0.57.

Table 4.15: Days in feedlot (d), energy intake (Mcal), slaughter weight(kg) and carcass weight(kg) for steers from different breeding schemes.

Variables	Novel	NS80/20	NS70/30	NS60/40	COMM
Days[1] (-0.17)	170	173	178	185	268
ME[2] (Mcal) (-0.17)	4539	4487	4559	4644	5801
Days[3] (0.57)	170	172	183	203	268
ME[4] (Mcal) (0.57)	4414	4477	4616	4886	5801
Slaughter wt.	534	534	534	534	534
Carcass wt.	320	320	320	320	320

[1] Average days in feedlot for steers and heifers using genetic correlation of -0.17 between weaning gain direct and mature cow weight.

[2] Average energy intake for feedlot steers and heifers using genetic correlation of -0.17 between weaning gain direct and mature cow weight.

[3] Average days on feedlot for steers and heifers using genetic correlation of 0.57 between weaning gain direct and mature cow weight.

[4] Average energy intake for feedlot steers and heifers using genetic correlation of 0.57 between weaning gain direct and mature cow weight.

Table 4.16: Average weighted[1] cow/calf costs for at two levels of genetic correlation between pre-weaning gain and mature cow weight.

Variable	Novel	NS80/20	NS70/30	NS60/40	COMM
AVG[1] (-0.17)	330.14	348.01	342.29	336.40	371.73
AVG[1] (0.57)	330.45	370.96	359.44	344.23	371.73
AVG + EB.[2]	461.49	499.36	493.64	487.75	398.73
AVG + EB.[2]	481.80	522.31	510.79	495.58	398.73

[1] Average weighted costs per animal age class

[2] Including embryo costs (151.35 CDN $) in average cow costs.

Table 4.17: Average costs per head associated with replacement heifers, feedlot steers and heifers for different breeding schemes (CDN$).

Variables	Novel	NS80/20	NS70/30	NS60/40	COMM
Replac. Heif.[1]	583.55	715.24	677.60	645.76	1167.44
Replac. Heif.[2]	582.11	881.69	806.41	719.54	1167.44
Feedlot[3]	217.93	220.33	223.86	228.13	251.31
Feedlot[4]	216.69	219.95	226.70	240.04	251.31

[1] Costs associated within replacement heifers when genetic correlation between pre-weaning gain and mature cow weight was -0.17.

[2] Costs associated within replacement heifers when genetic correlation between pre-weaning gain and mature cow weight was 0.57.

[3] Average feedlot costs for steers and heifers when genetic correlation between pre-weaning gain and mature cow weight was -0.17.

[4] Average feedlot costs for steers and heifers when genetic correlation between pre-weaning gain and mature cow weight was 0.57.

Table 4.18: Gross income from feedlot steers and heifers and cull cows, gross expenses exclusive of embryo costs, gross margin and embryo value for different breeding schemes (CDN$/embryo).

Breeding scheme	Gross income	Gross expenses	Gross[2] margin	Gross margin	Embryo value[3]
Novel (-0.17)	1141.18	723.13	418.05	266.69	142.81
Novel (0.57)	1140.89	733.61	407.28	255.93	132.04
NS80/20 (-0.17)	1164.70	782.91	381.79	230.44	106.55
NS80/20 (0.57)	1194.74	826.75	367.99	216.64	92.76
NS70/30 (-0.17)	1157.90	769.43	388.47	237.12	113.23
NS70/30 (0.57)	1181.14	810.91	370.23	218.87	94.98
NS60/40 (-0.17)	1152.23	764.15	388.08	236.73	112.85
NS60/40 (0.57)	1165.27	798.19	367.08	215.73	91.83
Commercial	1181.19	905.95	275.24	275.24	0

[1] Base embryo value was 151.35 CDN $

[2] Gross margin was gross income minus gross expenses

[3] Embryo value was defined as the breakeven price, or the price that a breeder could pay to attain the same gross margin as obtained in a commercial terminal herd.

Figure 4.1 Biological time line for beef cattle

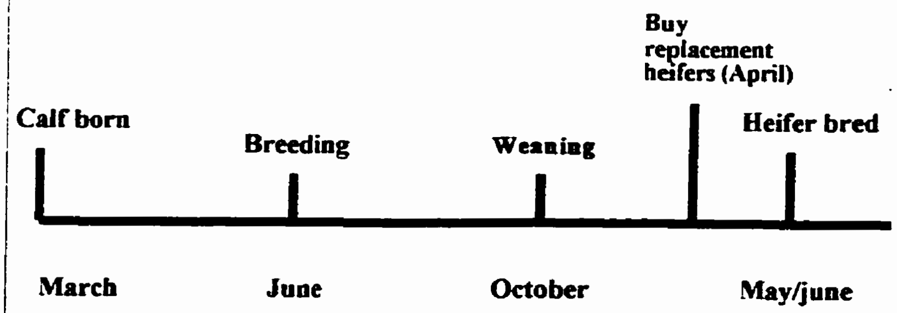


Figure 4.2. Making effective management decision

Analyze resources

Determine objectives
Producer's maximun profit

Identify problems
Use of A.I. in commercial breeding scheme
Or
Use of MOET in specialized/non specialized breeding schemes

Develop alternatives
i - Commercial A.I. breeding scheme
ii - Novel breeding scheme
iii- Non-specialized (NS80/20)
iv - Non-specialized (NS70/30)
v - Non-specialized (NS60/40)

Choose plan based on gross margin (CDN $)

Appendix 4.1 Genetic price of embryos over veterinary costs

Variables	Value
P1=male to female ratio	50%
P2 = probability of selling as a market steer/heifer	25%
P3 = probability of selling as an average bull	50%
P4 = probability of selling as a superior bull	25%
INCS = income for selling a feedlot steer	1095.00
INCH = income for selling a feedlot heifer	978.00
INCAB = income for selling an average bull/heifer	2500.00
INCSB = income for selling a superior bull/cow	5000.00
CFS = costs associated with feedlot steers	--[1]
CFH = costs associated with feedlot heifers	--[2]
TEST = costs for having a bull on performance test	700.00
OTH = other costs	100.00
AVBY = embryo yield per flush	6
NUMBF = number of flushes per year	4

Male income = p1 * (0.25*INCS+0.5*INCAB+0.25*INCSB)

Female income = p1 * ((0.25*INCH+0.5*INCAB+0.25*INCSB)

Male expenses = p1 * (0.25*CFS+0.25*CFH+0.75*(TEST*2 +(OTH*2))

Female expenses = p1 * (0.25*CFS+0.25*CFH+0.75*(TEST*2 +(OTH*2))

Return = Male income + Female income

Expenses = Males expenses + female expenses

Price = (Return - Expenses)/(AVBY * NUMBF)

[1] Costs associated to feedlot steers depends on breeding scheme simulated

[2] Costs associated to feedlot heifers depends on breeding scheme simulated

Appendix 4.2. Calculations for estimation of embryo value.

Expenses in specialized scheme (NOVEL)

Cow	330.14 (Table 4.17)
Replacement heifers	175.06 (583.55 * 30% replacement rate)
Feedlot(steers/heif.)	217.93
Total	723.13

Income in specialized scheme (NOVEL)

Feedlot	1035.19
Cull cows	105.99 (374.00 * 1.09 *26% culling rate) (Table 4.13)
Total	1141.18
Gross margin	418.04 CDN $
	Commercial herd
Gross margin	275.24 CDN $ (Table 4.18)

Embryo value = Specialized gross margin - commercial gross margin

Different in gross margin = 418.04 - 275.24 (Table 4.18)

Embryo value

142.81 CDN $

CHAPTER 5.

5.1 GENERAL DISCUSSION

The most basic effect of reproductive technologies is to increase reproductive potential (Betteridge, 1993). This means that fewer parents are required to produce a given number of offspring, compared with natural mating. Genetically, this results in increased intensity of selection, which in turn can result in an increase in the average genetic merit of offspring (Land and Hill, 1975). It follows that if a reproductive technology is used in a closed population, the rate of genetic improvement in the population can be increased. This is the essential genetic advantage offered by reproductive technologies.

Unfortunately, there is also a down side to the use of these technologies: they can create substantial problems in terms of inbreeding and variability of response (Villanueva et al.,1995).

It is necessary to predict the undesirable consequences, which have been in place for many decades. Only in the past ten years has the necessary theory been developed to enable us to account for variability in response when planning breeding programs. There is still much work to be done on the theoretical side. However, by using simulation, stochastic and deterministic, geneticists have been able to reach some substantial conclusions about the implications of various reproductive technologies, and have come up with practical suggestions about how best to use some reproductive technologies in improvement programs, accounting for their advantages and their limitations (Bourdon, 1997).

Over the last 20 years the non-surgical recovery and transfer of embryos has become a routine technique in cattle breeding, and scientific advances have led to the commercial introduction of techniques for in vitro embryo production (IVEP)(Luo et al., 1994).

The objectives of this thesis were to develop genetic and economic models to compare rates of genetic improvement attained in specialized and non-specialized beef lines and study the possibility of producing market animals using embryo transfer technology. In Chapter 3, the potential for using reproductive technology, such as multiple ovulation and embryo transfer (MOET), and in vitro embryo production (IVEP) in a closed nucleus breeding scheme, was investigated. Selection was carried out for 20 years in terminal and maternal traits in specialized sire and dam lines, and in a single line selection. Embryos from a terminal line were implanted in recipient cows from a dam line defining a NOVEL breeding scheme, comparatively embryos from single line selection were implanted within recipient cows also from single line selection, characterizing a NON- SPECIALIZED breeding scheme. The rates of genetic improvement attained in NOVEL and NON-SPECIALIZED schemes for a nucleus implementing MOET and IVEP where then compared at different levels of heritabilities, relative economic weights and genetic correlations for specialized and single line selection.

The comparison of the two different reproductive technologies showed that genetic response in the MOET nucleus was significantly ($P<0.01$) higher than genetic improvement achieved in the IVEP nucleus, independently of the breeding strategy studied. Implementing a nucleus beef herd by IVEP initially had the advantage of shortening generation intervals over the MOET scheme, but current rates of success in addition to lower accuracy of selection in IVEP were limiting factors and decreased competitiveness compared to the MOET nucleus.

Efficiency of selection in specialized sire and dam lines, relative to selection in a single line, was comparatively studied with different economic emphasis on terminal and maternal traits in a single line. Independently of the reproductive technology adopted for nucleus implementation, accumulated genetic response over 10 generations of selection for specialized sire and dam lines was significantly higher ($P<0.01$) than selection in non-specialized lines.

When genetic correlations between terminal and maternal traits were unfavorable, fairly substantial gains in efficiency were obtained by selecting specialized sire and dam lines.

Different levels of heritabilities of terminal and maternal traits also had an important function in determining the superiority of specialized sire and dam lines over single line selection. The larger the difference between the heritabilities of the terminal and maternal traits was, the better it was to select for specialized sire and dam lines. Efficiency of selection in specialized lines in relation to selection in a single line increased as the ratio of relative economic weights between terminal and maternal traits decreased in the single line selection. The dominance of the terminal or maternal trait in specialized beef lines showed that efficiency was mainly sensitive to changes in the dominant trait, as measured by relative economic weights and heritabilities.

In conclusion, the theoretical study in chapter 3 showed that selection on specialized sire and dam lines in a nucleus breeding scheme yielded higher genetic responses compared to selection for terminal and maternal traits in a single line. There is adequate evidence, based in this study and previous studies, that genetic progress to improve beef cattle can be enhanced over the conventional schemes, if selection is based on a clearly defined breeding goal. The question that remains is: Can an appropriate breeding goal be found for a diverse population? A second question to be asked is: Are breeders equipped to deliver the technology at relatively reasonable costs?

Chapter 4 of this thesis addressed economic aspects related to the feasibility of MOET versus A.I.. The possibility of applying MOET technology as a means of producing market animals was examined and compared to A.I.. Selection on a single line for maternal and terminal traits was economically compared to genetic gain on specialized sire and dam lines. Net returns over variable costs showed, that implanting embryos from highly selected lines for growth traits into cows that were selected for smaller body size was economically more viable than implanting embryos from a single line on recipient cows also from that single line.

Within a single line, gross margin favoured breeding schemes where selection on reduced cow weight was emphasized. A maternal trait, represented as mature cow weight, had a major economic effect on the breeding schemes simulated and should be included in breeding objectives.

Economic comparison of MOET schemes to commercial A.I. showed that besides the genetic superiority of embryos and recipient cows from specialized and non-specialized breeding schemes, current embryo costs are still too high to be implemented in commercial beef production. Embryo costs have to be reduced to be economically feasible for producing market animals.

The findings of this thesis indicated that breeding objectives should focus on selection for a specialized purpose. The rates of success of MOET and IVEP in addition to the costs of these technologies were a limiting factor, but production costs may be decreased shortly as technology is advancing, and in the near future a premium price could be developed by the Industry for specialized niche markets (Edwards, 1997).

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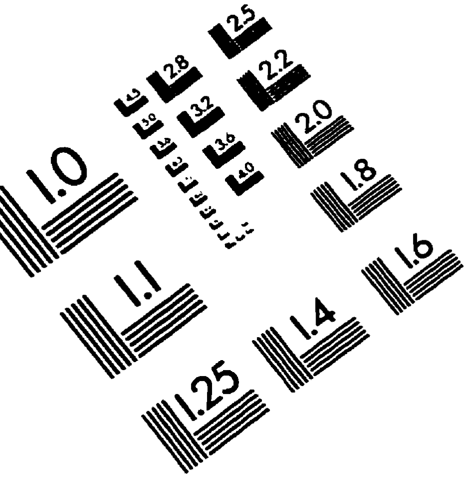
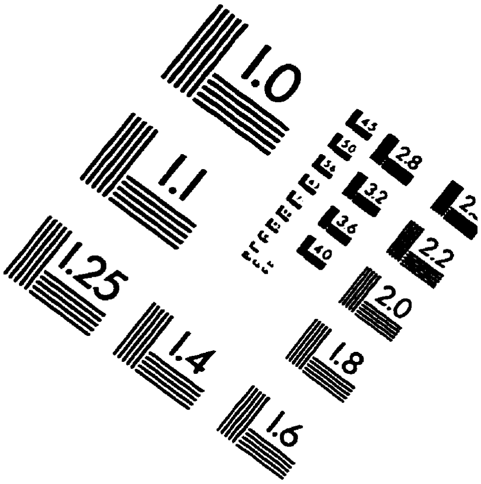
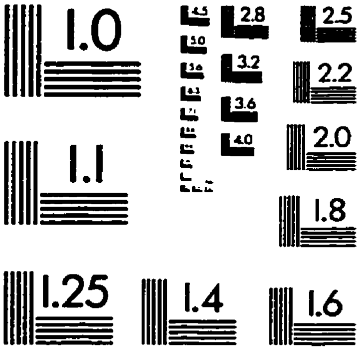
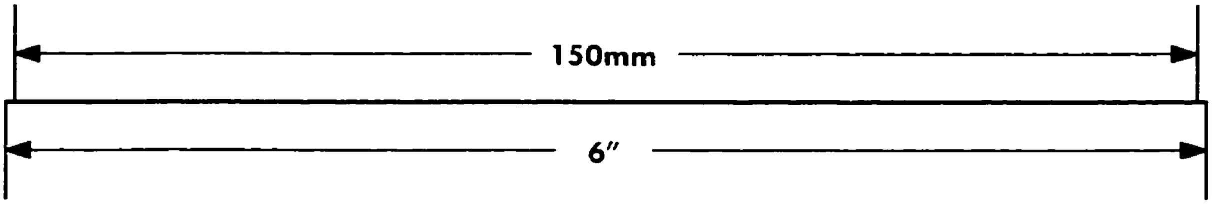
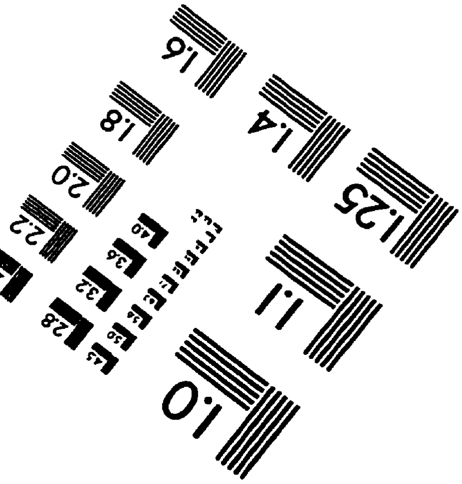
IMAGE EVALUATION TEST TARGET (QA-3)











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