IMPROVING BEEF PRODUCTION IN BRAZIL USING SELECTION AND CROSSBREEDING

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fulfillment of the requirements for
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MAURO LORDES PEREIRA

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MAR SALGADO

Ó mar salgado, quanto do teu sal
São lágrimas de Portugal!
Por te cruzarmos, quantas mães choraram,
Quantos filhos em vão rezaram!

Quantas noivas ficaram por casar
Para que fosses nosso, ó mar!
Valeu a pena? Tudo vale a pena
Se a alma não é pequena.

Quem quere passar além do Bojador
Tem que passar além da dor.
Deus ao mar o perigo e o abismo deu,
Mas nele é que espelhou o céu.

Fernando Pessoa

Extraido da obra poética Mensagen
de Fernando Pessoa

PORTUGUESE SEA

Salt-laden sea, how much of all your salt
Is tears of Portugal!
For us to cross you, how many sons have kept
Vigil in vain, and mothers wept!
Lived as old maids how many brides-to-be
Till death, that you might be ours, sea!

Was it worth? It is worth while, all,
If the soul is not small.
Whoever means to sail beyond the Cape
Must double sorrow - no escape.
Peril and abyss has God to the sea given
And yet made it the mirror of heaven

Fernado Pessoa

Mar salgado (Portuguese Sea) translated
into English by J.Griffin from Fernando
Pessoa's 'Mensagem'

Abstract

Beef industry is an important sector of the Brazilian economy. Brazilian beef production is very dependent on pasture, which, in all most its totality, is constituted by tropical forages characterized by abundance during the rain season and low quality and quantity during the dry season. Therefore, efficient beef production systems would include breeding adapted genotypes rather than attemptig large changes in the environment. As a result, animal breeding becomes a very important agent within beef production.

This project intended to investigate throughout computer modeling the effects of different breeding schemes applied to a hierarchical integrate beef production system, involving a three straight bred herds nucleus and a three-breed terminal crossing commercial herd. The study simulated a tropical system of production based on common Brazilian management practices and parameters published in the literature related to beef production on tropical and subtropical climates. A deterministic procedure was applied to develop a model for a hierarchical integrated beef production system involving a crossbred commercial herd and three straight-bred nucleus herds and it was developed on an annual basis using a Microsoft Excel spreadsheet.

Economic selection index methodology was applied to develop different selection indexes. The model was used first to estimate economic values for biological traits affecting returns and costs. A breeding objective was established based on economic values of traits that would significantly affect profitability of the production system. Basically there were two different scenarios that were tested. One scenario investigated the results of 20 years of selection taking in account the use of progeny tested bulls while the other scenario would investigated the outcomes of selection based only on individual selection of the bulls. Subsequently, the model was used to investigate which economic values would maximize profit per animal unit.

The two selection indexes that included information of progeny into the selection criteria were the best ones when compared to the selection indexes using individual selection independently of the relative economic values applied. The maximizing profit AU relative economic value selection index presented the best improvement in profit per AU, which was also followed by a higher profit per hectare and return rates.

Economic selection index proved to be an efficient tool to change profit since breeding schemes improved profit in all scenarios independent from the relative economic value applied or if information from progeny was included or not in the index. The adoption of progeny testing in breeding programs proved to be more effective than individual selection on a long-term basis. The advantage of selection indexes including progeny was to promote a greater increase in dressing out percentage and a lower change on mature size of the breeding cows.

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CONTENTS

Chapter 1

Introduction

Introduction

The beef industry is an important sector of the Brazilian economy and, as for many sectors of Brazilian society, is characterized by socioeconomic contrasts. Although, Brazilian beef farms and ranches, as a general rule, are a representation of inefficient extensive systems presenting deficiencies regarding nutrition, reproduction and health control of their herds, there are also some very efficient systems in Brazil applying improved technologies in order to maximize production.

Brazilian beef production is very dependent on pasture, which, in all most its totality, is constituted by tropical forages characterized by abundance during the rain season and low quality and quantity during the dry season. Therefore, efficient beef production systems would include breeding adapted genotypes rather than attempting large changes in the environment. As a result, animal breeding becomes a very important agent within beef production.

Although beef production in tropical areas seems to be restricted by socioeconomic and environmental conditions, the future of the Brazilian beef industry is very promising since the consumption of beef is increasing in Brazil while beef exports also assume an important place. Brazil has the largest commercial herd in the world and the beef production sector is already in transition from an extensive model of production to a modern and more efficient system.

Therefore, the beef production activity in Brazil would be soon a response to the world globalization and due to its competitiveness beef production would be more and more seen as an business enterprise rather than an extractive activity. Eventually, the inefficient extensive model of production would not survive any longer and the beef production sector would be forced to change in order to reach the new demands of the productive chain. As a result, it is necessary to identify crossbreeding systems that would combine the desirable characteristics in order to achieve efficient and, hence, profitable production systems.

Any agricultural production system is extremely complex and the intensification process would increase not only its complexity but its risks as well. It is clear the necessity of holding the best knowledge possible of all components of the system and the interactions among them is required to maximize its efficiency. Computer simulation has become an important research tool to investigate efficiency.

Modeling beef cattle production systems is a way of rapidly investigating its components and their interaction. It is a technique that allows us to apply research information for specific current conditions to better understand it. However, close attention should be paid to not over-simplify or over-extend modeling use and its results must be carefully interpreted because modeling does not substitute for carefully conducted experiments.

This project intended to investigate throughout computer modeling the effects of different breeding schemes applied to a hierarchical integrated beef production system, involving three straight-bred nucleus herds and a three-breed terminal crossing commercial herd. The study simulated a tropical system of production based on common Brazilian management practices and parameters published in the literature related to beef production in tropical and subtropical climates. The scenarios tested on this project economically evaluated the option between selection index using progeny test against individual selection and the economic values that would maximize profit per animal unit.

Chapter 2

Review of Literature

2.1 Brazilian beef industry and production

2.1.1 Beef cattle production

Brazilian beef cattle production is an important part of the country's economy since it represents a total revenue of US$ 13.17 billion involving around 6,834,000 jobs (Pitombo, 1995). In addition, although beef cattle production in tropical environments utilizes the same basic principles as in temperate regions, under tropical conditions beef cattle have a crucial role to utilize grasslands unsuitable for cropping (Ordonez, 1990). According to Anualpec 1998 (FNP, 1998), 2/3 of beef production in Brazil is undertaken in tropical environments representing around 100 million head.

Most tropical areas in Brazil are characterized by a period of rain during summer and a dry season in winter. These areas would present difficult conditions for beef production due to poor soils, low quality forages and high levels of parasite infestation (Euclides Filho 1997; Ordonez, 1990). Frisch and Vercoe (1984) have reported better performance of *Bos indicus* against *Bos taurus* in these stressful tropical conditions. A major part of the Brazilian herd is composed of Zebu breeds depending on tropical grass pasture and presenting on average a daily gain of 0.5 to 0.8 kg/day during the rain season (Felício 1999). However, during the dry season tropical pasture would barely be enough for maintenance and in many cases the cattle lose weight.

Consequently, the environmental constraints in addition to socioeconomic ones, such as low level of instruction of farmers, lack of professional technical assistance, and deficiency in transportation and communication, would lead to low indices of productivity. The principal causes contributing to these low indices of productivity were resumed by Felício (1999) as:

- The empty cows are kept in the herd for a long period.
- The heifers reach puberty at elevated ages.
- High slaughter ages.
- Low genetic gain (improved bulls used only by very few farms).
- Weak heifers are kept as replacements.

Pelicioni et al. (1999) reported that low reproductive efficiency, characterized by the long interval between calvings and the delayed age at first calving, is the major factor limiting beef production in Brazil.

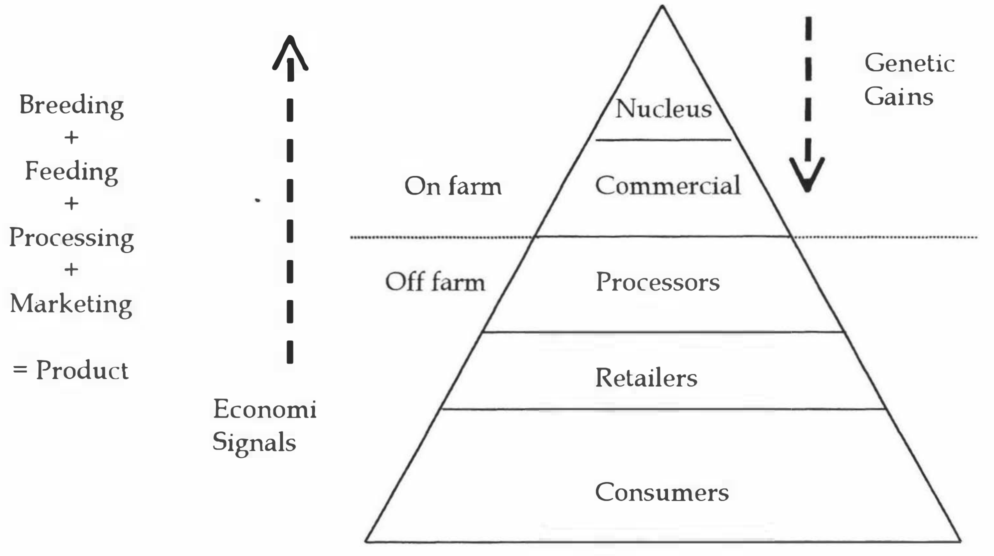
According to Faveret Filho and de Paula (1997) most Brazilian beef production has the purpose of serving the internal market. However, the authors also pointed out that even though 96% of the beef produced in Brazil in 1996 was sold in the internal market, Brazil was the fifth biggest exporter of bovine meat in the same period exporting 90,000 tons of beef representing 6% of the international beef market. Most of the exports were processed meat.

2.1.2 Brazilian beef industry structure

Similar to other countries such as New Zealand and USA the beef industry in Brazil could be represented by the pyramidal scheme of tiers (Figure 2.1). Genetic improvement arises from selection in the nucleus sector and the genetic gain should be intuitively directed to the commercial herd where the greatest proportion of end-products eaten by consumers are produced (MacNeil and Newman 1992). However, according to Felício (1998) the Brazilian beef industry, which was one of the worlds most modern beef industries in the beginning of the 1980's, is now at least 20 years behind.

The reason for this stagnation is very complex, although some facts should be reviewed.

Figure 2.1. Simplified beef industry structure adapted from MacNeil and Newman (1992) and Charteris (1995).



According to Faveret Filho and de Paula (1997) the relationship between the farm and off-farm sectors is weak leading to a lack of coordination among the sectors of the beef industry. Felício (1998) pointed out that the consumer needs, in general, are left out of the pyramidal flow chart. Moreover, Felício (1994) reported that the slaughter plants would still pay the farms as they did for the last eight decades. In other words, the beef plants would basically separate carcasses in three categories: breeding cows, bull and steers, not worrying about the carcass proportion of lean meat, fat and bone or the quality of the meat when paying farmers. However, other aspects of the carcass beside weight that should be considered is the amount of subcutaneous fat (Berg and Butterfield, 1976). According to Davis (1992) the USA market moves towards commercialization based on saleable meat yield of the carcass: "value based marketing".

The Brazilian beef industry seems insensible to farmers' claims to a fair remuneration rewarding the quality of the carcass, and to the new demands to compete in a modern market. Consequently, during the last two decades the beef industry in Brazil watched passively the dawn and the fast growth of a modern and very organized poultry industry with a large capacity to respond to the consumers needs (Felício, 1998). The chicken per capita consumption has grown 300 % from 1977 to 1997 against an increase of 23% in beef per capita consumption in the same period, although barbecue and steak still being the two most preferred meals with respectively 26% and 11% of Brazilian preference against only 9% from chicken (Fundepec, 2000). The actual beef per capita consumption is 38 kg (Zimmer, 1998).

2.1.2.1 An overview of tropical meat quality

Most of the meat produced in tropical regions is based on *Bos indicus* breeds of cattle. Traditionally, *Bos indicus* and *Bos indicus* crossbred cattle have been discriminated against by the meat industries (Johnson et al. 1990) since several publications have described meat of Zebu and its crosses being less tender than *Bos taurus*. However, meat quality is also related to other carcass traits beside tenderness and the concerns of a beef enterprise could not be resumed only in meat tenderness since fat and dressing-out percentages are two important traits affecting the lean meat yield. Cundiff (1992) reported a higher dressing-out percentage for crossbred Nellore x Hereford or Nellore x Angus when compared to other crossbred types at 417 days of age and over 500 kg of liveweight. Differences between *Bos indicus* and *Bos taurus* meat traits are reviewed later in this chapter.

The meat of Zebu breeds is well known to be lean almost devoid of marbling although it presents enough subcutaneous fat to avoid problems during the chilling process. According to Felício (1999) the meat of tropical cattle could be classified as flavorous but tough, since this meat would grade 4 or 5 for tenderness and 6 or 7 for flavor in scale of 0 being very tough and 10 very tender and 1 being flavorless and 10 being very flavorful. Tenderness is the major palatability trait affecting consumer acceptances of beef and consumers would pay higher prices for greater tenderness (Boleman et al. 1995). Therefore, Zebu meat tends to be treated as a commodity and commercialized in its majority as processing meat.

2.1.3 Challenges and perspective of the beef production

2.1.3.1 On Farm sector

Despite constraints related to Brazilian beef production and industry, changes are already happening and the future is very promising for this sector of the Brazilian economy. According to Euclides Filho (1997) the sector would be soon a reflex of globalization, which has introduced competitiveness in the world beef market. Therefore, any decision regarding beef production could not be made before an analysis of the whole productive chain involving the production system and objectives, the environment, the available technology and market demands. Therefore, the author also believes that the Brazilian beef production system would become more and more a business enterprise and the extensive model of production would not survive.

There are real signals that Brazilian society is changing to a more just society, in particular regarding the income distribution even though according to Zimmer (1998) half of the Brazilian population would have financial restrictions on meat consumption. A raise in per capita income could increase beef consumption in Brazil to 55 kg per capita similarly consumption in Argentina and Uruguay (Cezar and Euclides Filho, 1996). However, although the average price of beef in Brasilia (capital city of Brazil) is less than half of the beef price in Washington D. C., according to the United States Department of Agriculture (USDA) an average worker in Brasilia has to work at least three hours more than an worker in Washington in order to buy one kg of meat (Simpson and Farris, 1982).

According to Zimmer (1998), a raise of one kg per capita in beef consumption in Brazil would lead to a demand of 750,000 new heads. The actual beef surplus is around 300,000 tons, only enough to increase per capita beef consumption two kg. Consequently it is sine qua non a rapid increase in beef production and in Euclides Filho (1997) opinion there would be also a greater demand for quality as well. Therefore, the beef production efficiency must be intensified by enhancing the pasture support capacity, increasing reproduction efficiency, reducing age of puberty and age of slaughter. In other words, it is necessary to find the genotype-environment duality necessary to achieve suitable indices of production. In this circumstances animal breeding would assumes a crucial role in beef production (Euclides Filho 1997).

2.1.3.2 Off farm sector

Since 1996 when the European meat market suffered a strong reduction in meat consumption caused by the bovine spongiform encephalopathy disease, a new concept arose: traceability was one of the most important policies adopted to guarantee consumers the safety of the meat. As a result, it is important now to develop a traceability system able to track the original animal from its meat cuts (Fearne, 1998) and according to Felício (1999) that new concept demanded by the international market is changing the posture of the Brazilian beef industry. The development of a traceability system, able to track animals, carcass and cuts, poses a large challenge for the Brazilian beef industry.

Another important factor forcing the changes in the Brazilian meat industry is a law, established in April 22[nd], 1996, obligating that all meat commercialized by the slaughter plants should be refrigerated at a maximum temperature of 7° C, packed and labelled with its designation of origin. According to Faveret Filho and de Paula (1997) the law would not have a great impact in a short-term basis since there is not enough coordination and structure able to provide an efficient system of inspection. However, the authors believe that over a long-term basis the law would enforce the slaughter plan strategy of working with special cuts to establish a line of products that would differentiate the plant from the rest of plants in the market.

2.1.3.3 Alternatives programs for the system.

According to Faveret Filho and de Paula (1997), modernization efforts are spreading throughout all segments of the beef production chain, although the effects of this process for the whole chain would not be easily measurable since this process has presented differences of degrees from one segment to another. However, efforts such as vertical marketing alliance and the novilho precoce program have showed their worth. The marketing alliance of the Fundepec from Sao Paulo Estate and the marketing alliance Meat with Quality from Rio Grande do Sul Estate are both important efforts to enhance coordination of the productive chain since those programs involve farmers, slaughter plants and supermarkets (Faveret Filho and de Paula 1997).

The Meat with Quality program has the purpose of recovering the beef production increasing the inspected slaughtering, thus reducing the inactive time of the industry and offering a better product to consumers. One way of undertaking that would be through tax relief. The Fundepec alliance has the aim to establish reliable source and distribution of better quality meat to consumers willing to pay more. The Fundepec program involves a carcass classification system, similar to the official classification system, in which only carcasses of young animals, less then 36 months for steers and heifers and 24 months for bull, with subcutaneous fat between three to eight centimeters are allowed (Felício 1999). However, in the first semester of 2000 the Fundepec launched some changes in its program and now there is a reward for young animals that present subcutaneous fat between two and four millimeters.

Another alternative would be the program from the Agriculture Ministry encouraging the slaughtering of young (for Brazilian standards) called "novilho precoce". There has been a lot of discussion regarding what animal could be classified as a "novilho precoce", however Cezar and Euclides Filho (1996) classified "novilho precoce" as animals slaughtered between 24 and 30 months at450 kg liveweight. According to Faveret Filho and de Paula (1997) several States have been making efforts to attract farmers to their "novilho precoce" programs and in some cases GST relief could reach 66%. Finally, the adoption of alternatives program could be the only way to persuade farmers to modernize and intensify their production system (Felício 1999).

2.2 Beef production efficiency

The beef production efficiency could be split in biological and economical efficiency, and although they are not always synonymous for each other, there is no doubt the correlation between them is strong. The viability of the beef production system depends on many factors directly or indirectly linked to the production chain and a function that would express the biological efficiency of a system is kilos of good quality meat per hectare per year (Euclides Filho et al. 1991). Some basic components involved in that would be number of calves born, growth rates from birth to weaning and from weaning to slaughter, number of animals culled, mortality, slaughter weight and dressing out percentage.

The importance of reproduction traits is an unquestionable major aspect in beef production efficiency. According to Euclides Filho (1997) fertility is a major concern in the production system and reproductive precocity is a compelling demand and according to Bellows and Staigmiller (1994) fertility must be recognized as the major economic force in successful beef production. Literature reviewed by Bellows and Short (1993) showed that high environmental temperatures and humidity have major detrimental impacts on the conception rate, embryo survival, and embryo growth. As a result, reproductive traits become even more important determinant of efficiency in tropical beef production systems.

Profitability is a function of outputs and inputs thus the reduction of inputs should also be a relevant concern in beef production operations. Furthermore, the major economic input of any beef production system is feed since although the cost of feed in extensive grazing industries are hard to measure, it encompasses the expenses related to land, pasture improvement, irrigation, fertilizers, supplementary feed, costs of planting, and feeding labor (Farquharson 1993).

According to Cameron (1998) efficiency of nutrient utilization should be an important part of any breeding program and the pig and poultry industries are indeed successful examples of the benefits when breeding programs incorporate feed efficiency in their selection criteria. Only 6% of the total life cycle dietary energy expanded in beef production results in protein deposition in market progeny (Dickerson 1984) against 14 and 21% in pork and chicken respectively. Although almost all dietary energy in beef production is obtained from high fibre content feeds, which are relatively cheap and can not be used in poultry or pig operation, it is still clear that beef production is an inefficient process regarding the amount of energy used (Ritchie 1995). The energetic inefficiency of beef production seems to be related to a high cost for maintenance. 71% of the total dietary energy in a beef system goes to maintenance and 70% of that is expended with maintenance of the breeding herd (Johnson, 1984) hence 50% of the total dietary energy is consumed as maintenance requirements of the breeding cow.

Different ways to measure biological efficiency have been adopted by researchers thus it is a controversial issue of any trial involving biological efficiency, since it depends on feed inputs, reproductive traits and production outputs related to different classes of livestock within the production system. Ritchie (1995) presented the three more common ways that biological efficiency has been measured at slaughter time: pounds of slaughter progeny weight per unit of feed energy consumed by cow and slaughtered progeny, pounds of carcass weight per unit of energy consumed by cow and slaughtered progeny, and pounds of edible feed unit of energy consumed by cow and slaughter progeny. A table presented in another review by Morris and Wilton (1976) gives a good illustration of how measures of biological efficiency could differ among authors (see table 2.2).

Table 2.2- the definition of measurements of combined cow and calf efficiency to yearling stage or slaughter time.

Authors	Definition of measurements
1. Boyd and Koger (1974)*	(TDN (kg) calf feed to a given age + annual cow feed)/kg wt (to 9 or 15 months)
2. Ellison et al. (1974)*	As for 1 (to 12 months), taking Angus-Jersey cows relative to Hereford.
3. Fox (1973)*	Combined Mcal NE/kg edible beef for cows of 400, 500, 600 kg and their progeny-efficiency taken at optimality (in turn determined from the above definition)
4. Klosterman et al. (1974)*	As for 1, taken to constant body condition
5. Joandet and Cartwright (1969)*	As for 1, taken to optimality
6. Long et al. (1975)	Metric tons of beef per annum/$100,000 feed for cows of 430, 500, 600 kg and their progeny
7. Morris and Wilton (1976)	Kg beef sold/combined Mcal NE for cows of 400, 500, 600, 700 and 800 Kg and their progeny.

* These definitions were rations of (inputs for cow and calf)/outputs.

2.2.1 Breeding cow efficiency

Since half of energy expended in the system goes to the breeding cow and fertility has such an impact on efficiency, it seems that the breeding cow plays a crucial role regarding efficiency of the system. In a review Ritchie (1995) pointed out that beef cow biological efficiency measured until weaning time has been commonly used by authors and the three more common measurement are: pound of calf weaning per cow exposed, pound of calf weaned per cow exposed per pound of cow weight, and pound of calf weaned per cow exposed per unit of feed energy.

Despite the differences in measuring biological efficiency, in 1984 a forum in beef cow biological efficiency held at Colorado State University and Michigan State University came with some general conclusions. First, it was concluded that measures of mature cow size, such as weight, height, are not correlated with biological efficiency. In addition, acceptable market weight range should be a concern when decisions regarding breed size and mating system are made, and large differences in reproductive rates have a profound impact on cow efficiency and tend to over-ride all other factors. Also, the forum concluded that biological efficiency among the breeds changes when environmental conditions also change and biological types having moderate size and milk production seem to show better efficiency than large, heavier-milking types in restricted feed and stressful environments. However, large cows with high milk potential have shown a higher biological efficiency than moderate cows in good environmental condition. In addition, there is a strong association between cow's milk production and her calf weaning weight and Albuquerque et al. (1993) estimated correlation of 0.71 between these two traits.

Therefore, although a better biological efficiency could represent a better economic efficiency, moderate types seem to be more adequate to grazing system since due to the wide changes in pasture allowance and nutritional value throughout the year, grazing systems could be a very stressful environment. According to Euclides Filho et al. (1992) large cows could not be the most efficient since they would have high requirement levels. As a result, in Brazil, Fries (1996) suggested that the size of the breeding cow should be synchronized to the production system adopting moderate cows in size and milk production. That relationship among cattle size, feed allowance and efficiency is supported by Jenkins and Ferrel (1994) who compared biological efficiency of mature cows among nine pure breeds at low dry matter and high dry matter intakes during a five-year study (see table 2.3).

Table 2.3- Predicted biological efficiency at varying dry matter intakes of nine pure breeds of cattle (g calf weaned/kg DM intake per cow exposed).

Breed	3,500 kg DM intake per year	7,000 DM intake per year
Angus	39	17
Braunvieh	33	42
Charolais	27	45
Gelbvieh	29	36
Hereford	39	13
Limousin	33	42
Pinzgauer	38	44
Red Poll	47	24
Simmental	26	42

2.2.2 Feed efficiency

It is clear that feed efficiency is of major concern and has a close relationship to biological efficiency. Consequently, similar to biological efficiency and due to the same reasons, production system feed efficiency is a controversial issue since it is also related to feed inputs and production outputs of several classes of livestock and there are different ways to measure it. Therefore, many researchers have considered feed intake and production outputs over a limited part of production cycle, then created an index combining feed intake with production to show feed efficiency.

According to Archer et al. (1999), to compare different indices it is necessary to be aware that efficiency of beef production is influenced by many traits of the slaughter generation and the breeding herd. The importance of each trait would be different for each production system hence the overall efficiency of a beef operation would be a complex biological issue and it is simplistic to consider an index based on just one period of the whole production process. It is possible some indices will be correlated to feed efficiency and thus genetic improvement would lead to an improvement of feed efficiency of the beef production system.

2.2.2.1 Feed efficiency measurements

Probably the most common index of efficiency that appears in literature is the gross feed efficiency or its inverse, feed conversion ratio, and that measure is both genetically and phenotypically correlated to production traits. Breling and Brannang (1982) resumed four studies in which impressive genetic correlations (-0.61 to -0.95) between feed conversion ratio and growth rate were presented. However, according to Salmon et al. (1990) feed conversion ratio is strongly linked to mature size thus an improvement in feed conversion ratio might lead to an increase in feed requirements of the breeding herd. However, some trials indicated that the impact of mature size increasing would have little impact on production feed conversion efficiency, at least in maternal breeds (Anderson 1978; Dickerson 1978; Fitzhugh 1978; Barlow 1984).

As a result, economic gain would depend on the difference between the gain reached by the slaughter herd and the loss produced by the increase in feed requirements of the breeding herd. Also, although feed conversion ratio seems to be a good measure of efficiency in growing animals, it is a poor measure for the whole beef production system when the requirements of the breeding herd are included (Archer et al., 1999).

Another measure common in trials is maintenance efficiency since the cost of maintaining the breeding cow is an important point affecting the profitability of beef production operations. However, measuring the maintenance efficiency of a cow is a difficult job and cannot be done with growing animals since it is required to hold the animal in a constant live-weight and that could take two years (Taylor et al. 1986). Therefore, after examining several indices for feed efficiency Koch et al. (1963) suggested partitioning of feed intake into two components: the feed intake required to a certain level of production and a residual portion. Hence, through the residual portion, animals could be identified as efficient or inefficient animals based on their deviation of the expected level of feed intake with animals having lower residual portion being more efficient.

Residual feed intake is by definition phenotypically independent of production traits used to calculate expected feed intake and Kennedy et al. (1993) showed that residual feed intake may not be genetically independent of the production. Therefore, in order to obtain a measure of efficiency genetically independent of production traits, genetic (co)variances rather than phenotypic (co)variances should be used to calculate genotypic residual feed intake (Kennedy at al. 1993). However, to calculate genotypic residual feed intake it is necessary to have information of the genetic relationships between feed intake and production which are very rarely found in practical situations of animal production systems (Archer et al. 1999).

Cow/calf efficiency has been used in some trials as a measure to investigate the feed efficiency of beef production (Shuey *et al.* 1993; Jenkins and Ferrell 1994) and cow/calf efficiency calculation is based on the total of feed consumed by the cow and her progeny during a whole production cycle. That is usually from weaning a calf to the next and then the total feed intake of the production cycle is compared in terms of kg calf weaned per kg feed consumed. This method of measuring efficiency seems to be biologically and economically closely correlated to the real production efficiency of a beef operation (Archer et al. 1999). However, because cow/calf efficiency measures seem to be expensive and difficult to be done, and also because it is affected by the genetic merit of the cow and the calf, cow/calf efficiency is a limited measure when genetic variation in feed efficiency is investigated.

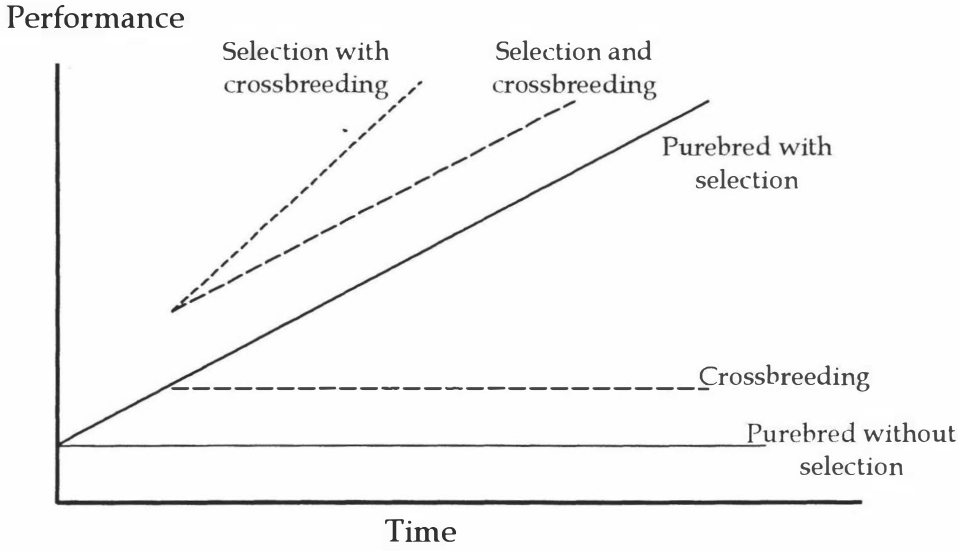
2.3 Breeding beef cattle

In order to achieve better production indices animal breeding would become more and more important to the beef production industry, and as it was also reviewed in figure 2.1, selection in the seedstock tier should provide genetic improvement that would be transferred to the commercial herds. The commercial herd would rely entirely on the continuous and cumulative improvement (Bichard 1971).

In addition, the commercial herds many utilize crossbreeding to undertake the benefits from heterosis and also to explore differences among breeds and strains (MacNeil and Newman 1992). Although crossbreeding is a quick and economic way to enhance animal performance, it does not exclude the necessity of selection neither diminish its importance (Euclides

Filho, 1996; Cunningham and Syrstad 1987) as it is shown in figure 2.2.

Figure 2.2- Illustration adapted from Warwick and Legates (1979) showing the expectation for performance of purebred and crossbred populations with different combinations of crossbreeding and selection after the initial heterosis level being reached by crossbreeding.



Genetic evaluation has improved dramatically in the last 25 years. Much of the improvement can be attributed to advances in statistical methods that overcame most of the biases inherent in genetic comparison using field data (Bourdon 1998). Increasing numbers of seedstock and commercial herds depend on the technology of genetic evaluation.

2.3.1 Crossbreeding beef cattle

Crossbreeding has been used in different animal production systems such as poultry and swine production. Although the benefits of crossbreeding have been known for many years, it has been accepted by commercial beef cattle producers only in the past few years (Simms et al., 1990). Crossbreeding is an efficient way to improve efficiency of beef production system allowing more flexibility to production systems (Barbosa, 1990). According to Euclides Filho (1996) the desirable principles involved in crossbreeding are the heterosis effects and breed complementarity that could be used to create a more adapted genotype-environment biotype increasing quality and production. Also, there is the possibility of rapid incorporation of desirable genes, which could be used to create new breeds.

2.2.1.1 Heterosis

Heterosis represents the deviation, in percentage, of the crossbreed F1 average phenotype when compared to the average phenotype of the two parental pure breeds and that should be measured in a reciprocal cross in order to cover possible differences in maternal ability of the two parental breeds (Sheridan, 1981). Therefore heterosis could be estimated by the formula:

$$\% \text{ Heterosis} = \frac{\text{Av. of reciprocal crossed - Av. of paternal breeds}}{\text{Av. of paternal breeds}} \text{x}100$$

Heterosis could be expressed as an individual, paternal or maternal characteristic (Nitter, 1978) and depending on the crossbreeding system adopted the different heterosis might appear or not. Individual heterosis is related to the improvement in the performance of the crossbred individual when compared to the average performance of parental straightbred lines. The use of crossbred dams may improve the performance of offspring and that is known as maternal heterosis. Similarly, paternal heterosis would be any advantage due to the use of crossbred sires.

The reason for heterosis is not well known but additive gene action does not contribute to heterosis for the simple reason that an additive allele would not be uncovered by its respective allele. Consequently, heterosis would be a result of non-additive gene action such as dominance or epistasis and the proportion of genetic variance that is controlled by non-additive action would be responsible for the level of heterosis presented by a certain trait (Cunningham 1982). The expression of heterosis is related to the genetic similarities or dissimilarities among the breeds that would be crossed and as a general rule: the level of heterosis increases as the degree of dissimilarity increases among the breeds. According to Land (1978) and Lasley (1978) the superiority of the crossed individual compared to the straightbred would depend on level of management, environment and the genetic differences or genetic distance between the parental lines.

Falconer (1989), assuming a linear relationship between heterosis and homozygosity, showed that expression of heterosis in the first generation is bond to genetic differences between the parental lines and the level of dominance and the second generation would retain half of the heterosis expressed in the first generation. However, according to Gregory et al., (1999), although the retained heterosis in advanced generation had a high relationship equal with the retention of heterozygosity, it was not a linear relationship for all situations. Consequently, for some traits in some case the heterosis retained could be either higher or lower than the retention of heterozygosity.

In addition, the level of heterosis presented in crossbred populations can be influenced by environmental factors and homozygotes seems to be more affected by environmental effects than heterozygotes (Lerner 1954), thus heterosis seems to be greater in stressful environments (Bibé at al 1977).

2.3.1.2 General types of beef cattle breeds

Domesticated cattle are usually classified into two major groups, Zebu (*Bos indicus*) and European (*Bos taurus*) cattle and although they are two different species, they are believed to descend from the same wild species, the Aurox (Epstein and Manson, 1984). In addition, they have the same numbers of chromosomes but differ in the morphology of the Y chromosome. According to Euclides Filho (1996) beef cattle breeds in Brazil could be spread in four major categories:

British Breeds - This group would present good survival and reproductive rates, and would produce good quality carcasses. As a disadvantage, the presence of dystocia could be mentioned. This group presents a lower growth rate than the continental European breeds thus they have a lower mature size, cows around 500 to 600 kg and males around 800 to 900 kg.

Continental European breeds - Characterized by high growth rates these breeds would have mature size around 700 to 800 kg for cows and 1,000 to 1,200 kg for males. Therefore they would present a high slaughter weight and lower fat in their carcasses. Dystocia and high nutritional requirements are disadvantages of this group.

Bos indicus breeds (Zebu type) - When compared to the European groups those breeds present a lower growth and reproductive rate. Also, their carcass would be lower in quality since meat from Zebu cattle is tougher than meat from the Europeans breeds. On the other hand, this group would present a greater survival rate and adaptability in stressful environments such as hot and humid climates. Cows around 350 to 450 kg and males around 600 to 700 kg.

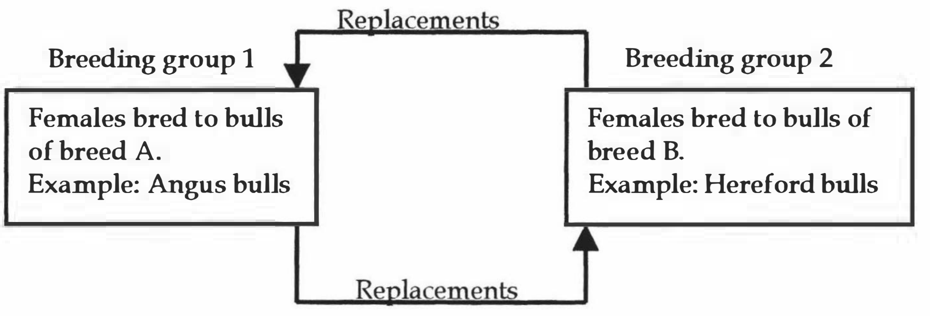
European breeds adapted to the tropics - This group would embrace all the criollo breeds of Latin America thus those breeds would present some of the production characteristics of European breeds with some of the adaptive characteristics of the Zebu type. Mature size for cows would be around 350 to 450 kg and for males would be around 600 to 700 kg.

2.3.1.3 Practical crossbreeding systems

Crossbreeding systems are frequently used by commercial farmers to provide better efficiency of their production system. There are different systems of crossbreeding and the adoption of one system would depend on several factors such as environment, target market, labor availability, system of production, opportunity for the use of artificial insemination, numbers of cows, size and number of pastures and aims of the enterprise (Euclides Filho 1996). The establishment of a composite breed is usually operationally easier than the organizational structure of a rotational crossbreeding system. Also, it is necessary to balance the questions of operational convenience and cost against the resulting estimated genetic benefits (Cunningham and Syrstad 1987). Therefore, there does not exist a crossbreeding system better than all other ones or a system suitable for every operation: each enterprise would have to find out the best mating plan based on the operational objectives.

However, there are certain types of crossbreeding systems that are more popular than other types. Variable percentage crosses, also known as rotational crosses, involving two or three breeds are some of the common crossbreeding systems used by farmers. In the two-breed rotational cross the crossed female (AB) are in alternate generation mated back to purebred sires of the two breeds and after some generations the proportion of each breed in the crossbred would be either 1/3A, 2/3B or 2/3A, 1/3B depending on the last breed that was used. In other words, females are always bred to the breed different to their own sire (Figure 2.3).

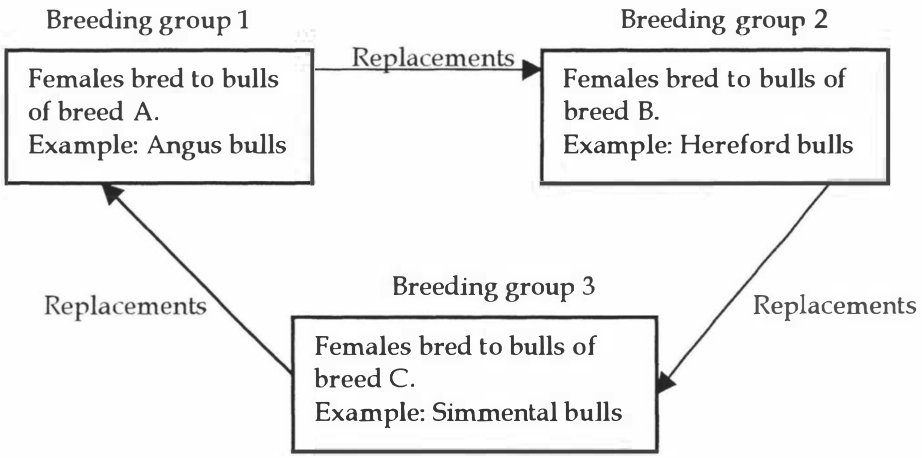
Figure 2.3. A two-breed rotation crossbreeding system (Simms et al. 1990)



The great advantage of the two-breed rotational system is that the female offspring could be incorporated as replacement females and those females would express maternal heterosis, although only 2/3 of individual and maternal heterosis would be expressed. According to Simms et al. (1990) this system would work better if the two breeds were genetically similar for birth weight, mature size and milk production in order to minimize both calf problems and the nutritional requirement variation within-herd. That nutritional requirement variation was point by Euclides Filho (1996) as one of the possible problems for the limited success of this system in Brazil since the majority of the two-breed rotational crossbreeding system in Brazil was based on Nellore and a continental European breed with great size and/or high milk production. In other words, in crosses between European and Zebu cattle the performance of 2/3 European generation could strongly differ from the 2/3 Zebu generation (Cunningham and Syrstad 1987). However, the use of breeds of similar performance characteristics restricts the use that can be made of breed complementarity to maximize average genetic merit for traits of economic values (Gregory and Cundiff 1980).

The rotational crossing could be extended to a three-breed plan and in that case the proportion of each breed after some generation would be 4/7, 2/7 and 1/7 depending on the mating order (Figure 2.4). A rotational three-breed plan would retain 6/7 of individual and maternal heterosis since a female would be mated to the sire breed which she has the lowest proportion of the genes, and it would also generate the replacement female. The great disadvantage of this type of crossing plan is that it requires a considerable degree of management to maintain the identity of the breeding groups over a long-term basis (Simms et al. 1990).

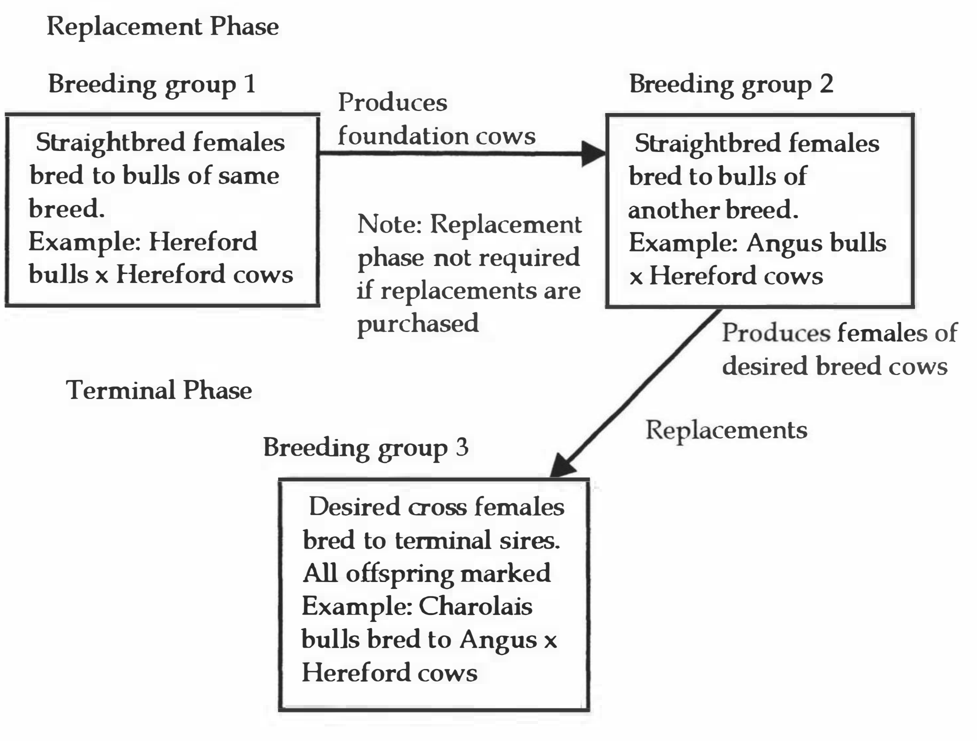
Figure 2.4. A Three-breed rotation crossbreeding system (Simms et al. 1990)



Other common crossbreeding systems are the fixed percentage crosses, also known as specific crosses and they consist in crossing two or more breeds and then selling the total offspring. However, if the number of breeds increases the complexity of the plan also increases hence the two-breed fixed percentage cross is the most simple mating plan, and in that case a breed A would be crossed to a breed B and the F1 (AB) would be sold. In this system female replacements could not be simply generated from the herd. Also, a disadvantage would be that the maximum of individual heterosis would appear but the maternal and paternal heterosis would not be exhibited.

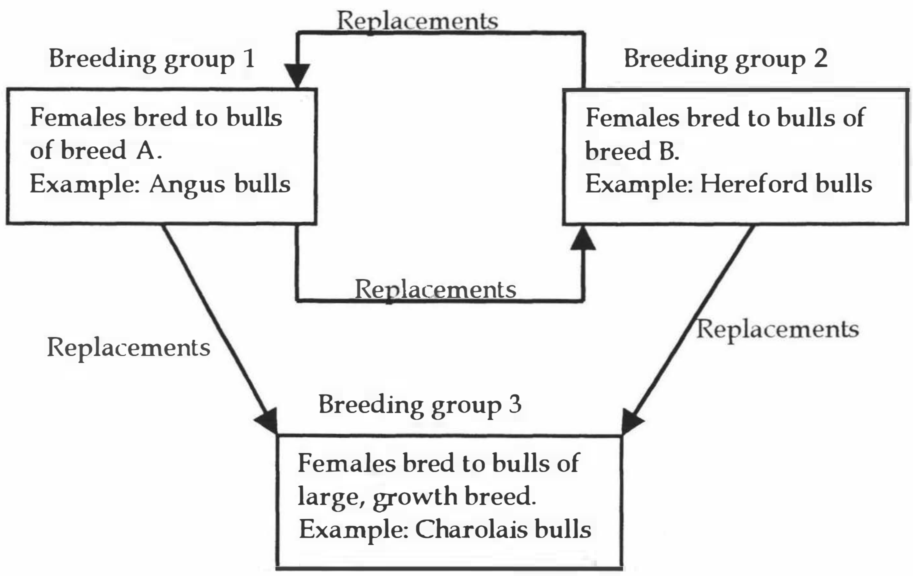
However, the system could be extending to three-breed fixed percentage crossbreeding system known as terminal sire system or industrial cross. In that case, a breed A would be mated to a breed B to generate crossbred females and those crossed animals would be mated to a third breed and all offspring would be marketed (Figure 2.5). According to Euclides Filho (1996) this system would maximize the use of heterosis and complementarity and it would also allow great flexibility in choosing the breeds. Therefore, this system ensures rapid adjustments regarding market demands and impositions. Although, the larger disadvantages in a three-breed system is that the replacements should be generated from a second herd or purchased outside thus this system would not be adopted by small operation unless the farmers would have the possibility of buying crossbred females at reasonable prices (Simms et al. 1990).

Figure 2.5. Terminal Sire Crossbreeding System with the breeding Groups Required to Produce Replacements (Simms et al. 1990).



In addition, the rotational crossbreeding system could be combined with the terminal crossbreeding system creating a rota-terminal system (Figure 2.6). In this system the rotational breeding groups would produce the crossbred replacements to the terminal system. According to Euclides Filho (1996) and Simms et al. (1990) this system would combine the advantages of producing its own replacements of the rotational crosses with the high levels of heterosis of the terminal crosses, although a high level of management would be necessary.

Figure 2.6. Rota-terminal crossbreeding (Simms et al. 1990)



Another well-known way to use crossbreeding is the composite crosses, also known as synthetic crosses or synthetic breeds. It consists in forming a new breed using two or more breeds by simply mating them until a desirable proportion of the breeds is achieved. A proportion that is frequently adopted by two-breed synthetic crosses is 5/8, 3/8. The advantages of having a new breed are that farmers would not need to have separate straightbred herds or buy replacements to carry on mating plans, and they would also have more uniform animals (e.g. color pattern) to sell. Another advantage indicated by Euclides Filho (1996) is that different of most of the others crossbreeding system, some of paternal heterosis is retained, and also is possible to have high overall levels of heterosis.

However, a proportion of heterosis would be lost since the formation of the new breed would involve a certain level of inbreeding. As a result, the potential of composite breeds, as an alternative to continuous crossbreeding system for using heterosis and complementarity in order achieve and to keep desirable additive composition, has to be investigated in comprehensive experiments (Gregory et al. 1999).

The amount of heterozygosity that would be retained by the F2 could be usually calculated by the formula n-1/n of the heterozygosity showed in F1, where n is the number of breeds involved in the new breed, when the breeds contributed equally to the foundation of the new breed (Wright 1922; Dickerson 1969, 1973). However, when breeds did not contributed equally for the foundation of the new breed, the percentage of heterozygosity retained is proportional to $1-\Sigma P_i^2$, where P_i is the fraction of each breed contributing breeds to the foundation of the new breed. However, if inbreeding is avoided, this loss of heterozygosity between F1 and F2 generation and also loss in further generation could be also avoided (Wright 1922; Dickerson 1969, 1973). Therefore, Euclides Filho (1996) suggest that the genetic base in forming a composite breed should be as large as possible and the animals of each breed involved in this process should be animals sired by a large number of genetically different bulls.

2.3.1.4 Some experimental results involving *Bos taurus* and *Bos indicus*.

Crossbreeding between *Bos taurus* and *Bos indicus* has been adopted by several Brazilian beef production systems as a quick way to improve the system efficiency. *Bos indicus* have a value regarding tropical and semitropical commercial system due to its adaptive advantages for heat and diseases and it is frequently used to maximize heterosis (Cole et al. 1963; Crockett et al. 1979). In addition, on Alencar et al. (1999) point of view crossbreeding could enhance Brazilian beef productivity. Crossbreeding has been exhaustively investigated by numerous authors.

2.3.1.4.1 Results in performance and liveweight

Studies involving *Bos indicus* crosses when compared to British cattle have shown conflicting results. Shackelford et al. (1991) reported no differences in live weights of 5/8 Brahman heifers when compared to Hereford-Angus heifers and Crouse et al. (1989) reported a decrease in final weights in cattle possessing greater than ¼ *Bos indicus* inheritance. On the other hand, Koch et al. (1982) observed heavier weights in F1 Brahman crossbreds relative to Angus x Hereford at constant age. Similarly, the results from comparisons of *Bos indicus* cross with Friesian and other continental crossbreeds have also shown contradictory results regarding live weights. Morris et al. (1992) reported similar full and empty live weights for progeny sired by Brahman and Friesian cattle and in spite of this result Purchas et al. (1997) observed a higher live weight in *Bos taurus* than in *Bos indicus* crosses although there were no differences in growth rates.

In Brazil, Felten et al. (1988) studying the performance in feeding lots of Charolais, Nellore, Charolais-Nellore and Nellore-Charolais reported liveweight gains of 1.211, 1.022, 1.158, and 1.085 kg respectively, although Nellore showed a better feed conversion ratio than the other groups. Manzano et al. (1986) also reported a better feed conversion ratio for Nellore when the diet was composed of a high percentage of forages. Besides, Alencar et al. (1998) investigating birth weight and weaning weight of different genetic groups of Charolais x Nellore reported that crossbred animals presented higher birth and weaning weight and also higher daily gains than the purebred Nellore animals. However, the superiority of the crossbred individuals would vary in accord with its genetic composition and percentages of maternal and individual heterozygosity.

In addition, Cardoso and Silva (1986) also reported different feed conversion rate among different genetic groups. Working with Charolais-Nellore, Chianina-Nellore, Fleckvieh-Nellore, and purebred Nellore, they reported the respectively feed conversion rate: 7.1, 6.58, 7.48, and 7.03. In a different trial, Alencar et al. (1994) scrutinized the performance of Limousin-Nellore and Charolais-Nellore and reported no significant differences between the two groups for birth and weaning weight. However, Souza et al. (1994) showed differences in birth weight of offspring from Nellore cows mated to Nellore, Angus, Brangus, Simmental, Canchim, Gelbvieh, Red Brangus, and Gir bulls. The Simmental, Angus, and Gelbvieh offspring presented higher birth weights than the other groups.

Recently, Muniz and Queiroz (1998) evaluated the differences in weaning weight and daily gain to weaning time for calves from Nellore cows mated to Angus, Brangus, Red Brangus, Canchim, Gelbvieh, Simmental, and Nellore bulls. The authors found that crossbred animals were heavier at weaning time than the purebred Nellore animals. Also, the Simmental and

Gelbvieh bulls produced heavier F1 than Angus bulls and Canchim-Nellore F1 was heavier than the Brangus-Nellore F1. In a second trial (Muniz and Queiroz 1999) the authors evaluated post-weaning performance to slaughter time. The crossbred individuals were heavier than the purebred Nellore, and the F1 from continental European breeds crossed with Nellore were heavier than the Angus-Nellore F1 at yearling age although there was no difference among them at 550 days of age. Barcellos and Lobato (1992a) concluded that the superior average daily gain until weaning time showed by Hereford-Nellore crossbred against pure Hereford was due to the individual heterosis presented by calves ½ Hereford-Nellore and ¾ Hereford-Nellore. The authors (1992b) also reported that the crossbred individuals were heavier at weaning, yearling and at age of one year and a half. However, the superiority was reduced with the increasing of Nellore proportion higher than 50%.

2.3.1.4.2 Results involving carcass traits and meat quality

Carcass weight is strongly associated with live weight and dressing-out percentage. The dressing-out percentage of *Bos indicus* has been reported by several researchers to be greater than the dressing-out percentage of *Bos taurus* (Koch et al. 1982; Morris et al. 1992; Purchas et al. 1997, and Wheeler et al. 1996). Morris et al. (1992) reported hot carcass weights of Brahman progeny to be heavier than Friesian progeny and saleable meat weight, trimmed fat weight were significantly heavier for Brahman-sired cattle. In addition, fat depth and bone weight were similar although the bone weight in percentage was less for Brahman-sired cattle. Crouse et al (1989) reported that percentage of *Bos indicus* had no consistent effect on adjusted fat depth and longissimus muscle area and Purchas et al. (1997) also reported similar adjusted fat depth and longissimus muscle area among Sahiwal-Friesian crosses and some *Bos taurus* crosses.

The results of those trials lead to a general conclusion that dressing-out percentage in *Bos indicus* crosses is higher than *Bos taurus* and that could represent more saleable meat for zebu cattle. Table 2.4 presents some of the results from Wheeler et al. (1996) related to some carcass traits of progeny of different sire breeds adjusted to constant age. Wheeler et al. (1996) concluded that not one of the sire breeds in the Table 2.4 excels in all economically important traits although the best chance to produce lean, tender meat out of F1 terminals from Angus x Hereford crossed cows was provided by Piedmontese.

Table 2.4-Least squares means for carcass traits adjusted to common age (426 days) for several sire breeds.

Sire breed	Live weight (kg)	Hot carcass weight (kg)	Dressing-out %	Adj. fat thickness (cm)	Longissimus area (cm^2)
Hereford x Angus	533	329	61.74	1.47	71.9
Charolais	560	347	61.84	0.97	79.2
Gelbvieh	541	335	61.86	0.94	78.4
Pinzgauer	531	325	61.09	1.05	74.2
Shorthorn	545	338	61.92	1.21	72.0
Galloway	489	304	62.21	1.21	73.4
Longhorn	458	283	61.58	0.93	70.0
Nellore	520	335	64.26	1.23	73.6
Piedmontese	515	328	63.69	0.77	85.8
Salers	541	337	62.32	1.00	77.7

There are other carcass traits that should be considered since color and texture might be important to consumer acceptance. Whipple et al. (1990)

reported no differences in color or texture between Hereford-Angus crosses and Hereford-Angus-Sahiwal crosses with different levels of Sahiwal inheritance. Crouse et al. (1989) reported that Hereford-Angus produce meat with finer texture than meat from Pinzgauer, Brahman or Sahiwal (table 2.5). In addition, Shackelford et al. (1991) found similar results with 5/8 Brahman crosses presenting more darker and coarser texture than Hereford-Angus crosses.

Table 2.5-Means for color firmness and texture of breed groups differing in proportion of *Bos indicus* and *Bos taurus* inheritance.

Breed group	Lean color score*	Lean firmness score*	Lean texture score*
Angus, Hereford	5.35	5.69	6.40
Pinzgauer (P)	5.03	5.72	6.02
Brahman (B)	5.04	5.60	5.92
Sahiwal (S)	4.88	5.69	6.08
B and S	4.99	5.64	5.98
¼ P	5.28	5.73	6.02
½ P	4.98	5.84	6.24
¾ P	4.82	5.60	5.80
¼ B	5.43	5.82	6.07
½ B	4.82	5.68	5.95
¾ B	4.88	5.30	5.73
¼ S	4.93	5.94	6.35
½ S	4.81	5.68	5.99
¾ S	4.91	5.46	5.89

*Scored: 1=Very dark, soft or coarse through; 8= Very light, cherry red, very firm or very fine.

In Brazil, Boin et al. (1994) working with Nellore, South Devon-Nellore, Hereford-Nellore, Angus-Nellore, Caracu-Nellore, did not find significant differences among carcass dressing out percentages of the different genetic groups. However, Luchiari Filho et al. (1985a) reported differences in dressing out percentage among Nellore, Canchim and Santa Gertrudis. Nellore and Canchim cattle showed better or equal dressing out percentage for chilled carcass when compared to Santa Gertrudis. In addition, Luchiari Filho et al. (1985b) reported better dressing out percentages of Canchim-Nellore for chilled carcass when compared to Nellore, Nellore-Santa Gertrudis, Nellore-Holstein, Nellore-Brown Swiss and Nellore-Caracu breeds, which did not differ from each other.

However, Felten et al. (1988) evaluated carcasses from Charolais, Charolais-Nellore, Nellore-Charolais and Nellore raised in feedlots and found that the only major differences was the low carcass weight of Nellore. Besides, Euclides Filho (1994a) studying the groups Nellore, ¾ Nellore-Fleckvieh, ¾ Nellore-Charolais, and ¾ Nellore-Chianina did not report any differences in carcass traits with the animals being slaughtered at 440kg.

2.3.1.4.3 Results involving reproductive traits

Pelicioni et al. (1999), compared the performance of Nellore cows and several crossbred Nellore x *Bos taurus* (F1) cows at first calving, and noticed a low first calving age to F1 Angus-Nellore cow and Red Brangus-Nellore cows being 29.7 and 30.3 months more precocious than the other genetic groups. However, there was no difference between calf performance before weaning of Nellore and F1 calves. In addition, Alencar et al. (1999) also studied age at first calving and reported that cows 5/8 Charolais- 3/8 Nellore were precocious when compared to cows ¼ Charolais- ¾ Nellore and purebred Nellore cows, being this last group the latest cows of all three groups. The author concluded that a purebred Charolais cow would produce 248g of calved weight less per kilo of cow at calving time than a purebred Nellore cow on the condition of this trial (pasture). On the other hand, a cow with 100% heterozygosity, ½ Charolais-½ Nellore, would produce 185g of calved weight less per kilo of cow at calving time than a cow with no heterozygosity.

José et al. (1991) evaluated age at first conception of Nellore, Guzera-Nellore (Guzera is a *Bos indicus* breed), Red Angus-Nellore and Marchigiana-Nellore heifers and reported a low conception age for Red Angus-Nellore (26.4 months) over the other crossbred groups showing respectively 33.8 and 30.5 month for age at first conception. The pure Nellore presented age of 38 months at the first conception. Norte et al. (1993) reported an average age for first conception of 14 months for Zebu-Red Angus heifers and a space of 354 days between the first and second conception withthe average fertility rate 94%. Restle et al. (1999) compared age at the first heat of Charolais, Nellore and their reciprocal crosses noticing that crossbred individuals were on average 89 days more precocious than the average of parental breeds showing 12.9% of heterosis. The crossbred heifers presented an average pregnancy rate of 98.5% against 73.9% of the parental average, equal to a heterosis of 33.3%.

The reproductive superiority of the crossbred individuals was also pointed out by Rosado et al. (1991a) who reported the pregnancy rate of 55.8, 83.3, and 83.8% respectively for pure Nellore, Chianina-Nellore, and Fleckvieh-Nellore. In a different study Rosado et al. (1991b), the Nellore group presented the lowest pregnancy rate (66.7%) against Chianina-Nellore, Limousin-Nellore, and Fleckvieh-Nellore (78.9, 93.7, and 88.8% respectively). Euclides Filho et al (1994b) evaluated the kilo of calf weaned per kilo of cow at weaning for Fleckvieh-Nellore, Charolais-Nellore, and Chianina-Nellore F1 cows, reported a better efficiency for the Fleckvieh-Nellore group (0.41kg). The other groups did not differ presenting an average of 0.38 kg. Alencar et al. (1988) did not find differences for efficiency measured as kilos of calf/kilos of cows between cows from Canchim and Nellore groups, although the authors reported a superiority in favor of Canchim cows when the measure was kilos of cow/age of cows at calving.

2.3.2 Selection in beef cattle

Selection is another fundamental tool besides crossbreeding to improve beef production and it should be part of any breeding program since the benefits resulting from crossbreeding could be easily overcome by selection in pure animals (Euclides Filho 1996). In addition, genetic improvement based on selection is a cumulative process, and although according to Smith (1984) the rates of improvement are modest ranging from 0.5 to 2% of the average per annum, the cumulative results in long-term basis could be substantial (Gibson and Wilton 1998). Therefore, the direction of genetic changes should remain relatively constant over prolonged periods.

Assuming that all the genetic gain on the top of pyramid is transferred to the commercial herds, although the two herds would improve at the same rate, a genetic lag would appear since there would be a time gap between the genetic level of individuals born in the nucleus and another one born in the commercial herd (Bichard 1971). As a result, although profit equation and models in literature almost always deal with current conditions, according to Gibson and Wilton (1998) it is obvious that profit equations and models should describe conditions at the time that genetic changes would have an impact on commercial population, rather than conditions when selection decisions are taken.

Alternative breeding programs have been relatively well researched in dairy cattle and pig populations (e.g. Niebel and Fewson 1979; Graser et al. 1985; Fewson and Niebel 1986; Bondoc and Simth 1993). Although there have been few similar studies in beef cattle, those comparisons of beef schemes have frequently been focused on selection efficiency based on the accuracy of evaluating animals for the breeding objective (e.g. Ponzoni and Newman 1989; Barwick et al. 1992), rather than on its economical aspects (Graser et al. 1994).

The breeding program is a process that could be briefly described in five steps (MacNeil and Newman 1994). The foundation of the process consists of defining the objectives and it is the base of a successful program. The second step is to choose the selection criteria, and the third step would be to organize performance records in order to allow genetically superior cattle to be identified. The utilization of that information to make selection decisions and the mating of selected animals would be respectively the fourth and fifth steps.

2.3.2.1 Breeding objective and selection criteria

A breeding objective is defined as the combination of economically important traits of the beef cattle system and should account for inputs, such as food, husbandry and marketing costs and also for outputs, such as income from sales of animals. On the other hand, the selection criteria are the characteristics used in estimation of breeding values of animals (James 1982 a and b). The traits in the selection criteria and the traits in the breeding objective are related through a genetic covariance matrix (Schneeberger et al. 1992). The inclusion of traits in the breeding objective should be based only on economic grounds and not on whether they are difficult and expensive to measure or difficult to change genetically (Ponzoni and Newman 1989).

Genetic considerations become relevant when animal genetic merit is estimated. According to Bourdon (1998) the formulation of selection criteria have two serious drawbacks. First, most of selection criteria lack accuracy since they do not incorporate information on relatives, and second selection criteria is biased because they do not account for genetic differences among contemporary groups. These problems can be overcome by using genetic prediction derived from BLUP and related procedures since according to Henderson (1963) if genetic prediction derived from BLUP are available to every traits in the breeding objective the genetic prediction could be substituted for the true breeding values in the breeding objective.

The definition of the breeding objective could be described in terms of the following four phases: specification of the breeding, production and marketing system; identification of sources of income and expense in commercial herds; determination of biological traits influencing income and expense; derivation of economic value of each trait. That methodology was used by Ponzoni (1986) for development of breeding objective for weanling beef cattle in Australia, although it is a general approach that could be used for other types of domestic livestock.

Carefully researched objectives are rare in beef production since it would require information of many sources to derive the objectives and measurable goals in which selection decisions would be based on (MacNeil and Newman 1994). In addition, not having an accrued selection objective might lead to selection of traits in an undesirable direction (Ponzoni, 1989). Blair and Garrick (1994) evaluated the effects of new and current technologies in New Zealand on genetic gain rate and improvement lag in beef cattle. The authors reported that although there are available technologies that could increase genetic gain at least 150%, the lack of objectivity on breeding programs has been responsible for not reaching the maximal genetic gain rate.

Alternative breeding programs for livestock need to be evaluated for their efficiency in making genetic progress and also for their return and profit for the investment made in the breeding program (Nitter et al. 1994). In addition, long term breeding objectives would lead to improved genetic merit and would also improve the competitive position over time for breeders that most accurately predict superior genotypes for future conditions (Gibson and Wilton 1998).

Researchers have developed general breeding schemes to be applied on a wide basis in poultry (Akbar et al. 1986), swine (Stewart et al. 1990) dairy cattle (Allaire and Thraen, 1985) and sheep (Ponzoni, 1986). These general breeding schemes are appropriate whenever the breeding objective is consistent across large segments of an animal population (Bourdon 1998). However, this universal approach in sheep and beef cattle are questionable since beef and sheep operations vary greatly in management and mating system, physical environment, size of the herd and marketing circumstances. The utilization of customized breeding objectives and specific selection criteria to seedstock and commercial beef operations was suggested by Upton et al. (1988).

2.3.2.2 Economic weights

Economic weights are traditionally determined in either an intuitive way, through the use of profit equation or neoclassical economic theory, or by bioeconomic simulation (MacNeil, 1996). The intuitive way has been suggested as a manner to familiarize farmers to the idea of economic weights using simple technology (Beef Federation, 1996). Farmers are asked to list the economically important traits and than attribute a subjective value to the traits as a percentage figure. Profit equations have been used to determine economic values of biological traits in beef cattle and sheep operations (Ponzoni, 1988; Ponzoni and Newman 1989; Urioste et al. 1998). Economic weights are obtained from a profit equation by calculating the partial derivative of profit with respect to each trait in the breeding objective and represent the economic value of one unit increase in phenotypic value for each trait, other traits held constant.

A bioeconomic simulation model is formed by a group of equations designed to simulate the biological relationships, management decisions, profitability and some other measure of economic efficiency. The economic weights are originated by simulating genetic changes in one genetic component of performance at the time and then assessing the differences in overall outcome (Bourdon 1998). This approach was used by Bourdon and Brinks (1987), Notter et al. (1979a and b) and Senders and Cartwright (1979a and b). The disadvantages of bioeconomic models include their complexity and the time and costs for their development.

2.3.2.3 Predicting Breeding Values

Few areas have improved as much recently as the methodologies to identify genetically superior animals, particularly due to the advances in computational technologies (Alves et al. 1999). However, the quality of the field data regarding accuracy is undoubtedly a crucial component of the basis for any breeding process. Current genetic evaluations are with rare exception conducted for purebred population on a within-breed basis. According to Bourdon (1998) those genetic evaluations produce predictions that when applied to purebred animals of the same breed in an average environment follows the model:

$$P_{offspring} = \mu + EPD_{sire} + EPD_{dam} + E_{c.g.} + E$$

Where, P is the phenotypic value for offspring, EPD is the expected progeny difference of the sire and dam, $E_{c.g}$ is the environmental effect of contemporary group, and E is an additional environment effect, nonadditive genetic effects, Mendelian sampling and prediction error.

From the model could be inferred that one-unit increase in the EPD of a sire or a dam would lead to an increase of one unit in the offspring performance. That interpretation is valid for the limit context in which it is assumed purebreds and average environments and it is not reliable when applied to crossbred and varying environments as they must be if it is to be used in customized breeding objective (Bourdon, 1998). The procedures for estimation of across-breed EPDs describe by Notter and Cundiff (1991) and Núñez-Dominguez et al. (1993) accounted for genotype x genotype, genotype x environment, and genotype x genotype x environment interactions.

However, Best Linear Unbiased Prediction (BLUP) has become the most widely accepted method for genetic evaluation of domestic livestock. BLUP has found widespread usage in genetic evaluation of domestic animals because of its properties and its application has been enhanced from simple models such as the sire model to more complex models such as the animal, maternal and multivariate models (Mrode 1996). This development has been boosted by advances in computational methods and nowadays most evaluation schemes are based on animal models based using BLUP.

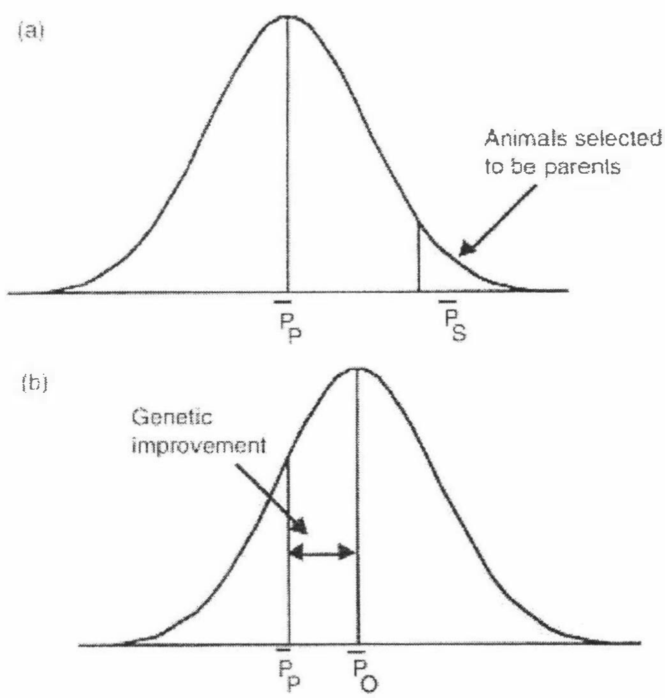
For most problems in genetic prediction there are two competing approaches: nonmechanistic meaning any solution that would not involve an understanding of underlying biological mechanisms and it tries to mimic reality, and mechanistic meaning solution that would incorporate biological relationships at more basic levels. Therefore, Bioeconomic simulations to estimate economic weights are basically a mechanistic approach and the concept of breeding value is a nonmechanistic approach since it is an empirical concept. Nonmechanistic solutions are often easier than mechanistic solutions although they are weak at accounting for nonlinear biological processes that are statistically interpreted (Bourdon 1998).

2.3.2.4 Genetic gain and responses through selection and its dissemination

Selection of animals of higher genetic merit than average and their utilization as parents of the next generation is the main principle behind any genetic improvement programs, since it is expected that the offspring of selected parents would have higher genetic merit than if the parents were chosen at random (Figure 2.7). In addition, if animals in the parental generation were ranked according to their breeding values and the proportion of those superior animals that were selected to be parents of the next generation is known, then it is possible to estimate the genetic gain that might result (Cameron 1997).

In other words, the genetic gain from one generation to another is the difference between the mean of the progeny and the paternal generation. The genetic gain would be a function from the superiority and proportion of the animals selected to be parents, which is called the selection differential, and the regression coefficient relating genotype to phenotype, which is called heritability. The response to selection also could be predicted in a year basis, and that would be possible by simply dividing the above function for the interval from one generation to the next one.

Figure 2.7. Distribution of phenotypes (a) in the paternal generation and (b) of the offspring. Pp is the average phenotype in the paternal generation, Ps is the phenotype of selection animals, and Po is the average phenotype of the offspring. (Cameron 1997)



As a result, the success of the responses to selection and the dissemination of its acquirement in any breeding program would be based on the following four principles (Alves et al. 1999):

- To measure with the highest possible accuracy the traits to be improved.
- To precisely identify the genetically superior animals.
- To ensure that the genetically superior animals would leave the highest possible number of descendents.
- To ensure that the flow of animals would always be from the genetically superior herds to those herds with inferior genetic merit.

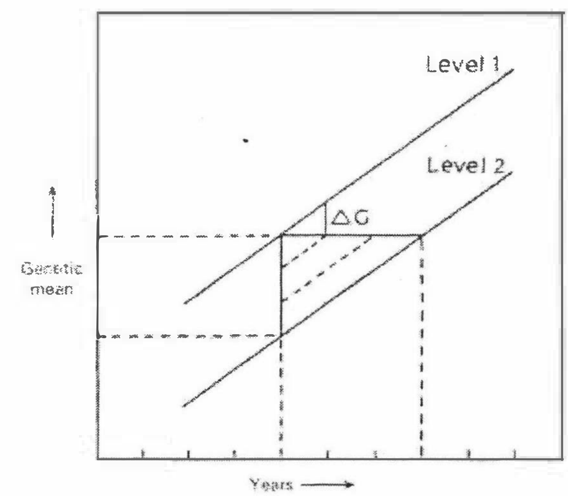
According to Alves et al. (1999) the first three principles have been discussed and they are well balanced in Brazil, although little has been said about the flow of genes from one herd to another. This is an essential principle in breeding beef cattle, not just considering a single herd but especially considering beef production as a whole. In other words, the application of breeding schemes cost money and work and dissemination from the nucleus to commercial herds would help to better compensate and justify those efforts.

It seems likely that when a self-contained herd has to retrieve the costs of selection from sales of some final product, then it can only afford to make relatively limited efforts and must thus accept a low response rate (Bichard 1971). However, when the herd is producing livestock the cost could be shared among the total population derived from this stock. In order to allow the commercial herd to have the best productive animals available it is necessary to reduce the improvement lags, that may not always result in maximizing profitability in the commercial herds, neither in maximizing overall profits regarding all herds in the pyramid (Bichard 1971).

In general, studies have pointed for low levels of response to weight selection for Zebu type in Brazil (Euclides Filho et al. 1997a, 1997b) and that could be due to a disarranged dissemination of the genes reducing the effects of the whole process. Therefore the low response to selection in Brazil would be a consequence of a disorganized market of animals, being bulls from inferior genetic merit herds purchased by farmer from a superior herd.

Another aspect regarding the dissemination of the genetic improvement is the existence of improvement lags between the nucleus and the commercial herd. As it was stated before, both herds would improve at the same rate but there would be an improvement lag between them (Figure 2.8). According to Guy and Smith 1981 the improvement lag would depend on the average age when the offspring are born, on the genetic superiority of the animals chosen to be parents regarding their contemporary mean, and on the equilibrium rate of genetic responses. Also, the lag would only be constant if all three components are constant or if the changes in one are compensated by changes in the others.

Figure 2.8. Diagram of the genetic trends in to breeding levels over time, with a constant equilibrium annual genetic change (R). In this case the genetic lag, the differences between the genetic mean of the two levels at any time, is equivalent to 3 years of annual genetic change. (Guy and Smith, 1981)



2.3.2.5 Selecting for liveweight and growth rate

Traditionally beef cattle breeding programs have focused on improving animal liveweights or/and growth rates thus weight gains and adjusted weights have been widely used as breeding objectives. Growth rate and weight traits are easy to measure; they respond to genetic selection and have a close relationship with the individual value of the animals (Parnell 1994). In addition, efficient beef production is heavily dependent on traits related to growth so most of selection experiments in beef cattle are related to growth traits (Arthur et al. 1997).

Selecting for growth rate would result in faster growing animals, which are heavier and larger at all ages. Selection for high line of yearling growth rate cattle had also correlated positive responses for birth weight, weaning weight, body size, pelvic area, and scrotal circumference (Arthur et al. 1997). Changes in weaning weight resulting from selection for growth rate would be partly due to response in the genetic potential for growth of calves and partly due to response in the maternal ability of the cows. Herd (1990) reported that 18% and 11% of the correlated responses in weaning and yearling weights, respectively, were due to maternal effects.

However, after reviewing the available evidence Barlow (1984) concluded that there was little reason for selecting for growth rate to improve efficiency of meat production in maternal breeds under favorable environments. The author suggested that the major limitation of selecting for growth rate was that any improvement in gross efficiency among growing stock appeared to be more than offset by the increase in maintenance requirement of breeding cows. In addition according to Albuquerque and Fries (1998) in different production systems the direct and indirect effects of selecting for mature size has lead to a disproportion between forage production and maintenance plus production requirements.

Graham (1994), compared a cattle line selected for high growth rate against a line selected for low growth rate, concluding that there was only marginal gains in efficiency based on liveweight production/ha from a given cow liveweight/ha. It seemed that although selection for growth rate would certainly give a response to that selection criteria, it would not provide a comparable response in efficiency therefore other selection criteria should be investigated to enable the industry to select for increased efficiency. Graser et al. (1994) evaluating seven different selection criteria for Australian beef cattle concluded that additional selection criteria besides the traditional weight criteria would lead to an increase in sale weight and a reduction in breeding cow's weight, which presented a negative economic value. Also, the response in fertility and carcass traits was increased.

2.3.2.6 Selecting for reproductive traits

Reproductive efficiency is the major reason cows are removed from the herd (Greer et al. 1980; Freeden et al. 1987). A heifer must reach puberty early in the first breeding season, maintain a viable pregnancy, calve without difficulty, breed and conceive early the second breeding season and wean healthy vigorous calves (Bellows and Staigmiller 1994). Therefore, fertility is an important factor contributing to profitability in beef cattle enterprises involving a range of traits from age at first heat until weaning rate (Euclides Filho 1997). However, reproductive characteristics are difficult to measure under commercial conditions and they are highly influenced by management practices and environmental conditions (Moser et al. 1996).

A review of literature conducted by Gregory (1984) showed low heritability for fertility. However, there is a probability that cattle traditionally in poor environments might have a higher genetic variance for fertility than cattle in favorable environments since cattle in poor environments would not be under the same selection pressure for fertility (Bellows and Staigmiller 1994). For instance, Deese and Koger (1967) concluded that in unfavorable environments where the reproductive rate is sub-optimal, heritability for fertility is high enough in many populations to allow significant progress through selection and culling procedures.

Selecting heifers for early age at puberty could result in positive effects on reproductive performance of a breeding cow. Heifers that conceive early in their first breeding season have greater lifetime productivity than those that conceive late in their first mating season (Laster et al 1973). Also, in contrast to many other fertility traits age at puberty shows heritability of around 0.43 (Gregory 1984) thus would present a satisfactory response to selection. Therefore, age at first heat could be the best measure of inherent fertility since it is relatively immune from interaction with others traits (Martin et al. 1992).

However, it seems that age at puberty has an antagonistic relationship with weight traits thus heavier heifers usually reach puberty in late stages (Arjie and Wiltblank 71; Smith et al. 1976; Laster et al. 1979). In addition, heifers sired by breeds with large mature size tent to be older and heavier at puberty than heifers sired by smaller mature size breeds (Martin et al. 1992). In contrast, Brinks (1994) reported a negative correlation between age at first heat and growth rate thus heifers that grow more rapidly from a genetic standpoint reach puberty earlier.

Heifer selection is usually based on some aspect of growth and weight resulting in greater growth and associated growth traits although the results in subsequent reproductive performance and calving difficulty have been largely unknown and in some instances slightly negative (Bellows and Staigmiller 1994). In addition, according to the authors dystocia has a genetic relation with calf losses and it is also highly genetically related to birth weight thus selection against dystocia would reduce birth weight.

Most problems with dystocia occur at first calving therefore age at puberty and calving difficulties are the two major factors affecting reproductive efficiency of heifers, and since most of the genetic gain is due to sire selection, a measure in yearling bulls, which would also predict measure in female offspring, would be helpful (Brinks 1994). Correlation between scrotal circumference and age at puberty or age at first breeding has been shown to be favorable (Brinks et al. 1978; Toelle and Robison, 1985). Gregory et al. (1991) among breed group means reported a high negative correlation of -0.92 between scrotal circumference in males and age at puberty, and a positive correlation of 0.97 between scrotal circumference and pregnancy rate in heifers. Bulls with larger scrotal circumference have been shown to present greater motility score and better breeding soundness than bulls with lower scrotal circumference (Moser et al. 1996; Knights et al. 1994).

Scrotal circumference could be used as a measure for age at puberty and fertility in males (Bergmann et al 1996). Its inclusion in breeding schemes has been recommended as a way to enhance reproductive efficiency in beef cattle (Bourdon and Brinks 1986; Nottre 1988). Graser et al (1994), when comparing seven different schemes of selection for Australian beef cattle, showed that the inclusion of fertility criteria in breeding schemes was undoubtedly cost-effective.

2.3.2.7 Selecting for feed efficiency

The majority of feed consumed in a beef production operation goes to the breeding herd. Consequently, an effective way to improve efficiency of a beef production system might be reducing the feed consumed by the breeding cow, excluding some systems where the slaughter herd would receive a high quality and expensive feed (Thompson and Barlow 1986). However, feed intake measurements in mature cows are expensive and definitely not practical in livestock improvement programs thus an alternative way is to select based on feed efficiency measured in growing animals causing a favorable correlated response in mature cattle (Archer 1999).

Although information regarding beef cattle is limited, there is evidence that a better feed efficiency could be achieved since Nieuwhof et al. (1992) in dairy cattle and Archer et al. (1998) in mice suggested that selection on residual feed intake in growing animals would cause a correlated response in adult animals. That seems to be more reasonable regarding selection programs since the animal would be tested before selection time. Beside those problems, according to Cameron (1998) selection on feed efficiency requires selection in males and females hence direct selection on feed efficiency would be inappropriate for genetic improvement in beef cattle. Therefore, indirect selection would probably be a better method in this case.

Although theoretically indirect selection is less efficient than direct selection, selection on one correlated trait could have a better result than direct selection on feed efficiency if genetic correlation and the heritability of the trait were high enough. In addition, more than one trait could be used at the same time in order to improve the accuracy of selection and both approaches, direct and indirect selection, could be combined to provide the most cost-effective method to identify animals of superior genetic merit for feed efficiency (Archer et al., 1999).

2.3.2.8 Selecting for meat quality traits

Emphasis on body composition traits is expected to become increasingly important in the development of breeding programs because consumers are more concerned with diet-health issues and the beef industry are more concerned of value-based marketing (Marshall 1994). As a result, beef industry has the challenge of producing cattle that consistently yield products of desirable quality, which is a difficult undertaking since there are large intrabreed and interbreed variations in body composition among beef cattle (Elzo et al. 1998).

Excess fat production (Smith et al. 1991) and inconsistency in predicting and providing tenderness (Morgan et al. 1991; Savell and Shackelford 1992) has been described as major concerns to the beef industry in USA. Selection of cattle within specific ranges of predicted intrabreed and multibreed genetic values for growth and carcass traits could further improve the degree of consistency of meat products (Elzo et al. 1998).

Recent literature shows that heritabilities for carcass traits are generally high to moderate in both age or time constant analyses. Arnold et al. (1991) reported heritabilities of 0.46, 0.49, and 0.35 for longissimus muscle area, fat depth, and marbling, respectively, at constant slaughter weight for Hereford steers showing that selection on most carcass traits would be relatively effective in many cattle populations. Besides, marbling is currently the major trait used by the industry to grade carcasses of young animals and it seems to have a positive relationship with palatability, although relatively weak, thus it still is a controversial issue (Wheeler at al 1993).

Genetic correlations between marbling and fat depth range from strongly positive to slightly negative and genetic correlation between marbling and retail yield range from moderately negative to slightly positive indicating a possible antagonism between increasing marbling and reducing fat depth (Marshall 1994). However, a trial using Angus, based on selection for high marbling and reduced fat thickness, indicated that intense selection could increase marbling without increasing fat depth (Bertrand et al. 1993).

However, according to Felício (1994) in spite of the USA, where excessive fat is a problem, in Brazil the farmers chose a slim type cattle that would have a better meat yield percentage and less fat than the compact type of cattle in USA. From that point of view the Brazilian beef production could be seen as a very competitive industry. On the other hand, regarding the world competition meat tenderness could be the greater problem facing Brazilian beef industry, not only because most of the meat comes from *Bos indicus* but also because the slaughter age is advanced for most of the commercial herds in Brazil. As a result, the farmer in Brazil should be concerned with producing a heavy carcass with high levels of subcutaneous fat from young animals (Felício 1994).

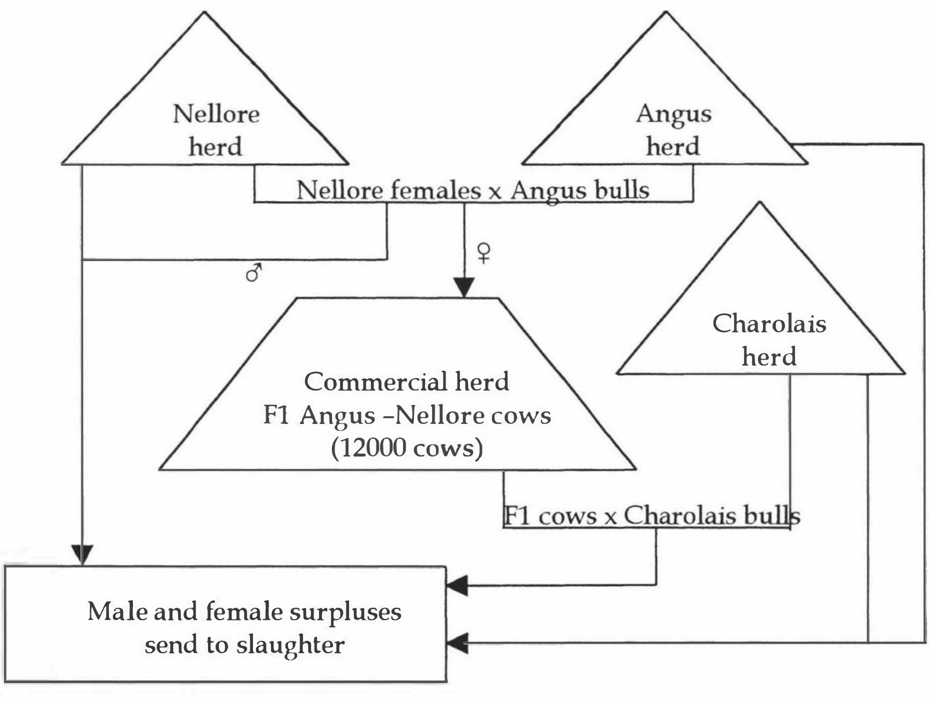
Chapter 3

Material and Methods

3.1 General aspects

A deterministic procedure was applied to develop a model for a hierarchical integrated beef production system involving a crossbred commercial herd and three straight-bred nucleus herds (figure 1). The model is non-integer (fraction of animals are allowed) and it was developed on an annual basis using a Microsoft Excel spreadsheet. Reproductive and productive performances were estimated based on parameters published in the literature regarding beef production in tropical and subtropical climates.

Figure 1- Composition of the herds and breeding scheme of the production system.



A three-breed terminal crossbreeding system was adopted in the commercial herd. The nucleus herds consist of three purebred herds in order to generate all females needed as replacements and all bulls used in the production system. Therefore, genetic gain would arise only from selection within the nucleus herds and would be transferred to the commercial herd through improved replacement heifers and improved bulls. Artificial insemination is assumed as the only reproduction technique available in the nucleus and commercial herds.

Common management practices of central-west Brazilian beef farms considering a high level of technology adoption were assumed and it would be the same for all herds. Breeding season would be during November and December, birth season would be during September and October and the weaning season would happen in March and April with calves around seventh months of age. Animals would be split in different categories according to their age and purpose. Appendix 1 shows the structure for each of the herds. There would be ten categories for cows, young animals would be divided in yearlings (from weaning until 18 months of age) and finishing (from 18 months of age to slaughtering time around 24 months of age). There would also be a category for teasers and for bulls.

Replacement heifers would enter their first breeding season in December just after completing two years of age thus their first calving would be at September or October of the consecutive year. The cows would have their last breeding season just after completing ten years of age thus old cows would be culled from the herd in March or May just after weaning their last calf at eleven years of age. Also, cows that would not get pregnant during the breeding season would be culled just after weaning season. However, the non-pregnant heifers would be culled 60 days after the breeding season and cows and heifer that lost their calves or would not complete their pregnancy due reproduction and calving problems would also be culled from the herd.

Only the size and number of animals do not give a precise idea of feed requirement of a herd. Therefore, to consider the necessary amount of land for a herd it is essential to take into account not only the pasture production but also the metabolic weight and physiological stage (growth, lactation, pregnancy, etc) of the animals, since the animal feed requirement are based on those parameters. In other words, stocking rate should be evaluated by parameter that would account for feed requirement of livestock rather than just the number of heads in a herd. In Brazil a common way of expressing stocking rate is animal units/ha since there is a parallel between animal unit (AU, one AU is approximately 450 kg of liveweight) and metabolic weight. Cocimano et al., (1975) present an equivalency between expected performance of heifers and steers and AU, and Corrêa (1994) showed a relationship among age, liveweight, metabolic weight and AU that should be consider when evaluating stocking rate for beef production on pasture.

The model assumes a pasture system with a fixed stocking rate of 1.1 AU/ha and the average AU for each herd is presented in appendix 1. The average AU was estimated based on the number of animals in each category (cows, calves, yearling, finishing, etc) throughout the year on a monthly basis and the equivalency between liveweight and AU. Changes in the land area required for the system would be allowed according to the changes occurred in the amount of AU due to selection. The amount of land required was estimated by dividing the average number of AU for the fixed stocking rate 1.1 AU/ha.

Feed supplementation would be provided for all animals during the dry period (May to September) and to calves during the pre-weaning period. Following a model created by Cezar and Euclides Filho (1996), supplementation would allow growing animals to gain 0.45 kg per day during the dry period and 0.5 kg during summer. Surplus heifers and steers would be sent to slaughtering during low season at September or October when prices are at highest levels due to the end of the dry period, thus surplus animals would be sold around two years of age.

The sources of income included the sale of surplus heifers and steers, heifers and cows with reproduction failure, old cows, and bulls. The price paid by the industry for each category is showed at appendix 1 and were based on values presented in the Anualpec 2000 (FPN, 2000). With a few exceptions, current price policy in Brazil would differ basically only according to gender and cows would be paid less than males although heifers may be paid as much as steers. The number of surplus animals (NS) would be a function of numbers of animals weaned and the mortality from weaning to slaughter time as follows:

$$NS = Nc \times Wr\% \times [(1 - m/12) \times M]$$

Where, Nc is the number of breeding cow in the herd; Wr% is the weaning rate percentage; m is mortality after weaning and M months from weaning to slaughtering time. The weaning rate percentage is defined as calving rate percentage times mortality before weaning (one minus survival rate to weaning).

The other important factor influencing income is carcass weight, which is a function of liveweight at slaughter and the dressing out percentage. The liveweight at slaughter for the surplus animals would be a result of weaning weight plus a fixed gain from weaning to slaughter. The model assumes that female weights are 90% of male weights. Brazilian slaughtering plants prefer working with animals that would give a carcass of 240 kg or over. According to the parameters assumed by this simulation all genetic groups may reach this weight at 24 months of age. The final liveweight and carcass weight for two-year-old steers and heifers are given in appendix 1.

Since animal unit is the common way to measure stocking rates in Brazil and it accounts for both changes in size and weight of the animals being also related to feed requirements of the herd, operational cost in Brazil are usually expressed per animal unit. Average production cost per AU was assumed taking into account feeding costs (pasture maintenance and feed supplementation), labour, husbandry, veterinarian and medicine, transport, vehicles, social fees and fiscal tax, administration expenses, other small expenses and fixed costs. Economic parameters used in the model were based on estimation from the Anualpec 2000 (FPN, 2000) which estimated cost and returns for Brazilian beef enterprises of three different size and technological levels. The model assumed a cost of US$73.00 per AU, which is the cost for an enterprise dealing with industrial cross, improved pasture and feed supplementation, and artificial insemination. The costs per herd and the total cost for the system is presented in appendix 1.

3.1.1 Commercial herd (Angus-Nellore F1 cows)

The commercial herd was formed by Angus-Nellore F1 cows distributed over ten different age categories, from the two-year-old heifers until 11-year-old cows. The number of cow in each category is a function of the total size of the herd, the average calving rate and annual mortality of cows. The model assumed a fix number of 12,000 cows in the beginning of the breeding season on the commercial herd (cows from 2 years of age until 10 years of age). Replacement heifers for the commercial herd are generated from the nucleus herds.

Charolais bulls would be used as terminal sires in addition to a fraction of the cows being used in progeny test to assist the selection process in the nucleus. Therefore, some cows would be mated to Angus sires (preferable heifers) and some to Nellore sires instead of being mated to Charolais sires. All offspring would be slaughtered around 24 months of age.

3.1.2 The Nucleus

The nucleus comprises three different herds representing three breeds. A Nellore herd would have two different functions: first it would be used to generate improved bulls and Nellore replacement heifers. A fraction of the Nellore females would be mated to Angus bulls in order to produce the replacement F1 heifers needed by the commercial herd. Therefore, the Nellore herd could be seen as the union of a multiplier herd and a nucleus herd. The size of the herd is based on the need for replacements in the commercial herd and its own purebred replacements needs, including a safety margin of 5%. The cows were divided into the same age categories as the commercial herd and the number of cows in each group would also be a function of cow's mortality rate and calving rate. All heifers were mated to Angus sires at their first breeding season and after that the best animals would be mated to Nellore sires.

The Angus and the Charolais herds have a similar structure as the Nellore herd. However, all cows and heifers of those herds were mated to the best sires of their respective breed. The herds were designed to produce the necessary number of males that would be progeny tested also with a safety margin of 5%. In all herds the surplus animals would be slaughtered around 24 months of age.

3.2 Economic Selection Index

Economic selection index (Hazel and Lush, 1942; Hazel, 1943) is a multiple trait selection methodology that consists of defining an individual's economic merit as a parent for a determinate breeding objective based on information from a selection criteria that combines measurements on all traits according to relevant genetic and phenotypic covariances. The breeding objective could be expressed in matrix notation as $H = a'Y$ since the economic objective is to improve all traits (Y_1, Y_2,...,Y_n) which are combined with their respective economic values (a_1,a_2,...,a_n) where the breeding objective $= Y_1 a_1 + Y_2 a_2 + \ldots + Y_n a_n$

The selection criteria or selection index is derived from the traits measured to predict the animal's breeding value (X_1, X_2,...,X_m) and a weighting factor or coefficient (b_1, b_2,..., b_m) which are combined as:
selection criteria $= X_1 b_1 + X_2 b_2 + \ldots + X_m b_m$
and could also be represented in matrix notation as $I = b'X$. The methodology determines the selection criteria coefficients in order to maximize the response in the breeding objective.

Information on the variances of the traits and the relationship between the traits in phenotypic and genetic levels are required in order to maximize the correlation between the selection criteria (I) and the breeding objective (H). Since several traits could be included in the selection criteria and in the breeding objective that information are organized in G and P matrixes: G is the genetic covariance matrix between traits in the breeding objective and characteristics in the selection criteria and P is the phenotypic variance-covariance matrix of characteristics in the selection criteria. The correlation between I and H are maximized when Pb=Ga thus the selection criteria coefficients can be obtained through the expression b= P^{-1}Ga.

3.2.1 Development of the breeding objective

The methodology used to develop the breeding objective and the selection index follows the four steps presented by Ponzoni and Newman (1989):

1. Specification of the breeding, production and marketing systems.
2. Identification of sources of income and expenses.
3. Determination of the biological traits that would affect income and expenses.
4. Derivation of economic values for each of those trait.

The first two steps have been already discussed leaving the last two to be explained in a more detailed view.

Income would be affected by traits that would have an influence on the number of the animals sold and/or on the weight of carcass of those animals. The cost would be affected by any trait that would change the average AU of the system and that could happen also by changing weight of animals or the number of animals utilized in the system. Several traits included in the model have an affect on costs or income and most of the time in both (see table 3.1). The inclusion of traits in the breeding objective should avoid double counting such as inclusion of weaning rate and calving rate.

Table 3.1- Traits that affect in costs and/or income.

Traits affecting profitability
Calf Surviving
Calving rate
Cow surviving
Cow weight
Dressing out %
Weaning rate
Weaning weight (final weight)*

* Model assumed a fixed liveweight gain after weaning

The economic value of a trait could be defined as the increase or decrease in profitability caused by a phenotypic increase of one unit of that trait while the other traits are held the same. Economic values could be expressed relative to an animal, the producer or the national interest. On bioeconomic simulation the economic value of a trait could be measured by simulating changes in each genetic component of performance holding the other genetic components constant. The genetic components could be defined as genetic potential, being the maximum performance given optimum environmental condition. Therefore, an increase of one unit on a genetic component would represent a phenotypic increase also of one unit for purebred animals. However, regarding crossbred animals, that phenotypic increased might be different to one unit since phenotypic performance of crossbred animals are predicted taking into account the genetic component of each breed involved on the mating plus heterosis effects which are also estimate based on genetic components of the breeds.

The derivation of economic values was done after identifying the traits that would affect income, costs or both and increasing the genetic component of one of these traits one unit as the other genetic components were held the same. The traits to be included in the breeding objective were chosen based on significant change in profitability of the whole system and not only on change in profitability of the commercial herd. According to those economic values different breeding objectives were stipulated for each of the purebred herds. The economic values used to develop the selection index were relative economic values, which could be obtained by dividing the economic values by the economic value of a chosen trait. Table 3.2 presents the traits chosen to be in the breeding objective for each nucleus herd. According to their economic values calving rate should be the one in the breeding objective rather than weaning rate. Alternatively, since there was not enough information regarding genetic parameters of calving rate on the literature, weaning rate was chosen and the model would assume no changes in calf or cow survival. Therefore, since weaning rate is a product of calving rate and calf survival, all changes in weaning rate would be assume to be due to changes in calving rate.

Table 3.2- Traits included in the breeding objective of the herds in the nucleus.

Nellore herd	Angus herd	Charolais herd
Calving rate (weaning rate)	Calving rate (weaning rate)	Dressing out %
Dressing out %	Dressing out %	

3.2.2 The selection criteria

In contrast to the selection objective, which is developed from economic considerations, the selection criteria to evaluate animals must account for genetic considerations. The traits included in the selection criteria would be chosen due to their recording feasibility under common Brazilian management practice and due to their genetic correlation with the traits in the selection objective. Table 3.3 presents the characteristics included as selection criteria. The selection criteria used to select females would be based on characteristics measured on the individuals and selection would be made around 24 months. However, all Nellore heifers would be mated to an Angus bull in their first breeding season thus calving ease could be included in the Nellore female selection criteria. Bulls would be selected at five years of age on individual measures and progeny records of 15 offspring (sons and daughters) thus carcass measures could be included in their selection criteria.

Table 3.3- Characteristics included in the selection criteria

Traits measured in the individuals	Traits measured in the bull's progeny
Birth weight	Birth weight
Weaning weight	Weaning weight
Yearling weight	Yearling weight
18 months weight	18 months weight
Pelvic area	Pelvic area
Scrotal circumference (males)	Scrotal circumference (males)
Age at puberty (females)	Age at puberty (females)
Calving ease (Nellore females)	Dressing out %
	Fat depth
	Eye muscle area

3.2.3 Prediction of breeding values and genetic gain

Selection of animals of higher genetic merit than average, to be parents of the next generation, is the basis of genetic improvement programs, as it is expected that the offspring of selected parents will have higher genetic merit than if the parents had been chosen at random. However, nowadays there is not a direct method to predict the true breeding value of an individual since a phenotypic measure (P) is basically the result of a genetic component (G) plus an environment component (E): $P = G + E$. Therefore the best phenotype is not necessary the best genotype.

However, the predicted breeding value, or the predicted additive genetic merit ($\hat{A}$), of an animal can be predicted by regression of the animal 's breeding value (A) on its phenotype (P) and with only one measurement on the individual the regression coefficient of additive genetic merit on phenotype is the heritability:

$$b_{AP} = \frac{\sigma_{AP}}{\sigma_P^2} = \frac{\sigma_A^2}{\sigma_P^2} = h^2$$

This has been examined by Cameron (1997) who showed that the breeding value of an individual is estimated by the expression $\hat{A}=h^2(P-\bar{x})$ being $\bar{x}$ the the phenotypic mean of the population, and by Weller (1994) who showed that breeding value estimated from single measure selection index can be formulated as follow: BV= b(X) where b is a regression constant and X is the phenotypic deviation from the population mean on the group of related individuals. Based on that, the breeding value estimated from multi-trait selection index with a single measure on the individual can be expressed as: $BV= b_1X_1+\ldots+b_mX_m$.

Measurements on an individual's relative can contribute to estimating breeding values once the genetic relationship between the individual and its relatives is accounted for. Progeny testing is standard practice in selection programs that include traits that can not be measured on the individual because sex-limitations such as milk production on males, or because it can only be measured on the carcass such as meat quality traits. The estimation of an individual's breeding value from progeny information can be done by deriving the regression coeficient of the animal's breeding value on the mean of its progeny tested as showed by Cameron (1997). The predicted breeding value of an individual estimated from a single trait measured on its progeny follows the expression:

$$BV = \frac{rnh^2}{1+(n-1)t}\overline{P}-\overline{x}$$

Where r=1/2, n = the number of progeny, t is the correlation between progeny, $1/2h^2+c^2$ for full-sib progeny (being c^2 a measure of common environment influences) and $1/4h^2$ for half-sib progeny and $\overline{P}$ the phenotypic mean of progeny. Where $\overline{x}$ is the phenotypic mean.

If the animals are ranked according to their predicted genetic merit and the proportion of animals selected to be parents is known, the selection response can be predicted as the difference in predicted genetic merit of the offspring and of the parental generation. The predicted response depends on both the proportion of animals selected and the regression coefficient of additive genetic merit on phenotype (heritability). Assuming that the selected animals have a mean phenotype value above the general population (S) the mean of their offspring can be predicted as $RS=h^2S$, being RS the response to selection. If the phenotypic measurements are normally distributed, the minimum phenotypic value of the animals selected to be parents would exceed the mean of parental generation by x phenotypic standard deviation, being x known as the truncation point. The mean phenotype value of the selected animals (S) clearly depend on the proportion of animals selected and can be define as $S=i\sigma_P$ where i is the selection intensity and $i\sigma_P$ is known as phenotypic selection differential. Therefore, the response to selection can now be rewrite as $RS=ih^2\sigma_P$. If the population is large and has a near normal curve i can be define as $i=z/p$ where z is the ordinate of the normal curve, and p is the proportion of individuals selected.

The genetic gain per generation obtained regarding one trait (Y) would be the product of the correlated response (CR) of the particular trait and the selection intensity. The correlated response is estimated by the regression of Y on I therefore $CR = \frac{cov(Y, I)}{\sqrt{var(I)}}$. The selection intensity is estimated based on the percentage of animals selected and would be fixed for males since every year the number of progeny tested bulls and the number of bulls selected would be the same. On the other hand, the intensity of selection regarding females would change according to changes in fertility since the number of replacements and available animals would be determined according to the fertility of the herds. Even though some important traits would not be included in some selection criteria, the correlated response would be estimated in order to monitor those traits.

3.2.4 Parameters and estimated performance

The genetic parameters such as breed effects, heritabilities, phenotypic and genetic correlations assumed by the model were chosen after a search of the literature (Koots et al 1994a and b; Urioste et al 1998; Toelle and Robison 1985; Koch et al. 1982) including Brazilian results (Restle et al. 1999). Breed effects and heterosis were also from the literature including comprehensive work from University of Florida (Peacock and Koger 1980; Peacock et al. 1981), which was compatible to recent Brazilian results presented by Trematore et al. (1998). Appendix 2 presents the genetic parameters assumed for this simulation.

Performance of an individual or the phenotypic value for one specific trait would be basically the result of an additive genetic component and an environment component: $P = G + E$. Since the model assumes no environment components or interactions, the performance of purebred animals would be equal to the additive breed effect. However, crossbred animal performance would take into account individual heterosis effects. Heterosis is known as the superiority in performance of a crossbred individual when compare to the average performance of the parental breeds and could be expressed either in percentage or trait units. The heterosis could be expressed in the animal itself (individual heterosis), in the dam's maternal traits (maternal heterosis), or in the sire's paternal traits (paternal heterosis). The performance of Angus-Nellore F1 animals would only account for individual heterosis since their parents are purebred animals. However, the animals born in the commercial herd would have crossbred mothers thus maternal heterosis effects should be taking into account in estimating their performance.

The performance of F1 animals can be easily estimated from the additive breed effects of the two breeds involved in the mating and the individual heterosis effect originated by crossing these two breeds. The performance of Angus-Nellore F1 animals would be the sum of half of additive breed effect from Angus (A_A), half of additive breed effect from Nellore (A_N) and the full individual heterosis effect between Angus and Nellore (IH_{AN}) as:

$P= 0.5A_A+0.5A_N+1IH_{AN}$.

For animals born in the commercial herd from Charolais sires (½ Charolais-¼Angus-¼Nellore animals) the performance would be expressed as:

$P=0.5A_C+0.25A_A+0.25A_N+0.5IH_{CA}+0.5IH_{CN}+ 1MH_{AN}$.

Where MH_{AN} is the maternal effect from the Angus-Nellore F1 dams.

Following that, performance of backcross offspring such as ¾Angus-¼Nellore and animals ¼Angus-¾Nellore would be predicted the respective expressions:

$P=0.75A_A+0.25A_N+0.5IH_{AN}+1MH_{AN}$

$P=0.25A_A+0.75A_N+0.5IH_{AN}+1MH_{AN}$

Since Nellore and Angus bulls would be progeny tested from in the commercial herd, a few backcross offspring would be generated.

3.2.5 Different scenarios

Basically there were two different scenarios that were tested. One scenario investigated the results of 20 years of selection taking in account the use of progeny tested bulls while the other scenario would investigated the outcomes of selection based only on individual selection of the bulls. The breeding objective and the relative economic values to define the selection index were the same in both scenarios. Subsequently, the model was used to investigate which economic values would maximize profit per AU. The economic values to maximize profit per AU were estimated using the Solver tool of Microsoft Excel setting. Those new economic values would then be used in the same two scenarios describe above. In the standard spreadsheet non-linear programming problems are solved with the Generalized Reduced Gradient (GRG) method. The GRG method assumes that the objective function and constraints are smooth nonlinear function of the variables and yields a locally optimal solution. This solution is probably best within the vicinity although it does not exclude other better solution that might be far away from the initial values of the variables. Lasdon and Smith (1992) presented a technical description of the nonlinear GRG method included on Microsoft Excel spreadsheet Solver.

Usually the implementation of breeding programs requires not only monetary but also technological investments, which definitely increase operational cost. However, since the model assumes an enterprise with high technological adoption, selection based on individual information may not represent an increase in costs because animals' measurements and records are already a current practice of the system in order to monitor production levels. Therefore, the model assumes no increase in cost due to individual selection. On the other hand, the model would assume a cost due progeny test selection of US$ 3.00 per AU per each AU from progeny involved in the test. In other words, keeping track and records of the progeny from sire candidates would increase the operational cost of those animals US$ 3.00 per AU. Since every year 500 candidates are tested based on record of a total of 15 sons and daughter, progeny test would assemble a total of 4500 animals representing approximately 6623.6 AU per year. Since the cost per AU is US$ 3.00 progeny test would increase operational costs in US$ 19,870.74, and since the whole system operates an average of the 67,584.79 AU per year the operational cost for the whole system would increase from the assumed US$ 73.00 to US$ 73.30 per AU when progeny testing is applied.

Animal breeding is a long-term process thus factors that affect costs and returns over the long-term must be considered in order to evaluate breeding schemes. The use of discount rate to evaluate breeding programs is a common practice. Here a discount rate of 5% per year was assumed when economic evaluation of the different scenarios was done.

Chapter 4

Results

4.1 General Aspects

The results related to structure of the herds, number of animals slaughtered per year, number of animal units per year, number of hectares, income, costs, profitability and returns for the whole enterprise, before starting the selection program is presented in appendix 1. Results after 20 years of selection based on selection index developed with the estimated relative economic values with progeny test and without progeny test are presented in Appendices 3 and 4 respectively. Appendices 5 and 6 present the same result when the relative economic values were changed in order to maximize profit per hectare.

4.2 Economic selection index

4.2.1 Breeding objective and economic values

According to the estimated economic values, calving rate and dressing out percentage on the Nellore and Angus herd, and dressing out percentage on the Charolais herd were the traits that would have a real impact on profitability considering the production system as a whole. Table 4.1 presents the estimated economic values for traits affecting profitability. Cow and calf survivals were excluded because the model assumed no changes in mortality due to selection. An increase of one unit on calving rate of the Angus and the Nellore herd would increase profitability by US$20,886.96 and US$62,154.50 respectively when other traits were held the same. Dressing out percentage showed the greatest impact on profitability and a unit increase in the dressing out percentage alone of the Angus, Nellore and Charolais herds would represent, respectively, improvements of US$37,314.37, US$74,449.83 and US$26,060.45 on profitability of the whole system. Cow liveweight of Angus and Nellore herds were the only traits to show a negative economic value. An increase of one kg on liveweight of Angus cows, holding the other traits constant, would represent a loss in profitability of US$1,086.37 and one extra kilo on Nellore cows would result in US$1,179.88 less profit.

Table 4.1- Traits affecting income and costs for each nucleus herd and their respective economic value

Traits	Economic values (US$)
Calving rate	
Angus	20,886.96
Nellore	62,154.50
Charolais	810.54
Cow weight	
Angus	-1,086.37
Nellore	-1,179.88
Charolais	15.45
Dressing out %	
Angus	37,314.37
Nellore	74,449.83
Charolais	26,060.45
Weaning rate	
Angus	391.12
Nellore	44,917.45
Charolais	811.16
Weaning weight (final weight)*	
Angus	3,307.53
Nellore	5,068.01
Charolais	2,355.67

* Model assumed a fixed liveweight gain after weaning

The economic selection index was based on the relative economic values of the traits chosen to be in the breeding objective. For each of the three purebred herds there was a different breeding objective and the relative economic values change according with the breed as well. Table 4.2 presents the traits in the breeding objective for each herd and their relative economic values. The relative economic values estimated in order to maximize profit per AU are presented between brackets. On both Angus and Nellore herds the relative economic values in order to maximize profit per AU increased the weight on dressing out percentage selection.

Table 4.2- Estimated relative economic values and relative economic values in order to maximize profit per AU for the traits included in each of the three breeding objectives.

Traits in the breeding objective	Estimated relative economic values	Relative economic values for maximizing profit per UA
Angus herd		
Calving rate (weaning rate)	0.5597	0.2281
Dressing out %	1	1
Nellore herd		
Calving rate (weaning rate)	0.8348	0.4158
Dressing out %	1	1
Charolais herd		
Dressing out %	1	1

4.2.2 Selection criteria and correlated responses

The coefficients for selection criteria in the selection indexes of each herd are presented in appendix 2. Table 4.3 presents the correlated responses per standardized selection differential for traits that would affect profitability from selection criteria used for sire and dams in each different herd and scenarios. Since dressing out percentage was the only trait in the breeding objective for the Charolais herd, the correlated responses between selection index using estimated relative economic values and the relative economic values in order to maximize profit per AU would not differ. Calving rate in the Charolais herd presented a negative response independently if the selection index for sires included information on progeny or not, and the response on the sire side seemed to be worst with individual selection. Calving rate dam responses on Charolais herd was also negative and it was lower than responses of sires progeny tested, although it was a little better than the responses of sires selected on individual measures. Weaning weight had a positive response when information on progeny was included on the selection criteria for Charolais bulls and a negative response without progeny test. However, the correlated response of weaning weight in the dam side was higher than on the sire side. The sire selection criteria using the progeny test also showed higher response for dressing out percentage than responses with individual selection on the Charolais herd. There was a considerable difference between cow weight responses for sires selected by progeny test and for sires selected by individual measures. The response of sires selected on individual measures higher than the response based on selection of progeny. The dam side correlated response for cow weight, similarly with the weaning weight response, was higher than the response on the sire side using progeny tested bulls and it was lower than the sire side based on individual selection.

Table 4.3-Correlate responses per standardized selection differential of dams and sires selection for traits affecting profitability on each herd and scenario.

Herd	Traits directly affecting profitability	Scenarios: Estimated relative economic values			Scenarios: Maximizing $/ AU relative economic values		
		Dams	Sires: Progeny tested bulls	Sires: Individual selection	Dams	Sires: Progeny tested bulls	Sires: Individual selection
Nellore	Calving rate (%)	2.483	1.057	1.292	2.431	0.634	1.795
	Weaning weight (kg)	3.717	1.765	1.638	3.778	1.229	2.557
	Dressing out (%)	-0.025	0.661	0.005	0.001	0.891	0.002
	Cow liveweight (kg)	6.272	3.263	4.970	6.805	2.400	6.569
Angus	Calving rate (%)	1.265	0.820	1.243	0.945	0.331	0.840
	Weaning weight (kg)	1.531	1.468	1.504	1.614	0.817	0.756
	Dressing out (%)	0.003	0.811	0.010	0.099	0.980	0.133
	Cow liveweight (kg)	5.831	2.791	5.688	7.148	1.708	7.492
Charolais*	Calving rate (%)	-0.402	-0.101	-0.434			
	Weaning weight (kg)	0.566	0.202	-1.074			
	Dressing out (%)	0.220	1.025	0.253			
	Cow liveweight (kg)	4.428	0.651	5.406			

* Charolais breeding objective had just one trait therefore the correlated responses would not differ regarding the relative economic values used.

4.2.2.3 Calving rate correlated responses on Nellore and Angus herds

Correlated responses for calving rate on Angus and Nellore sire sides were higher for selection indexes based on individual measures than selection indexes using progeny test, independently of the relative economic values used. However, on both herds, the correlated responses for calving rate, when relative economic values maximized profit per AU, were lower than responses from selection indexes based on estimated relative values. Nellore sire selection indexes were higher than Angus sire selection indexes when respectively compared within the same scenario. The best correlated response in calving rate among the sire selection indexes was caused by the Nellore sire selection index based on individual selection and maximizing profit per AU relative economic values. On the other hand, Angus sire selection index with progeny test and maximizing profit per AU presented the worst correlated response for calving rate among sire indexes.

On the Angus herd correlated response for calving rate on the dam side was higher with the estimated economic values than with the maximize profit per AU relative economic values and within the relative economic values calving rate dam responses were similar to sire responses with individual selection. On the dam side the correlated response for calving rate on the Nellore herd was slightly higher also with the estimated relative values than the response using the relative economic values that would maximize profit per AU. However, the correlated responses for calving rate on the Nellore dam side were bigger than responses on the Nellore sire side and also much greater than responses on the Angus dam side.

4.2.2.4 Weaning Weight correlated responses on Nellore and Angus herds

Weaning weight correlated response on the Nellore sire side, within the estimated relative economic values, was higher with progeny tested than the responses on weaning weight for sires selected on individual measures. Within maximizing profit per AU relative economic values, the best correlated response on the Nellore sire side was caused by selection index on individual selection which was also the best correlated response for weaning weight among the sire sides of both herds. On the Angus sire side the opposite occurred since the correlated response for weaning weight was higher for individual selection than selection including progeny information within the estimated relative economic values. Within maximizing profit per AU relative economic values weaning weight response on Angus sire side was higher for progeny tested bulls than bulls select only on individual measures. The Nellore responses were higher than the Angus correlated responses for weaning weight when selection indexes were respectively compared within same scenarios.

Weaning weight correlated responses for dams on Angus herds were a little higher with the estimated relative economic values than with the relative economic values to maximize profit per AU and that also occurred with weaning weight responses on the Nellore dam side. Comparing the selection indexes within the respective relative economic values, the Nellore dam side presented a much higher correlated response for weaning weight than both selection indexes used on the sire side. However, the same comparison on the Angus herd showed that weaning weight correlated responses were more balanced among dam selection index and sire selection index within the same relative economic values.

4.2.2.5 Dressing out percentage correlated responses on Nellore and Angus herds

Dressing out percentage presented a better correlated response when the progeny test was taking into account rather than selection based only on individual measures on Angus and Nellore bulls selection, independently of the relative economic value evolved. The correlated responses for dressing out percentage with progeny test were increased by the relative economic values to maximize profit per AU in both herds. Individual selection correlated responses for dressing out percentage on the Nellore sire side had a slight reduction with the maximizing profit per AU selection index. On the Angus herd, the individual selection correlated response for dressing out percentage showed an increase when the maximizing profit per AU relative economic values were applied. Comparing dressing out percentage correlated responses between Angus and Nellore sire sides within the same scenario, the Angus sire responses were always superior to responses on Nellore.

The dam dressing out percentage correlated responses in both Angus and Nellore herds were boosted by the use of relative economic values to maximize profit per AU. The selection index for Nellore dams with the estimated relative economic values was the only one among all indexes to present negative correlated response for dressing out percentage, although the responses became positive with the substitution of the estimated relative economic values per maximizing profit per AU relative economic values on the index. When comparing correlated responses from the dam side with responses on the sire side within the same economic values and herds, the responses for dressing out percentage of the dams, except for the

Nellore dam side based on estimated relative economic, were similar to individual selection correlated responses from the sire side but much lower than responses of selection indexes involving progeny test.

4.2.2.5 Cow liveweight correlated responses on Nellore and Angus herds

With same economic values, individual selection presented higher correlated responses for cow liveweight than correlated responses of selection indexes using progeny test on the sire side of both Angus and Nellore herd. The superiority of cow liveweight correlated response on sire side for selection index based on individual measures was increased by the change of relative economic values on both Angus and Nellore herds when comparing selection index within the same herds. Comparing correlated responses of Nellore sire side against Angus sire side within same relative economic values, correlate responses for cow liveweight based on selection index with progeny test were higher on the Nellore sire side than on Angus sire side. However, when the individual information was taking into account for selection, the responses on the Angus sire side were higher than on the Nellore sire side. The Angus sire selection index based on the maximizing profit AU relative economic values and individual selection presented the highest correlated response among all selection indexes.

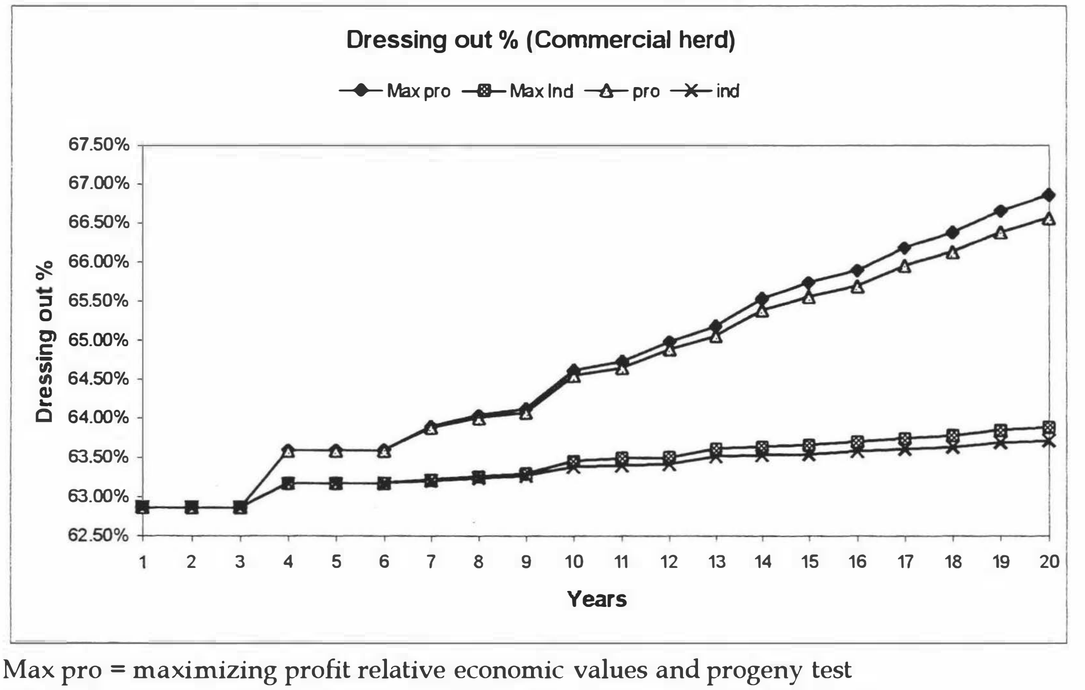
On the dam side within the same breed, both herds correlated responses on cow liveweight were higher with relative economic values to maximize profit per AU, although that difference was greater on the Angus herd than the Nellore herd. When comparing the responses on cow liveweight of the Nellore dam side against the Angus dam side, the correlated response on the Nellore herd was higher when estimated relative economic values were applied. However, the correlated response for cow liveweight on the Angus dam side was greater than the Nellore dam response when maximizing profit per AU relative economic values were used. Within same herds and same economic values, the dam correlated responses for cow liveweight were similar to the sire side with individual selection, greater than the responses of selection indexes with progeny test. The Nellore dam correlated response for the index using the estimated relative economic values was an exception since the cow liveweight response on this case was higher than the response in the sire side with individual selection.

4.2.3 Genetic gain

The genetic gain from one generation to the next one is the average of the correlated response per standardized selection differential times the selection intensity on sire and dam sides divided by the generation interval. Phenotypic responses must also account for heterosis effects when mating includes animals of different breeds. Figures 4.1 and 4.2 show the improvement in the commercial herd, for the different scenarios, through 20 years of selection for calving rate and dressing out percentage, respectively. The improvement on calving rate was higher for selection index based on estimated relative economic values with individual selection and increased from 87.69% to 93.43%. On the other hand, this scenario was the one that had the least increase in dressing out percentage. At the first year dressing out percentage of animals ½ Charolais- ¼ Angus- ¼ Nellore was 62.86% and after 20 years it was 63.71%.

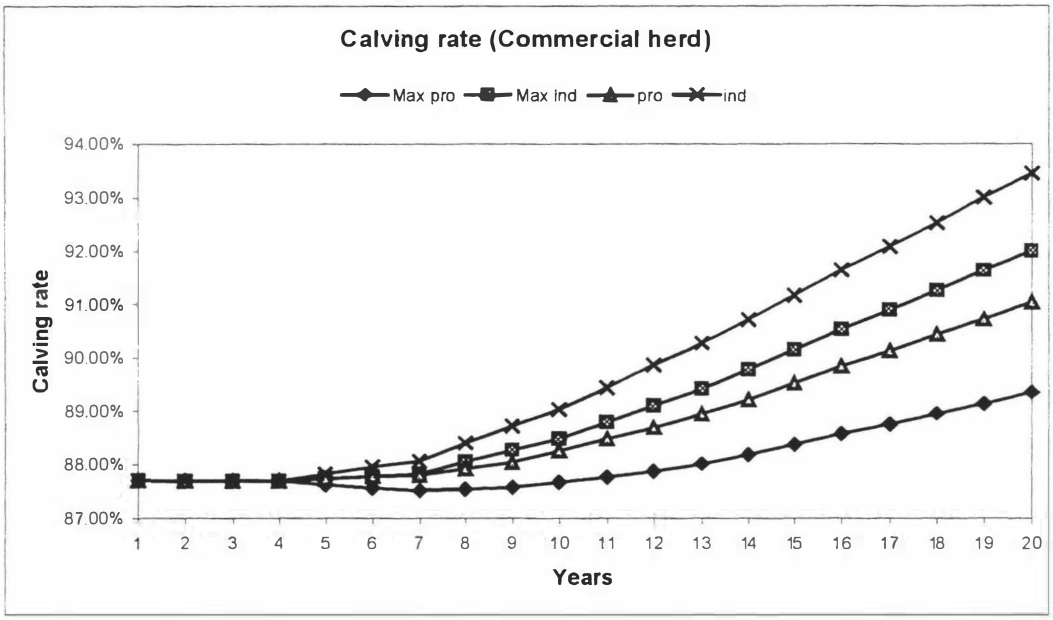
In an opposite situation was the development of selection through the selection index with progeny test and with relative economic values to maximize profit per AU. In this situation the calving rate improvement of females ½ Angus- ½ Nellore was the lowest increasing from 87.69% before selection to 89.35%. Although, the increased in dressing out percentage was the highest one jumping from 62.86% to 66.85% after 20 years of selection. The dressing out percentage graphic also showed that the evolution on dressing out percentage in the commercial herd for the two selection indexes using progeny test were very similar, independently of the relative economic values in the breeding objective. The same also happened with the two selection indexes using individual selection. However, that similarity did not occur with the improvement of calving rate.

Figure 4.1- Dressing out percentage improvement of ½ Charolais- ¼ Angus- ¼ Nellore steers and heifers on the commercial herd due 20 years of selection for the different scenarios.



Max pro = maximizing profit relative economic values and progeny test
Max ind = maximizing profit relative economic values and individual selection
Pro = Estimated relative economic values and progeny test
Ind = Estimated relative economic values and individual selection

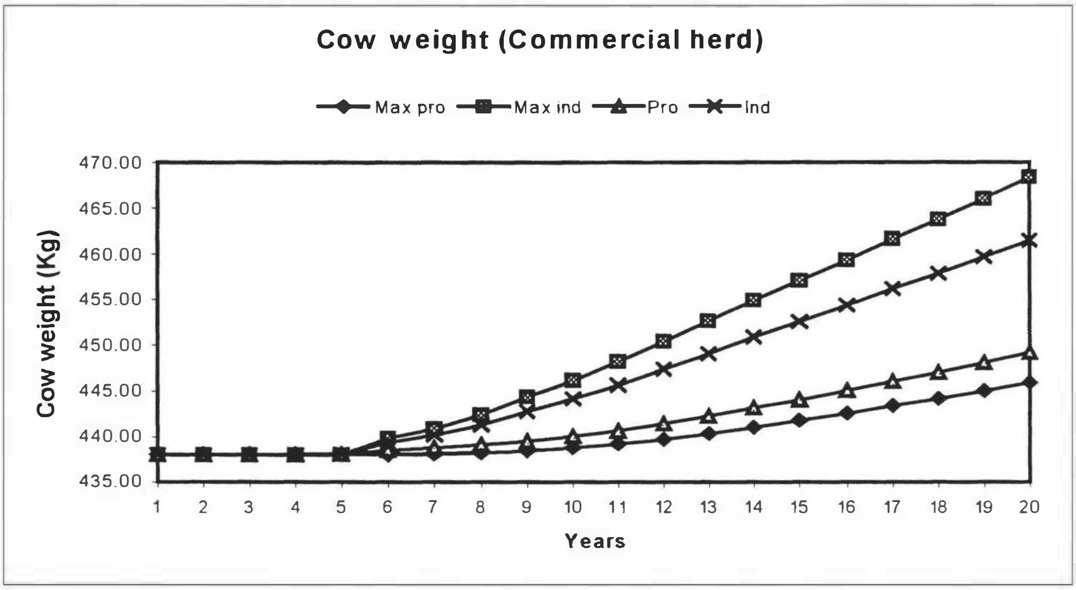
Figure 4.2- Calving rate improvement of females ½ Angus- ½ Nellore on the commercial herd due 20 years of selection for the different scenarios.



Max pro = maximizing profit relative economic values and progeny test
Max ind = maximizing profit relative economic values and individual selection
Pro = Estimated relative economic values and progeny test
Ind = Estimated relative economic values and individual selection

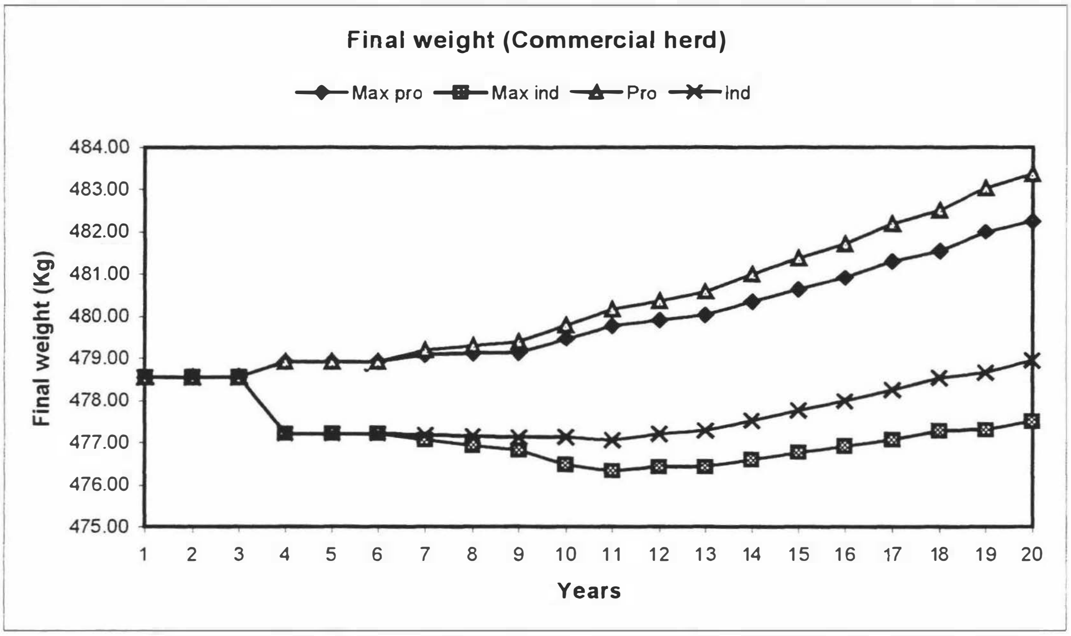
The evolution of cow liveweight and final liveweight would also be of interest since in the two biggest herds, commercial herd and Nellore herd, cow liveweight showed a negative economic value and carcass weight is a function of final liveweight and dressing out percentage. Figures 4.3 and 4.4 show the development respectively for cow liveweight of cows ½ Angus- ½ Nellore and final liveweight of animals ½ Charolais- ¼ Angus- ¼ Nellore on the commercial herd for the four different selection indexes. The selection index based on relative economic values to maximize profit per AU caused the biggest gain. The average cow liveweight enhanced from 437.97 kg before the selection program to 468.38 kg after the 20 years of selection, representing almost an increase of 7.06% on cow liveweight. The index based on relative economics values to maximize profit per AU and progeny test was the one that produced the lowest increasing on average cow liveweight. At the beginning of the program the average liveweight for a ½ Angus- ½ Nellore cow was the same 437.97 kg and at the end of the 20 years the cows were weighting only 445.88 kg representing a increase the only 1.81% on cow liveweight. Evolution of cow liveweight, like dressing out percentage, was similar for selection indexes that had same type of selection regarding the used of individual information or progeny test.

Figure 4.3- Cow liveweight evolution of ½ Angus- ½ Nellore females on the commercial herd due 20 years of selection for the different scenarios.



Max pro = maximizing profit relative economic values and progeny test
Max ind = maximizing profit relative economic values and individual selection
Pro = Estimated relative economic values and progeny test
Ind = Estimated relative economic values and individual selection

Figure 4.4- Final liveweight improvement of ½ Charolais- ¼ Angus- ¼ Nellore steers and heifers on the commercial herd due 20 years of selection for the different scenarios.

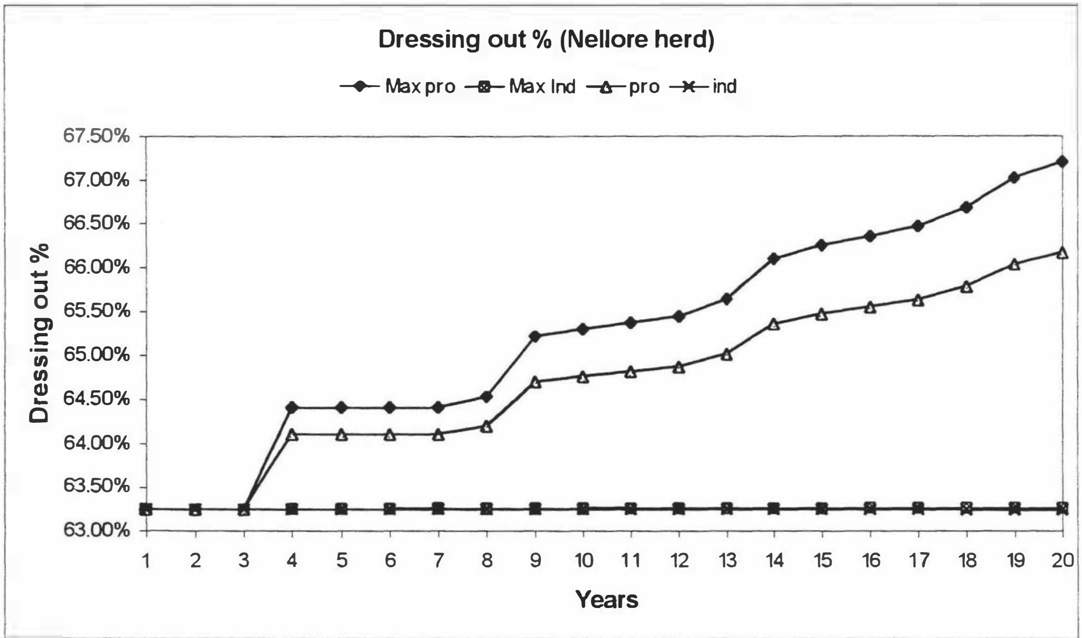


Max pro = maximizing profit relative economic values and progeny test
Max ind = maximizing profit relative economic values and individual selection
Pro = Estimated relative economic values and progeny test
Ind = Estimated relative economic values and individual selection

The evolution on final liveweight not only could be also spread into the group with progeny test and the group using individual selection but the progeny test group promoted improvement on final liveweight while the individual selection caused a decrease in final liveweight. The selection index base on the estimated relative economic values with progeny test was the one showing the highest improvement on final liveweight increasing 1.01% (from 478.55 kg to 483.36 kg). The selection index with progeny test and relative economic values that would maximize profit per AU came in second increasing 0.77%. On the other hand, selection index without progeny test and using the relative economic in order to maximize profit per AU was the one presenting the worst evolution on final liveweight showing a decrease of 2% (from 478.55 to 477.51).

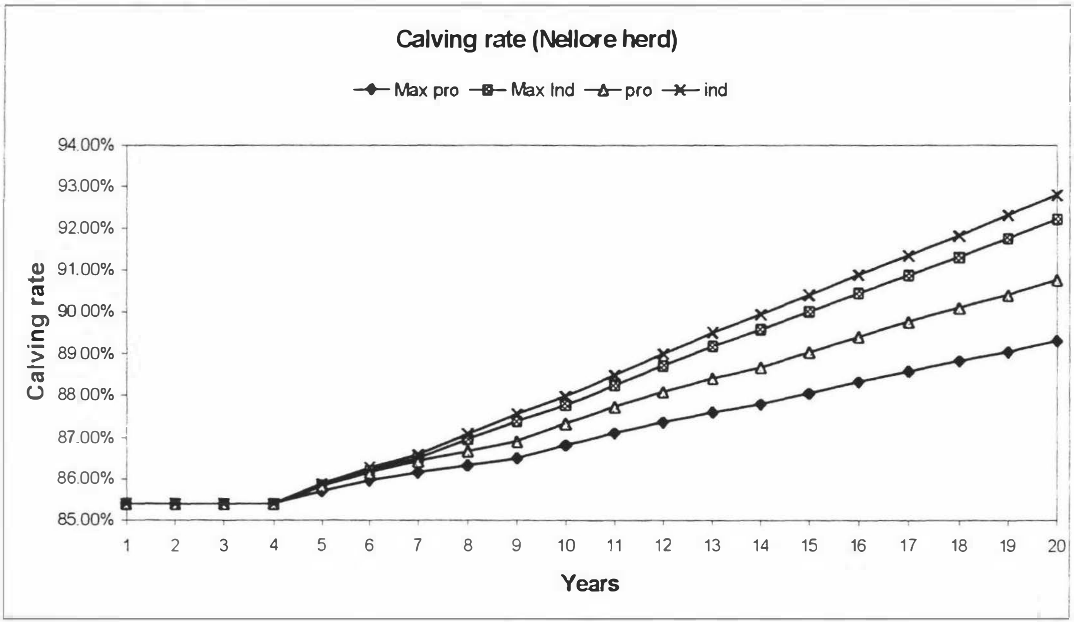
The evolution of traits on the Nellore herd would also be important regarding profitability of the whole system since the Nellore herd size was significantly larger than the other purebred herds. Figures 4.5 and 4.6 show the evolution for dressing out percentage and calving rate on the Nellore breed for the different scenarios. The evolution on average dressing out percentage for purebred Nellore steer and heifers was similar for both selection indexes in which progeny testing was not taken into account. However, there was little difference between them since the selection index based on estimated relative economic values showed a small reduction from 63.25% to 63.24% on dressing out percentage while the selection index based on relative economic values to maximize profit per AU presented a slightly increase from 63.25% to 63.27%.

Figure 4.5- Dressing out percentage improvement of Nellore steers and heifers due 20 years of selection for the different scenarios.



Max pro = maximizing profit relative economic values and progeny test
Max ind = maximizing profit relative economic values and individual selection
Pro = Estimated relative economic values and progeny test
Ind = Estimated relative economic values and individual selection

Figure 4.6- Calving rate improvement of Nellore females due 20 years of selection for the different scenarios.



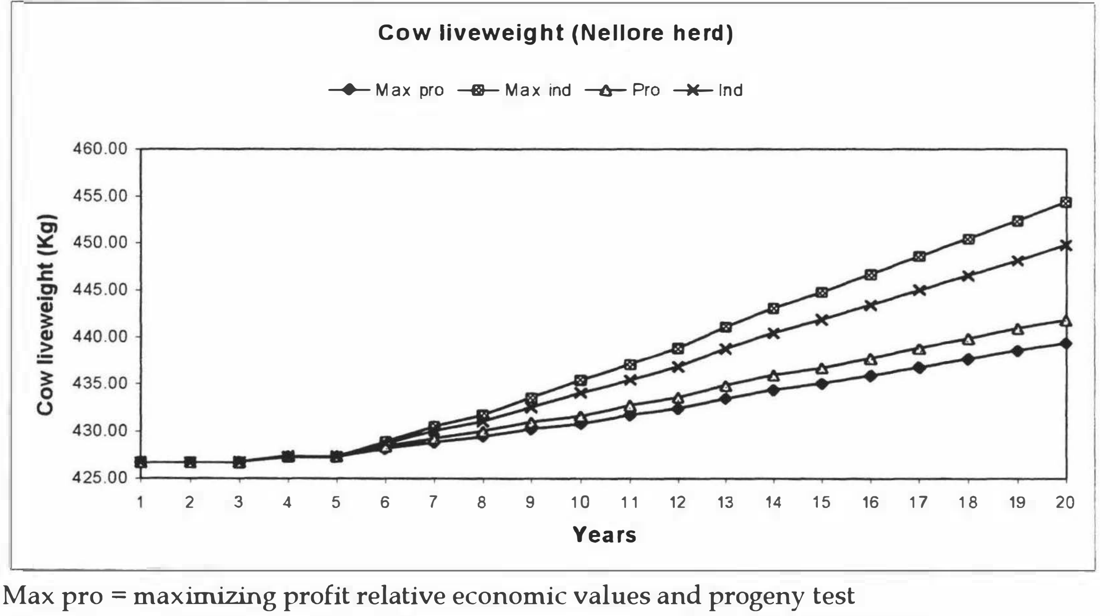
Max pro = maximizing profit relative economic values and progeny test
Max ind = maximizing profit relative economic values and individual selection
Pro = Estimated relative economic values and progeny test
Ind = Estimated relative economic values and individual selection

Both selection indexes using progeny testing caused a substantial improvement to dressing out percentage. Selection index with progeny test based on relative economic values to maximize profit per AU showed the best increase on the average dressing percentage of Nellore steers and heifers improving dressing out percentage in 6.3% (from 63.25% to 67.20%). Selection index with progeny test based on estimated relative economic values produced an increased of 4.7% on dressing out percentage of Nellore purebred steers and heifers.

The lowest response on calving rate on the Nellore herd was caused by the selection index with progeny test based on maximizing profit per AU relative economic values, on this scenario calving rate increased only 4.6% (from 85.40% to 89.31%). On the other hand, the selection index that caused the highest response in calving rate was that one based on estimated relative economic values using individual selection. The calving rate jumped from 85.40% to 92.78% during the 20 years of selection, representing an increase of 8.6%.

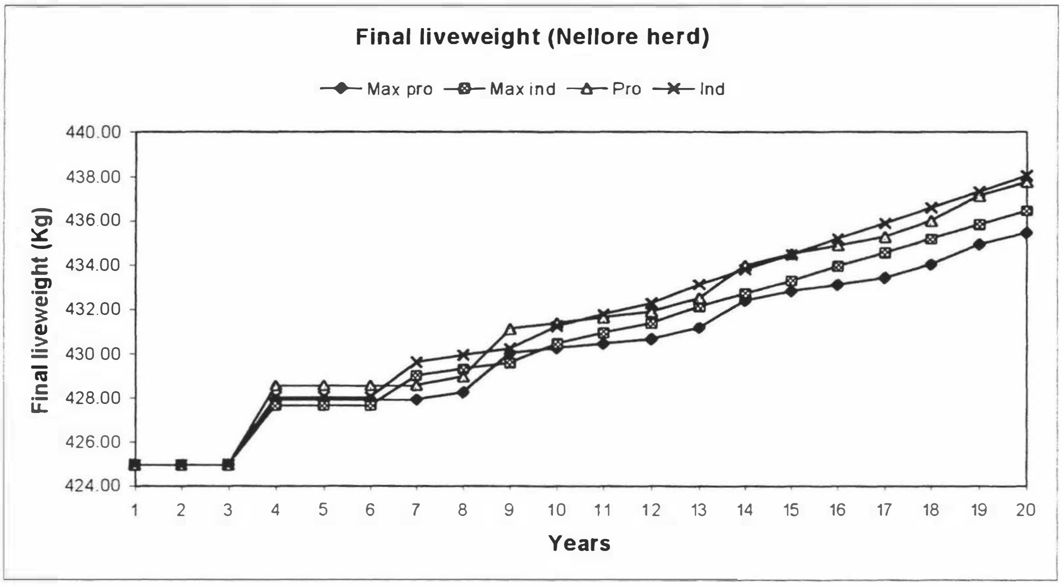
The changes in cow liveweight and final liveweight in the Nellore pure animals due to selection based on the four different selection indexes are illustrated by figures 4.7 and 4.8 respectively.

Figure 4.7- Cow liveweight evolution of the Nellore herd due 20 years of selection for the different scenarios.



Max pro = maximizing profit relative economic values and progeny test
Max ind = maximizing profit relative economic values and individual selection
Pro = Estimated relative economic values and progeny test
Ind = Estimated relative economic values and individual selection

Figure 4.8- Final liveweight improvement of Nellore steers and heifers due 20 years of selection for the different scenarios.



Max pro = maximizing profit relative economic values and progeny test
Max ind = maximizing profit relative economic values and individual selection
Pro = Estimated relative economic values and progeny test
Ind = Estimated relative economic values and individual selection

Like the response in ½ Angus- ½ Nellore cow liveweight, the highest response in liveweight of Nellore cows was due selection based on maximizing profit per AU relative economic values with individual selection. After 20 year of selection cow liveweight increased 6.5% going from 426.70 kg to 454.30 kg. The selection index based on maximizing profit per AU with progeny testing caused the lowest response in cow live weight increasing cow liveweight by only 2.9%.

Although the evolution of final liveweight for selection indexes based on estimated relative economic values with progeny test and the evolution for selection index based on estimated relative economic values with individual selection were different, the final results after 20 years of selection for both indexes were very close. The indexes caused an increase in final liveweight of Nellore steer and heifers of 2.93% and 3.7% respectively, presenting a last final liveweight of 437.74 against 438.00. The biggest response on final liveweight of Nellore animals was caused by the selection index based on estimated relative economic values and individual selection. Selection index based on maximizing profit per AU relative economic values with progeny test produced the lowest response increasing final liveweight of Nellore animals in only 2.2% equaling a final liveweight of 435.45 kg.

4.3 Economics

The total discounted net income for the 20 years and the discounted net income for each one of the 20 years, for the four different selection indexes and also for a scenario with no selection, are presented on table 4.4. The two selection indexes that included information of progeny into the selection criteria were the best ones when compared to the selection indexes using individual selection independently of the relative economic values applied. However, indexes based on individual selection presented a higher discounted net income from year four until approximately year ten. The maximizing profit per AU selection index with progeny test resulted in the highest total discounted net income presenting a increasing of US$2,513,025.00 (5.11%) on total discounted net income when compared to the no selection option. The estimated relative economic value selection index with progeny tested improved the total discount net income in US$2,369,742.08 (4.81%) comparing with no selection option discounted income for the 20 years. The selection indexes using individual selection based on estimated relative economic values and maximizing profit per AU relative economic values showed improvement on total discounted net income boosting the income US$1,627,551.32 (3.31%) and US$1,503,943.85 (3.06%), respectively, when compared to the no selection option.

Table 4.4-discounted net income for each year and total discounted net income for the different selection indexes and for a no selection scenario*

Years	No Selection	Estimated relative economic values		Maximizing $/AU relative economic values	
		Progeny tested bulls	Individual selection	Progeny tested bulls	Individual selection
1	3,761,247.55	3,761,247.55	3,761,247.55	3,761,247.55	3,761,247.55
2	3,582,140.53	3,582,140.53	3,582,140.53	3,582,140.53	3,582,140.53
3	3,411,562.41	3,411,562.41	3,411,562.41	3,411,562.41	3,411,562.41
4	3,249,107.05	3,292,522.10	3,303,570.40	3,298,378.55	3,304,121.17
5	3,094,387.67	3,232,304.80	3,250,089.86	3,217,937.71	3,246,187.17
6	2,947,035.88	3,106,166.63	3,132,317.26	3,077,131.43	3,116,285.14
7	2,806,700.83	2,997,326.16	3,028,301.10	2,961,382.12	3,007,419.30
8	2,673,048.41	2,864,741.93	2,918,238.40	2,828,102.60	2,892,853.10
9	2,545,760.39	2,704,959.70	2,756,275.15	2,680,788.89	2,728,934.54
10	2,424,533.71	2,600,277.45	2,606,198.57	2,589,555.15	2,585,927.76
11	2,309,079.72	2,478,796.22	2,471,420.09	2,473,702.18	2,455,561.08
12	2,199,123.55	2,375,800.93	2,330,710.51	2,377,766.42	2,316,927.24
13	2,094,403.38	2,260,234.19	2,193,556.35	2,270,252.06	2,185,443.32
14	1,994,669.88	2,143,125.13	2,063,601.64	2,163,891.80	2,059,747.67
15	1,899,685.60	2,031,527.02	1,939,785.57	2,063,126.50	1,939,379.05
16	1,809,224.38	1,926,598.63	1,819,537.99	1,964,047.09	1,822,273.15
17	1,723,070.84	1,837,639.08	1,712,677.84	1,880,360.22	1,718,083.81
18	1,641,019.85	1,746,860.82	1,612,858.59	1,793,422.13	1,620,104.57
19	1,562,876.05	1,659,234.66	1,519,207.05	1,708,613.56	1,526,978.83
20	1,488,453.38	1,573,807.22	1,431,385.54	1,626,747.18	1,439,897.53
Total	49,217,131.07	51,586,873.15	50,844,682.39	51,730,156.07	50,721,074.92

*Values in US dollars (discount rate of 5%)

The outcomes on number of animal units, profit per animal unit, number of hectares, profit per hectare and rates of returns after the 20 years of selection for the four different selection indexes comparing to a no selection option are presented in table 4.5. Better improvements in profit per AU due to selection led also to high increase in profit per hectare and better return rates. As expected, the maximizing profit AU relative economic value selection index presented the best improvement in profit per AU, which was also followed by a higher profit per hectare and return rates. The growth in profit per AU, profit per hectare and return rates represented respectively a difference of 16.37%, 16.36% and 14.02% above the results shown without selection. However, it was the scenario that showed the least reduction in the land area necessary to run the operation and the least reduction in amount of AU as well.

Table 4.5- outcomes regarding number of animal units, profit per animal unit, number of hectares, profit per hectare and returns rate after the 20 years of selection for the different selection indexes and a no selection option.

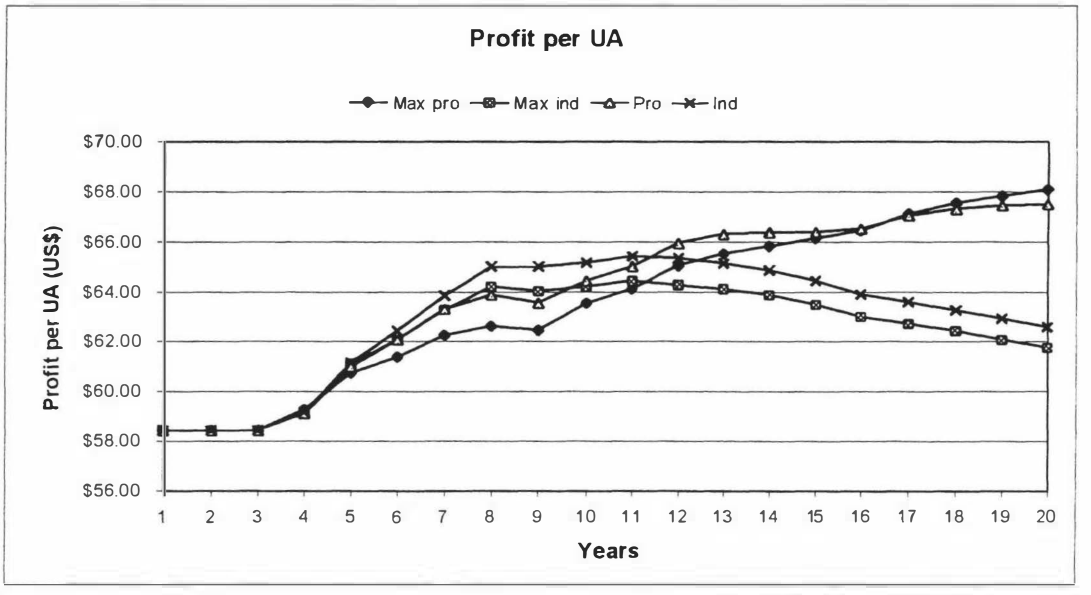
Breeding scheme		# AU	$/AU*	# hectares	$/hectare*	Return rates
No Selection		67584.69	58.43	61436.87	64.28	8.13%
Maximizing $/AU relative economic values	Progeny tested bulls	63474.84	68.00	57704.40	74.80	9.27%
	Individual selection	61890.70	61.73	56264.27	67.90	8.42%
Estimated relative economic values	Progeny tested bulls	61846.68	67.52	56224.25	74.27	9.20%
	Individual selection	60697.88	62.57	55179.89	68.83	8.19%

*Values in US dollars

The index based on estimated relative economic values and progeny testing showed the second best increase in profit per AU growing 15.54% during the 20 years of selection, which represented an increase of 15.54% in profit per hectare and 13.16% in return rates. On the other hand, this selection index was more efficient than the maximizing profit per AU index regarding down sizing the enterprise. The estimated relative economic value index with individual selection was the most efficient index regarding reducing the size of the operation. This index also resulted in a better improvement of profit per AU, profit per hectare and return rates than the maximizing profit per AU relative economic value index with individual selection, when compared with the no selection scenario. The estimated relative economic value index with individual selection increased profit per AU 7.08%, profit per hectare 7.07% and return rates in 3.57% against an increase of 5.64%, 5.63% and 0.74%, respectively, from the maximizing profit per AU relative economic value index with individual selection.

The evolution on profit per AU due to the different index is shown in figure 4.9. There was a parallelism between evolution in profit per AU of indexes with progeny test, and that also occurs between indexes using individual selection. The distinct difference between indexes with progeny test and indexes with individual selection was that individual selection indexes showed a better increase in profit per AU until around the 11th year but after half of the breeding program started to decline. Meanwhile, profit per AU of the progeny test indexes grew during the whole time. The estimated relative economic value index with progeny test, when compared to the maximizing profit per AU relative economic value index also with progeny, presented a superior growth in profit per AU until the 16th year of the program. After that, the maximizing profit per AU relative economic value index with progeny presented a higher improvement in profit per AU.

Figure 4.9- the evolution due to selection based on the different selection indexes regarding improvement in profit per AU.



Max pro = maximizing profit relative economic values and progeny test
Max ind = maximizing profit relative economic values and individual selection
Pro = Estimated relative economic values and progeny test
Ind = Estimated relative economic values and individual selection

Chapter 5

Discussion

5.1 Considerations regarding the model, production system and breeding objective

Defining the appropriate multiple trait selection objective is critical to a successful breeding program, and, although this has been often neglected, establishing the economic value of genetic improvement requires an adequate comprehension of the production system (Koots and Gibson, 1998). Improving economic efficiency is the ultimate of many breeding programs and any economic evaluation should begin by considering cost and returns. Economic efficiency could be defined as the ratio between returns and costs estimated on an annual basis.

According to Dickerson (1970) the costs of an enterprise depends on three main functions: female production, female reproduction and growth of the young. Notice that the costs of male production were left out since these costs could be considered insignificant comparing to those mentioned previously. Economic input of a production system is often separated into feed-related costs and non-feed related costs. The non-feed related costs include wide range of costs such as some of the labour, husbandry, veterinarian and medicine, transport, vehicles, social fees and fiscal tax, administration expenses etc. However, The major costs of any beef production system are feed related. Feed costs result from maintenance feed cost of breeding cows, the productive feed cost of breeding cows (amount of feed above maintenance level required by a breeding cow to produce and wean a healthy calf) and the feed cost involved in maintenance and fattening the offspring.

Comprehensive models usually estimate feed requirement based on the net energy requirements suggested either by the NRC (e.g. Koots and Gibson, 1998) or the AFRC, and then estimate the price of feeding the animals based on the cost of dry matter. However, the costs of feed in extensive grazing industries are hard to measure since feed costs include the expenses related to land, pasture improvement, irrigation, fertilizers, supplementary feed, costs of planting, and feeding labor. Therefore, the utilization of generalized estimated costs per unit of a parameter such as animal unit is a common practice when estimating the costs of a pasture enterprise. Animal unit is a measure sensitive to the energy requirement of the animals since there is a correlation among animal unit, metabolic liveweight and expected performance of an animal.

Beef breeding programs have usually neglected feed costs and feed efficiency mainly because of the difficulties involved in the process of measuring it and thus selecting superior animals, especially under extensive pasture systems. In addition, there is a lot of controversy around weight gain trials since the animals are evaluated on different condition than they would be performing. However, according to Cameron (1998) efficiency of nutrient utilization should be an important part of any breeding program. A drawback of the model developed for this simulation was that it did not account for feed efficiency as a trait that would affect feed costs, thus feed efficiency could not be a trait in the breeding objective.

Returns, the other component of economic efficiency, are a function of the product (or products) sold, the price received by the product (or by each different product), and the quantity produced. Analogous to costs, returns were divided by Dickerson (1970) in the return from female production and the return from offspring production. Return from female production was defined as the number of female per enterprise multiplied by the quantity produced and the price paid product. Return from offspring was defined as the multiplication of the number of offspring produced per breeding female by the weight of offspring product by the price paid per product. However, the model assumed an integrated beef production system in which the saleable product is the surplus offspring after being raised and fattened, hence the first part of the equation could be left out since the female production would be the number of offspring per breeding cow.

Breeding programs can increase returns of an integrated beef operation by increasing the number of offspring per breeding cow, the weight of slaughtered animals and the price paid by kilo of carcass. Breeding programs would have a greater impact on the weight of animals rather than on the number of offspring per breeding cow or the price paid per carcass weight since liveweight characteristics are highly heritable and they also have high phenotypic variance, while traits related to the number of offspring per breeding cow have low heritability and carcass traits are difficult to measure having usually small phenotypic variance. Traditionally, growth traits have been the main objective of beef breeding programs even though the correlated effects on reproductive performance have been largely unknown and slight negative some times (Bellows and Staigmiller, 1994).

Reproductive performance of females has a major impact on the economic efficiency of any production system, and it must be recognized as the major economic force in successful beef production system. The breeding objective developed in this study included calving rate as the reproduction trait to be improved. A major problem in developing a breeding objective including reproduction traits is that genetic parameters relating fertility traits to characteristics that could be measured on individuals are difficult to be found in the literature even though many authors reported desirable correlations among fertility traits and characteristics such as age at puberty, calving easy, pelvic are. On the other hand, there is strong evidence in the literature that fertility has a negative correlation to growth traits thus some loss in genetic gain for growth traits should be expected when fertility traits are included on breeding objectives. Graser et al. (1994) comparing traditional breeding schemes based on growth traits to an extended breeding scheme that would also include fertility traits for the Australian beef industry, reported that the breeding schemes including fertility traits were more profitable and fertility measures were the most cost effective additional selection criteria.

Since selecting for fertility is difficult, culling options assume an important role in beef production. Deese and Koger (1967) stated that culling cows for reproductive failure can dramatically change the average reproductive performance of a herd. The culling policy assumed by the model here is common practice in advanced systems in Brazil. Cows that would have any problem allowing them to calve a healthy calf are culled from the herd and replaced. Many advanced systems in Brazil are already allowing heifers to start their reproductive cycle between 16 to 18 month and some times at 14 months. On this study a more conservative policy is adopted since heifers start their reproductive life over two years of age. However, age at puberty is a characteristic included in the selection criteria.

Increasing the price paid per carcass is possible by improving the quality of meat traits. Nowadays, meat quality traits are included in many breeding programs (e.g. Graser et al., 1994; Koots and Gibson, 1998 and Amer et al. 1998), particularly in terminal sire lines. Carcass traits are difficult to measure and the assessment of those traits could be done through progeny testing or by ultrasonic measurements. In both cases, the inclusion of evaluation of carcass traits on a breeding program would represent an increase in costs. As a result, the returns obtained from the improvement in meat quality should cover the expenses of including such traits in the program. At present time the mainstream Brazilian payment system does not benefit farmers that provide better carcasses thus it would not reward breeding programs investing in meat quality. The breeding program developed on this study did not included meat traits on the breeding objective, although carcass characteristics were included on selection criteria of progeny tested bulls.

The meat industry in Brazil has been pressured to reward carcass improvement and alternative payment programs have been launched in recent years indicating that payment policy might change in the near future. Since genetic change by its nature is a long-term process and some changes in beef cattle breeding programs might take more than ten years to be realized, Breeders should start now to pay more attention to meat traits.

Crossbreeding has been adopted in many production systems in order to exploit the benefits of heterosis and complementarity among the existing breeds. As reproductive efficiency is one of the most important aspects of any beef operation, it is desirable that a crossbreeding scheme keeps the crossbred females in order to explore the maternal benefits of hybrid cows. The model adopted a three-breed terminal crossbreeding scheme since according to Euclides Filho (1997) this scheme would maximize the use of heterosis and complementarity allowing flexibility in choosing the breeds. A disadvantage of terminal sire schemes is that replacements have either to be bought or generated from a second herd.

There are a great number of beef cattle breeds and different lines available thus the choice of the most profitable parental combination could be quite difficult. With three breeds involved it is possible to have a few different parental combinations and some combinations would be more profitable than others. Assuming that the traits are additive genetic, the case of interest is when there is a line with high production and other lines with high fertility since if one line has both high fertility and high productivity there is no point in crossing them. Weller (1994) showed that if one breed involved on the dam line has higher fertility than the second breed, which has higher productivity, and there is a third breed that would be the most productive with lower fertility. The most profitable combination involving the three breeds would be to first cross the two breeds and then cross the F1 females with the most productive breed since the sire line would not affect reproductive traits. The parental combination assumed on this study followed the principles presented by Weller (1994) since Angus and Nellore have better reproductive performance than Charolais which is the most productive breed of all three.

5.2 Economic values and breeding objective

The economic values used in defining the breeding objective are important in determining the direction and amount of genetic change or improvement through index selection and economic values for genetic parameters could be determined in an ad hoc way, by profit equations or by bioeconomic simulation. A bioeconomic model is a combination of a group of equation that first simulate biological relationships, then management practices, and at last equations that would economically evaluate the result of the two first groups of equation. The bioeconomic simulation approach to estimate economic values was questioned by MacNeil (1996) since due the principles involved on bioeconomic models a change in a genetic component for performance would invariably cause a change in other traits. Therefore, the economic value would not represent the effect of an independent change in one single trait.

On the other hand, Koots and Gibson (1998) argued that treating interdependent traits as independent from each other, apart from being an over-simplification of reality, could lead to unrealistic impressions regarding the potential value of a genetic change. Bourdon (1998) suggested that the problem might only be one of semantics. However, if economic value is defined as a change in economic outcome due to an independent increase of one unit in the genetic component of a single trait instead of performance for this trait, and then include genetic potential in the breeding objective, the requirement of independent change is not violated. In fact, according to this definition simulation models might be the only appropriate way to estimate economic values (Bourdon 1998).

Gjedrem (1972) concluded that all traits with any economic value should be included in the breeding objective. According to Smith (1983) that would be correct if all other parameters were known. In practice, the genetic parameters among a large number of traits may not be well estimated and may be inconsistent with others (Hill and Thompson, 1978). Therefore, it might be better to just include in the breeding objective those traits that would present an outstanding value of ah^2, the product between the economic value and the heritability of the trait. Efficiency of the selection index is largely determined by the values of the factors ah^2, and if one trait dominates the index, efficiency would not be sensitive to changes in economic values of others traits unless they become dominant in the index

(Smith 1983). On this study, the traits that presented an outstanding value of ah^2 were the ones included in the breeding objective.

Among all traits affecting profitability that the model would allow to be changed through genetic programs, dressing out presented the highest economic value in all herds. Dressing out percentage was the only trait in the model that affected only income since all others traits would either change number of animals or liveweight. In other words, an independent increase of one unit in genetic component of dressing out percentage would not represent a variation in costs of any form since it would only increase the carcass weight. However selection for dressing weight would definitely affect liveweight since there is a strong positive correlation among dressing out percentage and growth traits.

The other trait included in the breeding objective because its impact on profitability of the production system was calving rate. However, changes in calving rate were important only for Angus and Nellore, the two breeds involved on the maternal line of the commercial herd breeding cows. Charolais calving rate had an insignificant impact on profitability and Koots and Gibson (1998) and MacNeil et al. (1994) reported economic values of zero for cow fertility when estimated for a sire line based on increase of profitability in the commercial herd.

The breeding objective emphasis on dressing out percentage in this study seems to agree with results presented by MacNeil et al. (1994) who reported a relation of 1:0.47 between economic values respectively of dressing out percentage and calving rate on specialized dam lines. In this study, the relation between estimated economic values for dressing out percentage and calving rate was represented by the relative economic values and in the

Angus breeding objective (1:0.56) was similar to that one presented by MacNeil et al. (1994). Koots and Gibson (1998) presented, however, an inversion of weight since the relation between economic values for dressing out percentage and calving rate on dam line was 0.49:1. The model developed by Koots and Gibson (1998) kept the number of pregnant cows fixed therefore a change on cow fertility would represent a change in age structure of the herd rather than an increase in marketed animals. However, the authors agreed regarding the relation between economic values for dressing out percentage and calving rate on general purpose population showing similar results of 1:0.33 and 1:0.19 respectively.

The relative economic values on the Nellore breeding objective (1:0.83) presented a better balance between the traits. The increase of calving rate weight inside of Nellore breeding objective could be due to the number of Nellore cows involved on the system. The Nellore herd was bigger than the commercial herd before the breeding program started, and improving calving rate would have an affect on the Nellore and on the commercial herd. Meanwhile, a change in Angus calving rate would basically only affect the commercial herd. Another aspect is that the dressing out percentage of Nellore animals was higher than the dressing out percentage of Angus animals.

Several authors have concluded that the efficiency of economic selection index is not very sensitive to changes in the economic values (Pease et al. 1967; Vandepitte and Hazel 1977). However, large changes in economic value (± 200%) of some traits might lead to substantial losses in efficiency (Smith 1983). In order to maximize profit per animal unit, the changes in the economic value for calving rate were around 50% and 59% in the Nellore and Angus breeding objectives respectively. According to Pease et al. (1967)

errors up to 50%, in one trait at a time, on economic value would represent small changes on efficiency. The results here showed that those changes of 50 and 59% were enough to affect the discounted net income and profit per animal unit for the 20 years of selection, with and without progeny test.

The increase in dressing out percentage emphasis on Angus and Nellore breeding objective in order to maximize profit per animal unit might be related to the fact that an increase in dressing out percentage would not affect the costs of the production system. Meanwhile, increase in calving rate would also increase the number of offspring per year changing the average animal units per year thus increasing costs. In addition, the value of ah^2 for calving rate in the Nellore breeding objective was higher than in the Angus breeding objective, when relatively compared to the values of ah^2 for dressing out percentage. Therefore, in the Nellore breeding objective calving rate had a higher importance than in the Angus breeding objective.

The negative economic values for cow liveweight estimated for the Angus and Nellore breeds were also in agreement with the results of MacNeil et al. (1994) and Koots and Gibson (1998) since those authors also reported negative values for cow weight economic value on the dam side lines. MacNeil et al. (1994) also reported that cow weight on the sire line had a null economic value, which could be considered compatible to the very small economic value found for Charolais cow weight in this simulation. Those results seem to be consistent with the idea supported by Jenkins and Ferrel (1994) that biological types having moderate size and milk production seem to show a better biological efficiency than large, heavier-milking types in restricted feeding and stressful environments. That could be even more significant in beef grazing production systems, since due to the wide changes in pasture allowance and nutritional value throughout the year, it could be a very stressful environment thus moderate types seem to be more adequate to grazing system.

5.3 Genetic responses and profit for the breeding schemes

There was a remarkable difference between the correlated response from the dam side selection indexes of Nellore herd and the correlated responses from other indexes. It was expected that individual selection would present correlated responses different than selection based on progeny test. Also, on the Angus herd it was expected that individual selection on the sire side would be similar to selection on the dam side since the breeding objective was the same on both dam and sire side and the characteristics included in the selection criteria were similar on both sides. However, the selection criteria of Nellore dams were different since Nellore heifers were allowed to calve before being selected thus easy calving was included in the selection criteria.

Easy calving has a strong favorable genetic correlation and a moderate favorable phenotypic correlation with calving rate therefore the superior correlated responses for calving ease on the Nellore dam side were not a surprise. However, the changes in other traits were less obvious since calving easy had negative phenotypic and genetic correlations with cow liveweight and the cow liveweight correlated response was higher in the Nellore dam side than on the Angus dam side. Although easy calving had a negative phenotypic correlation with weaning weight, the genetic correlation was positive, which might justify the increase in weaning weight.

Discounted cash flow methods to assess the value of livestock improvement programs and compare alternative breeding schemes are common practices among animal breeders and with discount rates commonly varying from 5% to 15% the value of genetic gain was substantially discounted, especially in large farm animals with long generation intervals (Weller, 1994). Discount rate can represent the time value of money invested elsewhere or the social preference of having the money today instead of having it in the future, or the risk associated with uncertainly about obtaining future returns. According to Bird and Mitchell (1980) the discounting rate should not account for inflation in agricultural improvement and it should not be higher than 5%.

In both cases, with estimated relative economic values and with maximizing profit per AU economic values, the selection schemes that included progeny on sire selection information were superior regarding either profit per AU or the discounted accumulated net income, than those based only on individual selection. The advantage of progeny testing seemed to be a better balance among the correlated responses of the traits that would affect profit. Although the improvement of calving rate in the two largest herds of the production system was higher in breeding schemes based only on individual selection, the breeding scheme with progeny testing presented better improvement in dressing out percentage on the commercial and the Nellore herd. Also, there was a better improvement in final liveweight in the commercial herd leading to a higher carcass weight than the breeding schemes based on individual selection. In addition, the carcass weight on the Nellore herd also had a better improvement for those breeding schemes utilizing progeny test. In other words, the difference in progress of the dressing out percentage on Nellore herd for breeding schemes involving progeny test was higher enough to overcome the slight better final liveweight achieved in those selection indexes with individual selection.

The better economic performances of those schemes using progeny testing also could be related to the slowest improvement in cow liveweight achieved by those breeding scheme when compared to schemes based on individual selection. On both commercial and Nellore herds, the increase in cow liveweight were slower for breeding schemes with progeny testing and that difference on cow liveweight between the breeding schemes with progeny testing and those without it were more prominent on the commercial than that on the Nellore herd. In addition, The high growth in cow liveweight combined with the poor responses in dressing out percentage of the selection index not using progeny test might be best reason why after some years of selection the profitability of those breeding schemes started to decline, which was showed by the decreased profit per AU on those Breeding schemes in figure 4.9.

The better economic performance of the breeding scheme with progeny testing using the relative economic values in order to maximize profit per AU over the breeding scheme with progeny testing using the estimated relative economic values could also be attributed to a better balance of the correlated responses. The increase in dressing out percentage was slightly better with the maximizing profit per AU relative economic values on the commercial herd and on the Nellore herd the improvement in dressing out percentage was definitely better for the breeding scheme based on progeny testing and maximizing profit per AU relative economic values. As a result, on both herds the carcass weight improvement was higher for the scenario with the progeny test and maximizing profit per AU relative economic values, although on both herds the scenario with individual selection and estimated relative economic values got higher final liveweights. Another advantage of the maximizing profit per AU relative economic value selection index against the estimated relative economic value within breeding scheme with progeny test was that the cow liveweight on the Nellore and the commercial herds presented a slower growth.

The model was designed to allow changes in the size of land needed to run the operation and there was a reduction in the number of hectares due to the application of breeding programs. In fact, the only herd that had the number of hectares reduced in practice was the Nellore since it was the only herd that the number of breeding cows were based on a fluctuant number of replacements needed (F1heifers needed for the commercial herd and also heifers needed in the Nellore herd). Therefore, the genetic gain on calving rate of Angus and Nellore would contribute to a smaller number of the heifers need as replacement in the Nellore and Commercial herd thus the land area could be dramatically reduced.

The commercial herd had a fixed number of breeding cows so changes in calving rate would increase the number of offspring produced and animals size also increased due to selection requiring a large land area for the herd. The Angus and Charolais herd had a particular number of bulls to produce thus changes on calving rate could lead to reduction in area needed but that was overcome by the increasing in animal weight since the land area required for this herd also increased. As a result, the dramatic reduction on the area needed by the Nellore herd overcome the increase on land required by the others herd in every breeding scheme tested here allowing a reduction in size of the whole operation.

The breeding scheme that resulted in the largest reduction in area was individual selection based on estimated relative economic values since there was a strong linear correlation between the number of AU and the area of land needed, this was also the breeding scheme that resulted in the greatest reduction in the number of AU. That reduction seemed to be explained by the improvement in calving rate achieved by this breeding scheme since it was this breeding scheme that presented the highest gain in calving rate in the Nellore and the commercial herd. In addition, individual selection based on estimated relative economic values breeding scheme presented the second best gain for cow liveweight on both Nellore and commercial herds and it was the greatest final liveweight on the Nellore herd. However, it presented a poor gain for final liveweight on the commercial herd.

According to Gibson and Wilton (1998) although animal breeders usually assume that genetic increase in product supply results in extra sales, demand for most agricultural products appears to be already saturated hence the genetic increase in product supply might not result in extra sales. Therefore in the authors' point of view, it seems more likely that genetic gain in output at the animal or enterprise levels would result in fewer animals or enterprise with no net increase in industry output. Under this perspective genetic gain could be an option for down sizing the operation since could reduce size while the profit per unit of production would increase. However, the market situation in Brazil seemed to be different since according to Cezar and Euclides Filho (1996) an increase in per capita income could raise beef consumption 55 kg per capita per year similar to consumption levels of Argentina and Uruguay, nowadays beef consumption in Brazil is around of 38 kg per capita per year.

On the other hand, the expansion of the agrarian frontier in Brazil has really reached a point in which there is not many new agricultural areas left to be occupied, therefore the market value of land would likely increase in the near future. In addition, the agrarian policy is a problem that has been neglected by the Brazilian government for too long raising rightful social-economic issues that eventually would have to be settled. As a result, it seems that large extensive enterprises would not be feasible for much longer since the demand for auto-sustainable production systems, that would combine efficiency, competition and production being at the same time social-economic fair and conservationist, is increasing. Animal breeding would definitely be a crucial tool for helping animal production systems to face the challenging transformation of society.

5.4 Value of modeling beef cattle breeding

Modeling beef cattle production systems is an alternative way to better understand the important components of the system and their interaction. The use of models can really help to guide investments to new areas in which knowledge is insufficient since simulation can be done rapidly and at same time cover a range of different situations or option. Therefore, models can integrate in an efficient way new ideas into production systems, and it can also help to set urgent areas for research.

According to Cartwright (1976) there is usually a time lag between identifying an important area for research and accumulating the right knowledge to solve the problem. In addition there is a high probability that at the time when results are obtained a new problem has already emerged as a priority. The utilization of models seems to be the best strategy to investigate situations in animal breeding since the success of breeding programs may depend on their capacity to identify changes and opportunities that might happen in the future much sooner than the time when they would become a reality.

Chapter 6

Conclusion

Conclusion

Economic selection index proved to be an efficient tool to change profit since breeding schemes improved profit in all scenarios independently from the relative economic value applied or if information from progeny was included or not in the index.

However, the adoption of progeny testing in breeding programs proved to be more effective than individual selection on a long-term basis. The advantage of selection indexes including progeny was to promote a greater increase in dressing out percentage and a lower change in mature size of the breeding cows.

Dressing out percentage was the most important trait affecting profitability of the production system although calving rate also showed to be an important trait affecting economic efficiency.

In this study, the most profitable breeding scheme was the one that maximized gain in dressing out percentage and at the same time minimized the increase in cow liveweight and that was achieved by changing the relationship between the economic values of traits included in the breeding objective.

The effects of genetic improvement over market demand should be carefully investigated in future studies to predict if genetic improvement in product supply would lead to extra sales, or producers should change their goals to enterprises with fewer animals keeping the industry output constant.

Modeling, when done properly, seems to be the best tool available in order to investigate new fields of research helping to integrate the new opportunities for investments with real beef production systems.

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Appendix 1- Economic parameters, herd structure and number of sales before selection

Table A1.1- Average AU per year, area required and economic parameters for the whole production system

HERD	Average UA/year	Hectares	US$ Dollars					
			Cost	Income	Profitability	Land	Animals	Return (%)
Commercial Herd	36763.99	33418	$2,683,771.61	$5,185,722.52	$2,501,950.91	$18,045,752.60	$7,205,513.68	9.9%
Nellore Herd	27825.76	25296	$2,031,280.71	$3,369,101.04	$1,337,820.34	$13,659,920.06	$7,053,378.10	6.5%
Angus Herd	928.69	844	$67,794.60	$102,315.34	$34,520.74	$455,903.93	$354,799.54	4.3%
Charolais Herd	2066.24	1878	$150,835.30	$225,853.25	$75,017.95	$1,014,334.55	$761,660.44	4.2%
Total	67584.69	61437	$4,933,682.22	$8,882,992.15	$3,949,309.93	$33,175,911.13	$15,375,351.76	8.13%

* Assuming price per hectare of US$540,00

Table A1.2- Herd structure for all herd on the system

Herd structure for all herds on the system				
Number of cows per age groups	Commercial Herd	Nellore Herd	Angus Herd	Charolais Herd
2 years old	2267	2922	70	147
3 years old	1948	2446	56	114
4 years old	1674	2047	44	89
5 years old	1439	1713	35	69
6 years old	1236	1434	28	54
7 years old	1063	1200	22	42
8 years old	913	1004	18	33
9 years old	785	840	14	26
10 years old	674	703	11	20
11 years old	580	589	9	16
Bulls	none	602	302	604
Teasers	400	477	10	20
Weaning	10049	10939	216	443
Yearling	9850	10718	212	424
Finishing	9768	10628	210	421
Bulls produced and tested per year	-	200	100	200
Number of bulls selected	-	2	2	4

* 11 years old cows do not participate on the breeding season

Table A1.3- Number and parameters of animals sold per year by categories and their contribution for total income

Type of animal	Number of animals	Liveweight (kg)	Dressing out %	Carcass weight (kg)	Price/kg (US$)	Price/carcass	Income (US$)
3/4Angus 1/4Nellore steers	610	485	62.76%	304	$ 1.54	$ 468.76	$ 286,174.17
3/4Angus 1/4Nellore heifers	610	436	62.76%	274	$ 1.54	$ 421.88	$ 257,556.76
1/4Angus 3/4Nellore steers	1221	483	63.09%	305	$ 1.54	$ 468.93	$ 572,565.00
1/4Angus 3/4Nellore heifers	1221	434	63.09%	274	$ 1.54	$ 422.04	$ 515,308.50
1/2 Charolais 1/4Angus 1/4Nellore steers	3052	504	62.86%	317	$ 1.54	$ 487.66	$ 1,488,561.28
1/2 Charolais 1/4Angus 1/4Nellore heifers	3052	453	62.86%	285	$ 1.54	$ 438.89	$ 1,339,705.15
Nellore steers	2785	447	63.25%	283	$ 1.54	$ 435.71	$ 1,213,566.60
Nellore heifers	63	403	63.25%	255	$ 1.54	$ 392.14	$ 24,686.63
Angus-Nellore steers	2329	468	62.93%	294	$ 1.54	$ 453.43	$ 1,056,026.45
Angus-Nellore heifers	62	421	62.93%	265	$ 1.54	$ 408.09	$ 25,128.30
Angus steers	5	449	62.60%	281	$ 1.54	$ 433.21	$ 2,261.77
Angus heifers	35	404	62.60%	253	$ 1.54	$ 389.89	$ 13,603.92
Charolais steers	10	491	62.80%	309	$ 1.54	$ 475.11	$ 4,961.07
Charolais heifers	64	442	62.80%	278	$ 1.54	$ 427.60	$ 27,267.27
Reproduction failures (F1)	1448	438	62.93%	276	$ 1.23	$ 338.99	$ 490,848.24
Reproduction failures (Nellore)	2047	427	63.25%	270	$ 1.23	$ 331.96	$ 679,670.48
Reproduction failures (Angus)	55	388	62.60%	243	$ 1.23	$ 298.75	$ 16,563.74
Reproduction failures (Charolais)	119	484	62.80%	304	$ 1.23	$ 374.05	$ 44,619.04
Old cows (F1)	575	438	62.93%	276	$ 1.23	$ 339.12	$ 194,897.35
Old cows (Nellore)	585	429	63.25%	271	$ 1.23	$ 333.75	$ 195,204.35
Old cows (Angus)	9	388	62.60%	243	$ 1.23	$ 298.75	$ 2,637.10
Old cows (Charolais)	15	488	62.80%	306	$ 1.23	$ 376.95	$ 5,800.08
Bulls (Nellore)	198	701	63.25%	443	$ 1.54	$ 682.87	$ 135,208.88
Bulls (Angus)	98	703	62.60%	440	$ 1.54	$ 677.83	$ 66,427.76
Bulls (Charolais)	196	745	62.80%	468	$ 1.54	$ 720.52	$ 141,221.36
Teasers	130	650	63.25%	411	$ 1.54	$ 633.13	$ 82,520.90
Total	20597						$ 8,882,992.15

Appendix 2- Breed effects, heterosis, heritabilities and genetic and phenotypic correlation

Table A2.1- Breed effects, individual and maternal heterosis effects for the principal traits affecting income and costs

Traits	Breed effects			Individual heterosis			Maternal Heterosis
	Angus	Nellore	Charolais	A x N	A x C	N x C	A x N
Calving rate %	81.1%	85.4%	79.50%	5.33%	-	-	-
Survival to weaning	91.0%	91.3%	93.6%	2.30%	-2.17%	5.38%	4.2%
Survival after weaning	98%	98%	98%	-	-	-	-
Weaning weight (kg)	183.2	180.8	223	10.34%	0.61%	7.63%	13%
Cow weight (kg)	388	429	488	7.26%	-	-	-
Dressing out %	62.6%	62.8%	63.25%	0	0	0	-

Table A2.2- Heritability, phenotypic standard deviation, genetic (below diagonal) and phenotypic (above diagonal) correlation for beef cattle traits used for estimate correlated responses.

Traits			Wr %	Dr %	BrW	WW	YW	18W	Sc	Pa	Ap	Ce	Fat D	EMA	CW
	h^2	σ_p													
Weaning rate %	0.05	36		-	-	0.05	-	-	-	-	-	0.15	-	0.1	-
Dressing out %	0.45	1.8	-		-	0.20	0.18	-	-	-	-	-	0.31	0.36	-
Birth weight kg	0.44	4.5	0	-		0.5	0.55	0.35	0.04	0.1	-0.14	-0.74	-0.27	0.31	0.67
Weaning weight kg	0.37	25	0	0.08	0.46		0.81	0.7	0.19	0.3	-0.17	-0.21	0.24	0.49	0.57
Yearling weight kg	0.35	40.4	-	0.19	0.38	0.71		0.7	0.39	0.45	-0.16	-0.29	0.32	0.51	0.72
18 month Weight kg	0.35	30	0.05	0.19	0.5	0.7	0.7		0.3	0.3	-0.01	-0.15	0.2	0.20	0.6
Scrotal circumference cm	0.43	2.7	0.2	-	0.13	0.34	0.36	0.25		0.1	0.22	-	0.78	-	-
Pelvic area cm^2	0.32	20	0.01	-	0.15	0.37	0.37	0.37	0.07		0.01	-	0.05	-	0.47
Age at puberty days	0.4	39	-	-	0.58	-0.04	-0.14	-0.14	-0.52	-		-	-	-	-0.1
Calving ease	0.1	30	0.5	0	-0.28	0.04	0.01	-0.2	0.05	0.06	-		-	-	-0.23
Fat depth	0.38	0.6	-	0.17	-0.17	0.16	0.3	0.1	0.27	-	-	-		0.01	0.21
Eye muscle area	0.4	10	-	0.08	0.17	0.23	0.35	0.3	0.05	-	-	-	0.2		-
Cow liveweight	0.35	40	0.05	-	0.34	0.45	0.54	0.6	-	0.4	-0.2	-0.03	-	-	

Appendix 3- Economic parameters, herd structure and number of sales after 20 years of selection using progeny test and the estimated relative economic values

Table A3.1- Average AU per year, area required and economic parameters for the whole production system

HERD	Average UA/year	Hectares	US$ Dollars						
			Cost	Income	Profitability	Land*	Animals	Return (%)
Commercial Herd	38200.29	34728	$2,800,081.23	$5,545,794.13	$2,745,712.90	$18,752,869.42	$7,593,336.87	10.42%
Nellore Herd	20622.00	18747	$1,536,339.26	$2,752,617.83	$1,216,278.57	$10,123,528.96	$5,346,685.13	7.86%
Angus Herd	939.78	854	$68,886.14	$109,865.79	$40,979.65	$461,348.34	$369,406.56	4.93%
Charolais Herd	2084.60	1895	$152,801.28	$240,710.00	$87,908.72	$1,023,349.74	$805,401.11	4.81%
Total	61846.68	56224	**$4,558,107.90**	**$8,648,987.74**	**$4,090,879.84**	**$30,361,096.45**	**$14,114,829.67**	**9.20%**

* Assuming price per hectare of US$540,00

Table A3.2- Herd structure for all herd on the system

Number of cows per age groups	Commercial Herd	Nellore Herd	Angus Herd	Charolais Herd
2 years old	2146	1947	65	151
3 years old	1877	1704	53	116
4 years old	1642	1490	43	90
5 years old	1437	1303	35	70
6 years old	1257	1140	28	54
7 years old	1100	997	23	42
8 years old	962	872	19	32
9 years old	842	763	15	25
10 years old	736	668	12	19
11 years old*	637	587	10	15
Bulls	none	602	302	604
Teasers	400	363	10	20
Weaning	10230	8843	216	433
Yearling	10028	8668	212	424
Finishing	9944	8596	210	421

* 11 years old cows do not participate on the breeding season

Table A3.3- Number and parameters of animals sold per year by categories and their contribution for total income

Type of animal	Number of animals	Liveweight (kg)	Dressing out %	Carcass weight (kg)	Price/kg (US$)	Price/carcas	Income (US$)
3/4Angus 1/4Nellore steers	627	491	65.43%	321	$ 1.54	$ 494.42	$ 310,169.33
3/4Angus 1/4Nellore heifers	627	442	65.43%	289	$ 1.54	$ 444.98	$ 279,152.40
1/4Angus 3/4Nellore steers	1255	491	65.47%	321	$ 1.54	$ 494.89	$ 620,923.54
1/4Angus 3/4Nellore heifers	1255	442	65.47%	289	$ 1.54	$ 445.40	$ 558,831.19
1/2 Charolais 1/4Angus 1/4Nellore steers	3137	507	66.65%	338	$ 1.54	$ 520.85	$ 1,633,758.46
1/2 Charolais 1/4Angus 1/4Nellore heifers	3137	457	66.65%	304	$ 1.54	$ 468.77	$ 1,470,382.61
Nellore steers	1719	460	66.23%	304	$ 1.54	$ 468.65	$ 805,793.27
Nellore heifers	301	414	66.23%	274	$ 1.54	$ 421.78	$ 127,037.00
Angus-Nellore steers	2216	477	66.32%	316	$ 1.54	$ 486.78	$ 1,078,926.50
Angus-Nellore heifers	150	429	66.32%	284	$ 1.54	$ 438.10	$ 65,703.83
Angus steers	5	458	66.20%	303	$ 1.54	$ 466.63	$ 2,436.26
Angus heifers	46	412	66.20%	273	$ 1.54	$ 419.97	$ 19,191.55
Charolais steers	10	493	67.60%	333	$ 1.54	$ 512.94	$ 5,356.09
Charolais heifers	60	443	67.60%	300	$ 1.54	$ 461.65	$ 27,595.46
Reproduction failures (F1)	1056	449	65.61%	294	$ 1.23	$ 362.05	$ 382,456.13
Reproduction failures (Nellore)	862	441	65.56%	289	$ 1.23	$ 355.82	$ 306,811.92
Reproduction failures (Angus)	42	402	65.48%	263	$ 1.23	$ 323.61	$ 13,751.04
Reproduction failures (Charolais)	124	494	66.73%	329	$ 1.23	$ 405.07	$ 50,165.07
Old cows (F1)	703	444	64.72%	287	$ 1.23	$ 353.48	$ 248,652.56
Old cows (Nellore)	566	439	64.80%	285	$ 1.23	$ 350.24	$ 198,187.82
Old cows (Angus)	11	396	64.49%	256	$ 1.23	$ 314.39	$ 3,436.67
Old cows (Charolais)	15	491	65.29%	321	$ 1.23	$ 394.46	$ 5,840.63
Bulls (Nellore)	198	713	65.68%	468	$ 1.54	$ 721.41	$ 142,838.97
Bulls (Angus)	98	711	65.41%	465	$ 1.54	$ 716.72	$ 70,238.82
Bulls (Charolais)	196	746	66.54%	497	$ 1.54	$ 764.90	$ 149,919.82
Teasers	109	650	65.40%	425	$ 1.54	$ 654.63	$ 71,430.79
Total	18527						$ 8,648,987.74

Appendix 4- Economic parameters, herd structure and number of sales after 20 years of selection using individual selection and the estimated relative economic values

Table A4.1- Average AU per year, area required and economic parameters for the whole production system

HERD	Average UA/year	Hectares	US$ Dollars					
			Cost	Income	Profitability	Land*	Animals	Return (%)
Commercial Herd	39520.58	35928	$2,885,002.63	$5,441,213.91	$2,556,211.28	$19,401,013.92	$7,795,886.92	9.40%
Nellore Herd	18134.00	16485	$1,323,782.05	$2,356,836.49	$1,033,054.45	$8,902,145.77	$4,585,589.17	7.66%
Angus Herd	946.85	861	$69,120.29	$106,365.18	$37,244.89	$464,818.89	$358,082.78	4.53%
Charolais Herd	2096.44	1906	$153,040.09	$230,422.74	$77,382.65	$1,029,161.26	$783,242.95	4.27%
Total	**60697.88**	**55180**	**$4,430,945.05**	**$8,134,838.33**	**$3,703,893.27**	**$29,797,139.84**	**$13,522,801.82**	**8.55%**

* Assuming price per hectare of US$540,00

Table A4.2- Herd structure for all herd on the system

Number of cows per age groups	Commercial Herd	Nellore Herd	Angus Herd	Charolais Herd
2 years old	1849	1271	53	158
3 years old	1693	1156	45	120
4 years old	1550	1051	39	92
5 years old	1419	955	33	70
6 years old	1299	869	29	53
7 years old	1190	790	24	41
8 years old	1089	718	21	31
9 years old	998	653	18	24
10 years old	913	594	15	18
11 years old*	818	547	13	14
Bulls	none	602	302	604
Teasers	400	269	9	20
Weaning	10707	6905	216	433
Yearling	10495	6768	212	424
Finishing	10408	6712	210	421

* 11 years old cows do not participate on the breeding season

Table A4.3- Number and parameters of animals sold per year by categories and their contribution for total income

Type of animal	Number of animals	Liveweight (kg)	Dressing out %	Carcass weight (kg)	Price/kg (US$)	Price/carcas	Income (US$)
1/2 Charolais 1/4Angus 1/4Nellore steers	5128	504	63.71%	321	$ 1.54	$ 494.61	$ 2,536,324.92
1/2 Charolais 1/4Angus 1/4Nellore heifers	5128	454	63.71%	289	$ 1.54	$ 445.15	$ 2,282,692.42
Nellore steers	1400	461	63.24%	292	$ 1.54	$ 449.05	$ 628,798.71
Nellore heifers	329	415	63.24%	262	$ 1.54	$ 404.15	$ 133,067.68
Angus-Nellore steers	2094	479	62.97%	301	$ 1.54	$ 464.12	$ 971,898.23
Angus-Nellore heifers	180	431	62.97%	271	$ 1.54	$ 417.71	$ 75,168.90
Angus steers	5	460	62.66%	288	$ 1.54	$ 443.56	$ 2,315.81
Angus heifers	52	414	62.66%	259	$ 1.54	$ 399.20	$ 20,826.22
Charolais steers	10	487	64.01%	312	$ 1.54	$ 480.05	$ 5,012.67
Charolais heifers	52	438	64.01%	281	$ 1.54	$ 432.05	$ 22,656.73
Reproduction failures (F1)	772	462	65.58%	303	$ 1.23	$ 372.26	$ 287,450.80
Reproduction failures (Nellore)	570	450	63.25%	284	$ 1.23	$ 349.85	$ 199,385.53
Reproduction failures (Angus)	34	419	62.65%	262	$ 1.23	$ 322.54	$ 11,082.51
Reproduction failures (Charolais)	132	510	63.80%	326	$ 1.23	$ 400.46	$ 52,914.68
Old cows (F1)	812	454	64.72%	294	$ 1.23	$ 361.40	$ 293,277.87
Old cows (Nellore)	543	446	63.25%	282	$ 1.23	$ 346.60	$ 188,364.98
Old cows (Angus)	13	407	62.63%	255	$ 1.23	$ 313.71	$ 3,926.78
Old cows (Charolais)	14	502	63.47%	319	$ 1.23	$ 392.15	$ 5,408.37
Bulls (Nellore)	198	715	63.25%	452	$ 1.54	$ 696.22	$ 137,851.35
Bulls (Angus)	98	713	62.65%	447	$ 1.54	$ 688.28	$ 67,451.83
Bulls (Charolais)	196	741	63.79%	473	$ 1.54	$ 727.72	$ 142,632.51
Teasers	103	650	63.25%	411	$ 1.54	$ 633.11	$ 64,965.76
Total	17864						$ 8,133,475.25

Appendix 5- Economic parameters, herd structure and number of sales after 20 years of selection using progeny test and maximizing profit per AU relative economic values

Table A5.1- Average AU per year, area required and economic parameters for the whole production system

HERD	Average UA/year	Hectares	US$ Dollars					
			Cost	Income	Profitability	Land*	Animals	Return (%)
Commercial Herd	37594.78	34177	$2,755,697.68	$5,538,189.71	$2,782,492.03	$18,455,621.33	$7,547,578.60	10.70%
Nellore Herd	22857.04	20779	$1,702,849.23	$3,042,359.51	$1,339,510.28	$11,220,727.07	$5,995,722.54	7.78%
Angus Herd	938.41	853	$68,785.67	$109,993.20	$41,207.53	$460,675.44	$372,926.82	4.94%
Charolais Herd	2084.60	1895	$152,801.28	$240,731.77	$87,930.49	$1,023,349.74	$805,530.29	4.81%
Total	63474.84	57704	**$4,680,133.85**	**$8,931,274.19**	**$4,251,140.34**	**$31,160,373.57**	**$14,721,758.25**	**9.27%**

* Assuming price per hectare of US$540,00

Table A5.2- Herd structure for all herd on the system

Number of cows per age groups	Commercial Herd	Nellore Herd	Angus Herd	Charolais Herd
2 years old	2146	1947	65	151
3 years old	1877	1704	53	116
4 years old	1642	1490	43	90
5 years old	1437	1303	35	70
6 years old	1257	1140	28	54
7 years old	1100	997	23	42
8 years old	962	872	19	32
9 years old	842	763	15	25
10 years old	736	668	12	19
11 years old*	637	587	10	15
Bulls	none	602	302	604
Teasers	400	363	10	20
Weaning	10230	8843	216	433
Yearling	10028	8668	212	424
Finishing	9944	8596	210	421

* 11 years old cows do not participate on the breeding season

Table A5.3- Number and parameters of animals sold per year by categories and their contribution for total income

Type of animal	Number of animals	Liveweight (kg)	Dressing out %	Carcass weight (kg)	Price/kg (US$)	Price/carcass	Income (US$)
3/4Angus 1/4Nellore steers	618	488	66.10%	323	$ 1.54	$ 496.84	$ 306,807.46
3/4Angus 1/4Nellore heifers	618	439	66.10%	290	$ 1.54	$ 447.15	$ 276,126.71
1/4Angus 3/4Nellore steers	1235	488	66.22%	323	$ 1.54	$ 498.14	$ 615,220.45
1/4Angus 3/4Nellore heifers	1235	440	66.22%	291	$ 1.54	$ 448.32	$ 553,698.41
1/2 Charolais 1/4Angus 1/4Nellore steers	3088	506	66.96%	339	$ 1.54	$ 522.00	$ 1,611,724.76
1/2 Charolais 1/4Angus 1/4Nellore heifers	3088	456	66.96%	305	$ 1.54	$ 469.80	$ 1,450,552.28
Nellore steers	2013	457	67.31%	308	$ 1.54	$ 473.62	$ 953,382.33
Nellore heifers	265	411	67.31%	277	$ 1.54	$ 426.26	$ 113,163.28
Angus-Nellore steers	2303	474	67.23%	318	$ 1.54	$ 490.21	$ 1,129,011.06
Angus-Nellore heifers	125	426	67.23%	286	$ 1.54	$ 441.19	$ 55,208.68
Angus steers	5	455	67.06%	305	$ 1.54	$ 469.58	$ 2,451.69
Angus heifers	40	409	67.06%	274	$ 1.54	$ 422.63	$ 17,027.04
Charolais steers	10	493	67.60%	333	$ 1.54	$ 512.94	$ 5,356.09
Charolais heifers	60	443	67.60%	300	$ 1.54	$ 461.65	$ 27,595.46
Reproduction failures (F1)	1262	445	66.33%	295	$ 1.23	$ 363.36	$ 458,476.59
Reproduction failures (Nellore)	1146	439	66.41%	291	$ 1.23	$ 358.35	$ 410,608.63
Reproduction failures (Angus)	49	399	66.19%	264	$ 1.23	$ 324.78	$ 15,933.71
Reproduction failures (Charolais)	124	494	66.73%	329	$ 1.23	$ 405.07	$ 50,165.07
Old cows (F1)	632	441	65.15%	288	$ 1.23	$ 353.74	$ 223,622.54
Old cows (Nellore)	583	438	65.35%	286	$ 1.23	$ 351.79	$ 205,235.11
Old cows (Angus)	10	394	64.92%	256	$ 1.23	$ 314.95	$ 3,087.86
Old cows (Charolais)	15	491	65.29%	321	$ 1.23	$ 394.46	$ 5,840.63
Bulls (Nellore)	198	711	66.56%	473	$ 1.54	$ 728.42	$ 144,226.19
Bulls (Angus)	98	708	66.08%	468	$ 1.54	$ 720.94	$ 70,652.60
Bulls (Charolais)	196	746	66.54%	497	$ 1.54	$ 764.90	$ 149,919.82
Teasers	115	650	66.17%	430	$ 1.54	$ 662.41	$ 76,179.77
Total	19130						$ 8,931,274.19

Appendix 6- Economic parameters, herd structure and number of sales after 20 years of selection using individual selection and maximizing profit per UA relative economic values

Table A6.1- Average AU per year, area required and economic parameters for the whole production system

HERD	Average UA/year	Hectares	US$ Dollars					
			Cost	Income	Profitability	Land*	Animals	Return (%)
Commercial Herd	39519.20	35927	$2,884,901.30	$5,431,175.08	$2,546,273.78	$19,400,332.52	$7,855,820.28	9.34%
Nellore Herd	19323.76	17567	$1,410,634.78	$2,480,385.57	$1,069,750.79	$9,486,211.50	$4,906,400.61	7.43%
Angus Herd	951.30	865	$69,445.05	$106,869.82	$37,424.77	$467,002.84	$363,271.62	4.51%
Charolais Herd	2096.44	1906	$153,040.09	$230,422.74	$77,382.65	$1,029,161.26	$783,242.95	4.27%
Total	**61890.70**	**56264**	**$4,518,021.23**	**$8,248,853.22**	**$3,730,831.99**	**$30,382,708.12**	**$13,908,735.46**	**8.42%**

* Assuming price per hectare of US$540,00

Table A6.2- Herd structure for all herd on the system

Number of cows per age groups	Commercial Herd	Nellore Herd	Angus Herd	Charolais Herd
2 years old	1948	1397	58	158
3 years old	1756	1262	48	120
4 years old	1583	1141	41	92
5 years old	1427	1031	34	70
6 years old	1287	931	28	53
7 years old	1160	841	24	41
8 years old	1046	760	20	31
9 years old	943	687	17	24
10 years old	850	621	14	18
11 years old*	752	567	11	14
Bulls	none	602	302	604
Teasers	400	289	9	20
Weaning	10543	7355	216	433
Yearling	10334	7210	212	424
Finishing	10248	7150	210	421

* 11 years old cows do not participate on the breeding season

Table A6.3- Number and parameters of animals sold per year by categories and their contribution for total income

Type of animal	Number of animals	Liveweight (kg)	Dressing out %	Carcass weight (kg)	Price/kg (US$)	Price/carcas	Income (US$)
1/2 Charolais 1/4Angus 1/4Nellore steers	5062	503	63.88%	321	$ 1.54	$ 494.43	$ 2,502,727.11
1/2 Charolais 1/4Angus 1/4Nellore heifers	5062	452	63.88%	289	$ 1.54	$ 444.99	$ 2,252,454.40
Nellore steers	1520	459	63.27%	291	$ 1.54	$ 447.62	$ 680,565.33
Nellore heifers	323	413	63.27%	262	$ 1.54	$ 402.86	$ 130,279.12
Angus-Nellore steers	2170	475	63.44%	301	$ 1.54	$ 464.05	$ 1,006,971.26
Angus-Nellore heifers	167	427	63.44%	271	$ 1.54	$ 417.64	$ 69,827.61
Angus steers	5	456	63.42%	289	$ 1.54	$ 444.96	$ 2,323.14
Angus heifers	47	410	63.42%	260	$ 1.54	$ 400.47	$ 18,949.87
Charolais steers	10	487	64.01%	312	$ 1.54	$ 480.05	$ 5,012.67
Charolais heifers	52	438	64.01%	281	$ 1.54	$ 432.05	$ 22,656.73
Reproduction failures (F1)	941	468	66.29%	311	$ 1.23	$ 381.95	$ 359,522.34
Reproduction failures (Nellore)	663	454	63.27%	287	$ 1.23	$ 353.52	$ 234,289.80
Reproduction failures (Angus)	40	428	63.25%	271	$ 1.23	$ 333.14	$ 13,487.26
Reproduction failures (Charolais)	132	510	63.80%	326	$ 1.23	$ 400.46	$ 52,914.68
Old cows (F1)	746	459	65.15%	299	$ 1.23	$ 367.93	$ 274,510.71
Old cows (Nellore)	563	449	63.26%	284	$ 1.23	$ 349.71	$ 196,869.29
Old cows (Angus)	11	413	63.03%	260	$ 1.23	$ 320.25	$ 3,620.18
Old cows (Charolais)	14	502	63.47%	319	$ 1.23	$ 392.15	$ 5,408.37
Bulls (Nellore)	198	713	63.27%	451	$ 1.54	$ 694.83	$ 137,576.64
Bulls (Angus)	98	709	63.25%	449	$ 1.54	$ 690.92	$ 67,710.19
Bulls (Charolais)	196	741	63.79%	473	$ 1.54	$ 727.72	$ 142,632.51
Teasers	105	650	63.26%	411	$ 1.54	$ 633.27	$ 66,698.69
Total	18128						$ 8,247,007.90