THE DEVELOPMENT OF ECONOMIC SELECTION INDICES FOR THE SIMMENTALER BREED IN SOUTH AFRICA

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PREFACE

In the Holy Bible we read the following in Genesis 1 and in Psalm 8:

Genesis 1: 26.

God said, "Let us make man in our image, after our likeness: and let them have dominion over the fish of the sea, and over the birds of the sky, and over the livestock, and over all the earth, and over every creeping thing that creeps on the earth."

Psalm 8: 6-8.

You make him ruler over the works of your hands. You have put all things under his feet: All sheep and oxen, yes, and the animals of the field, the birds of the sky, and whatever passes through the paths of the seas.

What a wonderfull opportunity and privilege. What an enormous responsibility!

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ABSTRACT

1. The purpose of the first chapter was to give a short introduction to the study. Although there were exponential increases in knowledge, there are still fields of study where there is little understanding and enormous gaps relating to information. A short history of the development of cattle was presented, with special reference to the Simmentaler breed. The objectives of this study were then stated. These objectives were: the definition of breeding objectives, derivation of economic values and development of economic selection indices for the Simmentaler breed in South Africa.

2. In Chapter 2 the development of breeding objectives and the derivation of economic values were reviewed. There seems to be general consensus that definition of breeding objectives should be the primary step in the design of structured breeding programs. Development of the breeding objective can be described in terms of the following phases: specification of the breeding, production and marketing system, identification of sources of income and expense in commercial herds, determination of biological traits that influence income and expense, derivation of economic values, choice of selection criteria, and estimation of phenotypic and genetic parameters. The modeling methods to derive economic values can be divided into simulation, dynamic programming and profit functions.

3. In Chapter 3 the important traits, which should be considered for the development of breeding objectives, as well as the criteria to be included in the selection index were reviewed. Traits were classified as fitness-, production-, product-, input-, type- and behavioural traits. The decision whether or not to include a trait in the breeding objective depends on the relative economic value of the trait, the potential for genetic improvement and the possibility of accurate and cheap measurement. Several traits determine economic efficiency, and the required balance of these traits is likely to differ between different production systems.

4. The purpose of Chapter 4 was the development of a general breeding objective for the Simmentaler breed in Southern Africa as well as the derivation of economic values for beef production traits. Income was partitioned between weaners (steers), surplus heifers and cull cows. Expenses were calculated for all classes and included feed cost, husbandry cost and marketing cost. Economic values for weaning weight (direct), weaning weight (maternal), yearling weight (400 days), final weight (600 days) and mature cow weight were derived as partial derivatives of the profit equation. These values, expressed per genetic standard deviation, in South African Rand per cow, corrected with the discounted gene flow and diffusion coefficient methods (in brackets) are, 25.57 (75.01), 15.21 (47.97), 28.49(83.63), -13.95 (-40.79) and -69.29 (-63.39) respectively.

5. The objectives of Chapter 5 were to expand the Simmentaler breeding objective by inclusion of functional traits and to derive economic values for the functional traits calving rate, days-to-calving, calving-ease (direct) and calving-ease (maternal). It was assumed, for these categorical traits, that there is an unobserved underlying normal distribution of the sum of genetic and environmental values, and that the phenotypic category is defined by threshold values on this distribution. The consequences of a change in fitness included changes in costs, changes in culling rate, number of barren cows and the number of surplus offspring available for sale. Results emphasised the relative importance of fertility. Economic values, expressed per genetic standard deviation in South African Rand per cow, corrected with the discounted gene flow and diffusion coefficient methods (in brackets) are, 18.98 (15.27), - 93.82 (- 75.51), 1.08 (1.31) and 1.15 (1.08) for calving rate, days-to-calving, calving-ease (direct) and calving-ease (maternal), respectively.

6. The objectives of Chapter 6 were to expand the Simmentaler breeding objective by the inclusion of product quality traits and to derive economic values for dressing percentage, backfat thickness, tenderness and marbling. A method to derive economic values for these optimum traits was described. It was assumed, for the categorical traits, that there is an unobserved underlying normal distribution of the sum of genetic and environmental values, and that the phenotypic category is defined by threshold

values on this distribution. The consequences of a change in the mean performance of a trait include changes in the number of animals in different quality classes and as a result thereof, changes in the expected value of a carcass. Economic values, expressed per genetic standard deviation in South African Rand per cow, corrected with the discounted gene flow and diffusion coefficient methods (in brackets) are, 20.96 (61.50), 0.39 (1.14), -3.52 (-10.33) and 0.18 (0.52) for dressing percentage, backfat thickness, tenderness and marbling respectively.

7. The development of economic selection indices for an integrated Simmentaler production system was described in Chapter 7. The breeding objective was defined in terms of production-, functional- and product quality traits. Criteria included in the total index are birth- and weaning weight (direct and maternal), yearling weight, final weight, mature cow weight, days-to-calving, backfat thickness, tenderness and marbling. The total merit index (I_T) for an integrated Simmentaler production system is $I_T = -1.65\ BW_D - 1.99\ BW_M + 2.28\ WW_D + 1.76\ WW_M + 1.48YW - 0.50\ FW - 2.02\ MCW - 13.21\ CD + 4.92\ BF - 2.34\ T + 12.77\ M$. The correlation between this index and the breeding objective is 0.987. The economic superiority, over the average progeny, of the progeny from the top 40% of animals selected on their ranking in the total index, is expected to be R116.49.

CHAPTER 1

GENERAL INTRODUCTION

Man, the great seeker, is as time is counted a newcomer to earth, yet his achievements have been enormous. These achievements, whether for good or for evil have been without exception the product of his chief distinctive quality, his power of thought. His curiosity, one aspect of his ability to think, has driven him to search for answers on a multitude of questions. This quest has both inspired and appalled him. It has been relentless, compulsive, unending and yet hopeless. We know much, and yet we know nothing.

J. C. Smuts (1870 – 1950) made the following statement in his book 'Holism and Evolution'**: "In spite of the great advances which have been made in knowledge, some fundamental gaps still remain; matter, life and mind still remain utterly disparate phenomena".**

Man's efforts to understand the universe in which he finds himself, the processes by which he evolved, and the historical context of his being are now even greater than ever before. This led to the exponential growth of knowledge and understanding. Scientific and technological revolutions of modern times transformed the world to the extent that isolation became impossible. Due to this lack of isolation there are continued increases in the flow of knowledge, technological innovations as well as genetic material. Since isolation was one of the key ingredients in breed creation this decrease in isolation may not only improve productivity but it may also increase the risk of losing valuable genetic material, especially from less productive but better adapted local breeds. This phenomenon emphasizes the importance of correctly answering the question of what will, in economic terms, be the best animal under future breeding, production and marketing circumstances and not what is currently the best animal. Correct definition of the breeding objective is, therefore, of utmost importance. As no one can read the future or predict it with any certainty, a multi-disciplinary approach to the development of breeding objectives is needed.

Due to these revolutionary developments, animal breeding has become increasingly less of an art and more of a science. However, since animal breeding is a science involved with living creatures and their relationship with the environment, the need for a practical approach will, to a certain extent, always exist. Furthermore, the demands placed on breeders and farmers, not only by changes in production and marketing circumstances, changing consumer preferences and demands but also by the declining terms of trade experienced by farmers, are ever increasing. Breeders and farmers need to adapt to these changes, they should accept technological change and they have to establish sustainable farming systems. A formal approach to breeding objective development is a prerequisite to face these demands successfully.

The question as to what is the best, most beautiful or most functional animal is, however, not a new issue as can be seen from the discourses of Epictetus. Epictetus was a Greek slave, philosopher and teacher of ethics, who lived during the reign of Nero (A.D. 54 – 68) and apparently also during the reign of Hadrian (A.D. 117 – 138). Epictetus once asked a student: **"Tell me if you do not think that some dogs are beautiful, and some horses, and so every other creature? Do we then, on the same grounds, pronounce each of these creatures in its own kind beautiful, or do we pronounce each beautiful on special grounds?"** Fortunately, Epictetus also gave the answer to this question. **"It would not be unreasonable for one to declare that each of them is beautiful precisely when it achieved supreme excellence in terms of its own nature; and, since each has a different nature, each one of them is beautiful in a different fashion. What is it, then, that makes a dog beautiful? The presence of a dog's excellence!"** This discourse of Epictetus may be one of the first philosophical attempts to define an objective. He furthermore realised that form follows function, that circumstances (nature) prescribes the best animal and that the best animal for specific circumstances is the one that achieves supreme excellence under those circumstances. Furthermore, these superior animals most probably owed their supremacy to excellence in more than one characteristic.

1.1 DEVELOPMENT OF THE SIMMENTALER

It is not clear where and when cattle were first domesticated (Porter, 1991), probably because this series of events is part of prehistory where the essential difference between "prehistory" and "history" is mental. History means the conscious and intentional remembrance of things past, in a living tradition transmitted from one generation to another. Therefore history only exists in a persisting society which needs history to persist (Garraty & Gay, 1985).

From the time of the first accepted domestication of cattle, some 10 000 years ago, in the Middle East region, different types of cattle were selected. The natural migration of early nomadic cattle farmers led to the isolation of groups of cattle and through the processes of selection, natural selection and crossbreeding several breeds were created (Curson, 1935; Kolesnic, 1936; Medrano, 1959; Phillips, 1961; Williamson & Payne, 1978; Sanders, 1980; Porter, 1991). Although Darwin (1809-1882) is credited with the theory and explanation of evolution (differential mortality and survival of the fittest), it is his predecessor, Lamarck (1744-1829), who first suggested the idea of adaptation (Garraty & Gay, 1985). According to Garraty & Gay (1985), Lamarck reasoned that the nature of a species at any one time (its structure, physiology and way of life) depended on the demands of the environment and in the process of adapting to the environment, organisms changed. Today the total environment includes the physical environment (e.g. temperature, humidity, photoperiod and parasites), management (e.g. feeding, housing, and disease control) as well as the market environment. Each one of these environmental factors influenced, and is still influencing, the development of cattle in a specific way. The development of the Simmentaler breed has been part of this natural evolutionary process in cattle breeding.

During the past 200 years these different "breeds" or isolated groups of nomadic cattle were formalized through breed societies and strict selection was directed at uniformity within each breed. As the Simmentaler breed also evolved through this process it was therefore particularly suited to specific environmental conditions and able to satisfy a specific purpose. According to Maule (1951), Venter (1980) and Barton (1984) the most likely steps in breed creation were the following:

- determine the best animals, best "breeds" and/or the best combination of breeds, also known as between breed selection (Bourdon, 1997), through test crossings or from available information;
- determine the best proportion of chosen breeds;
- establishment of breeding and selection policies;
- if the above mentioned procedures are successful in the creation of the desired animal, the breed becomes popular and more herds are established;
- creation of an organizational framework and herd book.

The ancestor of today's Simmentaler was the Bernese, a local breed found in the Simme Valley in the canton of Berne in Switzerland (Briggs & Briggs, 1980; Porter, 1991). Its colours included black-and-white or red-and-white pied and sometimes solid red. These were triple purpose cattle valued for their production of milk and meat as well as being work (draft) animals.

In 1806 the government (Great Council) of Bern set up a herd register (herd book) and with it a performance requirement for entry (Briggs & Briggs, 1980). The breed spread through Europe and became known by different breed names (Simmental, Simmentaler, Fleckvieh, Montbeliard, Pied, Red Pied, Abondance and Pie Rouge). Irrespective of the name, the association or the herd book of the country, the breed remained practically the same while emphasis was on utility.

Simmentalers were exported to Canada in 1967 and in 1968 semen from those bulls were available for use in the United States. The breed was taken to England and Ireland in 1969 (Briggs & Briggs, 1980).

The first Simmentalers in southern Africa were brought to Namibia (the then German South West Africa) in 1893 and to South Africa during 1905 by President M.T. Steyn (Simmentaler/Simbra Cattle Breeders Society of Southern Africa). Although the Breeders Society was only established in 1964, its membership has grown to the second largest of the 24 non-dairy breed societies in South Africa.

The World Simmental/Fleckvieh Federation, of which South Africa is a founder member, was founded in 1974 and is today, with 29 member countries, the largest cattle federation of its kind in the world.

1.2 OBJECTIVES FOR THIS STUDY

The main objective of this study was the development of an economic selection index for the Simmentaler breed in South Africa. Since the development of breeding objectives is the primary step in the development of structured breeding programs and in the construction of selection indices (Smith, 1985; Ponzoni, 1986; Ponzoni & Newman, 1989; Newman *et al*., 1992; Fewson, 1993a), the first objective was to define a general breeding objective for the Simmentaler. A breeding objective is defined as a linear combination of the economically important traits to be improved and the discounted economic values for these traits (Hazel, 1943; Falconer & Mackay, 1996; Bourdon, 1997). From this definition it is obvious that a number of sub-objectives existed for this study.

Firstly, a complete review (Chapter 2) of the methods and principles involved in the definition of breeding objectives was done.

Secondly, a review (Chapter 3) of the economically important traits and criteria, which should be considered for inclusion in the breeding objective and selection index, was done. This review included criteria that are routinely measured as well as traits not usually included in performance recording schemes. Comparisons among traits and criteria were also done to determine the best ones to include in both the objective and the index.

Thirdly, economic values for the important traits were derived (Chapter 4, 5 and 6). Since methods to determine economic values differ, traits were classified in groups for the derivation of economic values. The economic values for the different groups were then discussed together. Adaptations to existing methods of economic value derivation were done where existing methods were insufficient. Where no method exists new methods were developed.

After a breeding objective was defined the final step was the construction of an economic selection index (Chapter 7). This selection index was developed for an integrated Simmentaler production system. A primary index was also developed as not all the important traits and criteria are measured at present. The accuracy and economic efficiency of these indices were also determined.

Chapters 4 – 7 are experimental chapters written in a form of papers (interlocking articles) to be published. There is thus some contextual overlap between these chapters and the review chapters (Chapters 2 and 3).

Finally, where possible, suggestions were made to simplify future breeding objective development and to facilitate the implementation of selection indices.

CHAPTER 2

Development of breeding objectives for beef cattle – Derivation of economic values

2.1 INTRODUCTION

There seems to be general consensus that definition of breeding objectives, and developing selection criteria based on them, should be the primary step in the development of structured breeding programs (Smith, 1985; Ponzoni, 1986; Ponzoni & Newman, 1989; Newman *et al*., 1992; Fewson, 1993a). The maximisation of profit is probably the simplest (and most important) possible breeding objective (Harris, 1970). Therefore, the main aim of any selection program should be the improvement of traits of economic importance. When these traits are easily measured, progress is largely dependant on the effective utilisation of the additive genetic variance. Obviously, this necessitates accurate identification of traits and accurate estimates of genetic parameters for these traits under selection. Breeding objectives should, however, also account for inputs/costs as well as outputs/income. Failure to include costs in an economic evaluation can lead to economic values that differ substantially from evaluations including costs (Gibson, 1989).

Breeding in all classes of livestock has moved from a purebred appearance orientation to a performance (either purebred or crossbred) orientation. Unfortunately, the evolution from a performance orientation to an economic orientation has been incomplete (Harris & Newman, 1994). Placing breeding objectives into a mathematical form on a sound economic basis is the key to integrating modern developments in animal breeding into more purposeful industry programs. Where consensus is reached about an economic breeding objective, this objective can be used in conjunction with genetic predictions to rank animals within a breeding population.

In practice, several or many traits influence an animal’s value, although they do so in varying degrees (Hazel, 1943). Information on several traits can be combined in an index by a special use of Fisher’s discriminant function as proposed by Smith (1936) and Hazel (1943). The genetic gain which can be made by selecting for several traits simultaneously within a group of animals is the product of the selection differential, the correlation between the aggregate breeding value and the selection index, and genetic variability. The greatest opportunity of increasing the progress from selection is by ensuring that the correlation between the breeding objective and selection index is as large as possible. Hazel (1943) presented a multiple correlation method of constructing optimum selection indices. However, to solve the simultaneous equations the economic parameters (relative economic values), genetic parameters (heritability, genetic correlations) and phenotypic parameters (standard deviation, correlations) of/among traits must be known (Hazel, 1943). In addition, accuracy and cost of measurement of genetic means determine the definition of the breeding objective (Harris, 1970; Groen, 1989).

Although performance recording of beef cattle has been in operation for over 40 years in South Africa, breeding objectives and multitrait selection indices have not yet been implemented in the South African livestock industry. Scientists have, over the last decades, studied the theory of breeding objectives and the application of the principles to beef cattle breeding. The purpose of this chapter was to review the development of breeding objectives and the derivation of economic values for implementation in the Simmentaler breed in South Africa. The methodology developed from this thesis can, however, be used in all beef cattle breeds.

2.2 BREEDING OBJECTIVE / ECONOMIC SELECTION INDEX

When selection is applied to the improvement of the economic value (economic merit) of the animal, it is generally applied to several traits simultaneously (Hazel, 1943; Falconer & Mackay, 1996). When these traits differ in variability, heritability, economic importance, and in the correlation among their phenotypes and genotypes, index selection was more effective than independent culling levels or sequential selection (Hazel & Lush, 1943; Hazel *et al.*, 1994). With index selection, selection is applied simultaneously to all the component traits together, with an appropriate weight being given to each trait according to its relative economic importance, its heritability and the genetic and phenotypic correlations among the different traits (St-Onge *et al.*, 2002).

Therefore, with simultaneous selection for several traits (characters), the objective is to achieve maximum genetic progress toward a stated economic goal (Du Plessis & Roux, 1998, 1999) or to improve the net merit (Weigel *et al.*, 1995; Wilton *et al.*, 1998), economic efficiency (Dekkers, 1991) or the aggregate breeding value of animals. The aggregate breeding value represents a fundamental concept, the breeding objective, which is seldom fully implemented in livestock breeding industries (Harris & Newman, 1994).

The breeding objective or goal, towards which breeders are progressing, is a particular combination of weighting factors (economic weights / values) and genetic information (EBV's) of all the characters to be improved (Falconer & Mackay, 1996; Bourdon, 1997). Since change in breeding objectives requires a period of time, these objectives should be defined according to future market values rather than historical data (Harris & Freeman, 1993). When the objective is maximum improvement in economic merit, the index can appropriately be called an economic selection index (Gibson & Kennedy, 1990). If the economic values of traits of economic importance are linear functions of the trait values, the optimum selection index can be derived as a simple function of the genetic and phenotypic (co)variance matrices, and the vector of economic values (Hazel, 1943; Pasternak & Weller, 1993). Arbitrarily assigning monetary values to the traits in question is, however, not the best method of improvement (Falconer & Mackay, 1996). These economic values should be properly derived and construed in a scientific manner.

Henderson (1963), as quoted by Harris & Newman (1994), noted that in Hazel's (1943) approach, optimum selection toward a breeding objective:

$$H = \sum_{1}^{n} a_i G_i \qquad (1)$$

requires selection on an index or criterion (which correlates best with H):

$$I = \sum_{i=1}^{n} (b_i X_i) \qquad (2)$$

where H = aggregate breeding value, a_i = economic value for trait i, G_i = breeding value for trait i, I = selection index, b_i = a selection index weighing factor, X_i = a phenotypic measure and n = number of traits. In matrix notation the unrestricted index would be I = **b'X**, where **X** is a n x 1 vector of sources of information, **b** is a n x 1 vector of weighing factors. The elements of **b** are chosen as to maximise genetic gain in a total (aggregate) breeding value or breeding objective defined as A_T = **v'a**, where **v** is a m x 1 vector of economic values (weights) and **a** is a m x 1 vector of breeding values for the traits in the breeding objective. The optimum set of selection index coefficients are those which maximise the correlation (r_{HI}) or minimise the squared deviation between the selection index and the aggregate genotype (breeding objective)

(Weller, 1994). Hazel (1943) showed that maximum r_{HI} is achieved when $\mathbf{Pb} = \mathbf{Gv}$. Selection index weights are then calculated as $\mathbf{b} = \mathbf{P}^{-1}\ \mathbf{Gv}$, where **G** is a n x m genetic variance – covariance matrix for m traits affecting profitability and n correlated indicator traits and incorporates the additive genetic relationships between sources of information; **P** is a n x n phenotypic (co)variance matrix of correlated indicator traits; and **v** is a n x 1 vector of relative economic values (Cunningham *et al*., 1970; James, 1982; Gibson & Kennedy, 1990; Fewson, 1993b; MacNiel *et al.*, 1994).

A useful modification developed by C. R. Henderson was the separated application of the selection index in two steps (Hazel *et al.*, 1994). The first step is the estimation of individual breeding values, through multitrait analysis, for each trait included in the definition of the aggregate breeding value. The second step is application of the relative economic values. This separation has two important advantages. It permits the use of the most complex and accurate BLUP techniques to estimate individual breeding values for each index trait, including adjustment for differing amounts of information. It then allows the economic values applied to vary with differing selection objectives, depending upon how different breeds are used in a breeding system or the particular production and marketing system, without recalculating breeding values.

A clear distinction should be made between the traits in the breeding objective and those used as selection criteria (Ponzoni & Newman, 1989). Traits that appear in the breeding objective should be those that are economically important and therefore directly linked to the costs and returns of the production situation. By contrast, the selection criteria are the traits (characters) used in the estimation of the breeding values of animals. For example, lean percentage may be a breeding objective, and ultrasonically measured backfat thickness a selection criterion. Scrotal circumference, which has as such no economic value, may be the criterion for male and female fertility which are economically very important. It is obvious that some traits might affect profitability in one market but not in another. The greatest economic value to commercial cow-calf producers (weaner market) are increased weaning rate (maternal and reproductive characteristics) and weaning weight (pre-weaning growth). Feeders, on the other hand, are more interested in post weaning growth and consumption characteristics. Furthermore, consumer judgments of product quality such as tenderness, flavor and juiciness have (at present) no value to the commercial cow-calf producer who is not compensated for them (Melton, 1995). Traits in the breeding objective that are difficult or expensive to measure are often replaced with indicator traits. Food intake is an example of a trait that has often been left out of the breeding objective of grazing beef cattle because it is extremely difficult to measure. The breeding objective should describe how well animals suit a particular production purpose, a given market and environment. It is therefore obvious that breeding objectives will differ in different situations but the basic principle will remain the same and that is to maximise profit.

Using a breeding objective has several advantages (Barwick *et al*., 1991):

- It will enable breeders to use the combination of EBV's that gives them most (total) genetic progress for their particular situation. These EBV's are the potential selection criteria. The importance of individual EBV's (traits) does depend on the breeding objective.
- It will enable breeding to be targeted for specific markets. The ability and capacity to target specific markets successfully is, however, not an easy process (McDaniel & Darden, 1987; Thompson & Strickland, 1999).
- It will enable EBV's to be used more efficiently and enhances the value of existing EBV's by relating their interpretation to farm profit (Charteris *et al*., 1998).
- It will have financial rewards throughout the whole industry.

The beef cattle industry has a history of chasing and promoting maximum values (e.g. maximum weight). Yet, according to Beilharz *et al*. (1993), when environmental resources are limited, all major components of fitness are naturally selected towards intermediate optimal values. As all morphological features of a phenotype, its development, growth and actions of movement, require environmental resources, this situation thus applies to most characters, not only to components of fitness. Therefore, almost every quantitative trait in any species has an intermediate optimum (Crow, 1986). Saying that breeding should be for an optimum rather than a maximum is just another way of saying that selection should be in a balanced way (Barwick *et al*., 1991). This brings up the question, what is the balance that is needed between traits for maximum profitability (i.e. the breeding objective)?

Ponzoni & Newman (1989) developed a sequential procedure to derive breeding objectives for domestic livestock. Development of the breeding objective can be described in terms of the following phases. The first four phases concern economic aspects while the last two are genetic in nature:

- 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 the economic values of each trait.
- Choice of selection criteria.
- Estimation of phenotypic and genetic parameters.

2.2.1 Breeding, production and marketing system

Specifying the breeding system involves defining the role of the breed (for which the breeding objective is being defined) in the production system (Ponzoni & Newman, 1989). In broad terms the roles could be general purpose, maternal line or terminal sire line. The role of the breed influences the genetic contribution of the breed, in the various segments of the production system.

Specification of the production and marketing system involves the description of how animals are fed and managed, the age composition of the herd, the replacement policy and ages of animals at marketing and slaughter (Newman *et al*., 1992). Defining herd composition aids in identifying age and numerical distribution of the herd, the number of replacements required each year as well as the number of animals of all classes available for market each year. This information is required in the calculation of the economic values as not all traits are expressed with the same frequency or at the same time. A particular problem that arises is that a bull never expresses his genotype for all traits (e.g. days to calving, milk production) and that in his descendants the traits may be expressed quite unequally. Therefore, a standard unit of expression, for the trait under consideration, was defined by McClintock & Cunningham (1974) as one expression of a trait in the progeny in the year in which the mating (insemination) took place. The unit used was a single mating or insemination, which may lead to either a male or female offspring. If the former, it will result in a single expression of his genotype (e.g. weaning weight). If the later, it may result in several expressions of his genotype in the daughter (e.g. milk production) and the possibility of further expressions of all his traits in grand progeny and more remote descendants. Therefore, the value of a unit of genetic superiority for a trait, as realized through one mating, depends on the economic value per unit of superiority and the number of times that superiority is expressed. Factors which determine the numbers of standard units of expression of an animal's genotype for different traits following one successful mating (insemination) are:

- The probability that the mating results in a female offspring and that she is kept for breeding purposes. This factor is a function of the population structure (e.g. cow replacement rate).
- The degree of relationship of the animal to the descendants in which his/her genotype is expressed. If we limit consideration to additive genetic merit, the contribution of a parent to a descendant's genotype, is halved for each generation separating the parent from the particular descendant.
- The number of years separating each such expression from the year in which the mating took place.
- The number of years after the mating/insemination that are taken into account.

The third and fourth factors both concern the displacement in time of the expression of an animal's genotype. The basis of the discounting procedure is that deferred returns are worth less than the same returns now. It was seen by McClintock & Cunningham (1974) as compound interest in reverse and they called the procedure the discounted gene flow technique (DGF). Therefore, traits such as birth weight, weaning weight, etc. are expressed only once if the progeny is male. However, if the resultant progeny is female and is kept for breeding purposes, the traits will be expressed repeatedly in all her descendants.

One can assume that a hierarchical structure exists in the South African beef cattle industry (Van Zyl, 1983; Kluyts, 1993). Seedstock herds (stud, elite or bull breeding herds), multiplier herds and commercial herds can be distinguished. Most genetic improvement arises from the breeding herds in the seedstock sector. This genetic improvement is replicated in the multiplier herds that serve the commercial sector. The commercial herds produce virtually all the product (meat), but they are dependent on the breeding herds for permanent genetic improvement. This multilevel structure suggests that genetic improvement made in the seedstock sector should be directed toward its use in the commercial sector to satisfy consumer demands. However, in a conventional industry, improvement in the breeder's economic benefit is a major incentive for selection strategies to change (Howarth & Goddard, 1998). Likewise, economic signals indicating consumer desires should migrate from consumers to seedstock producers (MacNiel *et al*., 1994).

2.2.2 Identification of sources of income and expense

The identification of sources of income and expense in commercial herds enables the development of a profit equation (P = I – E), where profit (P) is a function of income (I) and expense (E) (Ponzoni & Newman, 1989). Amer & Fox (1992) formulate a profit equation of the general form as:

$$p = f\,(\mathbf{X}\ \mathbf{P}\ \mathbf{C}_v\ \mathbf{C}_f) \qquad (3)$$

where **X** is a vector of traits or animal characteristics, **P** is a vector of output prices, $\mathbf{C}_v$ a vector of variable input prices and $\mathbf{C}_f$ a vector of fixed input prices. $\mathbf{C}_v$ and $\mathbf{C}_f$ are typically considered to be constant for all levels of farm output. Equation (3) for a meat production enterprise can be of the form (Brascamp *et al*., 1985; Smith *et al.*, 1986):

$$p = N(nwV - nC_1d - C_2) \qquad (4)$$

where N is the number of breeding females producing n offspring per year, w is weight of the product per offspring with value V per unit grown over d days. C_1 is the cost per day of growth per individual and C_2 is the cost per female per year.

Agricultural economists have frequently used a Cobb Douglas production function to represent the technical relationships between levels of input bundles B and C, and output (y) (Amer *et al*., 1994a):

$$y = a\ w\ B^{ß}\ C^{?} \qquad (5)$$

For a meat enterprise, w is the carcass weight of individual animals sold and a is a constant. The exponents ß and ? are partial elasticity's of production. These show the proportional change in output obtained when the corresponding input bundle is changed by one percent. Profit from an animal enterprise constrained by the Cobb Douglas production function is calculated from the profit equation (Amer *et al*., 1994a):

$$p = yv - Bp_B - Cp_C \qquad (6)$$

where v is the price per unit of output, p_B and p_C are prices per unit for inputs B and C, respectively.

Harris (1970) suggested that, in the development of a mathematical function describing the livestock enterprise, income (I) and expense (E) can be combined in different ways as either Profit (P = I – E), Return on investment (? = I/E) or Cost per unit production (Q = E/I). However, Ponzoni (1988) indicated that when P was equal to zero, as suggested by Brascamp *et al*. (1985) and ? = Q = 1.0, the relative economic values from P, ? and Q were the same.

The cost of animal products depend primarily upon the efficiency of three basic functions namely reproduction, female production (milk) and growth of the young (Dickerson, 1970). To assess the economic importance of improvement in each major biological component of performance, it is helpful to separate total costs into those for the producing and reproducing female population as well as growing progeny to market size. Similarly, animal products are obtained directly from the female (milk) and from growth of her progeny (meat). Therefore, income depends on the sale of weaners, surplus heifers and cull cows as well as the value per animal sold. Expenses depend on food intake, the value of the food per kg, husbandry cost, marketing cost as well as fixed cost. Fixed costs are those costs incurred by the producer independent of the level of herd production. All other costs are variable costs and vary with the level of production (Ponzoni, 1986).

2.2.3 Determination of biological traits influencing income and expense

During this phase the profit equation is expressed as a function of biological traits that impact on income, expense or both (Ponzoni & Newman, 1989). Choosing selection criteria and organising logically based performance recording is difficult unless the traits that have to be improved have been identified and their relative economic importance have been established (Ponzoni, 1986). All criteria with a major impact on the efficiency of commercial production should be reflected in the traits chosen for the breeding objective (Fewson, 1993b). This statement is, however, open to different interpretations as the term “major impact” is ambiguous. It should be noted that in addition to the primary performance traits such as growth rate, feed intake and lean meat percentage, there are also secondary (indirect) traits such as fertility, longevity and calving ease which should be considered as traits having a major impact on efficiency. Furthermore, criteria of product/meat quality (marbling, tenderness) are also related to economic efficiency. One should be able to validate the major impact of a trait on the efficiency of commercial production. The term major implies also that a limitation should be set to the number of traits involved in the breeding objective. The economic values for certain traits may turn out to be negligible. These traits could therefore be excluded from the breeding objective (Weller, 1994). This is, however difficult to predict *a priori*. Since some less important traits may have non-zero economic values, Melton (1995) used t-values to reflect the statistical confidence in the coefficient estimate (economic value). Furthermore, it is important to note that only economic aspects are valid for the choice of traits in the breeding objective, as genetic parameters are considered later when the breeding values are estimated. The paucity of information on economic, phenotypic and genetic parameters for certain traits may, however, discourage the formal derivation of economic values and the inclusion of the trait in the breeding objective.

2.2.4 Derivation of economic weights / values

The net genetic improvement which can be brought about by selection among a group of animals is the sum of the genetic gains made for the several traits which have economic importance (Hazel, 1943). It is, therefore, logical to weigh the gain made for each trait by the relative economic importance of that trait. Economic theory suggests that optimisation of objectives at the farm level will cause adjustments in levels of variable inputs and output in response to a genetic trait change (Amer *et al*., 1994a). The estimated effects on farm profits are commonly termed economic weights / values and are used in selection indices to determine the weight to be placed on each genetic trait when selecting animals so as to maximise profit. Therefore, the relative economic value for each trait depends upon the amount by which profit may be expected to increase for each one unit of improvement in that trait, independent of effects from changes in other traits included in the definition of aggregate breeding value (breeding objective) (Hazel, 1943). Dickerson (1970) defined relative economic importance in terms of expected reduction in cost per unit of equivalent output rather than an increase in profit.

2.2.4.1 Discounting

Not all traits in the objective are expressed at the same time, or with the same frequency (Newman *et al*., 1992). These may be accounted for in deriving economic values by either calculating all income and expenses in one year (which accounts for frequency but not time lag) or by discounting (which accounts for both frequency and time lag) (Ponzoni & Newman, 1989). Economic values calculated by different methods and different discount rates (Newman *et al*., 1992) are presented in Table 2.1.

Table 2.1 Economic values (NZ$) calculated for beef cattle traits with different methods and different discount rates (Newman *et al.,* 1992)

Trait	Income and expense per year	Discounted gene flow 0%	5%	10%
Calves weaned /cows joined	251.63	198.75	127.40	86.83
Carcass weight – Steers	0.668	0.486	0.362	0.285
Heifers	0.361	0.160	0.120	0.094
Cows	0.188	0.013	0.008	0.005
Food intake – Steers	-0.016	-0.012	-0.010	-0.008
Heifers	-0.016	-0.012	-0.010	-0.008
Cows	-0.041	-0.033	-0.021	-0.015

It is obvious from Table 2.1 that economic values calculated with different methods and by using different discount rates, will not be the same. Discounted economic values are, in general, lower than non-discounted values. This effect is more conspicuous with higher discount rates.

Since animal breeding is a long-term process, the costs and benefits involved, are realised at different times and with different probabilities. It is, therefore, incorrect to ignore discounting as it will lead to bias in the relative selection emphasis on traits and to non-optimum genetic responses. A more complete discussion on discounting follows in Chapter 4.

Discounted expressions can be calculated with different programs which are based on the discounted gene flow (DGF) techniques of McClintock & Cunningham (1974) or the method of diffusion coefficients (DC) (McArthur & Del Bosque Gonzalez, 1990). The method of diffusion coefficients differs from the gene flow method in that it accounts only for the delay between the birth of the animal and the first time of expression of the improvement. The gene flow method accounts for the same delay and additionally for the delay between the joining and birth of the animal (Barwick & Graser, 1997). The number of discounted expressions of a trait is a function of the number of progeny or later descendants of the animal in question and the annual discount factor. The discount factor accounts for the fact that economic benefit at time t is more valuable than at time t + 1. Therefore, traits expressed sooner after selection should receive more emphasis.

2.2.4.2 Profit equations

The use of profit equations to integrate the cost and returns of a production system was proposed by Moav & Moav (1966) to compare the profitability of lines and crosses. Moav & Hill (1966) used the partial derivatives of the profit equation as economic values for within-line selection. It should be emphasised that the partial derivatives are taken at mean performance for the traits concerned because the aim is to estimate the effect on profit of changes in these means (Brascamp *et al*., 1985). The profit equation, and the economic values derived from it, depends on the perspective taken, whether in the national interest, in the producers interest or per unit of investment made (Brascamp *et al*., 1985). However, the improved stocks have to serve all interests simultaneously since all are involved in the same production system.

The profit equation, (equation 4, $p = N(nwV - nC_1d - C_2)$, can also be expressed with different bases (per female, per individual and per unit of product). The relative economic values (Table 2.2) are different for the three forms (bases) of the profit equation (Brascamp *et al*., 1985).

Table 2.2 Profit equations and economic values for number of offspring (n), days of growth (d) and weight of product (w) for three bases of evaluation (Brascamp *et al*., 1985)

Basis of evaluation	Profit equation	Economic value		
		dp/dn [a]	dp/dd [b]	dp/dw [c]
Per Female	$P_F = nwV - nC_1d - C_2$	$wV - C_1d$	$-nC_1$	nV
Per Individual	$P_I = wV - C_1d - C_2/n$	C_2 / n^2	$-C_1$	V
Per unit product	$P_P = V - C_1d/w - C_2/nw$	C_2 / n^2w	$-C_1 / w$	$1/w^2 (C_1d + C_2/n)$

[a] partial derivative of profit equation for number of offspring

[b] partial derivative of profit equation for days of growth

[c] partial derivative of profit equation for weight of product

If profit was zero, by considering profit as a cost of production (so called “normal profit” in economics), then the relative economic values are the same for all perspectives. However, this viewpoint of Brascamp *et al*. (1985) uses two assumptions. One of these assumptions is that averages for the traits are independent of the basis of evaluation. The second is that the economic parameters are also independent of the basis of evaluation. This may not be the case.

The use of profit equations for deriving economic values has led to anomalies both in theory and in practice. According to Smith *et al*. (1986) these anomalies can be removed by imposing two conditions. One is that any extra profit from genetic change that can be matched by rescaling the size of the production enterprise should not be counted since it can be achieved without any genetic change. Only savings in cost per unit of product value should be included. The second condition is that changes that correct previous inefficiencies should not be counted. Thus, it is assumed that resources are efficiently used, and changes in output will require proportional changes in input. This means that fixed cost, like variable cost, should be expressed per unit of output, rather than fixed total enterprise cost (Dickerson, 1970). Application of these two conditions is shown by Smith *et al*. (1986) to give economic values that are identical on different bases. With rescaling it becomes apparent that the only way real genetic improvements can be obtained is by improving the efficiency of the production system (Smith *et al*., 1986).

McArthur (1987) criticised the rescaling theory of Smith *et al*. (1986) arguing that a farm faces decreasing marginal returns with an increase in the scale of the enterprise and thus, if operating at an optimum, the farm could not scale up its output without a loss of profits per unit of input. Since, neither the argument of Brascamp *et al*. (1985) nor that of Smith *et al*. (1986) uses formal production economics theory when addressing the problem of different bases for economic values, Amer & Fox (1992) proposed a general approach which is based on the neoclassical theory of the firm (farming enterprise). This theory has evolved as economists have attempted to explain the behaviour of competitive firms in transforming materials into goods and services desired by consumers. The goals of farm managers are assumed to be profit maximisation or cost minimisation. Amer & Fox (1992) considered input prices to be unaffected by genetic improvement due to the relative small shares of individual animal industries in input markets. The model is set in the long run in line with conventional economic theory dealing with technological change. In the long run, costs such as capital investment, which are considered to be fixed in the short run, are treated as variable. Genetic improvement programmes involve considerable development and adoption time periods. In the process of developing this approach, Amer & Fox (1992) showed that the conventional approach and the rescaling arguments are based on a very restrictive set of assumptions about the behaviour of farming enterprises.

2.2.4.3 Linear programming

Harris & Freeman (1993) used a linear programming model to derive economic values for yield traits and herd life under various economic conditions and production quotas. The model allowed optimisation of the system over time, simultaneously optimising management, resource and capital allocation as well as optimising future genetics of the animal.

A linear programming problem may be written as (Harris & Freeman, 1993):

$$\max z = \mathbf{c'x} \quad \text{subject to meeting the following linear constraints:}$$

$$\mathbf{Ax}\{= = =\}\mathbf{b}$$

where z is the value of the objective function (e.g. net income), **c** is a 1 x n vector of objective function coefficients per unit of activity (e.g. price per unit product), **x** is a n x 1 vector of activity levels (e.g. amount of a certain input), **A** is a m x n matrix of resource or technical coefficients and **b** is a m x 1 vector of resource limits. Two properties characterise a linear programming problem. The first is additivity, in which levels of activities are additive in their combined effect. The second is proportionality, in which a multiplicative relationship exists between units of a resource required and the number of units produced (Harris & Freeman, 1993). Solving a linear programming model involves choosing activities in such a way as to obtain an optimal plan. An optimal plan maximises the objective function and is feasible for satisfying the constraints (Sivarajasingam *et al.* 1984). Linear programs are usually solved iteratively by using a simplex method or variant of this method (Harris & Freeman, 1993).

2.2.4.4 Non-linearity

Conventional selection index theory assumes that the total merit or profitability of animals is a linear function of measurable traits (Hazel, 1943). However, in some cases merit (profit) may be a non-linear function of these traits (Moav & Hill, 1966; Amer *et al*., 1994a). Non-linear profit equations cause difficulty because the economic value of a trait is not constant but changes as the population mean changes (Goddard, 1983) and no uniformly "best" solution exists (Pasternak & Weller, 1993). A similar problem may arise when the economic value of a trait depends on management decisions (e.g. herd size, cost of buildings, age at breeding or marketing) taken by the farmer (Groen, 1989). In order to maximise a non-linear profit function it seems reasonable to consider non-linear selection indices (Goddard, 1983). Kempthorne & Nordskog (1959) suggested restricted selection indices while Wilton *et al.* (1968) derived a quadratic index, which minimized the sum of squared differences between the index and genetic merit for a quadratic profit function. Gibson & Kennedy (1990), however, concluded that constrained indices should be avoided for economic genetic selection since the linear index is by definition optimal. This is in agreement with Goddard's (1983) findings, that for any profit equation (even non-linear) the linear index derived by the graphical method of Moav & Hill (1966) either achieves the maximum increase in profit possible for a given intensity of selection, or reaches the maximum of the profit surface with the minimum intensity of selection. This conclusion is in keeping with the basic assumption of quantitative genetics that it is the additive value of genes which determines response to selection. Estimating of economic values by **a** = ?y / ?**x** (a = dp / dx) should therefore be satisfactory. However, maxima or intermediate optima for some traits may be quite common especially in situations where natural fitness is an important part of profitability (Beilharz *et al.*, 1993). In these cases continued use of the index based on **a** = ?y / ?**x** will also be unsatisfactory (Goddard, 1983). The economic values for traits that are already at an optimum, are non-linear (Gibson & Kennedy, 1990). However, unless the non-linearity is extreme, non-linearity will cause second order effects that are of minor importance in relation to the rate of genetic gain expected. In such cases a linear selection index will be very close to optimum. Therefore, the appropriate economic value for a trait at an optimum is zero, and if the population moves away from the optimum following selection, the economic value should be continuously adjusted to equal the tangent to the profit curve at the population mean for that trait. This is in agreement with the suggestion of Ponzoni *et al.* (1998) that non-linearity can be accommodated by periodically revising the economic value assigned to the trait in question. Hovenier *et al*. (1993) developed a method to calculate marginal income functions and to derive economic values for traits with an intermediate optimum. Wilton *et al.* (1998; 2002) describes a bio-economic modeling method to overcome the problems associated with the non-linear relationship between economic value and level of performance in traits. Customisation of evaluations is possible through these models for variables such as product price and population means, as influenced by the heterogeneity of breeds, markets, production systems and breeding systems.

Bright (1991) concluded that the simplified linear profit equations are likely to be sufficiently accurate in most circumstances. Significant error is only likely to occur when the variable input exhibits a large coefficient or when the trait change is proportionally large. In practice, most individual coefficients tend to be small and trait changes are not likely to be large. However, the economic value refers to only one production period, whereas in fact the gain from a trait change may well continue into the future (Bright, 1991). Pasternak & Weller (1993) presented an iterative method, based on the method of Moav & Hill (1966), to derive the optimum linear selection index for any number of traits with linear or non-linear profit functions. For non-linear profit functions the index weights will be functions of the trait means prior to selection and to selection intensity. When all traits in the profit function are included in the selection index, Pasternak & Weller (1993) phrased the problem in terms of non-linear programming, as follows:

$$\text{maximize: } f\,(\mathbf{X} + \mathbf{?}\,)$$

$$\text{subject to: } \mathbf{?}\,'\,\mathbf{G}^{-1}\mathbf{P}\mathbf{G}^{-1}\,\mathbf{?} = i^2$$

where f ($\mathbf{X}$ + **?**) is the profit function of the vector of economic traits after selection, **X** is the vector of trait means prior to selection, **?** is the vector of genetic changes in the traits in **X** due to selection, **G** and **P** are the genetic and phenotypic variance-covariance matrices of the traits in **X**, and i is the selection intensity.

2.2.4.5 Bio-economic modeling

Defining the economic value of genetic improvement of different traits requires an adequate description of the production system. Simple profit equations describing the relationship between genetic change and enterprise profit may be adequate for very simple production systems. More complex systems are better described by computer modeling (Bourdon & Brinks, 1987a; Lamb *et al*., 1992a; Wilton *et al*., 2002).

Tess *et al*. (1983a,) constructed a deterministic computer model to simulate biological and economic inputs and outputs for life cycle performance. This bio-economic model simulates the effects of genetic changes in components of performance (weaning rate, growth rate, milk production) on several measures of production efficiency (e.g. feed or monetary inputs/kg of live weight). The approach used in constructing the model was to account as accurately as possible for the biological and economic inputs needed to sustain a predetermined genetic level of performance. Under this approach inputs (feed and non feed costs) are treated as dependent variables determined by genetic levels for the various performance traits (Tess *et al*., 1983b). Groen (1988) also indicated the sensitivity of economic values towards changes in prices and elements that influence quantitative relationships between levels of genetic merit and levels of inputs and outputs. A bio-economic model was elaborated by Phocas *et al*. (1998a) to derive economic values for 25 traits in purebred French beef cattle selection schemes.

Amer *et al*. (1994b) used bio-economic models to derive economic values for a limited number of traits in particular segments of the production system. These ignore the reality that animals must perform in all segments and levels of a production system. Koots & Gibson (1998a) developed a bio-economic model of an integrated beef production system to derive economic values for genetic improvement of multiple traits. In this study (Koots & Gibson, 1998a) economic values were derived by estimating the change in profit resulting from a small (0.05 phenotypic standard deviation) change in a given trait while holding all other traits constant. The breeding objective was assumed to be profit maximisation.

Selection of beef sires to improve a population of animals (either purebred or composite) and choice of sires to use in commercial production programs involving crossbreeding are two distinctly different aspects of cattle breeding (Wilton *et al.*, 2002). Rankings of sires evaluated for use on a range of populations were found to be sensitive to the means of those populations. Evaluations of purebred sires based on progeny results in that population would, therefore, be inappropriate for use in commercial populations or for breed improvement of a population to use in crossbreeding. Customisation of evaluations is possible through bio-economic models for variables such as price grids and population means as influenced by choices of breeds and crossbreeding programs (Wilton *et al.*, 1998).

Studies by Bourdon & Brinks (1987a) and MacNiel *et al*. (1994) have treated traits as being independent of each other. On the other hand, Koots & Gibson (1998a) stated that, in constructing bio-economic models for estimation of economic values, careful attention must be paid to the exact definition of traits and the inter-relationships among them. Since the conversion of economic values to selection index weights assumes linear genetic relationships among traits, no allowance is made for non-linear relationships among traits. Apart from being an over-simplification of reality, this approach can lead to unrealistic impressions about the potential value of genetic change by attributing substantial economic values to each trait of a highly interdependent set. Since selection indices are linear, the non-linear interdependencies among traits cannot be accounted for in subsequent derivations of selection indices and should be accounted for by directly incorporating them in the model (Koots & Gibson, 1998a).

According to Wolfovà *et al.* (1995) two different procedures for calculating economic values for ordered categorical traits in cattle can be found in the literature. The first approach is that an increase in the frequency in one class is connected with exactly the same decrease in frequency of one of the adjacent classes. In calculating the economic value only changes in the frequencies of these two classes were considered. The second approach assumed an underlying normal distribution and the economic value for the transformed (liability) trait was calculated.

2.2.4.6 Variations in economic values and objectives

Economic values/weights may vary from breed to breed, between sexes or from region to region within the same breed. This is illustrated in Table 2.3 (Amer *et al*., 1994b).

Table 2.3 Economic values ($ animal^{-1}) for changes of 1% of the mean in average daily gain (ADG) (+12g day^{-1}), feed intake (FI) (-80 g day^{-1}), dressing percentage (DP) (+6%) and fat depth (FD) (-0.1mm) for breeds by sex (Amer *et al*., 1994b)

	ADG		FI		DP		FD	
Sex [a]	S	H	S	H	S	H	S	H
Breed								
Charolais	3.8	4.0	1.9	1.9	8.5	8.1	-0.8	-0.9
Simmental	4.0	4.1	1.9	1.8	8.2	8.0	-0.6	-0.9
Limousine	4.2	4.2	1.9	1.8	8.0	7.6	-0.5	-1.1
Hereford	3.4	2.8	1.4	1.3	7.9	6.6	0.8	0.3
Angus	3.4	2.5	1.4	1.1	7.7	5.9	0.6	-0.1

[a] S steers, H heifers

Differences in economic value for ADG between breeds and sexes can be attributed to differences in the number of days on feed and the dressing percentage for each breed. Daily feed intake economic values were also affected by number of days on feed for each breed. Differences in dressing percentage can be attributed to the higher slaughter weights of exotic breeds compared to British breeds and of steers relative to heifers. However, these differences in economic values are relatively small and are unlikely to affect the efficiency of selection (Amer *et al*., 1994b).

Economic values may change, even while the breeding program is in progress, if permanent shifts in market demand occur (Hazel, 1943). Amer *et al*. (1994a) extended a neoclassical economic model, based on the Cobb Douglas type production function, to the long run and found that the absolute size of economic values can depend to a large extent on the profit equation method used. This is in agreement with the findings of Melton *et al*. (1979; 1993). Groen (1989), Koots & Gibson (1998b), Lazenby *et al*. (1998) and St-Onge *et al*. (2002) found that absolute and relative economic values vary with fluctuations in prices and costs. For instance, the economic value of mature size decreases with an increase in feed costs. In addition, different management (production) systems, different marketing systems and different genotypes (breed role, relative performance of traits) gave markedly different economic values (Wilton *et al*., 1968; Bourdon & Brinks, 1987a; Lamb *et al*., 1992; Hazel *et al*., 1994; Koots & Gibson, 1998b). This is illustrated in Table 2.4 (Koots & Gibson, 1998a).

Table 2.4 Estimated economic values for traits under a pure breeding or rotational crossing system (PB), a dam line (DL) and a sire line (SL) (Koots & Gibson, 1998a)

Trait	PB	DL	SL
Mature size (kg)	3.62	-1.33	3.24
Calving ease – direct (% Unassisted)	3.81	6.49	4.56
Calving ease – maternal (% Unassisted)	3.81	10.98	0.00
Cow fertility	14.72	18.56	0.00
Calf survival	17.53	18.11	9.43
Cow survival	3.72	4.24	0.00
Peak milk yield	0.45	0.46	0.00

An example of the influence of the relative performance of traits on economic values is the level of performance in reproductive traits (Table 2.5) and the relationship between market weight and carcass grade. The economic values for improvement in cow fertility traits depend on the phenotypic mean values of the traits. Definition of breeding objectives is therefore complicated because the phenotypic values for reproductive traits is expected to vary across farms and years and might also change with genetic progress (Amer *et al.*, 1996). Moav & Hill (1966) also demonstrated that, the higher the present level of reproductive performance, the greater the improvement necessary to produce the same increase in profit.

Table 2.5 Economic values (£ / 1% change) for conception rate (CR), interval to first post partum estrus (PPI), and calving day (CD) in four herds at either high or low levels of performance in these traits (Amer *et al.*, 1996)

Trait	CR		PPI		CD	
Level of performance	High	Low	Long	Short	5%[a]	10%
Herd						
A	0.13	0.13	-0.37	-0.20	0.50	0.84
B	0.10	0.13	-0.37	-0.20	0.44	0.85
C	0.34	0.70	-2.77	-0.92	0.63	1.13
D	0.21	0.49	-2.22	-0.56	0.60	1.02

[a] Barren rates

Notter *et al*. (1979a) showed that important economic traits (high economic values) for maternal breeds (breed role) include components of reproductive rate and weaning weight (milk), but that only growth rate, mature size, calving ease and carcass quality are primary for terminal sire breeds. Economic values are also likely to vary across years (Amer *et al*., 1996). This suggests a customised approach to estimation of economic values may be warranted. In practice, however, the effects of changes in economic values depend on which traits appear in the index (Koots & Gibson, 1998b). Although many traits were insensitive to changes in production systems, economic values for fertility, calf survival and mature weight, did fluctuate considerable (Table 2.4).

Australian researchers developed a PC – program to derive economic values for beef cattle (Barwick, 1993). This program is a beef breeding objectives and selection indexing package designed for use with genetic evaluation systems (Schneeberger *et al.*, 1992). It is a decision aid which combines EBV's and targets them at the needs of the commercial beef producer. This program can be customised for various on farm objectives. A program was developed to compare animals across breeds and crosses (mate or breed of cow is also important) and considers different markets Wilton *et* al. (2002). Wilton *et* al. (2002) compared the ranking of Charolais bulls for traits such as post weaning gain (carcass weight), backfat thickness and marbling, when mated to Charolais x Angus cows and purebred Charolais cows, for different markets (replacement heifers, specialised market for smaller carcass with high degree of marbling). Bulls ranked differently with different mates and for different markets. This is due to the non-linearity of pricing grids for different markets.

Koots & Gibson (1998b) concluded that a small number of selection indices may suffice to cover a wide range of production and economic circumstances. Simm *et al.* (1986) also concluded that the selection indices derived by them were fairly insensitive to changes in economic and genetic parameters, and should be sufficiently robust for use in a practical improvement program. If one trait, or a few traits, dominates the index [as measured by the product of the economic value (a) and the heritability (h^2) for the trait] the efficiency of index selection will be sensitive mainly to changes in that trait(s) (Smith, 1983). If there is a balance among traits in the index (similar ah^2 values) then only moderate losses in efficiency may be incurred through changes in the economic values.

According to Howarth & Goddard (1998) diversity between breeding objectives exists at three different levels. This diversity exists within a single production and marketing system where different objectives may be defined for different lines (e.g. terminal sire and dam lines). Within a single livestock industry several different breeding objectives may be required to define the overall economic objective. This situation would arise when differences between production and marketing systems existed. Between countries, different breeding objectives may be required to maximise the benefits of selection to the country involved. Howarth & Goddard (1998) suggested either a specialised or an averaged objective where selection was for the average of the different objectives. The choice depends on the time horizon, the size of the breeding herd (when taking the effects of inbreeding and genetic drift into account) and the correlations between objectives. This is in agreement with the findings of Wilton (1986) that breeding objectives are difficult to establish because of interactions with a range of factors which may broadly be classified as environmental. One of these factors is the structure of the industry, by which is meant the segmentation of the industry into purebred and commercial herds. Within the commercial segment there is also little connection and/or flow of information between cow/calf producer, feedlot, packer and retailer. Another set of factors relate to the programs of producing beef. These include market standards as well as level and intensity of production. A third factor is the set of resource constraints or limitations which typically include capital, feed, labour and land (Wilton, 1986).

To summarise, the modeling methods to derive economic values can be divided into simulation, dynamic programming and profit functions (Weigel *et al.*, 1995). Harris & Freeman (1993) subdivided simulation modeling into positive (data analysis) and normative (bio-economic modeling) methods. However, whatever method is used to estimate economic values, it is necessary to derive accurate profit functions (Von Rohr *et al.*, 1999). This means that returns and costs associated with a change in population mean due to selection must be accounted for. By expressing profit as a function of traits in the breeding objective, the economic values can be obtained by differentiating with respect to each trait, and evaluating the partial derivative at the mean value of all other traits (Ponzoni & Newman, 1989). When estimating the economic value of a trait only terms involving that trait need to be considered, as other terms vanish on differentiation.

Note that in Figure 2.1 (Amer & Fox, 1992) the slope of the profit curve, calculated as the partial derivative of Equation 3 $(p = f(\mathbf{X}\ \mathbf{P}\ \mathbf{C}_v\ \mathbf{C}_f)$ with respect to the animal characteristic (trait) of interest, is taken to be the appropriate economic value. When (3) is non-linear, partial derivatives are calculated at the level of the population mean for the specific trait.

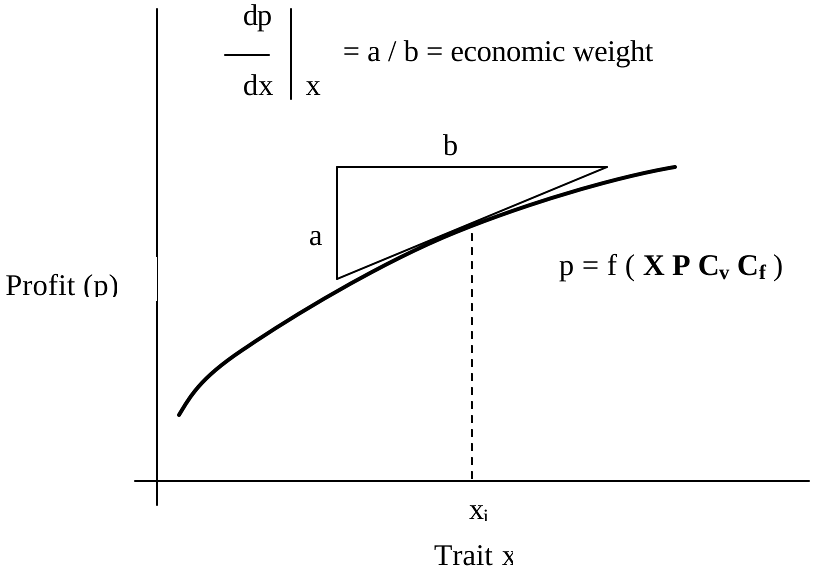

Figure 2.1 Profit (p) as a function of trait x where x_i represents the population mean

It is often easier to work with economic values if they are all scaled relative to each other. The easiest way of doing this is to standardise values by dividing by the standard deviation of each trait, so that the value now refers to a change of one (usually phenotypic) standard deviation in each trait (Table 2.6). Urioste *et al.* (1998) expressed economic values in actual monetary units and also in units of additive genetic standard deviations (s_A). The absolute value of the latter expression (|EV| x s_A) enables the comparison of traits in terms of 'economic–genetic' variation available. Alternatively, economic values can be expressed as a proportion of the value of one trait (usually the smallest value). The expression of economic values per unit of genotypic and phenotypic standard deviation is important because not all traits are measured in the same unit (Munoz-Luna *et al.*, 1988). The economic value per s_P is important for economists while the economic value per s_A and per dG is of use to geneticists and breeders. Where $dG = i \cdot h \cdot s A$ and $i = 1$.

Table 2.6 Expressions of economic values for different traits as either per unit used, per $s_{P,}$ per s_A and per dG (Munoz-Luna *et al.*, 1988)

Trait Method of expression	Weaning weight (kg)	ADG g/day	Age at slaughter (days)	Milk Yield (kg)	Mature weight (kg)	Dystocia (%)
Per unit used	158.12	15269.51	62.11	79.34	-83.49	-169.14
Per s_P	3130.78	2443.12	2670.59	31737.83	-4174.63	-4888.33
Per s_A	1434.70	1424.57	1710.01	15868.91	-1913.06	-1466.50
Per dG [a]	657.46	830.66	1094.94	7934.46	-876.67	-439.90

[a] $dG = i \cdot h \cdot sA$, $i = 1$

Trait economic values, and thus relative economic values, can only be estimated. They depend on estimates of future production system characteristics, including future prices. This highlights the need for revision of economic values at reasonable intervals of time. Economic values should, however, not be changed continuously in an attempt to chase short term fluctuations of the market, but they should be re-examined if market values appear to have changed in a way likely to last for some time.

2.3 CONCLUDING REMARKS

Breeding and management involve decisions followed by actions. Decisions are based on information of the environment, markets, and traits and on differences between animals and groups of animals. The better the information is, the better the decisions, the more effective the actions and the better the chance of maintaining or increasing profitability in the short and long term.

Performance recording is the systematic measurement of performance traits or of indicators of performance. These records become a data bank and, upon proper manipulation and analysis, are used in breeding and management programs to improve decision making. Performance recording will increasingly be involved in maximising the value of the information per unit of investment in terms of either money and/or time. This means effectively addressing the problem of what traits should be measured, how and when they should be measured and what other data should be recorded. Furthermore, performance recording will increasingly become central to all genetic improvement initiatives, especially as pressures to describe the product (animal) and to increase productivity and product quality, intensify. However, performance recording schemes have been put in place before viable breeding objectives and relative economic values have been evaluated. This defect needs to be addressed.

Unless more effective animal genetic improvement activity for meaningful breeding goals is introduced and sustained, many developing countries will, in future, experience even greater difficulty to meet their food and agricultural imperatives (Djemali & Wrigley, 2002). The effectiveness of breeding strategies depend heavily on the degree of compatibility between production systems, the animal component and physical environment, the social, political and economic environments and the livestock general and specific producer targets. When this context is clearly defined and adequate to support genetic improvement activities, the definition of meaningful breeding goals and the design and implementation of breeding strategies which are increasingly and sustainably used by farmers is feasible.

Animal genetic improvement as an element of livestock development can offer valuable tools to help meet the overall livestock development objective (LDO), if a structured process based on specific frames is dealt with properly prior to deciding what the breeding goals should be and before the detailed operational design of the program is finalised (Djemali & Wrigley, 2002). This sequential analysis should be based on the principles of strategic planning (including a SWOT-analysis – Strengths, Weaknesses, Opportunities and Threats – Thompson & Strickland, 1999) and end with the formulation of a sustainable LDO. This sustainability should make verifiable contributions to improve livestock productivity, reduce the level of risk and uncertainty, increase the protection and effective management of natural resources, be economically viable and meet consumers' needs in a cost effective manner as well as being socially acceptable to both breeders and consumers. The risk of breeding schemes comprises the variance of the selection response and the inbreeding (drift variance) (Meuwissen, 1998), the uncertainty in long term market trends (Lazenby *et al.*, 1998) as well as possible socio-political change (Land, 1981). Grundy *et al.* (1998) and Meuwissen (1998) presented methods to deal with the risk associated with inbreeding. For the genetic improvement element the LDO analysis will have delivered the required institutional, economic and production information. This formal approach is especially important for genetic interventions because of the relative permanence of genetic change, the time required to make or reverse widespread genetic changes and the depth of the impact of genetic change on production and market systems.

The basic approach to genetic improvement in the beef industry is summarised by the so-called Modern Breeding Approach (Hammond, 1991). According to this approach only three primary components cover all formal and practical aspects of breeding:

- The breeding objective which establishes the direction to breed in economic terms. Although this has been done intuitively in the industry to date, it can also be done using formal calculation. In future it will be necessary to use a formal approach, as outlined above, if the beef industry is to maximise the exploitation of genetics.
- Genetic evaluation which provides the estimates of genetic merit for each animal. Genetic evaluation enables animals to be ranked on their overall economic merit, for a particular breeding objective. These two components are linked by the selection index which is a formally or mentally derived combination of EBV's which has the maximum association with the breeding objective.
- Breeding program design establishes the optimum selection and mating structure.

Meuwissen (1998) also emphasised the fact that definition of breeding objectives, design of breeding strategies and genetic evaluation are interacting components of a genetic improvement program that often cannot satisfactorily be dealt with in isolation. The approach outlined by Hammond (1991) not only requires the identification of different markets and the establishment of market requirements but also that cost-effective and accurate measurements exist which relate to all traits in the breeding objective. This is not currently the case for the range of major production-marketing combinations in the beef industry. Better low cost, direct and indirect measurements of reproduction, production and product, which can be taken early in life, need to be established. Finally, estimation of the necessary parameters such as economic values, heritabilities and correlations provides the formal backbone to the total breeding operation.

CHAPTER 3

Development of breeding objectives for beef cattle – Traits, criteria and parameters

3.1 INTRODUCTION

The primary objective in the approach adopted in the economic model is to describe genetic improvement in terms of the increase in profitability of the animal within a specified set of conditions of production and marketing. The basic assumption is derived from the fact that the profitability of an animal depends on its level of performance in more than one trait (character). Overall productive merit may therefore be expressed as a linear function of an individual's phenotypic value for each such trait. Similarly, the net merit of an individual as a future parent may be described as a linear function of its separate breeding values (Fowler *et al.*, 1976). In constructing a selection index, a decision is taken first on which traits should be the selection objectives, and the relative emphasis which should be ascribed to each. Secondly, consideration is given to the question of which traits are to be measured (selection criteria) and combined into the selection index. These may include the traits which are themselves the objects of selection, as well as others which merely help to predict the desired traits.

A clear distinction should be made between the traits in the breeding objective and the traits used as selection criteria (Ponzoni & Newman, 1989). The breeding objective is defined as the combination of economically important traits that breeders want to improve. By contrast, the selection criteria are the traits used in the estimation of the breeding values of the animals. Decisions about which traits to include in the breeding objective, should be based on purely economic grounds, and not whether they are difficult or easy to measure or to change genetically. The traits in the breeding objective are the ends, whereas the characters / traits used as selection criteria are the means used to achieve the ends. The selection criteria will, of course, be influenced by which traits are in the breeding objective.

The information needed in addition to the economic values, to allow prediction of the breeding objective, is information on the genetic variances and covariance's among the selection criteria in the index and on the genetic covariances among the selection criteria and the objective traits (Schneeberger *et al.*, 1992; St-Onge *et al*., 2002). Traits differ not only in economic importance but also in variability, heritability as well as genetic and phenotypic correlations (Hazel *et al*., 1994). Because beef cattle are used to harvest a wide variety of forages under diverse climatic, management and marketing systems, the relative importance of performance traits for selection can differ greatly among breeds and breeders.

Choosing selection criteria and organizing logically based performance recording is difficult unless the traits that have to be improved have been identified and their relative economic importance has been established (Ponzoni, 1986). Increased emphasis on performance recording must, however, be coupled with an understanding of the relationships between genetics and economics of livestock production. Breeding objectives provide this bridge. The purpose of this chapter was, therefore, to review the traits, criteria and parameters necessary to allow prediction of the breeding objective and construction of selection indices for beef cattle breeding. The purpose was not to do a full review of parameters as this was comprehensively done by both Mohiuddin (1993) and Koots *et al*. (1994a; 1994b).

3.2 TRAITS AND CRITERIA

Selection is the process that determines which individuals become parents, how many offspring they produce, and how long they remain in the breeding population (Bourdon, 1997). Selecting an animal for only one trait is simple as only the best animals according to that trait should be selected, preferably based on the estimated breeding value (EBV) from a BLUP (Henderson, 1953; Henderson *et al.*, 1959) animal model. However, more than one trait usually affects the value of an animal although they do so in varying degrees (Hazel, 1943). Moreover, these traits are not equally important or independent of each other. The information regarding different traits may vary widely, some coming from an animal’s relatives and some from the animal’s own performance for traits which are expressed once or repeatedly during its lifetime (Harris & Newman 1994).

Several authors have stressed the importance of accurate estimates of genetic parameters to maximize the response to index selection (Harris & Newman, 1994). Performance should be recorded in an objective, quantitative and logical manner. Estimation of variance and covariance components for a wide array of economically important traits is fundamental to the development of genetic improvement programs. The design of selection programs for various classes of livestock is greatly influenced by mating ratios and reproductive rates for each sex as well as what traits are recorded, when traits can be measured and when selection can occur (Harris & Newman, 1994). However, profit equations describing the breeding objective often include traits that are not routinely recorded. Whenever feasible, expanding the performance recording scheme to include all traits of economic importance, is ideal. An alternative is to include another trait (or set of traits) that provides a reliable indicator of the unobserved economic trait. A reliable indicator has a high genetic correlation with the economic trait, has sufficient variability, is relative easy and cheap to measure, is heritable and can be measured early in life (Harris & Newman, 1994).

The efficiency of index selection is not very sensitive to small changes in the economic values (Smith, 1983). With larger changes it is shown that considerable losses in efficiency can be incurred. If one trait, or a few traits, dominates the index [as measured by the product (ah^2) of the economic value per standard deviation and heritability for the trait] the efficiency will be sensitive mainly to changes in that trait. Large losses in efficiency occur when important traits are omitted or unimportant traits are given importance, or when the direction of selection is reversed for important traits. Any loss in efficiency is affected by both the phenotypic and genotypic correlations. Losses in efficiency were usually larger with unfavorable correlations among traits. Gjedrem (1972) concluded that all traits with any economic value should be included in the aggregate breeding value. This would be correct if all other parameters (heritabilities, correlations) were known (Blake, 1984). However, in practice, the genetic parameters among a large number of traits may not be well estimated and may even be inconsistent with each other (Hill & Thompson, 1978). Thus, it may well be better and simpler, to limit the number of traits in the breeding objective to those with non-trivial ah^2 values. Changes and trends in other minor traits would then be reviewed over time to determine if deleterious changes were occurring or whether critical threshold levels had been revealed, changing the economic values and other parameters for such traits.

Often in animal breeding a limited set of breeding objectives has been defined, such as growth rate. Rather, the whole life-time production efficiency must be considered, including feed or other inputs, viability, reproductive rate, age at breeding, product quality, mature size and length of productive life. Animal breeders must, therefore, determine which biological components offer the greatest opportunity for genetic improvement in net efficiency of production (Tess *et al.*, 1983a). According to Harris (1970), the three main aspects of efficiency in livestock production are (1) efficiency of animal industries relative to other food industries, (2) efficiency of animal industries relative to each other and (3) efficiency of one producer relative to others in the same industry. The primary manifestation of the first of these will be in the magnitude of money spent by consumers for animal products relative to other food products. The second aspect of efficiency leads to the relative levels of consumption of beef, mutton, pork and chicken. However, the main source of long term profit for a livestock producer seems to lie in his efficiency relative to other livestock producers. Thus the goal of genetic improvement in livestock should either be profit, return on investment or cost per unit production. In all three forms, breeders are concerned with the magnitude of expenses or cost of production relative to income or, equivalently, quantity of product adjusted for quality. Therefore, we need to study an individual animal's contribution to income and expenses to obtain an indication of the traits of economic importance and the relative importance of each (Harris, 1970).

The cost of animal products depends primarily upon the efficiency of three basic functions, female production, reproduction and growth of the young (Dickerson, 1970) and, according to Harris & Newman (1994), the major economic categories of concern are product income, female parent expenses and progeny growth expenses. Product income usually involves number of progeny per parent, quantity of product per progeny and quality of product. Therefore, the major genetic opportunity for reducing cost seems to be in increasing the total product value per female with minimum increase in metabolic body size or in non-feed cost per female as well as higher rate of reproduction and more efficient lean growth of progeny to market weight. Selection should, however, not be for larger body size *per se*, but rather for higher yield relative to body size. Under intensive management both milk and meat production can be important, especially in dual purpose cattle, in reducing cost per unit of production. Growth efficiency is more important in beef cattle than in other meat animals because of the low rate of reproduction or high cow-herd cost per animal marketed (Dickerson, 1970).

In ruminants, separate consideration of biological and economic efficiency is nearly impossible (Notter, 2002). The separate and highly significant contributions of both grazed forages and harvested concentrates to beef production, and the potential substitution of one feed source for another, dictates that economic considerations must influence our view of biological efficiency. Biological efficiency is defined as "the capacity to convert physical inputs (feed) into marketable product (beef) under prevailing production conditions." Biological efficiency in the cow herd is most clearly reflected in the number of calves weaned per cow exposed, the weaning weight of calves, annual feed intake, appropriate transmitted effects to support efficient post weaning growth and high levels of maternal calving ease to support the use of terminal sires (Notter, 2002). The biological traits influencing efficiency in the growing market animal, particularly in the feedlot, differ considerably from those in the cow herd. Issues of appetite, lean growth potential, maintenance requirements, growth efficiency, and carcass fat level and fat distribution become primary. Efficient growth involves the combined effects of rapid growth (to dilute maintenance requirements), desirable composition of gain, and efficient utilization of consumed feed (Notter, 2002).

The relative emphasis to be placed on the traits in a selection program depends on the combination of economic importance of each of the traits, potential for genetic improvement for each of the traits and the genetic interrelationship among traits. The potential for genetic improvement involves genetic variability and the accuracy of measuring these differences (both directly and indirectly through correlated traits). Therefore, the decision to include a trait (or not) in a testing program depends on the economic importance of the trait, potential for genetic improvement and cost of measurement (labor, facilities, time). In other words, this decision depends on the additional amount of economic improvement that can be made relative to the cost of making that improvement (Harris, 1970). In the context of selection index theory, comparisons between traits depend on the amount of genetic variation in each, the extent to which this variation can be exploited through selection on the traits themselves or on correlated traits, and their economic values (Ponzoni, 1992). According to Groen (1989) relative economic values, genetic potentials of improvement of traits and possibilities of accurate measurement of genetic means determine the definition of the breeding objective (goal).

Some traits in the breeding objective may be difficult or expensive to measure. Furthermore, there may be characters highly correlated with the traits in the objective, but they are not included between the set of traits in the breeding objective and the set of characters / traits used as selection criteria (Ponzoni & Newman, 1989). Blake (1984) stressed the importance to assess traits that merit consideration either directly (e.g. trait in a selection index because of a substantial product of economic value by heritability – ah^2) or indirectly in programs of genetic improvement (e.g. correlated traits).

The greatest limiting factor in the development of breeding objectives and appropriate selection indices is the lack of estimates of genetic and phenotypic correlations between growth, food intake, reproduction and carcass composition. Estimates of (co)variances for a wide range of characteristics will become increasingly important as the barriers identifying traits of economic importance and the major genes (QTL's) influencing them become apparent (Newman et al., 1992). Realistic evaluation of selection criteria for improving efficiency of beef production should, however, include their effects on carcass composition, meat quality and optimum economic weight at slaughter of calves as well as mature size, milk production and calving difficulties of cows (Dickerson *et al*., 1974). Ponzoni (1986) also stressed that special attention should be given to increased feed requirements likely to result from genetic change in reproduction and live weight.

3.2.1 Trait combinations included in breeding objectives

Trait combinations and criteria used by different researchers in their definition of breeding objectives and formation of selection indices respectively are summarised in Table 3.1

Table 3.1 Summary of the traits and criteria used in the breeding objectives and in the selection indices that were developed by different researchers

Traits	Criteria	Comment	Author
Calving day	Calving day	Profit [a]	Ponzoni & Newman (1989)
Carcass weight	9 month live weight	Cow-calf [b]	
Fat depth	Ultra sound fat record	Australia [c]	
Food intake		Beef [e]	
Net reproduction	Birth weight (d + m)	Profit [a]	Newman *et al.* (1992)
Carcass weight	Weaning weight (d + m)	Cow-calf [b]	
Food intake	Yearling Weight	New Zealand [c]	
	Carcass weight	Beef [e]	
	Net reproduction of dam		
	Scrotal circumference		

Table 3.1 continues: Summary of the traits and criteria used in the breeding objectives and in the selection indices that were developed by different researchers

Mature size		Profit [a]	Koots & Gibson (1998a)
Calving ease (d + m)		Integrated [b]	
Cow fertility		Canada [c]	
Survival (cow + calf)		Beef [e]	
Peak milk yield			
Residual post weaning growth rate			
Residual feed intake (growing animals)			
Residual slaughter weight			
Dressing percentage (constant fat)			
Marbling			
Lean percentage			
Weaning rate	Calving day	Profit [a]	Urioste *et al.* (1998)
Calving ease (d + m)	Calving ease	Cow-calf [b]	
Sale weight (cow + calf)	Scrotal circumference	Uruguay [c]	
Feed intake	Birth weight	Beef [e]	
	Weaning weight		
	18 months weight		
Cow weight		Profit [a]	MacNiel *et al.* (1994)
Fertility (male + female)		Integrated [b]	
Calf survival		Canada [c]	
Weaning weight (d + m)		Beef [e]	
Post weaning rate of gain			
Feed conversion			
Dressing percentage and cutability			
Percent A grade			

Table 3.1 continues: Summary of the traits and criteria used in the breeding objectives and in the selection indices that were developed by different researchers

Net daily gain		Profit [a]	Wolfovà *et al.* (1995)
Dressing percentage		Feedlot [b]	
Fleshiness		Czech Republic [c]	
Fat covering		Dual purpose [e]	
Post weaning growth rate		Profit [a]	Amer *et al.* (1992)
Feed conversion ratio		Feedlot [b]	Amer *et al.* (1994b)
Dressing percentage		Canada [c]	
Fat depth		Beef [e]	
Mature cow weights		Efficiency [a]	Lamb *et al.* (1992a)
Pregnancy rates		Cow-calf [b]	
Calving difficulty			
Total milk yield			
Calf weaning weight			
Sale life weight (d + m)	Birth weight	Profit [a]	Nitter *et al.* (1994)
Calving difficulty (d + m)	200 day weight	Integrated [b]	
Dressing percentage	400 day weight	Australia [c]	
Saleable meat percentage	600 day weight	Beef [e]	
Fat depth on rump			
Cow weaning rate			
Bull fertility			
Cow survival rate			
Cow live weight			

Table 3.1 continues: Summary of the traits and criteria used in the breeding objectives and in the selection indices that were developed by different researchers

Weaning weight		Profit [a]	Munoz-Luna *et al*. (1988)
Slaughter age		Integrated [b]	
Growth rate		Spain [c]	
Dystocia		Dual purpose [e]	
Milk yield			
Mature weight			
Rate of reproduction	Individual body weights	Economic efficiency [a]	Dickerson *et al*. (1974)
Efficiency of lean growth	Post-weaning feed consumption		
Quality of lean cuts	Backfat measurements		
Growth rate	Birth weight	Efficient production [a]	Simm *et al.* (1986)
Feed conversion efficiency	Growth rate	Feedlot [b]	
Killing out proportion	Feed conversion efficiency	England [c]	
Carcass lean proportion	Ultrasonic fat area	Beef [e]	
Total food intake	Birth weight	Profit [a]	Simm *et al.* (1986)
Calving difficulty score	200 day weight	Integrated [b]	
Weight of saleable meat	400 day weight		
	Calving difficulty score		
	Muscling score		
	Ultrasonic fat area		

[a] Objective; [b] Production system; [c] Country; [e] Breed type

d = direct; m = maternal;

From Table 3.1 it is clear that differences exist between different objectives in terms of the traits and criteria included. Furthermore, some overlap between traits and criteria do occur. According to Morris (1980) the most important traits contributing to higher biological and economic efficiency of beef cattle production are higher carcass weights of finished animals (obviously within the limits set by consumer preferences) and higher net calf crop. Morris (1980) also pointed out that since a large proportion of total herd food intake is required for non-productive processes (e.g. maintenance), increasing net calf crop weaned can decrease parental cost per calf and thus spread annual herd maintenance cost over more animals marketed. Selection of animals that more efficiently convert food into lean tissue will also increase efficiency.

Specific biological traits (Table 3.1) were chosen by Ponzoni and Newman (1989), because of their effect on profit, because their recording is feasible on-farm and because of their genetic correlations with the traits in the breeding objective. Ponzoni & Newman (1989) concluded that under most circumstances the trait making the greatest positive contribution to genetic gain in economic units was calving day (CD). Food intake of calves, heifers and cows also made an important negative contribution to total gain in economic units. The cost effectiveness of recording food intake in at least part of the offspring appeared worth investigating. Ideally, food intake should be measured in a pasture situation (Newman *et al*., 1992).

Traits defined by Amer *et al*. (1992; 1994b) (Table 3.1) in the breeding objective for feedlot production represent only a subset of the overall selection objective for beef production. Furthermore, economic values derived for a feedlot need to reflect the incentives to cow-calf producers to improve the genetic traits of feeder calves. Lamb *et al.* (1992b) measured economic efficiencies in the feedlot segment as input costs per kilogram of carcass weight, input costs per kilogram of lean weight and input costs per carcass value.

Koots and Gibson (1998a; 1998b) defined most traits as functionally independent of each other. Thus, traits related to mature size were redefined as residual traits after accounting for the non-linear relationships among mature size, growth and feed intake traits following mammalian size scaling rules.

In the dual purpose breeding goal for German Simmentaler cattle a total merit index assessed milk traits with 41% and beef traits with 21%. Longevity, somatic cell count and fertility traits were additionally considered with a relative weight of 12.33% each. Beef components in the aggregate genotype are net gain (carcass weight divided by age) as well as carcass grade and lean meat content which represent the market value of the carcass (Engellandt *et al*., 1999).

Even though traits may be defined in various ways by different authors, broadly, they may be grouped into those related to reproduction (fitness), growth, carcass attributes and feed intake (Urioste *et al*., 1998).

3.2.2 Fitness / Functional traits

All evolutionary changes in allele frequency must funnel through the reproduction achieved by phenotypes and the survival of their progeny, i.e. fitness. Fitness is a product of several components with a multiplicative relationship (Beilharz *et al*., 1993). Each component uses metabolic resources which are usually limited by the environment. The consequence is that, when environmental resources are limited, all major components of fitness are naturally selected towards intermediate optimal values. A further consequence is that each component can and will respond to selection, but as one component increases and uses more resources others have to decrease. As the system moves from its optimal values total fitness is likely to decrease as well. Thus, when researchers study only small components of fitness, they may readily find that their measure of reproductive fitness is improvable, but they are likely to have missed the negative side effects in other components and total fitness (Beilharz *et al*., 1993). However, environmental limitations are not necessarily present when animals have entered a new environment, their management system has recently been changed, or specific resources are continually increased. In these conditions rapid genetic progress in many traits, including fitness, is possible. The above mentioned led to the conclusion that fitness is a difficult trait to improve and that a holistic approach is needed. This can probably be achieved through a well defined breeding objective.

Furthermore, selection for a quantitative trait often leads to a decline in traits closely related to natural fitness despite the fact that fitness was uncorrelated with the character under selection in the base population (Goddard, 1983). For instance, Olori *et al*. (2002) concluded that the decline in reproductive efficiency of Holstein Friesian cattle has been attributed to selection for increased production. Fitness is often maximized at an intermediate value of a quantitative trait and so correlated changes in this trait as a result of selection could explain the decline in fitness. The analysis of Goddard (1983) showed that including fitness traits in the profit function is not sufficient to prevent this decline unless the curvilinear nature of the relationship between traits is recognized. As more is learned about profitability and its constituents, multiple trait evaluation may need to account for intermediate optima to achieve maximum gains in profit (Blake, 1984). Moav and Hill (1966) also stressed that, since profit is linearly related to productivity, changes in productivity produce the same change in profit at all levels of productivity. On the other hand, there is a non-linear relationship between profit and reproductive performance. Therefore, changes in reproductive performance yield changes in profit dependant on the level of reproductive performance. Thus the higher the present level of reproductive performance, the greater the improvement necessary to produce the same increase in profit.

Researchers have generally agreed that improved reproductive performance, namely better fertility and increased survivability, improves overall production and economic efficiency in beef cattle (Bourdon & Brinks, 1987b). However, when adjustments were made for cows slaughtered, biological efficiency did not change. Grazer *et al.* (1994b) demonstrated that the inclusion of reproductive measures as selection criteria is highly profitable. Fertility or reproductive performance has been reported to be at least twice as important, economically, as production traits under a conventional cow-calf production system (Donoghue, 2002). However, EBV's for fitness traits are difficult to estimate, report and interpret not only because most measures of reproduction are only small components of the total fitness (Beilharz *et al.*, 1993) but also because the expression of the reproductive potential (e.g. age at first calving) is often constrained with the management system employed (Notter & Johnson, 1988; Meyer *et al.* 1990), and depends on the existing recording scheme used by the breed (Rust & Groeneveld, 2001). This is particularly true for pasture mating situations, where information on females is limited. EBV's for fertility traits will, however, allow breeders to take a more balanced approach to genetic change in their herds (McDonald, 1991a), especially in view of the negative association between certain growth and fitness traits (Scholtz *et al.*, 1990).

As reproduction is a complex trait there are many different measures of reproductive performance (Donoghue, 2002). According to Rust & Groeneveld (2001) attempts to understand the genetics of a composite trait such as overall reproductive performance can involve two approaches. The trait to be investigated can consist of the overall reproductive performance itself or, alternatively, its constituent components. It is to be expected that these different components of the composite trait will have different heritabilities. This invokes the possibility of concentrating on the most important components during selection and thereby possibly achieving a higher overall genetic response (Rust & Groeneveld, 2001). However, Beilharz *et al*. (1993) demonstrated that these small components of fitness may give quite erroneous conclusions about possible changes in total fitness.

Some of the fitness traits/criteria, including days-to-calving/calving date, stayability, heifer pregnancy, calving rate, pregnancy rate, age at first estrus, age at first calving and physiological measures, were reviewed by Donoghue (2002) who came to the conclusion that calving date is a suitable criterion for reproductive performance. No conclusions regarding heritability of heifer pregnancy can be made (Donoghue, 2002). Calving rate, pregnancy rate and age at first estrus appears to have some potential as criteria for reproductive performance. Measuring physiological parameters would be difficult outside of experimental populations and age at first calving reflects management decisions to a greater extent than genetic merit (Donoghue, 2002). Earlier age at puberty resulted in only minor improvements in efficiency probably due to the relative young age at which puberty was simulated by Bourdon & Brinks (1987b).

In a review of female fertility traits in beef cattle Rust & Groeneveld (2001) concluded that indices of genetic reproductive merit that are easily measured at low cost, in most management systems, would include traits such as age at first calving, calving success, calving interval, calving rate, calf survival, days to calving and calving date. However, after testing a number of potential fertility traits McDonald (1991a) concluded that the most useful traits were Days to Calving (DC) and Scrotal Circumference (SC). The DC measurement is genetically influenced by age at puberty, ability to start cycling soon after calving, ability to conceive readily and gestation length. Johnston & Bunter (1996) computed DC as the interval in days between the first joining date each year for a cow under paddock mating and subsequent calving. Herd, year-season of joining, service sire, previous joining season and age at joining significantly influenced DC. This is in agreement with Van der Westhuizen *et al*. (2001b) who concluded that calving date and age at first calving may be considered as selection criterion for improving reproduction in beef cattle herds.

Profit equations describing the breeding objective often include economic traits that are not routinely recorded (Harris & Newman, 1994) and, too often, genetic evaluation has focused only on output traits and has neglected costs of inputs. The period between weaning of offspring and parturition represents a major cost of the breeding herd that may be reduced through parent stock genetically able to rebreed sooner. Thus, rebreeding intervals as well as age at first breeding are potential economic traits. However, expression of these traits is subject to management decisions. Olori *et al*. (2002) concluded that, in a grass based production system with seasonal calving, calving interval is an objective trait of economic importance. Economic losses due to poor fertility are generally due to the cost of a prolonged calving interval, increased insemination cost, reduced return from calves born and forced replacement in the event of culling. Secondly, in the absence of data on direct measures of fertility, calving interval can be considered a good indicator of cow fertility because of the high correlation between calving interval and several direct measures of fertility (Campos *et al*., 1994; Grosshans *et al*., 1997; Pryce *et al*., 1997; Pryce *et al*., 1998). Overall improvement in cow fertility can therefore be achieved by an initial selection on first lactation heifer fertility based on calving interval.

According to Bourdon & Brinks (1983) selection for shorter calving interval could, however, result in indirect selection for later age at puberty. Because calving date is likely to be more heritable and has a clear economic significance, and because selection for earlier calving date should not lead to an adverse response in other reproductive traits, calving date was preferred by Bourdon & Brinks (1983) and Van der Westhuizen *et* al. (2001b) over calving interval as a reproductive measure. Meacham & Notter (1987) and MacGregor & Casey (1999) also concluded that calving interval does not appear to be a useful selection criterion to improve reproduction and that calving date appears to be the most useful potential selection criterion to improve reproductive fitness.

Amer *et al*. (1996) identified gestation length, post partum anoestrus interval, conception rates and calving day as reproductive traits in seasonal calving beef suckler herds. There is, however, limited scope for direct measurement of, and selection on, individual conception rates, the length of the post partum interval or even gestation length in practical breeding programs.

Selected heritabilities for functional / fitness traits are summarised in Table 3.2.

Table 3.2 Summary of selected heritabilities for functional / fitness traits

Traits	h²	Author
Age at first calving (direct – d)	0.06	Koots *et al.* (1994a)
(maternal – m)	0.19	
	0.40	Van der Westhuizen *et al.* (2001b)
Calving date (day) / Days to calving	0.08	Koots *et al.* (1994a)
	0.08	Urioste *et al.* (1998)
	0.04	Van der Westhuizen *et al.* (2001b)
	0.11	Johnston & Bunter (1996)
	0.17	Meyer & Johnston (2001)
Calving interval (cow – c)	0.01	Koots *et al.* (1994a)
(heifer – h)	0.06	
	0.01	Van der Westhuizen *et al.* (2001b)
Conception rate (d, c)	0.17	Koots *et al.* (1994a)
(d, h)	0.05	
(m, c)	0.02	
(m, h)	0.01	
Prenatal mortality (d, c)	0.01	Koots *et al.* (1994a)
(d, h)	0.15	
(m, c)	0.11	
(m, h)	0.11	
Calving rate	0.17	Koots *et al.* (1994a)
	0.14	Martinez – Velazquez *et al*. (2003)
Scrotal circumference	0.43	Arthur *et al*. (2001)
	0.40	Urioste *et al.* (1998)
	0.48	Koots *et al.* (1994a)
	0.41	Martinez-Velazquez *et al.* (2003)

Table 3.2 continues: Summary of selected heritabilities for functional / fitness traits

Longevity	0.06	Weigel *et al*. (1995)
	0.08	Van der Westhuizen *et al.* (2001a)
Calving ease (d, c)	0.13	Koots *et al.* (1994a)
(d, h)	0.10	
(m, c)	0.12	
(m, h)	0.09	
(d + m)	0.10	Urioste *et al.* (1998)
(d)	0.17	Gregory *et al.* (1995a)
Calving success	0.03	Van der Westhuizen *et al.* (2001a)
Stayability	0.03 – 0.11	Van der Westhuizen *et al.* (2001a)

The economic importance of herd life (longevity, survival, stayability) has been well documented (Van Arendonk, 1991; Harris & Newman, 1994; Jagannatha *et al*., 1998). Longevity or stayability represents a desirable quality in cows to sustain profitable production that, when accumulated across cow lifetimes and discounted, results in greatest net returns for those surviving longest (Blake, 1984). Melton & Colette (1993) recognized that the optimal economic life may be different for different breeds and that it would impact on the relative profitability of breeds. Two distinct effects of longer herd life on profitability are lower replacement cost and more cows producing at mature levels. The benefits of longer herd life could also result in reduced culling losses and reduced health costs. The optimum replacement policy of the farmer and optimal levels of fertility are, however, affected by the relative levels of rearing costs of replacement heifers, the cost of maintaining mature cows and the carcass values of the culled cows (Rogers *et al*., 1988; Bourdon and Brinks, 1987b; Groen, 1989). Decreased fertility causes changes in sources of products, not product loss *per se*. For this reason, survivability may be a more important aspect of reproduction than fertility. Several non-yield traits have been considered to be associated with longevity e.g. traits thought to impart resistance to disease, injury, or physiological imbalance; disposition (temperament); udder, feet and leg problems, and type score (Blake, 1984). However, heritability estimates for and correlations among stayability, longevity and calving success derived by Van der Westhuizen *et al*. (2001a) were of such a low magnitude that selection for these characteristics (stayability, longevity, calving success) would result in limited genetic improvement (Table 3.2).

Meyer et al. (1990) also identified scrotal circumference and days-to-calving as the most suitable male and female reproductive traits, respectively, to include in a genetic evaluation scheme for beef cattle. Early calving has been reported to be associated with increased biological and economic efficiencies (Johnston & Bunter, 1996). High genetic correlations among repeat days-to-calving records ($r_g = 0.85$) and between days-to-calving and calving success ($r_g = -0.97$) were observed. Genetic correlations between early weight traits and days-to-calving were positive and low, but not significantly different from zero. Criteria for reproductive fitness should include direct measures such as pregnancy rates and calving dates as well as indirect measures of indicator traits such as reproductive tract scores in heifers and scrotal circumference in males (Notter, 2002). The composite trait, calving rate, can be decomposed into traits such as post partum interval, ovulation rate, conception (pregnancy rate), dystocia and post natal survival (Jenkins & Ferrell, 2002).

Although genetic evaluation of beef cattle so far has generally concentrated on growth traits, there is evidence of sizeable genetic variation in male and female reproductive performance and of favourable genetic relationships between them (Meyer et al., 1991).

Further work on the incorporation of disease resistance traits, as functional traits, could also result in valuable refinements for genetic improvement programs. Hetzel & Seifert (1986) concluded that, where economically viable vaccines, chemical treatments or nutritional supplements exist, it will not be appropriate to select directly for adaptation or disease resistance. However, selection for disease resistance is likely to be improved through the use of molecular genetics and MAS.

3.2.3 Production / growth traits

Growth is a fascinating process. An animal starting from a single fertilized egg grows and develops, through division and multiplication, into a complex unit, capable of carrying out all of life's functions. Animals, in their adaptation to particular conditions of life, have developed a form and function uniquely suited to survival and reproduction (Berg & Butterfield, 1978). Man, in his quest for survival, is not only trying to understand the intricacies of growth but also to manipulate the process regardless of the consequences to the animals. The word "growth" has been used to describe many biological phenomena (Hafez & Dyer, 1969).

Growth and development can be regarded as a stochastic process in continuous time (Tallis, 1968). Moreover, in some situations of primary production, certain growth patterns may be more economical, or otherwise more desirable, than others. Hence, some optimal growth curve can perhaps be specified towards which the average herd performance is to be pushed. Different breeds of livestock are not only characterized by the quality of the primary product, but also by how rapidly, in what quantity, and how efficiently it is produced. Under any specific set of circumstances it makes sense to use the particular breed which has, among other things, the correct growth pattern. Practically, one would probably be satisfied to have the growth curve approach the optimal curve at a finite number of points since intuition suggests that intermediate points would also be brought near optimality automatically. Measurable points on the growth curve would include birth weight (end of prenatal growth), weaning weight (end of pre-weaning growth), yearling weight (average age of puberty for beef and dual purpose breeds – Osterhoff *et al.*, 1979), 18-months weight (average age of first breeding) and mature cow weight (mature weight). Therefore, growth traits usually considered are birth weight (BW), weaning or 200-day weight (WW), yearling or 400-day weight (YW), final or 600-day weight (FW) and mature cow weight (MCW) (Meyer, 1993; 1997; 1999; Bullock *et al.*, 1993).

When comparing growth curves of different species, many of the sigmoid-shaped curves look very similar but on a different scale. It appears that animals grow according to a general standard life program, which determines the animal's design from conception to maturity (Rauw *et al.*, 2000). Specific ontogenetic events, like weaning age and sexual maturity, and their intervals, like gestation length or lifespan, correspond to similar fractions of mature body weight among species. Taylor (1980) generalized this concept with the genetic size-scaling theory, a set of scaling rules which relate all traits associated with growth and metabolism to a genotype-specific genetic size factor (adult body weight) as a general procedure to describe the similarities in all aspects of the growth process of different genotypes. Two major outcomes of the scaling rules are "metabolic age" and "degree of maturity in body weight". Observed phenotypic variation of a trait may therefore, not only be the result of genetic and environmental variation, but also of variation in the stage of physiological development (Luiting, 1998). Compared with genetically small animals, genetically large animals at a fixed body weight grow faster, are leaner and have better feed efficiencies, not because of true superiority in these traits but because the large animals are physiologically less mature than the smaller animals. According to Taylor (1980), the genetic variation can be further divided into scale effects and specific genetic factors (SGF's). It is the SGF's that cause the genotype to deviate from the standard expected values (Taylor, 1985). It is these factors that are of genuine interest for animal breeders. Short-term selection response results mainly from differences in genetic size factors and rarely from differences in SGF's. However, in the long term, SGF's become more important and statistically detectable which means that long-term selection for a single growth trait does more than merely change mature size (Rauw *et al.*, 2000). This viewpoint is in agreement with the conclusion of Venter (1987) that high performing bulls occurred in all frame types, although the larger frame types had the highest percentage of high performers.

In recent years the usefulness of growth rate as a breeding objective has been questioned. Nitter *et al.* (1994) stressed that selection on growth measures only, is far from an optimal strategy while Barlow (1984) concluded that there appears to be little justification for selection for growth rate (direct effects) to improve the efficiency of meat production in breeds that function largely as maternal breeds in favourable environments. Furthermore, although body weight is an important indicator of growth, it fails to indicate body composition of the animals (Fourie *et al.* 2002). Concern is based on the results of a number of studies in a range of species which indicate that whilst increased growth results in higher gross efficiency (gain/feed intake) in growing stock, the higher maintenance costs of heavier breeding females leads to no advantage or even lower efficiency at the herd level (Hetzel & Seifert, 1986). However, growth rate has been advocated as a breeding objective because the criteria (e.g. birth weight, weaning weight, yearling weight) are easy and cheap to measure, normally recorded in genetic evaluation systems (Newman *et al.*, 1992), results are readily visible (Hetzel & Seifert, 1986) and their correlation with the objective is generally high (Ponzoni & Newman, 1989). Hetzel & Seifert (1986) concluded that for the foreseeable future, increased growth rate is a valid breeding objective for the more tropical regions. With increased emphasis being placed on certain traits (growth) in beef cattle it is also important to understand what the effects are on other traits (Bullock *et al.*, 1993). Furthermore, Frisch (1981) and Neser *et al.* (1998) stressed the importance of selection in the environment in which the progeny are to be reared since the genes and alleles governing performance in one environment are only partly the same as those governing performance in another environment.

In a review of the causes, relations and implications of dystocia and stillbirth in cattle, Meijering (1984) concluded that selection for beef traits, like body size, growth rate or muscularity will have a detrimental effect on the level of dystocia. No selection program can, therefore, ignore the effects of dystocia as it is indirectly related to reproductive performance, survival and productivity (Meijering, 1984; Meyer *et al.*, 2001; Arthur *et al.*, 2000; Tozer *et al.*, 2002). Relationships between calving difficulty in heifers and reproductive traits such as calving interval and conception rates are typically highly significant (Amer *et al.*, 1996). Birth weight appears to have value as a trait upon which to base indirect selection to control calving difficulty.

Economic values generated from a simulation study by Bourdon and Brinks (1987a) indicated the importance of selection for rapid early growth (weaning weight, yearling weight) followed by selection for lighter birth weight. Indirect effects on cow herd costs from increased cow size and milk production also need to be included in any realistic evaluation of genetic improvement expected from selection for yearling weight. Selection for faster growth (primarily among bulls) will increase birth weights of calves before it increases cow size (Dickerson *et al.*, 1974). On the other hand, Arthur *et* al. (2000) reported that selection for yearling growth rate increased yearling weight to a higher degree (14%) than birth weight (10%) and could, therefore, reduce the incidence of dystocia (through a more favourable weight ratio). Furthermore, optimal cow size depends on economic conditions (e.g. beef-to-feed price ratio) and the production system (McMorris *et al.*, 1986). This is in agreement with the findings of Notter *et al*. (1979b) that a wide range of size classes is potentially optimal, depending upon prevailing economic conditions. From the results of Groen (1989) it appears that the change in economic efficiency when increasing mature weight is small, but negative. Furthermore, production efficiency, whether expressed in biological or economic terms, should be evaluated for the integrated system, not just the individual animal (Cartwright, 1970; Fitzhugh, 1978). Improvement of production efficiency will involve adjustment of the size of the breeding female to suit a particular environment or adjustment of the environment to suit a particular size or both. Results from Meyer (1999) also showed that weights of adult cows throughout their lives cannot be regarded as repeated measures of a single trait with constant variance and heritability. Genetic correlations between weights on 2-

year-old cows and older animals were less than unity. Table 3.3 summarizes selected heritabilities for certain growth traits.

Table 3.3 Summary of selected heritabilities for growth traits

Trait		h^2	Author
Birth weight	(direct – d)	0.31	Koots *et al.* (1994a)
	(maternal – m)	0.14	
		0.24	Mohiuddin (1993)
	(d)	0.40	Urioste *et al.* (1998)
	(m)	0.15	
	(d)	0.62	Schoeman & Jordaan (1999)
	(d)	0.52	Groeneveld *et al.* (1998)
	(m)	0.07	
Weaning weight	(d)	0.24	Koots *et al.* (1994a)
	(m)	0.13	
		0.20	Mohiuddin (1993)
	(d)	0.30	Urioste *et al.* (1998)
	(m)	0.20	
	(d)	0.57	Schoeman & Jordaan (1999)
	(m)	0.13	
	(d)	0.23	Groeneveld *et al.* (1998)
	(m)	0.13	
Yearling weight	(d)	0.33	Koots *et al.* (1994a)
		0.41	Mohiuddin (1993)
	(d)	0.17	Groeneveld *et al.* (1998)
	(m)	0.06	
Final weight (600 days)	(d)	0.17	Groeneveld *et al.* (1998)
	(m)	0.03	

Table 3.3 continues: Summary of selected heritabilities for growth traits

Mature cow weight	0.50	Koots *et al.* (1994a)
	0.35	Urioste *et al.* (1998)
Feed conversion	0.32	Koots *et al.* (1994a)
Feed intake	0.34	Koots *et al.* (1994a)
Weaning gain (d)	0.29	Koots *et al.* (1994a)
(m)	0.24	
Yearling gain	0.34	Koots *et al.* (1994a)
Post weaning gain	0.31	Koots *et al.* (1994a)
Relative growth rate (RGR)	0. 22	Koots *et al.* (1994a)
Preweaning - RGR (d)	0.71	Schoeman & Jordaan (1999)
(m)	0.22	
Postweaning – RGR (d)	0.13	Schoeman & Jordaan (1999)
(m)	0.04	
Preweaning Kleiber ratio (d)	0.35	Schoeman & Jordaan (1999)
(m)	0.13	
Postweaning Kleiber ratio (d)	0.16	Schoeman & Jordaan (1999)
(m)	0.03	

Absolute and relative growth rate in the same age interval were genetically highly correlated (Fitzhugh & Taylor, 1971). However, the genetic correlations with weight were much lower for relative growth rate than for absolute growth rate. Hence, an increase in absolute growth rate with little concomitant increase in weight to be maintained could be accomplished by selection for relative growth rate. Absolute growth rate is defined as an animal's change in weight over time while relative growth rate is defined as an animal's growth rate relative to its current weight (Prinsloo, 1997). Selection for either post-weaning (200 to 452 days) or post-natal (birth to 452 days) relative growth rate would seemingly be an effective criterion for changing the shape of the growth curve (Smith & Cundiff, 1976; Smith *et al.*, 1976).

Another production trait to consider in the development of breeding objectives is milk yield. Milk yield of beef cows is positively related to efficiency of beef production from birth to weaning and from birth to slaughter (Miller & Wilton, 1999). Evaluating animals for milk yield when selecting in commercial situations is accomplished through genetic evaluations for maternal weaning gain (maternal environment). The genetic correlation between maternal weaning gain and milk yield is important to determine how effective selection for the indicator trait, maternal weaning gain, can be at changing the economically important trait, milk yield. Meyer *et al*. (1994) indicated that milk production is the main determinant of maternal effects on the growth of beef calves with breed differences in the importance of maternal effects largely attributable to differences in milk production. In considering maternal effects, it is usually distinguished between a genetic component and a permanent environmental component due to the cow. When maternal effects are ignored, direct heritability (h^2) estimates were inflated substantially, in particular for growth till weaning (Meyer, 1992).

Results from computer simulation (Notter *et al*., 1979a) suggest that for a given environment, a feasible range of milk production levels can be defined. Milk yields within the feasible range are potentially optimal, depending on the relative costs of forage and concentrate feeds. Production levels outside the feasible range, however, are incompatible with acceptable calf survival (very low milk production levels) or cow fertility (high milk production levels). The feasible range was broad in good environments but was sharply constricted in poor environments.

Cows need to have adequate condition at parturition or be increasing in weight at mating to minimise the postpartum interval. Therefore, it is necessary to ensure that the maintenance energy requirements of cows are met during the period between parturition and breeding. Two characteristics that influence the ability of a cow to meet maintenance nutrition requirements are milk production and mature weight (Bullock *et al*., 1993).

3.2.4 Product / product quality traits

The consumer’s decision to buy meat and meat products forms the basis of the meat industry (Naudè, 1985). Consumers have widely diverging expectations of the product of which their own conception of “value” is the most important parameter, i.e. the quality and quantity of the product relative to other foods and consumer commodities. Meat quality, as defined by Naudè (1985), comprised five categories, namely appearance, palatability, nutritive value, processibility and shelf-life. This is in agreement with Shorthose (1991) who considered quality traits under the headings of appearance, eating quality, keeping quality and retail display life. Important aspects of palatability are tenderness, marbling, flavour, juiciness and aroma. These quality characteristics are influenced biologically and technologically, and finally established during the different stages of the meat production chain which form part of an integrated system covering the entire range from conception to consumption. To satisfy the consumer, combining genetics and technology (effective pre- and post-slaughter protocol) seems obvious. Applying technology to remedy a poor quality product is costly, would render the product more expensive and less acceptable. However, the relative low genetic variation and inconsistent genetic correlations in temperate breeds suggest that genetic improvement in beef tenderness may be less important than effective pre- and post-slaughter management protocols (Robinson *et al*., 2001).

Melton (1995) concluded that consumer judgments regarding meat acceptability or non-acceptability do not directly translate into differences in either the price or quantity of meat purchased and that these important relationships can not be properly examined except in the context of market price-quantity (or demand) relationships. These findings support the general believe that the current beef market, at least at the weaned calf level, is dominated by “average price purchasing” in which genetic post-weaning or consumption superiority (or inferiority) is not adequately reflected by price premiums (discounts). According to Melton (1995) the long-term survival and prosperity of the beef industry depends, therefore, on its economic viability, which is better served by improving its competitiveness, profitability and economic efficiency than by (unduly) focusing on characteristics that customers may want, but for which they are unwilling or unable to pay. However, Lusk *et al*. (2001) found that, when tenderness was known to consumers, 84% preferred and 51% were willing to pay for the guaranteed tender steak. Surveys of beef packers, purveyors, restuaranteurs and retailers indicated that product uniformity, consistency and tenderness were among the highest ranked beef quality concerns (Lusk *et al*., 2001). Hearnshaw & Shorthose (1995) as quoted by Robinson *et al*. (2001) reported that, among these quality traits, consumers have consistently rated tenderness as the most important contributor to beef palatability in all markets.

The economic value of slaughtered animals is determined by carcass weight, dressing percentage and carcass quality (Wolfovà *et al.*, 1995). Although carcass weight and dressing percentage are clearly defined traits, carcass quality may be characterized in different ways. Indicators of carcass quality can be roughly subdivided into two groups: (1) indicators measured on a continuous scale (lean meat, fat percentage, fat depth) and (2) indicators measured on an ordered categorical scale (classes for fleshiness and fat covering). The price per kilogram of carcass is usually determined by ordered categorical traits.

In South Africa the opening of export markets for meat, the increase in consumer awareness and preferences for a certain (and consistent) quality product as well as the need for traceability will increase the need for a formal genetic evaluation system for carcass traits. The production of better quality red meat may be achieved, in part, through genetic selection provided that consumer demand dictates change through the entire market chain back to the producer and that packers buy fed cattle in a manner that will reward producers for putting selection emphasis on carcass traits (Woodward *et al*., 1992). However, if processors do not pay producers for differences in carcass value, the producers will seek stocks improved for reproductive and growth traits, and not for carcass traits. Heritabilities for carcass traits are summarised in Table 3.4.

Table 3.4 Summary of selected heritabilities for carcass traits

Trait	h^2	Author
Backfat (constant age – a)	0.44	Koots *et al.* (1994a)
(constant finish – f)	0.43	
(constant weight – w)	0.46	
(bulls -12 months)	0.50	Crews & Kemp (2001)
(bulls -14 months)	0.35	
(heifers -12 months)	0.44	
(heifers -14 months)	0.49	
Cutability (a)	0.47	Koots *et al.* (1994a)
(w)	0.48	

Table 3.4 continues: Summary of selected heritabilities for carcass traits

Carcass weight (a)	0.23	Koots *et al.* (1994a)
(f)	0.36	
(w)	0.24	
Dressing percentage (a)	0.39	Koots *et al.* (1994a)
(w)	0.38	
	0.22	Gregory *et al.* (1995b)
Lean - to - bone ratio	0.63	Koots *et al.* (1994a)
Marbling (a)	0.38	Koots *et al.* (1994a)
(f)	0.65	
(w)	0.36	
	0.38	Barwick & Henzell (1999)
	0.45	Gregory *et al.* (1995b)
Market weight (a)	0.41	Koots *et al.* (1994a)
(f)	0.56	
(w)	0.48	
Rib eye area (a)	0.42	Koots *et al.* (1994a)
(f)	0.40	
(w)	0.41	
(bulls - 12 months)	0.61	Crews & Kemp (2001)
(bulls - 14 months)	0.52	
(heifers - 12 months)	0.49	
(heifers - 14 months)	0.47	
Tenderness	0.29	Koots *et al.* (1994a)
Tenderness score	0.12	Gregory *et al.* (1995b)
Shear force	0.05	Gregory *et al.* (1995b)

Ultrasonic scanning technology has been developed to allow the scanning of eye muscle area (EMA) and fat depth (McDonald, 1991b) while a model has also been developed to provide EBV's for both carcass quantity and quality traits (e.g. backfat thickness) utilizing both scanned and direct carcass measurements. Real time ultrasound (RTU) is considered a cost effective method to measure carcass merit for the genetic evaluation of carcass merit (subcutaneous fat depth, longissimus muscle area) in potential replacement beef cattle (Crews & Kemp, 2001). Crews & Kemp (2001) indicate that longissimus muscle area and backfat may be under sufficiently different genetic control in bulls vs. heifers to warrant being treated as separate traits in genetic evaluation models. Furthermore, traits measured using RTU in potential replacement bulls and heifers at 12 and 14 months of age may be considered different from the corresponding carcass traits in steers. Ponzoni & Newman (1989) also proposed to consider the same trait in male and female progeny as two different variables.

The increasing importance of carcass traits (product quality traits) is clearly demonstrated by the fact that (in beef cattle) meat quality has to date received much of the attention in the search for QTL (Quantitative Trait Loci) (Van Marle-Köster & Nel, 2003). The reason that tenderness is the focus of QTL studies is because it is difficult to change tenderness through more traditional methods. The primary reason for this is that tenderness is not routinely measured, due to the high cost, and widespread EBV's are, therefore, not calculated. Diagnostic tests for a major gene for marbling as well as tenderness have now been developed and are commercially available. The use of DNA marker technology, therefore, provides a means to identify carriers of the major genes (QTL's) for marbling as well as tenderness. These developments will, in future, facilitate the inclusion of product quality traits in performance recording schemes as well as in breeding objectives.

Woodward *et al*. (1992) concluded that selection for weight traits may result in calves that yield more weight of retail cuts at younger ages with less external fat without deleteriously affecting marbling, thus maintaining carcass quality. Woodward *et al*. (1992) therefore suggested that, due to the paucity of carcass data (which is still the case in South Africa) breeders should, in the meantime, continue to put primary selection emphasis on reproductive and growth (direct and maternal) traits. Adding pre-weaning growth information to genetic evaluations for carcass traits slightly decreased prediction error variances for breeding values and would be recommended when information on carcass traits is limited (Crews & Kemp, 1999).

Observed breed differences in lean-to-fat ratio at varying ages may be indicative of variation among breeds for appetite (Jenkins & Ferrell, 2002). In general, breed ranking for body fat at 450 days, was similar to the ranking among breeds for appetite. Results furthermore suggested substantial genetic variation in appetite among breeds.

To increase the market share of red meat the production of highly palatable meat is a challenge for the beef industry. Where genetic improvement is feasible, it provides permanent benefits for the beef industry. Before a genetic evaluation program for improving beef tenderness can be justified several steps are required. Firstly, the cost of the measuring and data collection relative to the benefits of selection will need to be quantified. Secondly, the relationship between mechanical measures of beef tenderness and the economically important trait of consumer-determined tenderness will need to be quantified. Thirdly, the necessity of some form of incentive for breeders and producers is obvious. Finally, for this trait to be improved by selection, more extensive use of Marker Assisted Selection (MAS) should in future find greater application.

3.2.5 Type traits

Type traits are usually features of a more aesthetic nature where personal preference is important. These traits are subjectively scored and cannot be measured directly like most quantitative traits. Type traits may include scores for conformation (physical appearance), feet and legs, udder and teats as well as coat colour and coat type. Aspects of structural soundness would also be included.

Cattle breeders in general are showing increasing interest in the muscularity of their cattle since the more muscular cattle, at the same level of fatness, generally have a higher dressing percentage and increased yield of saleable meat. The traditional visual scoring systems were reported by Robinson *et al*. (1992) to be quick, cheap and simple. However, assessment of muscularity by direct measurement of muscle area using ultrasound (RTU) has been shown to be costly but accurate and repeatable.

In a study to compute economic values for dairy cattle traits, St-Onge *et al*. (2002) concluded that a unit genetic increase in conformation affected profitability measurements positively and a unit genetic increase in capacity tended to decrease the profit of dairy cows. Capacity of cows was related to stature and size of the animal. Cows with longer productive life had higher lifetime profits. Longer productive life (herd life) may be due to higher longevity, lower selection pressure or better conformation where conformation included feet, legs and mammary system (structural soundness). However, De Haan *et al.* (1992) concluded that physical characteristics of dairy cows did not enable prediction of lifetime profit with appreciable greater accuracy than production alone. Perhaps the influence of random or environmentally mediated variation on individual cow profit is so overwhelming that the influence of individual type traits cannot be detected (De Haan *et al.*, 1992). Although, Erasmus *et al*. (2001) indicated that selection improvement for acceptability (visual appraisal) in Merino sheep is possible, the relationship between acceptability and performance is not stated. On the other hand, Heyns & Rautenbach (1984) indicated a statistically significant but negative relationship between standards of excellence for breed characteristics in Afrikaner cows and the pre-weaning performance of their progeny. Visual appraisal should, therefore, be directed at functional efficiency and should be combined in a balanced way with breeding values.

3.2.6 Input traits

Profitability of beef production depends on both inputs and outputs. In the past, genetic improvement has been aimed mainly at output traits such as fertility and body weight, and more recently carcass and meat quality traits, with little emphasis placed on reducing inputs (Arthur *et al.*, 2001). Providing feed to cattle is the single largest expense in most commercial beef production enterprises. Feed intake is generally correlated with output traits, and therefore examination of feed intake or production outputs in isolation of each other usually provides little or no indication of the efficiency of production. Furthermore, production system feed efficiency depends on the feed inputs and production outputs of several classes of livestock within the production system and it is, therefore, not possible to measure production system efficiency on individual animals (Archer *et al*., 1999). It is important to determine whether variation exists in context of the whole production system, including both the breeding herd and the slaughter generation. Several traits determine production system feed efficiency, and the required balance of these traits is likely to differ between different production systems. The cost of providing feed to grazing animals is, however, difficult to quantify (Arthur *et al.* 2001). Notter (1986) also stressed that the development of breeding objectives for beef cattle requires consideration of the available feed resources. Important genotype x environment interactions may be observed. Under conditions of nutrient restriction, antagonistic phenotypic relationships may also be observed among traits such as milk production and reproduction (Notter, 1986).

It has been estimated that the cow herd (cow-calf component of the production cycle) uses approximately 72% (65 – 85%) of the energy required for beef production (Archer *et* al. 1999; Jenkins & Ferrell, 2002). Furthermore, feed cost for maintenance is estimated to represent at least 60 to 75% of total feed requirements for the cow herd, with considerable variation among individual animals independent of their body size (Koch *et al*., 1963; Archer *et al.*1999). The cost of keeping breeding cows is clearly an important factor in determining the efficiency and profitability of beef production systems.

Ferrell & Jenkins (1985) showed that energy is required for maintenance, growth, gestation and lactation, and that requirements for each of these functions vary among cattle types. Variation in maintenance requirements appear to be greater than variation in requirements for growth, gestation and lactation. According to Archer *et al.* (1999) the physiological basis of variation in feed efficiency are differences in maintenance requirements, differences in body composition and composition of gain, differences in the relative proportion of visceral organs, and physical activity. Ferrell & Jenkins (1985) furthermore concluded that metabolism of visceral organs constitutes a major proportion of total animal energy expenditures. Maintenance efficiency can be defined as the ratio of body weight to feed intake at zero body weight change (Archer *et al*., 1999). Although maintenance efficiency in general and more specific the metabolism of visceral organs is clearly of great importance, there are practical difficulties associated with its measurement.

Factors that affect the energy required for production either directly or indirectly influence efficiency. With an increased genetic potential for mature size, both post weaning growth and milk yield will affect the efficiency ratio. This effect is mediated both through increased output and higher energy requirements. This greater energy need may again affect cow efficiency through introduction of an energy constraint to reproduction by extending the post partum interval and reducing fertility. Therefore, if feed utilization is to be improved, reducing the amount of energy expended on maintenance without reducing appetite appears to be desirable (Jenkins & Ferrell, 2002). Selection to reduce the maintenance requirements of the producing female could also have negative effects on reproductive performance. Rather than seeking to reduce energy requirements for maintenance, perhaps stabilizing these requirements over a wide range of nutritional scenarios is more desirable. Fitzhugh (1978) suggested that differences in output and input requirements among genotypes may lead to important genotype x environment interactions. Therefore, an efficient cow for one producer may be ineffective under a different management program under different market scenarios or a different nutritional environment.

Koch *et al*. (1963) compared three measures of feed efficiency: (1) feed consumption adjusted for differences in gain, (2) gain adjusted for differences in feed consumption and (3) ratio of gain to feed. Selection for gain and efficiency should be effective and lead to increased feed efficiency while selection for feed consumption should lead to no improvement in efficiency. However, efficiency expressed as gain adjusted for differences in feed consumption (i.e. ± deviation from the regression of gain on consumption) was considered the most accurate mathematical description of the cause and effect relationship and resulted in the highest h^2 of the three measures studied. Therefore, residual (net) feed intake, as an alternative measure of feed efficiency, was proposed by Koch *et al*. (1963). It is the difference between actual feed intake and the expected feed requirements for maintenance of body weight and some measure of production (such as growth in beef cattle). The residual portion of feed intake can be used to identify animals that deviate from their expected level of feed intake, with efficient animals having lower (negative) residual feed intakes.

The review by Archer *et al.* (1999) indicates that genetic variation in feed efficiency exists for growing cattle and for cattle at maintenance. Measures of feed efficiency that incorporate both live weight and ADG (gain) seek to capture some of the underlying variation in feed use for both growth and maintenance. The expectation is that when such a trait is used for selection the resultant progeny will be efficient as steers for slaughter as well as mature cows in the breeding herd where growth has virtually ceased and efficiency of feed use for maintenance is of prime importance (Arthur *et al*., 2001). Post weaning feed efficiency, generally expressed as the feed required per unit of gain, or the reciprocal, is an important component of the life cycle efficiency of beef production and as such merits consideration in selection programs. Arthur *et al*. (2001) indicate that genetic improvement in feed efficiency can be achieved through selection and, in general, correlated responses in growth and other post weaning traits will be minimal.

Although selection for improved feed conversion ratio, whether by direct or indirect selection, may improve efficiency during the growth and finishing phase of beef production, it will not necessarily improve the efficiency or profitability of the entire production system. Genotypes with high growth rates, and hence improved feed conversion ratio, also tend to have high mature cow weights and consequently higher feed requirements for the cow herd. Feed conversion ratio of growing animals is largely a function of maturity patterns and if an increase in feed requirements of the breeding herd offsets the gains in growth efficiency there will be no change in production system feed efficiency. However, a gain in economic efficiency may result if the value of feed for the slaughter generation is higher than for the breeding herd (Archer *et al.*, 1999). Barlow (1984) concluded that an increase in mature size will have little impact on production system feed efficiency in maternal breeds while Archer *et al.* (1999) concluded that feed conversion ratio of growing animals is unlikely to be correlated with feed efficiency of beef production systems when requirements for the breeding herd are included.

Feed conversion ratio is expressed as a ratio, whereas residual feed intake is a linear index. The use of ratio and product traits for genetic selection presents problems relating to the prediction of the change in the component traits in future generations (Simm, *et al.*, 1987). This is due to the disproportionate fashion by which selection pressure is exerted on the component traits. A linear index, however, places a predetermined amount of selection pressure on the traits and thus results in a predictable amount of genetic change (Arthur *et al.*, 2001). Given the associated problem with selection for ratio traits and the fact that residual feed intake is strongly correlated with feed conversion ratio, Arthur *et al.* (2001) suggested that residual feed intake should be the preferred trait (criteria) for genetic improvement in post weaning feed efficiency.

Gunsett (1984; 1987) concluded that heritability (h^2) estimated from the intra-class correlation among half-sibs does not provide an accurate method to determine genetic change for a ratio trait (R) (e.g. feed conversion ratio) and would impair the ability to predict genetic progress if it were used in developing the selection criterion. The discrepancy between the realized heritability (H^2) and h^2 supports the idea of utilizing the components of the ratio trait in a linear index when the selection goal is to maximize the genetic change in the ratio trait. Davis (1987), however, indicated little advantage to the use of an index of feed intake and gain in place of the feed: gain ratio if the goal is to bring about genetic improvement in post weaning feed conversion of beef cattle.

Archer *et al*. (1999) discussed strategies to improve feed efficiency by selection. The feed efficiency and profitability of beef production systems are determined by the performance of cattle of different classes (breeding cow, growing animals) with different functions in the system. These different classes of cattle are often managed under different conditions. The challenge is to identify genotypes which provide the optimum balance of traits to maximize profitability and/or feed efficiency of the production system. Selection to produce efficient and profitable genotypes for beef production must therefore account for genetic relationships (whether favourable or unfavourable) between traits expressed in different sectors of the production system. As the majority of feed used for beef production is consumed by the breeding herd, it would seem logical to target a reduction in feed consumed by breeding cows as perhaps the best way to improve feed efficiency of beef production. However, the breeding herd normally uses feed which is of lower quality and relatively cheap, whereas stocks which are being finished for slaughter generally consume higher quality, more expensive feed. Therefore, the feed consumed by growing animals is also of importance. Archer *et al.* (1998) suggested that selection on residual feed intake of growing animals may lead to a favourable correlated response in residual feed intake of mature animals in the breeding herd. An alternative strategy for improving efficiency would be to identify one or more traits which are genetically correlated with efficiency and could be used to select indirectly for efficiency. The difficulty and expense of measuring feed intake and efficiency means that the concept of a cheap indirect indicator of feed efficiency is attractive. The cost of measurement compared with the benefits obtained is an important issue if performance testing of animals for feed efficiency is to be used to select animals. There are three options that could be used for direct measurement of feed efficiency. These include centralized testing facilities, on-farm testing or measurement of feed intake on pasture. Measurement of feed intake on pasture is currently not suited to measuring feed efficiency of individual animals (Archer *et al*., 1999).

The Cornell Value Discovery System (Fox *et al.*, 2002) provides a method for determining feed required for individuals fed in a group on a biological basis, considering differences known to affect requirements (breed differences, body weight and mature size, stage and rate of growth, and diet composition). An analysis of data by Fox *et al*. (2002) indicated these variables accounted for 83% of the variation in feed efficiency. The remaining 17% of the variation in feed efficiency (primarily differences in basal maintenance requirements and efficiency of use of absorbed energy) are, at present, impractical to measure in commercial feeding situations (Fox *et al*., 2002).

As biological and economic efficiency are not necessarily synonymous, the target of most breeding programs should be to improve profitability or economic efficiency. Therefore, when formulating criteria on which selection decisions are based, the economic target should be recognized. Indices of efficiency mentioned (e.g. feed conversion ratio) are biological indices which combine component traits of feed intake and growth in different ways. When biological indices are used in selection programs, the relative selection emphasis placed on the component traits are determined by the variances and covariances of the component traits (Simm *et al*., 1987). This does not account for two important pieces of information. Firstly, biological indices do not directly account for correlations with traits not included in the index. Secondly, selection on biological indices does not recognize that the true target of the breeding program is to improve economic efficiency. An alternative method for using information on feed intake and growth in selection is to incorporate the traits into an economic selection index which uses both biological and economic parameters to determine appropriate weightings for selection criteria traits (Archer *et al*., 1999). When it is recognized that profitability or economic efficiency is the real target, economic indices are preferable to biological indices. Economic indices provide a framework whereby relationships between all traits of economic importance influence the relative emphasis placed on the criteria traits. Selection decisions are, therefore, optimized in terms of the true economic target (Hazel, 1943).

3.2.7 Behavioural Traits

Behavioural traits are increasingly important in so far as animal welfare (Willis, 1991); the social acceptability of husbandry practices and even the quality of animal products (Preston & Willis, 1975) are concerned. Animal behaviour is the overt and composite functioning of animals individually and collectively (Fraser, 1980). Behaviour is also the means whereby the animal mediates dynamically with its environment, both animate and inanimate. Behaviour in mature animals is a mixture of inherited, or innate, and acquired components. Innate components consist of simple reflexes, compound responses and complex behaviour patterns while acquired components consist of conditioned reflexes, learned responses and general habits. These various components can mix and create a great range of behaviours. Important components of behaviour include reactivity, ingestion, exploration, kinesis, association, body care, territorialism and rest (Fraser, 1980).

Docility or temperament, defined by Burrow & Corbet (2000) as an animal's behavioural response to handling by humans, can be regarded as one of the more important behavioural traits. Under extensive grazing systems, the economic value of temperament arises mainly through a reduction in production costs (for more docile animals). Under intensive systems the economic value of temperament (less docile) also arises from losses in production. Several researchers demonstrated the negative influence of bad temperament on the growth and feedlot performance of animals, conception rates following A.I. programs as well as the appearance and tenderness of beef (Tulloh, 1961; Preston & Willis, 1975; Fraser 1980; Dalton, 1981; Fordyce *et al.*, 1985; 1988). Stressed animals are also, by nature, predisposed to disease (Fraser, 1980).

Burrow (1997) reported that tests used to measure temperament could be categorised into non-restrained and restrained categories. Few commercial beef producers regularly handle their cattle in restrained situations, but they have a much greater requirement to muster, move and draft cattle for routine management purposes. Hence, ease of handling in paddocks or yards is likely to be the preferred trait for improvement in commercial enterprises. Temperament can be scored subjectively at weaning or shortly afterwards (Sundstrom *et al.*, 2001). The behaviour of each animal is scored on a 1-5 scale as docile, restless, nervous, wild or aggressive. An objective measurement (flight time) has also been developed to measure temperament (Burrow & Corbet, 2000). It is a test in the non-restrained category that is safe, quick and simple to implement on-farm.

Burrow (1997) concluded that temperament of beef cattle is unlikely to be modified significantly by management practices such as short term intensive training of young animals. However, it was concluded by Burrow & Corbet (2000) that temperament was at least moderately heritable ($h^2 = 0.35\text{-}0.50$ for flight speed) and should respond to selection.

3.2.8 Alternative criteria

The possibility of improving a trait while selecting another, positively correlated one in the opposite direction is of considerable importance to breeders. An example would be the combination of high early weight gain and low mature weight. Mohamed *et al*. (1998) concluded that selection in opposite directions can be successful insofar as it changed the traits in the desired direction. However, this was achieved with considerable cost as gains were 10 to 15 % of gains of direct, unimpeded selection. It is therefore obvious that the choice of criteria is of great importance.

The importance of fast growth rate and high weaning weights in beef cattle is not debatable. Unfortunately, high weaning weights are being associated with increased birth weights and thus an increase in calving difficulties (Bellows *et al*., 1971). Meijering (1984) and Tozer *et al*. (2002) concluded that feto-pelvic incompatibility, because of calf size or pelvic dimensions of the dam, seems to be the most important single cause of dystocia. Dystocia is a major determinant of stillbirth incidence (Meyer *et al*., 2001) and therefore of economic loss (Bourdon & Brinks, 1982; Arthur *et al*., 2000). Similarly, high weaning weights are being associated with high mature weights and corresponding increases in maintenance requirements of the breeding female (Burrow *et al*., 1991). There are also indications from the literature that selection for increased body weight or growth rate may have an adverse effect on fertility and viability (Scholtz & Roux, 1984; Scholtz *et al*., 1990) as well as longevity (Luesakul-Reodecha *et al*., 1986). A negative association between production and fertility has also been observed in several dairy cattle breeds (Olori *et al*., 2002). This decline in reproductive efficiency has been attributed to selection for increased production.

Consequently, researchers have considered some alternative criteria to overcome these undesirable correlated responses. Fitzhugh & Taylor (1971) suggested proportional or relative growth rate as a strategy to alter the shape of the growth curve, while Scholtz & Roux (1988) and Bergh *et al*.(1992) proposed the use of the Kleiber ratio (growth rate/metabolic weight) as another alternative to improve growth efficiency.

A restricted selection index, which allows for selection for weaning weight while restricting change in birth weight, is another way of altering the shape of the growth curve (Dickerson *et al*., 1974; Bourdon & Brinks, 1982; Mendoza & Slanger, 1985; Winder *et al*., 1990). These criteria have, however, either been evaluated using limited data or without taking the maternal components thereof into consideration (Schoeman & Jordaan, 1999). There is also a fundamental difference in philosophy between economic selection indices and restricted or desired gains indices (Gibson & Kennedy, 1990). With economic selection indices, the response to selection is entirely determined by the economic values of the traits contributing to economic merit, the phenotypic covariances among the traits in the index, and the genetic covariances among the traits in the index and the traits of economic interest. With restricted and desired gains indices, there are predetermined constraints on genetic response of some traits that partially or completely override the response determined by their economic values. In the case of restricted indices, economic values for the restricted traits are not defined. Justification for the use of restricted or desired gains indices has been either that some traits are considered already at an economic optimum or economic values are difficult or impossible to determine.

Van der Westhuizen (1997) suggested that the use of cow efficiency (measured as a trait of the calf), in combination with traits like weaning weight (direct and maternal EBV's) and age at first calving (as a predictor to mothering ability) could lead to effective selection relatively early in the productive life of the animal.

A number of estimates (using field data) of genetic correlations between direct and maternal effects have tended to be negative (Bertrand & Benyshek, 1987; Cantet *et al*. 1988; Swalve, 1993; Waldron *et al*. 1993; Koots *et* al. 1994b; Van Vleck *et al*. 1996; Meyer, 1997). Clearly an antagonistic relationship between direct and maternal effects would have consequences for the breeding program (Swalve, 1993). However, Mendoza & Slanger (1985) concluded that maternal ability can be improved by selection on weaning weight, regardless of whether or not direct and maternal effects for weaning weight are negatively correlated genetically. Robinson (1996), on the other hand, concluded that negative correlations between direct and maternal genetic effects were a consequence of other effects in the data, rather than evidence of a true negative genetic relationship. Estimation of maternal effects and the corresponding genetic parameters has always been considered problematic. Not only are direct and maternal effects generally confounded, but the expression of maternal effects is sex-limited, occurs late in the life of the female and lags by one generation (Willham, 1980). Robison (1981) suggested that selection for maternal effects should be based on weights at 90 days or on direct estimates of milk production, whereas selection for growth should be based on post weaning growth. More recently the availability of Restricted Maximum Likelihood (REML) algorithms for analyses fitting an animal model has become popular in the estimation of variance components. Such analyses allow the separation of the animal's direct, maternal direct, maternal permanent environment and residual components (Meyer, 1997).

Schoeman & Jordaan (1999) suggested a selection index, calculated by applying a procedure described by Cunningham *et al*. (1970), with cow efficiency and pre-weaning Kleiber ratio as alternative selection criteria for a multi-breed synthetic beef cattle herd.

An examination of lifetime cow fertility in the tropics showed that cows with high pre-weaning growth reared more calves to weaning, had less neonatal mortality and calved earlier than cows with low pre-weaning growth, leading to the conclusion that cows with high weaning weight per day of age have improved lifetime fertility (Burrow *et al*., 1991). Selection for high weaning weight per day of age resulted in increased live weights at all ages in all genotypes, with the exception of birth weight in Bos Taurus. Overall parasite and heat resistance did not change significantly as a result of selection (Burrow *et al*., 1991).

Scrotal circumference (SC) has been found to be favourably correlated with several growth and reproductive traits e.g. total sperm production, semen quality, age at puberty, first breeding and first calving in females, as well as pregnancy rates (Kriese *et al*., 1991). According to Kriese *et al*. (1991) SC may provide the selection link between growth and reproductive performance and selecting bulls with larger SC should not adversely affect the birth weight of their progeny.

Analysis of several selection indices combining birth weight and yearling weight, gestation length and yearling weight indicated that continued response to selection for growth without excessive increase in birth weight is feasible (Bourdon & Brinks, 1982). Both indices resulted in shorter gestation, but the index combining YW and BW also had the capability of selecting individuals whose BW was acceptable for reasons other than short gestation. Thus, it appears that unless shorter gestation is desired for its own merits, inclusion of gestation length in a combined selection scheme would be ineffective. The better method would be to select for post natal growth and acceptable birth weight.

As it is common practice to keep cows on natural pasture and to feed slaughter animals to market finish in feedlots on concentrate diets, a system of feeder-breeder dimorphism (large offspring for slaughter from small breeding animals) would be profitable (Theron *et al*., 1994). According to Roux (1992) feeder-breeder dimorphism can be achieved through terminal crossbreeding and by manipulating growth. Evidence favourable to the dietary induction of feeder-breeder dimorphism follows from observations by Falconer (1960) and Bateman (1974) that gains in the favourable environment did not carry over to the less favourable (extensive) conditions. It is therefore important to estimate the genetic relationships for different traits between intensive and extensive conditions and to formulate alternative selection criteria based on these findings. There must however, be a clear distinction between intensive and extensive tests/environments since selection for post weaning growth, especially when taking place in the same environment of production and reproduction, will lead to lower productivity in the cow-calf unit (Van der Westhuizen, 1997).

Nitter *et al.* (1994) showed positive economic responses for growth and reproduction whereas the economic response in carcass value, maintenance and calving difficulty were negative. This unbalanced economic response of the different traits in the breeding objective found by Nitter *et al*. (1994) might be expected to change with the availability of other selection criteria. Graser *et al*. (1994a) concluded that breeding schemes which utilize performance recording beyond traditional weight measures were more profitable. More intensive performance recording should therefore lead to a more balanced genetic gain, especially in fertility and carcass traits.

Undoubtedly breeders' attention has been diverted by growth rate in the past. Breeders and researchers alike have tended to consider alternative criteria either to difficult to measure or offering to slow a means of progress. We will need to examine alternative criteria, their genetic variances, correlations with the objective and the benefits and cost associated with including them in multivariate (multitrait) selection indices.

3.3 CONCLUDING REMARKS

It is obvious from the discussion that a linear selection index is the best method to increase profitability of beef production. To build selection indices, economic values are needed as well as genetic and phenotypic parameters. Economic values are indicators of the economic importance of traits, but without any knowledge of heritabilities, genetic and phenotypic variances and covariances of traits, new selection indices cannot be built. Lack of relevant economic and genetic parameters is often a limitation in deriving selection indices and results may depend on the parameters used. The decision whether or not to include a trait in the breeding objective depends on the relative economic value of the trait, the potential for genetic improvement and the possibility of accurate and cheap measurement.

With some exceptions, performance recording was based solely on weight (growth) records, reproductive and carcass traits were neglected and feed intake (on pasture) was completely ignored. However, reproductive and carcass traits are now seeing more emphasis in selection and mating programs. There is also resurgence in the recording of feed intake under intensive production systems. Meanwhile there is a need to seek alternative selection criteria which are correlated with the breeding objectives defined at herd or breed level.

Efficiency of beef production depends on the summation of many traits expressed in the breeding herd as well as in the slaughter generation. These traits include feed intake of the breeding herd and the slaughter generation, growth traits, and other traits which influence the age structure of the herd (such as reproductive rate). Furthermore, the relative importance of each trait to determine efficiency will differ according to the production system. Consequently, the overall efficiency of a beef production system is a complex biological trait (Archer et al., 1999). According to Vercoe & Frisch (1990) beef cattle productivity is a function of fitness (fertility, mortality), growth and carcass composition. This is in agreement with the general consensus regarding the importance of reproductive and growth traits. No trait, group of traits or the effects thereof can, however, be seen in isolation and a holistic approach is always needed. Bourdon and Brinks (1987a) also emphasized the importance of interactions among genotype, management system and economics, to overall herd efficiency.

Genetic types are required that can maintain acceptable levels of performance in all primary productive functions (growth, gestation, lactation, reproduction) in the environment of interest. In developing selection criteria, one must be aware of potential antagonisms among production traits such that improvement in genetic merit for one trait may limit the expression of genetic potential for other traits. These antagonisms may also act at a phenotypic (nutritionally mediated) rather than genetic level (Notter, 1986).

From the discussion it seems that traits to be included in the breeding objective would include the fitness traits, days to calving, scrotal circumference and calving ease (direct and maternal). Production traits to include would be birth weight, weaning weight (200 days), yearling weight (400 days), final weight (600 days) and mature cow weight. Product traits included traits related to carcass weight and carcass quality. Dressing percentage, fat level, fat distribution and marbling, rib eye area and tenderness should be considered. As input traits residual feed intake and mature cow weight should be included. Pre-weaning Kleiber ratio as well as maternal weaning gain should be considered as possible alternative criteria.

It should also be remembered that selection progress is only sustainable under certain conditions. Some of these conditions are:

- an increase in herd productivity in terms of fitness and efficiency;
- a decrease in the risk of mortality and low fertility associated with dystocia;
- the effective management of genetic resources especially in terms of retaining genetic variability;
- an increase in the net income (profitability) of the herd;
- acceptance of the methods employed and acceptance of the final marketable product by consumers.

CHAPTER 4

Derivation of economic values for the Simmentaler breed in South Africa: Production / Growth traits

4.1 INTRODUCTION

Animal breeding is part of the strategic (long term) planning of production (Groen *et al*., 1997). Breeding is aimed at changing the genetic merit of animals in coming generations, so that they can produce the desired products economically more efficient (relative to the present generation) under future economic, natural and social circumstances (Dekkers, 1991). Development of the breeding program involves three major steps. The first step, the breeding goal definition, includes definition of the aggregate genotype and deriving discounted economic values. The second step is breeding value estimation. This step includes deciding what traits to include in the index as well as derivation of regression coefficients (b - values) to be included in the index. The third step is breeding program optimisation.

Hazel (1943) defined the breeding objective (aggregate genotype) as a linear function ($H = ?\ a_iG_i$) of the economically important traits to be improved and the discounted economic values for these traits, where H = aggregate breeding value, a_i = discounted economic value for trait i and G_i = breeding value for trait i. Also, $\mathbf{a} = \mathbf{c'v}$, where **c** is a m x 1 vector of cumulative discounted expressions of m aggregate genotype traits and **v** is a m x 1 vector with economic values of m aggregate genotype traits in a specific situation (Groen, 1990). Information on several traits can be combined in an index by a special use of Fisher’s discriminant function as proposed by Smith (1936) and Hazel (1943). Hazel (1943) presented a multiple correlation method of constructing optimum selection indices. However, to solve the simultaneous equations the economic parameters (relative economic values), genetic parameters (heritability, genetic correlations) and phenotypic parameters (standard deviation, correlations) of/among traits must be known.

Methods to derive economic values can be divided in objective and non-objective methods (Groen *et al*., 1997). The principle tool in objective methods is modeling (systems analysis) where a model is an equation or a set of equations that represent the behaviour of a system. Two approaches of systems analysis can be distinguished: (1) The positive approach or data evaluation and (2) the normative approach or data simulation (Harris & Freeman, 1993; Weigel *et al.*, 1995). For data simulation models, the terms "profit function" or "profit equation" and "bio-economic model" are used. There is no basic difference between profit functions and bio-economic modeling. A profit function is a single-equation model while a multi-equation simulation model is referred to as bio-economic modeling (Tess *et al*,. 1983a; Groen 1988). By using simulated systems, economic values are derived by studying their reaction to a change of production factors related with the genetic merit of the animal for the specific trait, without changing other traits. With profit equations (efficiency functions), this is performed by partial differentiation.

Non-objective methods, as opposed to objective methods, do not derive economic values by direct calculation of influences of trait changes on profit and/or efficiency. Desired or restricted gains indices are classified as non-objective methods since there are predetermined constraints on genetic response of some traits that partially or completely override the response determined by their economic values. In the case of these indices, economic values are not defined (Gibson & Kennedy, 1990) but can be derived indirectly (Hirooka & Sasaki, 1998).

Beef cattle selection programmes in South Africa have evolved over many years. There was, however, no economic definition of an overall breeding objective or any attempt to derive economic values for beef cattle breeding. The objectives of this chapter, therefore, were: (1) to define breeding objectives for the Simmentaler breed in Southern Africa; (2) to develop profit equations; (3) to derive economic values for production traits in production circumstances without product output restrictions and; (4) to present a complete description of methodology that can be used to expand the breeding objective in following chapters.

4.2 MATERIALS AND METHODS

The sequential procedure developed by Ponzoni and Newman (1989) to derive breeding objectives for domestic livestock was used in this study. According to this method development of the breeding objective can be described in terms of the following phases: (1) Specification of the breeding, production and marketing system. (2) Identification of sources of income and expense in commercial herds. (3) Determination of biological traits influencing income and expense. (4) Derivation of the economic values of each trait. (5) Choice of selection criteria. (6) Estimation of phenotypic and genetic parameters. The first four phases concern economic aspects and the first three are prerequisites for the derivation of economic values (which was one of the objectives of this study). The last two phases are genetic in nature.

Specifying the breeding system involves defining the role of the breed (for which the breeding objective is being defined) in the production system (Ponzoni & Newman, 1989). In broad terms the roles can be general purpose, maternal line or terminal sire line. The role of the breed influences (determines) the genetic contribution of the breed in the various segments of the production system. For this study a general purpose pure breeding system was modeled based on the parameters of the Simmentaler breed in South Africa. Data was provided by the Simmentaler Cattle Breeders Society of Southern Africa (SCBSSA).

For the derivation of economic values different perspectives can be taken: short or long term; for the whole industry or individual breeders; where cost and returns are combined as profit or as economic efficiency; and profit where profit can be expressed per female, per individual or per unit product (Miller & Pearson, 1979; Barwick & Hammond, 1990; Howarth & Goddard, 1998). The perspective taken in this study was to define the breeding objective for a breeding industry (SCBSSA), but in the interest of individual breeders and commercial cow-calf-producers (at farm level) where profit is expressed per female unit (producing cow). Reasons for taking this perspective were that beef breeding programmes suffer a number of difficulties (Amer *et* al., 1998) including (1) small herd sizes which means that selection within contemporary groups is relatively ineffective because of low selection intensity, (2) there are a wide number of traits to improve which may lead to confusion, and (3) the associations of traits with income and costs are not clear and consistent under all production circumstances. Although economic values are sensitive to production circumstances (Wilton *et al*., 1968; Bourdon & Brinks, 1987a; Lamb *et al*., 1992a; Hazel *et al*., 1994; Koots & Gibson, 1998b), the definition of one common goal gives opportunities of obtaining large genetic improvement through high selection intensities (Groen *et al*., 1997). However, the definition of one common goal, based on predicted average future production circumstances of individual farmers, may lead to losses in revenues because of the heterogeneity of farms and/or production systems, or of uncertainty about future circumstances. Conclusions concerning the need for diversification of breeding goals should be based on additional revenues and costs calculations (Smith, 1985). However, Groen (1990) concluded that diversification at the level of the breeding organization will not readily be advantageous. Furthermore, specification of more than one index compromises the advantages of simplification that come from using the index in the first place (Amer, *et al*., 1997).

The multilevel (hierarchical) structure that exists in the South African beef cattle industry (Van Zyl 1983; Kluyts 1993), suggests that genetic improvement made in the seedstock sector should be directed towards its use in the commercial sector to satisfy the needs of commercial producers which in turn have to satisfy consumer demands. However, this approach was slightly modified for this study. The reasons were that, (1) in a conventional industry; improvement in the breeder's economic benefit is a major incentive for selection strategies to change (Howarth & Goddard, 1998). (2) If one takes into account that less than 30% of bulls and 60% of heifers are retained for stud breeding (mostly in the minority of stud herds), the majority of breeders (multiplier herds) are in fact also cow-calf-producers and the objectives of breeders may, therefore, be consistent with those of commercial farmers. Furthermore, accounting for the requirements of each commercial customer would lead to a formidable task of developing as many separate selection objectives as there are customers. To simplify this task, the role of the breed within the breeding industry should be considered. Since the production (on natural grazing) and sale of weaner calves to feedlots (cow-calf producers) is the most popular production system that beef producers in South Africa employ (Van Zyl *et al*., 1993), it was also the system modeled for this study. However, the production of steers raised to marketing / slaughtering age from a herd consisting of a smaller proportion of breeding females, is a more flexible system in regions with higher risk levels due to poor and unpredictable rainfall. Herd composition and age at marketing are closely related in these systems. A production system of steers marketed at one year of age (long weaners) was, therefore, also considered in this analysis. Although this system can be intensified by the replacement of grazing with grain based feeds, grazing of natural pasture was assumed since profit in a grain based system also depends on the value of the carcass (product quality). Product quality traits will be discussed in Chapter 6.

Specification of the production and marketing system involves the description of how animals are fed and managed, the age composition of the herd, the replacement policy and ages of the slaughter animals (Newman *et al*., 1992). (Table 4.1) It was assumed that male calves are sold at weaning (or as yearlings). The decision as to which heifers are retained as replacements and which are sold as being surplus occurs coincident with there attainment of final weight. Definition of the production system also includes level and size of the system. A system is considered a finite number of elements together with relationships between them and the environment. The animal level is the lowest system level considered in deriving economic values.

Table 4.1 Management variables included in the model

Variable	Value
Number of cows	100
Cow age groups	6
Number of lactations / calvings	5
Number of bulls	4%
Age at weaning	± 200 days
Market age - weaners	weaning (7 – 9 months)
Market age - steers	± 12 months
Market age - heifers	± 19 months
Age at breeding	± 15 - 21 months
Primary breeding and calving season	± November / August
Secondary breeding and calving season	± June / March
Feeding system	grazing on natural pasture
Dipping	3 treatments per year
Drenching	2 treatments per year
Vaccination	standard program [a]

[a] as prescribed by Onderstepoort Veterinary Institute

Defining herd composition aids in identifying age and numerical distribution of the herd, the number of replacements required each year as well as the number of animals of all classes available for market each year. This is required in the calculation of the number of discounted expressions for the derivation of economic values as not all traits are expressed with the same frequency or at the same time.

Since animal breeding is a long-term process it is incorrect to ignore discounting as it will lead to bias in the relative selection emphasis on traits and to non-optimum genetic responses. Furthermore, the costs and benefits in animal breeding are realised at different times, and with different probabilities. Therefore, factors that affect costs and benefits over the long term must be considered in the economic evaluation of genetic differences or genetic improvement. Long term considerations will affect both the attractiveness of investment in animal breeding as well as the relative economic value of the individual traits included in the breeding objective. The main long-term considerations in animal breeding are the discount rate, risk, profit horizon, reproduction rates and cow replacement rate (Cunningham & Ryan, 1975; Weller, 1994). In order to compute net present value, it is necessary to discount future benefits and costs. This discounting reflects the time value of money. Benefits and costs are worth more if they are experienced sooner. All future benefits and costs, including non-monetized benefits and costs, should be discounted. The higher the discount rate, the lower the present value of future cash flows. For typical investments in animal breeding, with costs concentrated in early periods and benefits following in later periods, raising the discount rate tends to reduce the net present value and tends to lower the investment in animal breeding. Analysis should also attempt to characterise the sources and nature of uncertainty (risk). Ideally, probability distributions of potential benefits, costs and net benefits should be presented. It should be recognized that many phenomena that are treated as deterministic or certain are, in fact, uncertain. In analyzing uncertain data, objective estimates of probabilities should be used whenever possible (www.whitehouse.gov/omb/circulars/a094/a094.html). Market data, such as private insurance payments or interest rate differentials, may be used in identifying and estimating relevant risks. It was also suggested that the standard deviation of asset price fluctuation (market value of the trait e.g. weaning weight), expressed as a percentage of the mean value, can be regarded as the proxy of risk.

The proper discount rate to use depends on whether the benefits and costs are measured in real or nominal terms. However, a real discount rate that has been adjusted to eliminate the effect of expected inflation should be used to discount constant-Rand or real benefits and costs. A real discount rate can be approximated by subtracting expected inflation from the nominal interest rate. An appropriate discount rate was chosen according to the methods discussed by Smith (1978). Although many authors have used discounting, these rates were not formally derived. With the commonly used rate of 10% the value of genetic gains were substantially discounted, especially in large farm animals with long generation intervals (Smith, 1978). This led to reduced inputs in breeding and selection work. Smith (1978) discussed the three schools of thought and concluded that the appropriate rate is the real opportunity cost rate. That is the market cost of borrowing in real terms, in terms of goods rather than money. Thus for breeding programs it is necessary to correct the nominal interest rate (d_i) by the rate of inflation (d_t). The interest rate (d_q) in real terms is given by Smith (1978) and Weller (1994) as:

$$d_q = (d_i - d_t) / (1 + d_t) \qquad (1)$$

To account for risk (d_k) and tax (d_x) the required nominal rate of return (d_r) is given by:

$$d_r = \frac{[(1 + d_q)\ (1 + d_t) / (1 - d_k)] - 1}{(1 - d_x)} \qquad (2)$$

Clearly d_r can be considerably higher than d_q even for relatively low rates of inflation, risk and taxation. Expected long term values for these terms were supplied by the S.A. Reserve Bank (SARB) (personal communication A.J.H. Casteleijn, senior economist SARB) and summarised in Table 4.2.

Table 4.2 Summary of symbols in equations (1) and (2), their meanings and expected long term values

Symbol	Meaning	Value (%)
d_i	nominal interest rate (prime)	12
d_t	rate of inflation (CPI)	4 - 5
d_k	risk	2 - 9
d_x	tax rate	30 - 40
d_q	real interest rate (corrected for inflation)	8
d_r	nominal rate of return	23

Economic values were adjusted for both time and frequency of expression by using the discounted gene flow (DGF) method of McClintock & Cunningham (1974) and the diffusion coefficient (DC) method of McArthur & Del Bosque Gonzalez (1990). For the method of McClintock & Cunningham (1974) tables of the possible number of standard expressions were first computed. The numbers of standard expressions were then adjusted with equation (3) for: (1) the dilution of the bull's genotype in his descendants; (2) the time interval separating each expression from the time mating (insemination) took place and; (3) the probability that each possible expression actually took place.

$$N'_{gy} = N_{gy} \cdot (0.5)^{(g-1)} \cdot (100 / 100 + r)^{y} \cdot P \qquad (3)$$

Where N'_{gy} = the number of discounted expressions, N_{gy} = the number of standard expressions, g = the generation in which the expression took place, y = the year in which the expression took place, r = the discount rate (8%) (d_q in Table 4.2) and P is the probability that the expression actually took place. P can be $1 / L^g$ for traits expressed by cows or repeatedly by the same animal (WW_M as trait of the dam), or $(SL – 1) / L^g$ when traits are expressed by the progeny and only once when sold (WW_D as trait of the calf). Where S = the survival rate (0.8) and L = the average number of lactations per cow (5). These standard discounted expressions were then summed over years and generations to give the total number of discounted expressions for each trait. For this study a 10 year evaluation period was taken. This is according to the conclusion of Cunningham & Ryan (1975) that little is to be gained by considering more than ten years since most of the economic gains from genetic improvement are realised in the early years. The exception to this arises when discount rates are low and cow turnover is slow, which was not the case in this analysis with a discount rate of 8% and cow turnover or replacement rate of 29%. A simpler method (equation 4) to adjust uncorrected economic values for time, based on the diffusion of genetic improvement in the herd, was proposed by McArthur & Del Bosque Gonzalez (1990). A diffusion coefficient is a function of (1) the proportion of the cash flow from the trait change realised at each point in time or the diffusion of the genetic improvement in the herd (replacement rate with genetically improved animals) and (2) the discount rate.

$$D_i = r \left(\sum_{j=0}^{m} a_j \, d_{ij} + a^m / r \right) \qquad (4)$$

D_i = the diffusion coefficient for trait i, d_{ij} = the marginal cash flow at the end of year j resulting from a unit improvement in trait i, m = the year of complete diffusion and a = the discount factor for one year computed as 1 / (1 + r) where r = the real interest rate (d_q in Table 4.2).

The demography (herd structure) of an assumed typical Simmentaler herd was constructed from data provided by the SCBSSA and is presented in Figure 4.1. A calving and weaning rate of 86% and 80% respectively were modeled. Due to limitations in the data set certain assumptions had to be made. It was assumed that mortality between birth and weaning is ± 6-7% and unequal between the sexes. This difference is due to the higher incidence of dystocia experienced by male calves. Calf losses were also higher in males than in females when both experience dystocia (Laster *et al*., 1973; Laster & Gregory, 1974; Meijering, 1984). It was further assumed that one heifer was lost due to mortality between weaning and breeding and that mortality in the cow herd was ± 4% per year.

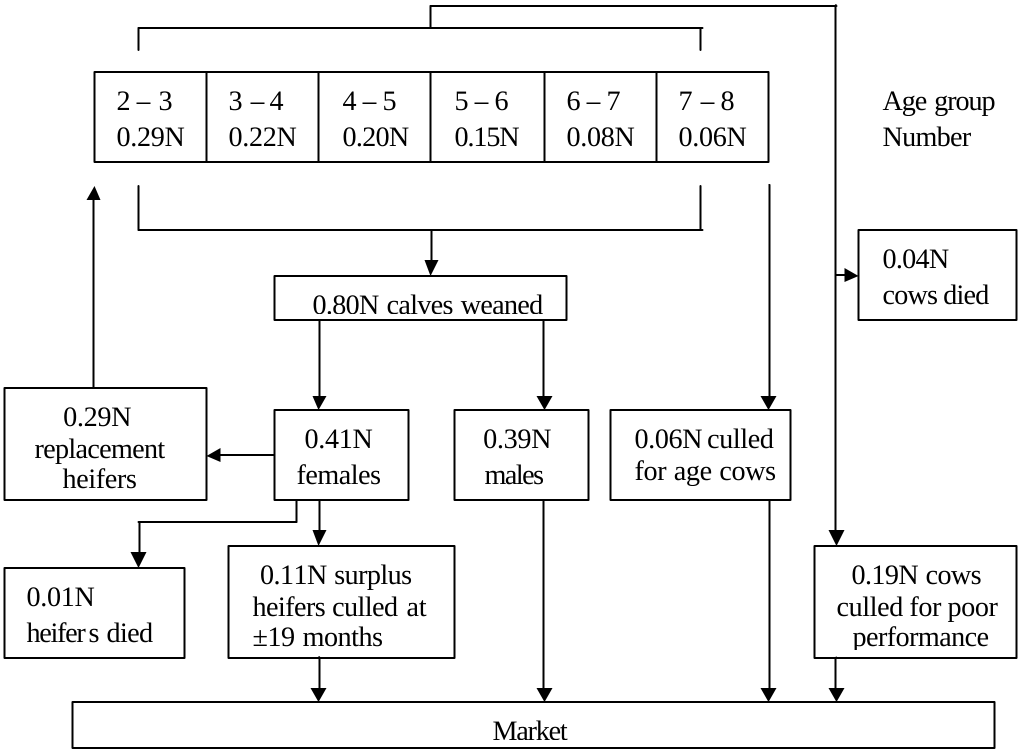

Figure 4.1 Demography of an assumed typical Simmentaler herd based on a constant number of cows (N = 100)

The second step is the identification of sources of income and expense i.e. the modeling of profit from this typical herd or breeding industry. Amer & Fox (1992) formulate a profit equation of the general form as p = f ($\mathbf{X}$ $\mathbf{P}$ $\mathbf{C}_v$ $\mathbf{C}_f$) where $\mathbf{X}$ is a vector of traits or animal characteristics, $\mathbf{P}$ is a vector of output prices, $\mathbf{C}_v$ a vector of variable input prices and $\mathbf{C}_f$ a vector of fixed input prices. $\mathbf{C}_v$ and $\mathbf{C}_f$ are typically considered to be constant for all levels of farm output. The traits in the profit equation should relate as directly as possible to sources of income and costs. The identification of sources of income and expense enables the development of a profit equation (Ponzoni & Newman, 1989), where profit (P) is a function of income (I) and expense (E):

$$P = I - E \qquad (5)$$

To assess the economic importance of improvement in each major biological component of performance, it is helpful to separate total profit into different components and expressed per cow. This follows from the notation of Brascamp *et al.* (1985) that economic values are different when expressed with different bases (per female, per individual, per unit of product) and Weller's (1994) observation that economic values are equal to constants only when expressed per female. Therefore, and since cost of animal products depend primarily upon the efficiency of three basic functions namely reproduction, female production and growth of the young (Dickerson, 1970), and income depends on the sale of marketable weaners (male), surplus heifers and cull cows, Equation (5) was expanded as:

$$P_T = P_M + P_H + P_C \qquad (6)$$

where P_T = total profit, P_M = profit due to male weaners, P_H = profit due to surplus heifers and P_C = profit due to the sale of cull cows. Profit due to weaners in the cow-calf production system can be replaced with profit due to steers (P_S) in the long-weaner production system. Expenses depend on feed intake and the value of the feed per kg (FC), husbandry cost (HC), marketing cost (MC) as well as fixed cost. Fixed costs are those costs incurred by the producer independent of the level of herd production. All other costs are variable costs and vary with the level of production (Ponzoni, 1986). Equation (6) was further expanded as:

$$P_T = [(I_M - MC_M - FC_M - HC_M) + (I_H - MC_H - FC_H - HC_H) + (I_C - MC_C - FC_C - HC_C) - \text{Fixed Costs} \qquad (7)$$

Where I = income and the subscripts M, H and C denotes male weaners, heifers and cows respectively. Fixed costs can be ignored where profit is defined as the difference between income and expense (Ponzoni & Newman, 1989; Newman *et al.*, 1992).

During the third phase the profit equation is expressed as a function of biological traits that impact on income, expense or both (Ponzoni & Newman, 1989). A summary of the more general traits (classified in groups) that influence income and/or expense, and that should be considered for inclusion in the breeding objective as well as the selection criteria to consider for the index, are presented in Table 4.3.

Table 4.3 Biological traits that should be considered for inclusion in the development of the breeding objective and estimation of economic values because of their affect on profit

Trait group	Trait	Criteria
Fitness traits /	Cow fertility	Calving / weaning rate
Functional traits		Days to Calving
	Bull fertility	Scrotal Circumference
	Cow survival	Cow survival / longevity
	Calving ease (direct + maternal)	Calving ease score
		Birth weight (direct + maternal)
Production traits /	Sale weight (direct + maternal)	Weaning weight (direct + maternal)
Beef traits	Sale weight (direct)	Yearling weight
		18 months weight
		Mature cow weight
Product traits /	Dressing percentage	Dressing percentage
Quality traits	Fat depth	Subcutaneous fat depth
	Saleable meat percentage	Longissimus muscle area
	Meat quality	Marbling / Tenderness
Input traits	Cow weight	Mature cow weight
	Feed intake	Feed intake

Choosing selection criteria and organising logically based performance recording is difficult unless the traits that have to be improved have been identified and their relative economic importance has been established (Ponzoni, 1986). In constructing a selection index, a decision is taken first on which traits should be the selection objectives, and the relative emphasis which should be ascribed to each. Secondly, consideration is given to the question of which traits are to be measured (selection criteria) and combined into the selection index. These may include the traits which are themselves the objects of selection, as well as others which merely help to predict the desired traits. A clear distinction should be made between the traits in the breeding objective and the characters used as selection criteria (Ponzoni & Newman, 1989). The breeding objective is defined as the combination of economically important traits that breeders want to improve. By contrast, the selection criteria are the characters used in the estimation of the breeding values of the animals. Decisions about which traits to include in the breeding objective, should be based on purely economic grounds, and not whether they are difficult or easy to measure or to change genetically. The traits in the breeding objective are the ends, whereas the characters used as selection criteria are the means used to achieve the ends. The selection criteria will, of course, be influenced by which traits are in the breeding objective. Furthermore, traits differ not only in economic importance but also in variability, heritability as well as genetic and phenotypic correlations (Hazel *et al.*, 1994).

Only the beef production traits (sale weight at different ages) will be analyzed in this chapter (Table 4.4). Although the weight of the weaned calves is generally of secondary efficiency in defining biological efficiency in integrated systems, it plays a significant role in defining economic efficiency for the cow-calf producer (Notter, 2002). In the long-weaner production system the weight at yearling age is of major importance. This investigation will also include mature weight which can be regarded as a production trait as well as an input trait. A linear relationship between profit and the level of performance in these traits was assumed. Traits from the other trait groups will be discussed in the following chapters.

Table 4.4 Parameters [a] for the beef production traits included in the breeding objective

Trait	Symbol	h^2	Mean (kg)	s_P	s_A
Weaning weight –direct	WW_D	0.21	237	26.49	12.04
Weaning weight – maternal	WW_M	0.12	237	26.49	9.0
Yearling weight (400 days)	YW_S	0.33	385	32.07	18.42
Final weight (600 days)	FW_H	0.32	458	38.05	21.47
Mature Cow weight	MCW	0.43	567	52.92	34.64

[a] provided by Breedplan International for S.A. Simmentaler

Each of the terms in equation (7) can now be expressed as a function of the traits in the breeding objective. In a general form this equation would be (Newman *et al*., 1992):

$$P = \sum_{i=1}^{m} [\, n_i (V_i - C_i) X_i \,] - K \qquad (8)$$

where for each m traits in the profit equation, n is the number of expressions for trait i, V is the value and C the cost per unit of trait X, and K is fixed costs. A profit (p) equation was then developed from equations (7) and (8). The term in equation (9) involving weaners in a cow calf production system can be replaced with the term for steers for a long-weaner production system.

$$\begin{aligned}
p = {} & n\,\{NCW_M\,[(WW_M \cdot v_M) - (WW_M \cdot v_M \cdot 0.07) - (WW_M \cdot hc_M)]\} \\
\text{or } & n\,\{NCW_M\,[(YW_S \cdot v_S) - (YW_S \cdot v_S \cdot 0.07) - (YW_S \cdot fi_S \cdot v_F) - (YW_S \cdot hc_S)]\} \\
+ {} & n\,\{NSH\,[(FW_H \cdot v_H) - (FW_H \cdot v_H \cdot 0.07)] - 0.4N_H\,[(FW_H \cdot fi_H \cdot v_F) + (FW_H \cdot hc_H) + mc]\} \\
+ {} & n\,\{NCC\,[(MCW \cdot v_C) - (MCW \cdot v_C \cdot 0.07)] - N_C\,[(MCW \cdot fi_C \cdot v_F) + (MCW \cdot hc_C) + mc]\} \qquad (9)
\end{aligned}$$

The meanings and assumed values of the symbols in equation (9) are summarised in Table 4.5. Upper case symbols denote traits and n is either 1.0 when income and expense are expressed per year, the total discounted expressions (McClintock & Cunningham, 1974) or the diffusion coefficient (McArthur & Del Bosque Gonzalez, 1990). NCW, NSH, NCC and N can be obtained from Figure 4.1. The subscripts M, S, H and C denote male weaners, steers, heifers and cows respectively. Marketing cost was assumed to be proportional to the value of the animal sold (7% commission to be paid on auctions). It was further assumed that food intake (DM intake) is related to steer, heifer and cow body weight. A part of husbandry costs (dipping and drenching costs) was related to the size of the animal while vaccination and labour were not. Before differentiating this profit equation the husbandry costs were partitioned into these different parts.

Table 4.5 Summary of symbols in the profit equation, their meanings and assumed values

Symbol	Meaning		Value	
		Weaners (?)	Heifers	Cows
NCW	number calves weaned	0.39N	0.41N	-
NSH	number surplus heifers	-	0.11N	-
NCC	number of cull cows	-	-	0.25N
WW	weaning weight	240 kg	234 kg	-
YW	yearling weight	385 kg		
FW	cull weight / sale weight	-	458 kg	-
MCW	mature cow weight	-	-	567 kg
fi	food intake (% DM / kg live weight)	2.6%	2.3%	2.2%
v	animal value (R / kg)	R7.70	R6.07	R5.54
v_F	feed value / kg DM	R0.45	R0.45	R0.45
	agistment rate / kg DM	-	R0.09	R0.09
hc	husbandry cost:			
	dipping 1.1cent / kg / treatment	R5.28	R15.12	R18.72
	drenching 3.9cent / kg / treatment	R9.36	R36.10	R44.68
	vaccination	R20.59	R11.54	R11.54
	labour R3.33 / man / hour			
mc	mating cost / year	-	-	R160.00

Since future prices cannot be predicted without error and one can assume that the relative magnitude of prices will remain more or less the same, the current (last quarter of 2003 first quarter 2004) pricing structure was used. Animal values were the mean values for 2003. It was assumed that weaners and long-weaners have the same value per kg of body weight. A dressing percentage of 50% and 48% were assumed for heifers (Class AB) and cows (Class C) respectively. These prices and values were obtained from Agrimarket Trends, Onderstepoort Veterinary Institute and suppliers of products. There are, however a number of situations when these relativities may change: (1) The terms-of-trade (ratio of returns to costs) in agriculture is expected to continue to decline (Brash *et al*., 1990) at an annual rate of 2-3% (First National Bank). This relative change was not taken into account since the largest cost factor (feed) is produced in the same industry. (2) When non-linear relationships exist, i.e. the next unit of improvement in a trait has an economic value independent of the present level of the trait. Economic linearity was assumed in this study. Economic values for traits for which this is a poor assumption will need to be revised more often. (3) The value of a trait is affected by genetic and/or non-genetic improvements in other traits. For example sale weight will increase the price per animal sold and, therefore, the economic value of fertility (weaning rate). (4) When consumer preferences change due to, for instance, socio-economic changes.

The difficulty and expense of measuring feed intake and efficiency in grazing animals means that feed intake is usually excluded as a trait in the breeding objective. However, providing feed to cattle is the single largest expense in most commercial beef production enterprises (Archer *et* al. 1999; Jenkins & Ferrell, 2002). Feed intake is generally correlated with output traits and therefore examination of feed intake or production outputs in isolation of each other usually provides little or no indication of the efficiency of production (Archer *et al*., 1999). For these reasons feed intake was included as a cost function in the profit equation. Economic values for carcass / sale weight were, therefore, adjusted for anticipated correlated responses in food intake as suggested by Amer *et al*. (1998). The cost of providing feed to grazing animals is, however, difficult to quantify (Arthur *et al*. 2001). It was, therefore, assumed that animals have a certain intake of dry material (DM) which is related to size as well as stage and level of production. This amount was derived from NRC-tables (Van der Merwe & Smith, 1991) and from a technical review by an ARC working party under the chairmanship of Blaxter (1988). As a first alternative it was assumed that intake was from a standard reference feed (*Eragrostus curvula*) with known general quality and average price (R400.00/ton or R0.40/kg feed with 90% DM = R0.45/kg DM). This is to a certain extent similar to the methods used by Groen & Korver (1989) and Amer *et al*. (2001). As a second alternative food costs can also be calculated based on agistment rates in the following manner (Ponzoni & Newman, 1989). An average sized Simmentaler cow's yearly intake was estimated from NRC-tables to be 4553 kg dry matter (DM). The agistment rate over 12 months at R35.00 per month is R420.00, which yields a cost per kg DM of R0.09. However, if one assumes that resources (grazing) are efficiently and optimally used, changes in output will require proportional changes in input (feed) bought by the farmer at R0.45 per kg DM and not provided by the pasture at R0.09 per kg DM. Furthermore, due to the large spatial and temporal variation in the quality and quantity of natural pastures it is difficult to generalise. Therefore, for the derivation of economic values for production traits, the first alternative was employed.

The economic value of a trait represents the change in profit or costs per unit product as a result of one unit change in genetic merit of the trait considered (Groen *et al.,* 1997). Economic values are derived by partial differentiation of the profit equation (efficiency equation) with respect to individual traits. The partial derivative gives the slope (rate of change) of the profit equation at the population mean value for all other traits (Harris, 1970; Bekman & Van Arendonk, 1993; Phocas *et al*., 1998b). This procedure corresponds to a linearization of the profit equation (Moav & Hill, 1966).

By applying the following rules of differentiation (Haeussler & Paul, 2002), economic values were derived as the partial derivative of the profit equation (Eq.9). These rules state that (1) the derivative of a constant function is zero. This implies that, since terms not involving the trait concerned remain constant, these terms will vanish on differentiation. (2) The derivative of constant power of ? is the exponent times ? raised to a power one less the given power. (3) The derivative of a constant times (multiplied by) a differentiable function is the constant times the derivative of the function. This rule implies that the number of expressions (n), which is a constant times the differentiable function (or profit equation), become a constant times the derivative of the function. (4) The derivative of the sum (difference) of two functions is the sum (difference) of their derivatives.

4.3 RESULTS AND DISCUSSION

The partial derivatives (uncorrected economic values) for WW (direct and maternal), yearling weight, final weight (heifers) and cow weight are presented in equations (10) to (14).

$$dp / dWW_D = n\,[(v_W) - (v_W \cdot 0.07) - (hc_W)] \tag{10}$$

$$dp / dWW_M = n\,[(v_W) - (v_W \cdot 0.07) - (hc_W)] \tag{11}$$

$$dp / dYW = n\,[(v_S) - (v_S \cdot 0.07) - (fi_S \cdot v_F) - (hc_S)] \tag{12}$$

$$dp / dFW = n\,[(v_H) - (v_H \cdot 0.07) - (fi_H \cdot v_F) - (hc_H)] \tag{13}$$

$$dp / dMCW = n\,[(v_C) - (v_C \cdot 0.07) - (fi_C \cdot v_F) - (hc_C)] \tag{14}$$

Uncorrected economic values for the direct and maternal component of WW were considered to be equal as suggested by Ponzoni & Newman (1989) and MacNiel *et al.* (1994). Differences in corrected economic values will therefore be as a result of a different number of expressions. However, according to a study by Phocas *et al*. (1998b), feed costs for increased calf weaning weight depend on whether additional feed comes from milk (maternal effect and mainly converted from forage) or from more expensive concentrate feeds (direct effect). Thus, Phocas *et al*. (1998b) concluded that the economic value for maternal effect is, therefore, higher than the economic value for direct effect. The system of Phocas *et al*. (1998b) is, however, different from the pasture based production system modeled in this study. Note that economic values for body weight are usually derived without considering changes in body composition. The number of expressions (the symbol n in equations 10 – 14)) for each trait at present in the breeding objective, and derived by different methods (DGF, DC), are summarised in Table 4.6.

Table 4.6 Summary of the number of expressions (n) when income and expense are expressed per year (IE), total discounted expressions (TDE), cumulative total discounted expressions (CTDE) and the diffusion coefficient (DC) for traits in the breeding objective

		DGF-method		
Trait	IE	TDE	CTDE	DC -method
WW_D	39	0.767	29.91	0.878
WW_M	29	0.821	23.81	0.750
YW_S	39	0.767	29.91	0.878
FW_H	11	0.695	7.65	0.812
MCW	25	0.821	20.53	0.750

The differences in TDE and CTDE (Table 4.6) among different traits are a function of the number of times a trait is expressed and when these expressions take place. Since this study assumed breeding in the primary breeding season (November), calving occurred in August and weaning in March. Based on this assumption WW_D and YW are expressed in the same year and only a few months apart. These traits have, therefore, the same number of discounted expressions and the same diffusion coefficient. WW_M and MCW are expressed repeatedly and also more or less at the same time. Although WW_D is expressed earlier in time than WW_M it is expressed only once. FW_H is also expressed once but later in time than WW_D. The higher number of expressions for the maternal component of WW is similar to the results obtained by McClintock & Cunningham (1974) and Amer *et al.* (2001). However, if the period of evaluation had been shorter than 9 years the direct component of WW would have had a higher number of discounted expressions due to the earlier expression of the trait. It is also clear from Table 4.6 that the two methods (DGF and DC) used to correct economic values, gave different results. These differences are due to the fact that the DC – method calculates the diffusion of genetic improvement through the herd assuming that every new generation carries the same improvement. The DGF – method, on the other hand, takes into account the number of times the improvement is expressed as well as the dilution of this one step genetic improvement in future generations.

The diffusion coefficient is therefore higher the earlier traits are expressed. The reason for this is the faster diffusion of the improvement through the herd and the fact that future economic gains are discounted less since it is realised sooner.

By substituting the values from Table 4.5 into Equations (10) to (14) and multiplying with the number of expressions (Table 4.6) the corrected economic values were derived. These corrected economic values expressed per unit used, per s_P and per s_A (from Table 4.4) are summarised in Table 4.7 (economic values corrected with the DGF-method) and Table 4.8 (economic values corrected with the DC-method).

Table 4.7 Economic values (R / 1 unit change) for different traits corrected with the DGF-method and expressed per unit used, per s_P and per s_A

Trait Method of expression	WW_D (kg)	WW_M (kg)	YW_S (kg)	FW_H (kg)	MCW (kg)
Per unit used	2.1238	1.6904	1.5464	- 0.6495	- 2.0004
Per s_P	56.2595	44.7787	49.5931	- 24.7135	- 105.8612
Per s_A	25.5706	15.2136	28.4847	- 13.9448	- 69.2939

DGF corrected economic values were scaled from a herd basis to a per cow-year basis by division by the total number of cows (100) in the herd i.e. to be expressed as per female unit. The absolute value of the latter expression (¦ EV¦ x s_A) enables the comparison of traits in terms of 'economic–genetic' variation available. The expression of economic values per unit of additive genetic and phenotypic standard deviation is important because not all traits are measured in the same unit or have the same variance. The economic value per s_P is important for economists while the economic value per s_A is of use to geneticists and breeders. At this stage it is important to remember that economic values are increasingly more important the further from zero these values are, both in a positive and negative direction.

Table 4.8 Economic values (R / 1 unit change) for different traits corrected with the DC-method and expressed per unit used, per s_P and per s_A

Trait Method of expression	WW_D (kg)	WW_M (kg)	YW_S (kg)	FW_H (kg)	MCW (kg)
Per unit used	6.23	5.33	4.54	- 1.90	- 1.83
Per s_P	165.03	141.19	145.60	- 72.30	- 96.84
Per s_A	75.01	47.97	83.63	- 40.79	- 63.39

The magnitude of the economic values in Tables 4.7 and 4.8 emphasize the importance of rapid early growth. It is also clear that WW and MCW are the production (growth) traits of major economic importance. Selection should, however, aim to increase WW and to decrease MCW. This is consistent with the idea of feeder-breeder dimorphism (large offspring for slaughter from small breeding animals) (Theron *et al*., 1994). According to Roux (1992) feeder-breeder dimorphism can be achieved through terminal crossbreeding and by manipulating growth. Therefore, it seems that selection should aim at bending the growth curve after the point of marketing. Given the positive genetic correlation between MCW and WW ($r_G = 0.4$) means that inclusion of MCW (with a negative value) and WW (with a positive value) in the breeding objective will not necessarily cause weaning weight to increase or mature weight to decrease but it might prevent mature weight from increasing.

These results are in agreement with the conclusion of Groen *et al*., (1997) that mature body weight of cattle usually has a negative economic value since marginal costs associated with increased feed requirements exceed marginal revenues from increased body weight of culled animals. Furthermore, Spelman & Garrick (1997) concluded that inclusion of live weight (MCW) with a negative economic value in a selection index resulted in higher economic response. If feed intake had not been included as a cost function in the profit equation, heifer sale weight (FW_H) and cow weight (MCW) would have had positive economic values. Furthermore, if feed costs were derived from agistment rates (R0.09 / kg DM) marginal costs associated with increased feed requirements would have been lower than marginal revenues from increased body weight. Economic values for body weight would then also have been positive. Based on agistment rates, DGF corrected economic values (R / unit) of +2.01, +0.19 and +0.37 were derived for YW, FW and MCW respectively. These results would obviously have a major effect on the breeding objective, economic response through selection and production efficiency.

As mentioned, the economic values of growth traits, especially heifer and cow weight, depend, to a large extent, on the value of the feed consumed and beef prices. Note that in South Africa approximately 70% of cattle slaughtered are finished through a feedlot (expensive feed) whereas the cow herd is usually kept on pastures (relatively cheap feed). These results illustrate the importance of feed intake and of an accurate estimate of the cost of feed. Ideally, feed intake should be measured in a pasture situation. However, accounting for the cost of feed in the objective may be sufficient for improving overall response to selection for improved productivity. There are two options to account for feed inputs. The approach taken in this study reflects the situation faced by individual producers in an environment where they are individually inconsequential to prices for inputs and products. Therefore, producers would have the option to buy or rent pasture or purchase feedstuffs to meet any increased need for feed resources. It is important to realize that these different options (rent pasture, purchase feedstuffs, and rescale enterprise) will result in different economic values. Alternatively, feed resources could be considered fixed and the production enterprise rescaled in response to changes in feed requirements. This latter approach seems warranted only in planning nationwide breeding programs where the possibility of obtaining additional feed resources may be limited.

The breeding objective for an integrated system, including only production (growth) traits at present, is presented by equation (15). DGF corrected economic values, expressed per additive genetic standard deviation, were scaled from a herd basis to a per cow-year basis by division by the total number of cows (100) in the herd i.e. to be expressed as per female unit and rounded to two decimals.

$$H = 25.57\ WW_D + 15.21\ WW_M + 28.49\ YW_S - 13.95\ FW - 69.29\ MCW \qquad (15)$$

Since the relative importance of traits differs between different production systems, all of these terms will not necessarily be included in the breeding objective of every production system. YW, for instance, can be excluded from the objective of a cow – weaner calf production system. The high correlation ($r_G = 0.75$) among FW and MCW and the relative small economic value of FW suggest that FW can also be excluded from the breeding objective to simplify construction of the selection index. However, inclusion of these traits will define a more comprehensive breeding objective and improve accuracy. Inclusion of FW may also assist in bending the growth curve and help to prevent MCW from increasing.

4.4 CONCLUDING REMARKS

In this chapter a detailed description of the development of breeding objectives and derivation of economic values for production traits, for dual purpose and beef cattle, was presented. Only the Simmentaler situation was investigated but the model enables the examination of the effect of variations in, for instance, herd composition, product values and costs, phenotypic and genetic parameters, as well as production systems. However, the lack of sufficient information on phenotypic and genetic parameters may still limit the expansion or practical application of the model. Development of breeding objectives is, at present, restricted by the available information. Therefore, recording of beef cattle performance should, in future, aim at satisfying the needs of breeding objective development. Furthermore, the necessity of economic data recorded across several years, to have economic values with reasonable precision, suggests a need for a long-term commitment to systematic recording of both economic and production information at the producer level. The findings of the present study are a function of the assumptions made during the development of the model and can, therefore, not be compared directly with the results from other studies.

CHAPTER 5

Derivation of economic values for the Simmentaler breed in South Africa: Functional / Fitness traits.

5.1 INTRODUCTION

All evolutionary changes in allele frequency must funnel through the reproduction achieved by phenotypes and the survival of their progeny, i.e. fitness. Therefore, fertility or reproductive performance has been reported to be at least twice as important, economically, as production traits under a conventional cow-calf production system (Donoghue, 2002). However, economic values (and EBV's) for fitness/functional traits are difficult to estimate, report and interpret not only because most measures of reproduction are only small components of the total fitness (Beilharz *et al*., 1993) but also because the expression of the reproductive potential (e.g. age at first calving) is often constrained with the management system employed (Notter & Johnson, 1988; Meyer *et al*. 1990), and depends on the existing recording scheme used by the breed (Rust & Groeneveld, 2001). This is particularly true for pasture mating situations, where information on females is limited. Moav and Hill (1966) also stressed that there is a non-linear relationship between profit and reproductive performance and changes in reproductive performance yield changes in profit dependant on the level of reproductive performance. Thus the higher the present level of reproductive performance, the greater the improvement necessary to produce the same increase in profit.

Derivation and use of economic values for fertility traits will, however, allow breeders to take a more balanced approach to genetic change in their herds, especially in view of the possible negative association between certain growth and fitness traits (Scholtz *et al*., 1990). Furthermore, selection for a quantitative trait often leads to a decline in traits closely related to natural fitness despite the fact that fitness was uncorrelated with the character (trait) under selection in the base population (Goddard, 1983). This analysis of Goddard (1983) also showed that including fitness traits in the profit function is not sufficient to prevent this decline unless the curvilinear nature of the relationship between traits is recognized.

Different researchers (Bourdon & Brinks, 1983; Meacham & Notter, 1987; Meyer *et al*., 1990; McDonald, 1991a; Amer *et al*., 1996; Rust & Groeneveld, 2001; Van der Westhuizen *et al*., 2001a;

Donoghue, 2002) concluded that indices of genetic reproductive merit that are easily measured at low cost, in most management systems, include calving rate (CR), days-to-calving (CD) and scrotal circumference (SC). Furthermore, no selection program can ignore the effects of dystocia as it is indirectly related to reproductive performance, survival and productivity (Brinks *et al.*, 1973; Laster *et al.*, 1973; Laster & Gregory, 1974; Meijering, 1984; Amer *et al*., 1996; Arthur *et al*., 2000; Meyer *et al.*, 2001; Tozer *et al*., 2002).

The consequences of a change in fitness include changes in mating (insemination) costs and veterinary costs (Boichard, 1990), changes in culling rate (Phocas *et al.*, 1998b), number of barren cows (Amer *et al*., 1996) and the number of surplus offspring available for sale (Ponzoni & Newman, 1989; Newman *et al.*, 1992). Economic values for functional traits can, therefore, be derived as a function of these changes.

The cost of a barren cow can be used directly as an economic value for reproductive success (Amer *et al*., 2001). Alternatively, it can be used indirectly in more complex reproductive and breeding models which assign economic values to component factors, such as conception rates, length of the post-partum anoestrus interval (PPI) and gestation length (GL), which contribute to reproductive failure (Amer *et al.*, 1996). Information on these components is, however, limited in pasture/extensive production systems. Furthermore, because variation in CD reflects variation in the reproductive variables mentioned (conception rate, PPI and GL), it is not appropriate to include these variables together with CD in the breeding objective.

A higher culling rate, due to a decrease in fertility, increases replacement costs and the proportion of younger and, therefore, cows less productive than mature cows (Boichard, 1990). These losses are only partly compensated for by the high culling value of infertile cows. The economic value of fertility was estimated by Boichard (1990) as the sum of the components mentioned, obtained independently from each other. The desired fertility criterion must be independent of culling policy and must provide an overall estimate of the value of fertility, including culling cost. According to Boichard (1990) only the probability of conception satisfies this condition. This probability was called the average conception rate (calving rate).

The economic value of mortality (trait of the calf) can be taken as the opportunity cost of lost revenue from not being able to sell the calf at weaning after an allowance for saved costs (Amer *et al*., 2001).

Furthermore, the derivation of economic values for functional traits is complicated by the fact that these traits are not scored or measured on a continuous scale. Some functional traits (fertility, mortality, survival) are scored in two categories (binary data), while others (calving ease) are often measured in a small number of categories. It is usually assumed for these categorical traits that there is an unobserved underlying normal distribution of the sum of genetic and environmental values, and that the phenotypic category is defined by threshold values on this distribution (Koots *et al*., 1994a; Falconer & Mackay, 1996).

However, in spite of the importance of functional traits, these traits have received little attention in the development of breeding objectives, possibly due to the difficulties outlined above. The objectives of this chapter were, therefore, (1) to expand the breeding objective by inclusion of functional traits (2) to derive economic values for functional traits and (3) to give a complete description of the methodology to derive economic values for functional traits.

5.2 MATERIALS AND METHODS

The sequential procedure developed by Ponzoni and Newman (1989) to derive breeding objectives for domestic livestock was used in this study. According to this method development of the breeding objective can be described in terms of the following phases: (1) Specification of the breeding, production and marketing system. (2) Identification of sources of income and expense in commercial herds. (3) Determination of biological traits influencing income and expense. (4) Derivation of the economic values for each trait. (5) Choice of selection criteria. (6) Estimation of phenotypic and genetic parameters.

Specifying the breeding system involves defining the role of the breed in the production system (Ponzoni & Newman, 1989). A general purpose, pure breeding system was modeled based on the parameters of the Simmentaler breed in South Africa. Data for this analysis was provided by the Simmentaler Cattle Breeders Society of Southern Africa (SCBSSA). Specification of the production and marketing system involves the description of how animals are fed and managed, the age composition of the herd, the replacement policy and ages of the slaughter animals (Newman *et al*., 1992) (Table 5.1). A more complete description of materials and methods employed was presented in Chapter 4.

Table 5.1 Management variables included in the model

Variable	Value
Number of cows	100
Cow age groups	6
Number of lactations	5
Number of bulls	4%
Age at weaning	± 200 days
Market age - males	weaning(7 – 9 months)
Market age - heifers	± 19 months
Age at breeding	± 15 - 21 months
Primary breeding and calving season	± November / August
Secondary breeding and calving season	± June / March
Feeding system	grazing on natural pasture
Dipping	3 treatments per year
Drenching	2 treatments per year
Vaccination	standard program [a]

[a] as prescribed by Onderstepoort Veterinary Institute

The second step is the identification of sources of income and expense i.e. the modeling of profit from this typical herd or breeding industry. This enables the development of a profit equation (Equation 1)

$$
\begin{aligned}
p = n\,&\{NCW_M\,[(WW_M \cdot v_M) - (WW_M \cdot v_M \cdot 0.07) - (WW_M \cdot hc_M)]\} \\
&+ n\,\{NSH\,[(FW_H \cdot v_H) - (FW_H \cdot v_H \cdot 0.07)] - 0.4N_H\,[(FW_H \cdot fi_H \cdot v_F) + (FW_H \cdot hc_H) + mc]\} \\
&+ n\,\{NCC\,[(MCW \cdot v_C) - (MCW \cdot v_C \cdot 0.07)] - N_C\,[(MCW \cdot fi_C \cdot v_F) + (MCW \cdot hc_C) + mc]\} \qquad (1)
\end{aligned}
$$

During the third phase the profit equation is expressed as a function of biological traits that impact on income, expense or both (Ponzoni & Newman, 1989). The meanings and assumed values of the symbols in equation (1) are summarised in Table 5.2. Upper case symbols denote traits and n is either 1.0 when income and expense are expressed per year, the total discounted expressions (TDE) (McClintock & Cunningham, 1974) or the diffusion coefficient (DC) (McArthur & Del Bosque Gonzalez, 1990).

Table 5.2 Summary of symbols in the profit equation, their meanings and assumed values.

Symbol	Meaning	Value		
		Weaners (?)	Heifers	Cows
NCW	number calves weaned	0.39N	0.41N	-
NSH	number surplus heifers	-	0.11N	-
NCC	number of cull cows	-	-	0.25N
WW	weaning weight	240 kg	234 kg	-
FW	cull weight / sale weight (heifers)	-	458 kg	-
MCW	mature cow weight	-	-	567 kg
fi	food intake (% DM / kg live weight)	2.6%	2.3%	2.2%
v	animal value (R / kg)	R7.70	R6.07	R5.54
v_F	feed value / kg DM	-	R0.45	R0.45
	agistment rate / kg DM	-	R0.09	R0.09
hc	husbandry cost:			
	dipping 1.1cent / kg / treatment	R5.28	R15.12	R18.72
	drenching 3.9cent / kg / treatment	R9.36	R36.10	R44.68
	vaccination	R20.59	R11.54	R11.54
	labour R3.33 / man / hour			
mc	mating cost / year	-	-	R160.00

The subscripts M, H and C denote male weaners, heifers and cows respectively. Marketing cost was assumed to be proportional to the value of the animal sold (7%). It was also assumed that food intake (DM intake) is related to heifer and cow body weight. A part of husbandry costs (dipping and drenching costs) was related to the size of the animal while vaccination and labour were not. The terms NCW, NSH and NCC relate directly to functional traits. NCW is a function of fertility and survivability. When it is assumed that barren cows are replaced with heifers the terms NSH and NCC are also a function of fertility. Husbandry cost can be expanded to include the cost of a calving. Since calving cost is a function of calving ease, the trait calving-ease (CE) can also be included in the profit equation.

Biological and economic efficiency of the cow herd is most clearly reflected in the number of calves weaned per cow exposed. The weight of the weaned calves is generally of secondary importance in defining biological efficiency in integrated systems, but plays a significant role in defining economic efficiency for the cow-calf producer (Notter, 2002). Achievement of high levels of cow efficiency would also be facilitated by high levels of maternal calving ease. Therefore, the number of calves weaned (NCW) can be seen as a function of the calving rate (CR) or days to calving (CD) and mortality due to dystocia. CR was defined as the number of calves born (0 or 1) per cow present in the herd and CD as the day number in which the cow calved within the calving season relative to the first day (Ponzoni, 1992). Table 5.3 summarizes the functional traits to be included in the breeding objective for which economic values will be derived.

Since scrotal circumference (SC) and birth weight (BW) do not have determinable economic values, these important measures of fertility and calving ease can not be included as traits in the breeding objective but can be included as criteria in the selection index. Since there are, at present, no parameter estimates for functional traits for the Simmentaler breed in Southern Africa, heritability estimates reported in the literature were assumed and summarised in Table 5.3. Although more recent estimates were available, the weighted mean heritabilities reported by Koots *et al*. (1994) were used. Phenotypic standard deviations (s_P) were statistically derived from the available data. Genetic standard deviations (s_A) were then computed from $h^2 = s^2_A / s^2_P$.

Table 5.3 Parameters for the functional traits to be included in the breeding objective

Trait	Symbol	h^2	Mean	s_P	s_A
Calving rate	CR	0.17	86%	3.47	1.43
Days to calving	CD	0.08	60 days	25.0	7.07
Calving ease (direct)	CE_D	0.13	95.7% [a]	2.02	0.73
Calving ease (maternal)	CE_M	0.12	95.7%	2.02	0.70

[a] % unassisted calvings

The right choice of functional / fitness traits to include in the breeding objective is difficult for several reasons. (1) Functional traits are complex traits and most measures of reproduction are only small components of total fitness (Beilharz *et al*., 1993). (2) Several economically important functional traits have multiple indicator traits (criteria). (3) Many traits which are measurable on animals do not directly affect profit. CD, for instance, cannot be related directly to profit especially when weaning is at a fixed age (Ponzoni, 1992). However, when weaning is on a fixed date, one calving day earlier will result in a slightly higher weaning weight. On the other hand, if CD can be related to an increase in the number of calves weaned (weaning rate) or to a decrease in the number of barren cows, the effect on profit through an improvement in CD will be obvious. (4) Furthermore, traits (e.g. CD) are defined differently by different researchers (Meyer & Johnston, 2001).

It is clear, from a simplified profit equation [$p = N(nwV - nC_1d - C_2)$, equation 4 from Chapter 2], that the economic value of fertility can be regarded as the number of surplus offspring that are available for sale (Brascamp *et al*., 1985; Ponzoni & Newman, 1989; Newman *et al*., 1992). Where N is the number of breeding females producing n offspring per year, w is weight of the product per offspring with value V per unit grown over d days. C_1 is the cost per day of growth per individual and C_2 is the cost per female per year.

Each calf born in the herd belongs to one of the following cattle categories k, male ($?_W$), heifer ($?_H$) and mortality ($?_M$) with a certain probability $P_k (0 = P_k = 1)$. It can formally be written as k ? O with O =

$\{?_{W}, ?_{H}, ?_{M}\}$. However, for the derivation of economic values for functional traits it was assumed that, for the sake of simplicity, that the extra calves born, due to an increase in the mean performance of the trait, will be male weaners. Therefore, for this study, $A = \{?_{W}\}$, $A^{c} = \{?_{H}, ?_{M}\}$ and $A \text{ n } A^{c} = Ø$ (Steyn *et al*., 2003).

5.2.1 Calving rate (CR)

Data for the derivation of the economic value for CR was provided by the SCBSSA. For this analysis a herd size of 100 cows and a mean calving rate of 86% were assumed. It was further assumed that CR is a binary trait [bi (100, 0.86)] and, therefore, scored in only two categories. If X is the number of successes in n independent events (n = 100) of a binomial experiment with probability p of success (calving) (p = 0.86) and q the probability of failure in any event (not calving), then the probability distribution f for X is given by:

$$f(x) = P(X = x) = {}_{n}C_{x}\, p^{x} q^{n-x} \qquad (2)$$

where x is an integer such that 0 = x = n and q = 1 – p (q = 0.14) (Haeussler & Paul, 2002). Since n is large the distribution of X can be approximated by a normal random variable. It can be written as X ~ N (µ, s^{2}) (Rice, 1995). The mean and standard deviation of X is given, respectively, by equations (3) and (4):

$$\mu = np \qquad (3)$$

$$s = v\,\overline{npq} \qquad (4)$$

With equations (3) and (4) the mean (µ = np = 86) and standard deviation ($s = v\,\overline{npq} = 3.47$) for CR were computed from the data. If the mean performance in the herd for this trait, increase by one unit (µ = 87), the probability of success will increase as well (p = 0.87). This implies that, for this assumed typical Simmentaler herd, there will be one more calf available for sale. The economic value of CR can, therefore, be related directly to the number of calves weaned (NCW).

5.2.2 Days to calving (CD)

Data to derive the economic value for CD was also provided by the SCBSSA. However, this data was very limited as information on only 2226 calvings, recorded over a 10 year period (1992 – 2001), were available. Although records on bull entry dates and calving dates exist on farm level these records were not readily available. To properly capture this information is of utmost importance. For this study only four herds had reliable information available for a restricted calving season. Since these calvings were recorded as independent events occurring in four 28 day periods (112 days), CD was considered to be a discrete random variable. Thus, (for this data set) if f is the probability function for X, f(1) = P(X = 1) = 0.2575; f(2) = P(X = 2) = 0.4375; f(3) = P(X = 3) = 0.2175 and f(4) = P(X = 4) = 0.0875. According to Haeussler& Paul (2002) and Steyn *et al.* (2003), if X is a discrete random variable with probability distribution f, then the mean or expected value of X is given by equation (5) and the variance by equation (6).

$$\mu = E\,(X) = \sum_{x} x\,f(x) \qquad (5)$$

$$\mathrm{Var}\,(X) = s^{2} = \sum_{x} x^{2}\,f(x) - \mu^{2} \qquad (6)$$

From equations (5) and (6) the mean (μ = 2.135 = day 60) and standard deviation (s = 0.898 = 25 days) for CD were computed. In this study it was assumed that surplus offspring were slaughtered at a fixed age. Thus a reduction in CD would result in slaughtering at an earlier date but not in the slaughter of heavier animals, and consequently not in a change in profit per animal (weaner) sold. This is according to the reasoning of Ponzoni & Newman (1989).

If one assume that the mating period was sufficiently long, all cows in the herd would calve. However, because the mating period was restricted, conception (and consequently calving) is truncated, resulting in 14% of cows that do not calve. The expected duration of the calving period (CP) can be calculated as:

$$CP = \mu_{CD} + t \cdot s_{CD} = 87 \text{ days} \qquad (7)$$

Where t is the truncation point (1.08) to the right of which the area under the standard normal curve is 0.14. If cows were able to conceive (calve) on average one day earlier (one unit improvement in the trait CD) and the mating period remained unchanged, then the new truncation point (t*) can be calculated as:

$$t^* = \frac{CP - (\mu_{CD} - 1)}{s_{CD}} = 1.12 \qquad (8)$$

The area under the standard normal curve to the right of the new truncation point (t*) is 0.1314 which is approximately 13%. Therefore, a reduction (improvement) in one day in the mean CD reduced the number of barren cows by 1%. It also means that there is a 1% increase in surplus weaners for sale and one less heifer needed to replace a barren cow. The economic value of CD can, therefore, also be related directly to the NCW and expressed as:

$$NCW - [NCW\ (CD - \mu_{CD})\ 0.01] \qquad (9)$$

This reasoning assumes a linear relationship between CD and the number of calves produced. This assumption holds for small changes in CD.

5.2.3 Calving ease (CE)

Data for the derivation of economic values for calving ease was also provided by the SCBSSA. A total of 240367 calving ease scores were available. These calvings were subjectively classified by breeders in five calving ease categories. Since calving ease is measured in a limited number of categories it is classified as a categorical trait. It is usually assumed for these categorical traits that there is an unobserved underlying normal distribution of the sum of genetic and environmental values, and that the phenotypic category is defined by threshold values on this distribution (Koots *et al*., 1994a). CE was considered as a categorical trait (CE – score) for the derivation of economic values; however, the parameters presented in Table 5.3 are for the binary trait CE-%. For the binary trait (CE-%) calvings were classified as either unassisted or assisted. Gregory *et al*. (1995a) reported higher variances for CE-% but higher h^2 for CE – score. For the derivation of economic values for CE, the 1006 scores in category 5 (abnormal presentation) were ignored. The cost structure of dystocia, summarized in Table 5.4, was provided by the South African Veterinary Association (SAVA). Labour costs were estimated following the reasoning of Meijering (1980).

Table 5.4 Summary of cost structure (R / calving) associated with different calving ease scores

Calving ease score	1	2	3	4	5
Legend	No difficulty	Easy pull	Hard pull	Surgical	Abnormal presentation
Costs					
Professional work [a]	0	0	274.43	1011.20	274.43
Medicines etc.	0	32.67	277.04	305.79	277.04
Travel [b]	0	0	241.50	241.50	241.50
Additional labour [c]	3.33 [d]	6.66	13.32	26.64	13.32
Total	3.33	39.33	806.29	1585.13	806.29

[a] rendered by a registered veterinarian

[b] R4.83/km for average of 50 km

[c] provided by farm workers @ R3.33/hour/man

[d] labour cost for observation only

Functional traits are phenotypically and genetically related to production traits as well as other functional traits. For example, dystocia reduces calving rate and weaning rate, increases the number of days to calving and lowers weaning weights by about 12% (Brinks, *et al*., 1973). However, to avoid double counting, reduced performance (indirect costs) in other traits as a result of dystocia should not be accounted for in the derivation of economic values for dystocia (Groen *et al*., 1997). If dystocia, fertility (CD) and growth (WW) are all included in the aggregate genotype, index calculations using an appropriate correlation structure will account for these aspects. Furthermore, the definition of economic values state that these values are derived at the mean value of other traits. Therefore, changes in these traits are not taken into account and it will then also be incorrect to account for the indirect costs associated with these changes. The costs summarised in Table 5.4 are, therefore, only the direct costs associated with dystocia.

For the purpose of the breeding objective, the economic value of calving ease was defined on an underlying liability scale with animals assumed to have phenotypic values distributed on a standard normal distribution (Meijering, 1980; Bekman & Van Arendonk, 1993). The approach adopted for the derivation of the economic value of CE was as follows. If X is the cost (for a breeder) associated with a calving in his herd, then X is a random variable that may assume the values x_1, x_2, x_3 and x_4 (Table 5.4 and Table 5.5). If f is the probability function for X, then f(x) = P(X = x). Table 5.5 summarizes the values, probabilities and truncation points on the standard normal curve, associated with calving ease scores. P and t indicates the probabilities and truncation points before any change in the trait, and P* and t* after an improvement in CE.

Table 5.5 Summary of values in Rand (x), probabilities (P) and truncation points (t) associated with CE – scores where P* and t* represent probabilities and truncation points after a trait change

CE – score	x	f(x) = P(X = x)	t	P*	t*
1	3.33	0.957		0.967	
2	39.33	0.0345	1.72	0.0264	1.84
3	806.29	0.0072	2.39	0.0056	2.48
4	1585.13	0.0013	3.01	0.001	3.10

The thresholds (t) on the underlying distribution were derived according to the probabilities of observing the different scores. The expected value (cost) of X (a calving) is given by E(X) = ? x f(x) (equation 5). The expected cost associated with a calving before any improvement in the trait CE was computed from the data in Table 5.5 as R12,41 [E(X) = 12.41]. After one unit (1%) improvement in the number of unassisted calvings (score 1) the probabilities (P*) for the different calving ease scores change to the values given in Table 5.5. For these new probabilities the expected value of X was then computed as R10.36 [E(X)* =

10.36]. The change in profit due to an improvement in the trait is $E(X) - E(X)^* = R2.05$. The expected cost of a calving (cc) can, therefore, be related to CE by equation (10) as:

$$cc = \mu_{cc} + (\mu_{CE} - CE)\ 2.05 \tag{10}$$

Where cc is the expected cost of a calving, μ_{cc} is the cost of a calving at mean performance in the trait CE, μ_{CE} is the mean performance in the trait CE (% unassisted calvings) and CE can be seen as the % unassisted calvings in a specific herd or the new level of performance in the trait after an improvement. This reasoning assumes a linear relationship between CE and the cost of a calving. This assumption holds for small changes in CE.

Although the uncorrected economic value for CE has been computed mathematically as R2.05, one can assume that the partial derivative of a profit equation including CE is known and that it is:

$$dp / dCE = (\mu_{cc} - cc) = 2.05 \tag{11}$$

Therefore, to find the correct term to include in the profit equation, one can find the anti-derivative or indefinite integral of equation (11). In other words find:

$$\int 2.05\ d\,CE \tag{12}$$

Where $\int$ is the integral sign, 2.05 is the integrand and CE the variable of integration (Haeussler & Paul, 2002). The result is:

$$2.05\ CE + C \tag{13}$$

Where C is the constant of integration. If one assumes that C is the cost of a calving at mean performance in the trait CE (μ_{cc}) and CE represents the change in CE (μ_{CE} – CE) then equation (13) is similar to equation (10).

It was assumed that the direct and maternal component of CE have the same uncorrected economic value as suggested by Ponzoni & Newman (1989) and MacNiel *et al.* (1994). Differences in corrected economic values will then be a function of the frequency and time of expression of the specific component of the trait. To account for the differences in the time and frequency of expression of traits, discounted expressions were calculated with different programs which are based on the discounted gene flow (DGF) techniques of McClintock & Cunningham (1974) and the method of diffusion coefficients (DC) (McArthur & Del Bosque Gonzalez, 1990). The appropriate discount rate was computed by employing the methods discussed by Smith (1978) and Weller (1994), as well as in Chapter 4, from data presented by the S.A Reserve Bank. A discount rate of 8% and an evaluation period of 10 years were used.

The economic values for each trait were derived as the amount by which profit may be expected to change for each one unit of improvement in that trait, independent of effects from changes in other traits included in the definition of aggregate breeding value (breeding objective). Therefore, the economic value (a) of a given trait (i) is defined as the partial derivative (d) of the profit equation (p) with respect to the trait concerned whereby all traits (x) are assumed to take their mean (µ) values:

$$a_i = dp / dx_i \,|_{\,x = \mu} \qquad (14)$$

5.3 RESULTS AND DISCUSSION

The effect on profit from the herd, due to a one unit increase in the traits CR and CD, have three components. One component is due to the sale of weaner calves, the second component is due to the sale of surplus heifers and the third component due to the number of cull cows (barren rate). As shown in the previous section, an improvement in CR and CD will result in one more weaner for sale and, therefore, one less barren cow to be replaced with a heifer. That is an increase in NCW and NSH and a reduction in NCC. Partial derivatives (uncorrected economic values, from Equation 1) for CR and CD are presented in equations (15) and (16).

$$\begin{aligned}dp / dCR = n \{&0.01[(WW \cdot v_W) - (WW \cdot hc_W) - (WW \cdot v_W \cdot 0.07)]\\ &+ 0.01[(FW_H \cdot v_H) - (FW_H \cdot fi_H \cdot v_F) - (FW_H \cdot hc_H) - (FW_H \cdot v_H \cdot 0.07)]\\ &- 0.01[(MCW \cdot v_C) - (MCW \cdot fi_C \cdot v_F) - (MCW \cdot hc_C) - (MCW \cdot v_C \cdot 0.07)]\} \qquad (15)\end{aligned}$$

$$\begin{aligned}dp / dCD = n \{&-0.01[(WW \cdot v_W) - (WW \cdot hc_W) - (WW \cdot v_W \cdot 0.07)]\\ &- 0.01[(FW_H \cdot v_H) - (FW_H \cdot fi_H \cdot v_F) - (FW_H \cdot hc_H) - (FW_H \cdot v_H \cdot 0.07)]\\ &+ 0.01[(MCW \cdot v_C) - (MCW \cdot fi_C \cdot v_F) - (MCW \cdot hc_C) - (MCW \cdot v_C \cdot 0.07)]\} \qquad (16)\end{aligned}$$

The values 0.01 in equation (15) and – 0.01 in equation (16) (from equation 9) represents the percentage change (increase or decrease) in NCW, NSH and NCC as a result of a one unit change in the mean performance of these traits. The value 0.07 represents marketing costs (7% commission). Since an improvement in CD constitutes a negative change (less days to calving), the economic value of CD is negative but of the same magnitude as the economic value for CR.

The part of the profit equation (1) concerned with cows can be expanded to include the costs associated with a calving (CE) as in equation (17).

$$n \{(MCW \cdot v_C) - (MCW \cdot fi_C \cdot v_F) - (MCW \cdot hc_C) - mc - [CE \cdot (\mu_{cc} - cc)] - (MCW \cdot v_C \cdot 0.07)\} \qquad (17)$$

The partial derivative (uncorrected economic value) for CE is presented in equation (18). This can be read as: the economic value of CE is the rate of change in the cost associated with a calving, at the level of mean performance in the trait, multiplied by the number of discounted expressions (n) of the trait to obtain the corrected economic value.

$$dp / dCE = n (\mu_{cc} - cc) \qquad (18)$$

The number of expressions (n) for functional traits are summarised in Table 5.6.

Table 5.6 Summary of the number of expressions (n) when income and expense are expressed per year (IE), total discounted expressions (TDE), cumulative total discounted expressions (CTDE) and the diffusion coefficient (DC) for functional traits in the breeding objective.

		DGF		
Trait	IE	TDE	CTDE	DC
CR	100	0.932	93.200	0.750
CD	100	0.932	93.200	0.750
CE_D	86	0.838	72.068	0.878
CE_M	86	0.932	80.152	0.750

The differences in TDE and CTDE (Table 5.6) are a function of the number of times a trait is expressed and when these expressions take place. The diffusion coefficient (DC) is higher the earlier traits are expressed. The reason for this is the faster diffusion of the genetic improvement through the herd and the fact that future economic gains are discounted less since it is realised sooner.

It was assumed that CR and CD are expressed at the same time and with the same frequency during the 10 year evaluation period. Since CE_D is expressed earlier but with a lower frequency than CE_M, the number of expressions (TDE) is lower but the DC is higher for CE_D. By substituting the values from Table 5.2, as well as the expected marginal increase in costs associated with a calving, into Equations (15), (16) and (18) and multiplying with the number of expressions (Table 5.6) the corrected economic values were derived. These corrected economic values expressed per unit used, per s_P, per s_A (Table 5.3) and per dG are summarised in Table 5.7 (DGF-method) and Table 5.8 (DC-method).

Table 5.7 Economic values (R / 1 unit change) for functional traits corrected with the DGF method and expressed per unit used, per s_P, per s_A and per dG

Trait	CR	CD	CE_D	CE_M
Method of expression				
Per unit used	13.27	- 13.27	1.48	1.64
Per s_P	46.05	- 331.75	2.99	3.31
Per s_A	18.98	- 93.82	1.08	1.15
Per dG [a]	7.83	- 26.54	0.39	0.40

[a] $dG = i \cdot h \cdot sA$, $i = 1$

DGF corrected economic values were scaled from a herd basis to a per cow-year basis by division by the total number of cows (100) in the herd i.e. to be expressed as per female unit. The absolute value of the expression ($|EV|$ x s_A) enables the comparison of traits in terms of 'economic–genetic' variation available. This expression is also known as the trait relative economic value (REV) (Barwick & Henzell, 1999). It describes trait importance to the breeding objective by valuing a standard amount of trait change. The expression of economic values per unit of additive genetic and phenotypic standard deviation is important because not all traits are measured in the same unit or have the same variance.

The equation $dG = (r_{A,\hat{A}}) (i_p) (s_A)$ predicts the expected superiority of the selected proportion (p) where selection is based on $\hat{A}$ (Van Vleck *et al*., 1987). Therefore, the absolute value of the latter expression (| EV | x dG) indicates the expected monetary value of the superiority due to selection in one generation. It was assumed that the accuracy of prediction ($r_{A,\hat{A}}$) is equal to the square root of h^2 (h) and the selection intensity factor (i_p) is equal to one (1).

Table 5.8 Economic values (R / 1 unit change) for functional traits corrected with the DC method and expressed per unit used, per s_P, per s_A and per dG

Trait Method of expression	CR	CD	CE_D	CE_M
Per unit used	10.68	- 10.68	1.80	1.54
Per s_P	37.06	- 267.0	3.64	3.11
Per s_A	15.27	- 75.51	1.31	1.08
Per dG [a]	6.30	- 21.36	0.47	0.37

[a] $dG = i \cdot h \cdot sA$, $i = 1$

The magnitude of the economic values in Tables 5.7 and 5.8 emphasize the relative economic importance of fertility. Compared with the economic values for production traits derived in Chapter 4, fertility is at least six times as important as growth (WW) in a typically Simmentaler herd employing a pasture based cow-calf production system.

Ponzoni (1992) examined the genetic consequences of using either CD or CR as a measure of female fertility and concluded the choice should only depend on the relative values of reliable phenotypic and genetic parameters. This conclusion by Ponzoni (1992) was also demonstrated in this study, where the best option seems to be CD. Johnston & Bunter (1996) found a high genetic correlation (r_G = - 0.97) among CD and CR and similar heritabilities for both traits, leading to the conclusion that the same trait was being measured. Since these are complex traits and the components of both include factors such as conception rates, length of the post-partum anoestrus interval (PPI) and gestation length (GL), this conclusion is probably correct. As CD is able to distinguish between early and late calvers, Johnston and Bunter (1996) were in favour of using CD as a measure of fertility. In contrast, Phocas *et al*. (1998b) preferred calving success on a year basis (CR) because they were unable to demonstrate the economic importance of CD. In their study CD had a positive economic value, i.e. they preferred calving later in the season. This is in contrast to the results of this study as well as those from Ponzoni & Newman (1989). In the study of Phocas *et al*. (1998b) calving took place in winter. Therefore, high feed costs were included in the profit equation as the first two months of lactation occurred while the animals were indoors. This is completely different from the South African situation where calving usually occur when the quality and quantity of grazing is optimal.

At mean values of close to 100% the scope of improvement by selection for CR will be exhausted. By contrast, genetic gains in CD at that point could still be possible. The economic value of CD would, however, be different to that assumed in this study. Benefits would no longer be the consequence of improved reproductive rate, but rather, of a more concentrated calving.

The economic value of a trait may depend on the level of performance in the trait itself, or on the level of other traits. Evaluation of non-linearity of economic values can be performed by deriving economic values at different starting values for genetic merit of the animals. Groen *et al*. (1994) studied the relative efficiency of non-linear indices versus regular updating economic values according to new population averages and concluded that directly optimizing response over multiple generations yield slightly higher economic responses than stepwise (each generation) adjustment of a linear index. Furthermore, a quadratic index was less efficient than a linear index when considering multiple generations. Groen *et al*. (1997) concluded that for non-linear profit functions there are no uniformly best solutions. Maximum progress will always be achieved by a linear index, but for a non-linear profit function, the index that results in maximum genetic gain in the future will be a function of the selection intensity.

Therefore, to evaluate the non-linearity of the economic value for CE it was assumed that the percentage unassisted calvings is only 75% ($P_{\text{score }1} = 0.75$) and not 95.7%. This higher number of assisted calvings can be related to heifer calvings (Gregory *et al*., 1995a). It was further assumed that the probability of other calving ease scores change proportionally. The expected cost of a calving at this level of performance in the breed was computed as R56.52. The uncorrected economic value of R2.28 is R0.23 higher than the value previously derived from the data. These results emphasize not only that non-linearity does exist but also that this non-linearity is not extreme. By employing equation (10) the expected cost of a calving (cc) was computed as R54.85 indicating that equation (10) is fairly robust to changes in the mean performance of the trait CE. It was, therefore, concluded that, unless the non-linearity for functional traits is extreme, non-linearity will cause second order effects that are of minor importance in relation to the rate of genetic gain expected.

Direct comparison of the results from this study with other studies is not possible. Munoz-Luna *et al*. (1988), for instance, derive a negative economic value for dystocia percentage. However, since dystocia can be regarded as the opposite of calving ease (with a positive economic value) this negative value is to be expected. Koots & Gibson (1998a) and Amer *et al*. (2001) included indirect costs associated with reduced production, fertility and survival. In this study, these indirect costs were not accounted for because they were already included in the mean performance of traits also included in the breeding objective.

5.4 CONCLUDING REMARKS

The choice of the right selection criterion seems to be one of the most important decisions to be taken not only by breeders but also by administrators of performance recording schemes. Under most circumstances the difference between using different criteria will be small compared to the effect of ignoring reproduction altogether. The choice would not only depend on the relative values of reliable phenotypic and genetic parameters but also be influenced by non-genetic considerations such as ease and cost of incorporation into the performance recording scheme as well as acceptance by breeders. It is, however, recommended that breeders adopt a management system that will enable them to record bull entry dates, calving dates and pregnancy status of cows.

The economic values for calving-ease were derived from a purely economic point of view. Aspects of animal welfare may, in future, become increasingly relevant and these cannot be passed over lightly. Integration of functional traits in beef cattle breeding objectives remain a major challenge for animal breeders.

CHAPTER 6

Derivation of economic values for the Simmentaler breed in South Africa: Product quality traits

6.1 INTRODUCTION

The consumer’s decision to buy meat and meat products forms the basis of the meat industry (Naudè, 1985). Consumers have widely diverging expectations of the product of which their own conception of “value” is the most important parameter, i.e. the quality and quantity of the product relative to other foods and consumer commodities. Meat quality, as defined by Naudè (1985) and Shorthose (1991), comprised five categories, namely appearance, palatability, nutritive value, processibility and shelf-life. Important aspects of palatability are tenderness, marbling, flavour, juiciness and aroma. These quality characteristics are influenced biologically and technologically, and finally established during the different stages of the meat production chain which form part of an integrated system covering the entire range from conception to consumption. To satisfy the consumer, combining genetics and technology (effective pre- and post-slaughter protocol) seems obvious. However, applying technology to remedy a poor quality product is costly, would render the product more expensive and less acceptable.

Improving product quality and consistency, especially with respect to tenderness, has been identified as a critical element in the industry’s efforts to arrest the steady decline in beef’s market share (Tatum *et al.*, 1999). The beef industry’s focus on improving product consistency and quality is predicted on information suggesting that (1) tenderness and taste of beef are two primary drivers of consumers purchase decisions, (2) consumers are not satisfied with beef’s consistency of quality or its tenderness, and (3) improvements in tenderness and consistency of eating quality would motivate consumers to increase beef consumption.

According to Wolfovà *et al.* (1995) the monetary value of slaughtered animals is determined by carcass weight, dressing percentage and carcass quality. Although carcass weight and dressing percentage are clearly defined traits, carcass quality may be characterized in different ways. Indicators of carcass quality can roughly be subdivided into two groups: (1) indicators measured on a continuous scale (lean meat, fat percentage, fat depth) and (2) indicators measured on an ordered categorical scale (classes for age, fleshiness and fat covering). The price per kilogram of carcass is usually determined by ordered categorical traits. This is similar to the South African situation where meat quality is managed by means of a meat classification/grading system based on animal age, carcass fat content, sex and conformation (www.samic.co.za).

In most present applications the economic values of traits are assumed to be independent of the population mean of these traits. However, many traits present an optimum range, resulting in a dependency between the economic value and the population mean. Examples of this can be found especially in traits related to carcass quality. An approach that can be followed in these cases is the use of a restricted index (Kempthorne & Nordskog, 1959). The purpose of this approach is to keep the trait at a particular (optimum) level. However, a restricted gains index is classified as a non-objective method since there are predetermined constraints on genetic response of some traits that partially or completely override the response determined by their economic values (Groen *et al*., 1997). Although a linear index is by definition optimal (Goddard, 1983; Gibson & Kennedy, 1990) an alternative is to include quadratically the optimum trait in the profit equation (Wilton *et al*., 1968). Whatever method is used, it is always necessary to calculate an accurate profit function / equation (Hovenier *et al*., 1993). However, for quality traits a profit function is in most cases only approximately known in terms of the thresholds below and above which the product is only acceptable for lower prices (e.g. fatness) or not acceptable at all (e.g. tenderness or the lack thereof). The calculation of economic values for traits with an optimum range (optimum traits) assumes that this optimum range can be defined (Hovenier *et al*., 1993). Furthermore, the magnitude of these price differences has to be generated by the market.

The purpose of this chapter, in spite of limitations set by the current classification/grading and payment system of the beef market, as well as the paucity of parameter information regarding quality traits, is to derive economic values for dressing percentage, backfat thickness, tenderness and marbling.

6.2 MATERIALS AND METHODS

The sequential procedure developed by Ponzoni and Newman (1989) to derive breeding objectives for domestic livestock was used in this study. For the derivation of economic values for product quality traits (this part of the study) a commercial beef herd comprising 100 purebred Simmentaler cows was simulated assuming herd age structure, slaughter age and replacement rates representative of an integrated production system (Chapter 4). Input variables for this model, obtained from feedlot data (and assumed for certain variables) are summarised in Table 6.1.

Table 6.1 Input variables included in the model

Variable	Symbol	Value
Number of cows in herd		100
Number of weaners/steers available for feedlot	NCW	39
Weight in	WW	239 kg
Final weight	FW	436 kg
Carcass weight	CW	240 kg
Dressing percentage	DP	55 %
Value weaner / kg	v_W	R7.70
Value carcass / kg < A2A3[a] (13%) [b]		R12.94
= A2A3 (86%)	v_C	R13.50
> A2A3 (1%)		R12.86

[a] age / fatness class where A represents a young animal with no permanent incisors and 2/3 indicate backfat thickness from 1 to 5 mm

[b] from feedlot data

It was assumed that male calves born on the farm were not sold at weaning but fed till slaughtering. Only the post weaning or feedlot phase was, however, considered. This can also be regarded as a system where farmers/producers of weaned calves are compensated for the superior quality of their calves. This is, however, not the case in practice as the current beef market, at least at the weaned calf level, is dominated by "average price purchasing" in which genetic post-weaning or consumption superiority (or inferiority) is not adequately reflected by price premiums (discounts). The production of better quality red meat may be achieved in part through genetic selection provided that consumer demand dictates change through the entire market chain back to the producer and that packers buy fed cattle in a manner that will reward producers for putting selection emphasis on carcass traits (Woodward *et al.*, 1992). However, if processors do not pay producers for differences in carcass value, the producers will seek stocks improved for reproductive and growth traits, and not for carcass traits. It was, therefore, assumed that a better system will, in future, exist and that breeders will, therefore, include product quality traits in their breeding objectives.

It is clear, from a simplified profit equation [$p = N(nwV - nC_1d - C_2)$ – equation 4 from Chapter 2], that income is a function of the number of animals (weaners / fed steers) available for sale, the weight of these animals (carcasses) as well as the quality (value) of these carcasses. The value of the carcass is a function of the carcass quality (grading). For this study it was further assumed that there are also classes (with price differences) for tenderness and marbling which influence the value of the carcass. N is the number of breeding females producing n offspring per year, w is weight of the product per offspring with value V per unit grown over d days. C_1 is the cost per day of growth per individual and C_2 is the cost per female per year. This is in agreement with the conclusion of Hovenier *et al*. (1993) that, the marginal income per animal (carcass) is a function of the fraction of the population (carcasses) within the optimum range (quality), the price difference between products within and products outside the optimum range, and the amount of product produced per animal (weight). Wolfovà *et al.* (1995) also included dressing percentage and fat covering (quality class) in their analysis.

Furthermore, surveys of beef packers, purveyors, restuaranteurs and retailers indicated that product uniformity, consistency and tenderness were among the highest ranked beef quality concerns (Lusk *et al.*, 2001). This would obviously include uniformity in carcass size and finish. Boleman *et al*. (1997) and Devitt *et al*. (2002) indicated that tenderness of beef is a primary determinant of consumer satisfaction followed by marbling (flavour and juiciness). It was, therefore, concluded that the highest income would be from the heaviest acceptable carcasses with the optimum finish and quality, and that the traits to be included in the breeding objective should be dressing percentage, fat depth, tenderness and marbling (Table 6.2). Since there are, at present, no parameter estimates for carcass traits for the Simmentaler in Southern Africa, estimates reported in the literature were assumed. The mean (μ) and phenotypic standard deviation (s_P) of fatness

(Table 6.2) were computed from Simmentaler feedlot data. The genetic standard deviation (s_A) of fatness was then computed from $h^2 = s^2_A / s^2_P$.

Table 6.2 Parameters for the product traits to be included in the breeding objective

Trait	Symbol	h^2	Mean	s_P	s_A
Dressing percentage (%)	DP	0.39[a]	55[d]	1.9	1.19
Backfat (mm)	BF	0.44	2.4[d]	1.3	0.86
Tenderness (WBS kg)	T	0.29	4.3[b]	1.3	0.70
Marbling (score)	M	0.38	3.0[c]	0.82	0.50

[a] from Koots *et al.* (1994a)

[b] from Cundiff *et al.* (2004)

[c] Barwick & Henzell (1999)

[d] from feedlot data

In a feedlot net returns per head are determined by the gross margin (selling price minus buying price) minus feed and non-feed variable costs (e.g. veterinary, labour, marketing) (Meissner, 1993). In this analysis it was, however, assumed that carcass quality is not a function of these costs as suggested by Wolfovà *et al*. (1995).

Hovenier *et al*. (1993) developed a method to calculate marginal income functions and to derive economic values for traits with an intermediate optimum such as meat quality (e.g. fatness). They expressed income per carcass as a function of the trait means and assumed that carcasses were classified into different quality classes with different prices. This marginal income function (equation 1) will be dependant on the population level for the optimum trait (µ), the standard deviation for this trait (s), the width of the optimum range (and other ranges), the price difference between products within and outside the optimum range, and the amount of product produced per animal (Hovenier *et al*., 1993).

$$MI = p_W \cdot PD \cdot W \qquad (1)$$

Where MI = mean marginal income per animal, p_W = fraction of the population within the optimum range, PD = price difference between products within and outside the optimum range, and W = amount of product produced per animal.

The calculation of economic values for these optimum categorical traits requires the definition of quality classes (truncation points between classes) for each trait. Furthermore, it was assumed, for these categorical traits, that there is an unobserved underlying normal distribution of the sum of genetic and environmental values, and that the phenotypic category is defined by threshold values on this distribution (Koots *et al.*, 1994a; Falconer & Mackay, 1996). Therefore, given a certain population mean µ and a normal probability distribution [$X \sim N(\mu, \sigma^2)$] of the trait $f(x \mid \mu)$, the fraction of the population within the defined quality classes can be determined. It is also necessary to know (or assume) the price for carcasses within a given quality class. Income per carcass I(µ) can then be seen as the average value of carcasses in the population or as the expected value of a carcass [E(X)] (Haeussler & Paul, 2002; Steyn *et al.*, 2003) (equation 2).

$$E(X) = I(\mu) = \sum_{i=1}^{n} p_i \, f(x) = \sum_{i=1}^{n} p_i \cdot \int_{LB}^{UB} f(x|\mu)\, dx \qquad (2)$$

Where I(µ) = average income per carcass or the expected value of a carcass at the population mean (µ), n = the number of quality classes, p_i = the price per carcass in the i th quality class, f(x) = the probability of a carcass to be in the i th class or the fraction of the population within the class, LB / UB = the lower / upper boundary (truncation point) of the i th class, and $f(x|\mu)$ = the probability distribution [$X \sim N(\mu, \sigma^2)$].

Economic values are defined as marginal changes in profit (income) due to a one unit change in the population mean due to selection. Since income is non-linear in µ, the economic value EV(µ) is also a function of µ. From equation 2 it follows that:

$$EV(\mu) = d\ I(\mu)\ /\ dx = d\ \Big[\overset{n}{\underset{i\,=\,1}{?}}\ p_i \cdot \overset{UB}{\underset{LB}{?}} f(x|\mu)\ dx\Big]\ /\ dx \qquad (3)$$

To calculate the probability of a carcass being in a certain class or, in other words, the fraction of the population in the class, the normal density function (equation 4) [f(x) in equation 3] can be integrated numerically by using either the Trapezoidal Rule or Simpson’s Rule (Cheney & Kincaid, 1999; Haeussler & Paul, 2002). Simpson’s Rule usually gives a better approximation of the area under the curve (distribution).

$$f(x) = [1\ /\ (s\ v\overline{2\ p})\ ]\ \cdot e\ (exp.)\ \{-\ 0.5\ [(\ x - \mu\ )\ /\ s\ ]^2\},\quad -\ 8\ <\ x < 8 \qquad (4)$$

Where s = standard deviation of the trait, µ = population mean, p and e are mathematical constants, and the term in brackets {} is the exponent of e.

In this study X, a normally distributed random variable with mean µ and standard deviation s, was first transformed into a standard normal random variable (Z) with µ = 0 and s = 1 by employing the change-of-variable formula (equation 5) where after the values for integrals was read from tables (e.g. Appendix D in Haeussler & Paul, 2002).

$$Z = (X - \mu)\ /\ s \qquad (5)$$

6.2.1 Dressing percentage (DP)

For the derivation of the economic value for dressing percentage it was assumed that profit (p) is a function of the number of animals available for sale (NCW), final weight (FW), dressing percentage (DP) and the average value (v_C) of a carcass (equation 6)

$$p = [NCW\ (FW\ \cdot DP \cdot v_C)] \qquad (6)$$

The economic value of DP was derived as the partial derivative of the profit equation (equation 6) with respect to the given trait whereby all traits are assumed to take their mean values (equation 7).

$$dp / dDP = n \{0.01[NCW (FW \cdot v_C)]\} \qquad (7)$$

Upper case symbols denote traits and n is either 1.0 when income and expense are expressed per year, the total discounted expressions (TDE) (McClintock & Cunningham, 1974) or the diffusion coefficient (DC) (McArthur & Del Bosque Gonzalez, 1990). The factor 0.01 was included to express the economic value as the change in profit per one percent increase in dressing percentage.

The mean dressing percentage in the population, before any change in the trait, was 55 %. At this level of performance in the population the expected value of a carcass was R3237.30. With a one unit increase in the mean performance of the trait, to a dressing percentage of 56 %, the value increased to R3296.16. This resulted in an uncorrected economic value for dressing percentage of R58.86.

6.2.2 Backfat thickness (BF)

The method described above was used to derive the economic values for carcass quality (optimum) traits. In South Africa the price per kilogram of carcass is usually determined by ordered categorical traits (classes for fleshiness / conformation and fat covering / backfat thickness). Conformation is a subjective (visual) classification of carcasses in five classes where 1 is a very flat carcass and 5 a very round carcass (www. samic.co.za). Although retailers purchase in bulk (hind or fore quarter) and may choose carcasses with better conformation, no economic value for conformation was derived due to the subjective nature of classification and the lack of consumer awareness with regard to conformation. Fatness is measured between the 10th and 11th rib, 50 mm from the carcass midpoint. Fat classes vary from 000 (no visible fat) to 666 (excessively fat). Truncation points for fatness classes (L, I, F) representing lean, intermediate and fat respectively, the price per kg carcass weight within each category as well as the probabilities (dependant on population mean level of performance) for carcasses to be in a certain class, are shown in Table 6.3. Truncation points were chosen based on the South African meat classification system.

Table 6.3 Summary of values/prices (x) in R/kg carcass weight, probabilities before (P) and after a trait change (P*), and truncation points (t) in mm backfat thickness associated with different fatness classes

Fatness class	Range	x (p_i)	f(x) = P(X = x)	t	P*
L	A0/A1	12.94	0.125	< 1mm	0.027
I	A2/A3	13.50	0.856	1 – 5 mm	0.878
F	>A3	12.86	0.019	> 5 mm	0.095

The average value of carcasses in the population or the expected value of a carcass, before any change in fatness (µ = 2.4 mm BF), was computed (equation 2) from the data in Table 6.3 as R13.42 [E(X) = 13.41784]. After a one unit (1.0 mm) increase in the mean performance (µ = 3.4 mm) of the trait the expected value of a carcass stayed almost the same on R13.42 [E(X)* = 13.42408]. The change in profit due to a one unit increase in the trait is E(X)* – E(X) = R0.00624 / kg carcass weight. At a mean carcass weight of 240 kg (Table 6.1) the uncorrected economic value for BF would then be R1.50.

6.2.3 Tenderness (T)

Boleman *et al*. (1997) and Lusk *et al*. (2001) concluded that consumers could discern between categories of tenderness and were willing to pay a premium for improved tenderness. Tenderness is assessed in Warner-Bratzler shear force (WBS). The reported shear force is the average kilograms of force required to shear through eight one centimeter cores from steak and lower values indicate more tender steak (Devitt *et al*., 2002). WBS remained the most popular and accurate instrumental measurement of meat tenderness (Wheeler *et al.*, 1997) with tenderness ratings highly repeatable when measurement protocols are executed properly (Shackelford *et al*., 1997).

Table 6.4 Summary of values/prices (x) in R/kg carcass weight, probabilities before (P) and after a trait change (P*), and WBS-truncation points (t) in kg shear force associated with different tenderness classes

Tenderness class	x (p_i)	f(x) = P(X = x)	t [a]	P*
T	14.70	0.3791	< 3.9	0.3502
I	13.50	0.2123	3.9 – 4.6	0.2110
U	12.30	0.4086	> 4.6	0.4388

[a] from Shackelford *et al.* (1991)

Truncation points for beef tenderness classes (T, I, U) representing tender, intermediate and tough (unacceptable) respectively, the price per kg carcass weight within each category as well as the probabilities (dependant on population mean level of performance) for carcasses to be in a certain class, are shown in Table 6.4. Truncation points were chosen similar to those reported by Shackelford *et al.* (1991).

A guaranteed tender steak costs, in the butcheries of a well known supermarket chain in the Gauteng province of South Africa, on average R7.00/kg more than a standard steak. If it is assumed that 30% of beef cuts (proportion of high priced cuts – SAMIC – South African Meat Industries Company) on a weight basis would benefit from improved tenderness, the price per kg of carcass would increase (premium paid) by about 9% from the average value of R13.50 to R14.70. It was further assumed that the same amount would be discounted from the tough (unacceptable) carcass (Table 6.4).

The average value of carcasses in the population or the expected value of a carcass, before any change in the trait T, was computed (Equation 2) from the data in Table 6.4 as R13.46 [E(X) = 13.46]. After a one unit (0.1 kg WBS) increase in the mean performance of the trait the expected value of a carcass decrease to R13.39 [E(X)* = 13.39]. The change in profit due to a one unit increase in the trait is E(X)* – E(X) = -R0.07 / kg carcass weight. At a mean carcass weight of 240 kg (Table 6.1) the uncorrected economic value for tenderness would then be -R16.80 and the corrected economic value -R5.03. The economic value of tenderness is negative since an improvement in the trait results from a negative change i.e. a smaller WBS score.

6.2.4 Marbling (M)

Derivation of the economic value for marbling was also based on the method developed and discussed above. Since Boleman *et al*. (1997) and Devitt *et al*. (2002) indicated that marbling (flavour and juiciness) is also an important determinant of consumer satisfaction it was assumed that consumers would be prepared to pay for better marbling (a higher marbling score). Marbling can be assessed subjectively on the carcass or through real time ultrasound (RTU) measures taken on live animals (Crews & Kemp, 2001). RTU is considered a cost-effective method for genetic evaluation of carcass merit in potential replacement animals (Wilson, 1992). Although marbling were scored differently by different researchers and in different countries (Woodward *et al*., 1992; Gregory *et al*., 1995b) the Australian 7-point scale (0 lowest – 6 highest) (Barwick & Henzell, 1999) was assumed for this study.

Jeremiah *et al.* (1993) as quoted by Devitt *et al*. (2002) reported that the relative choice of consumers between tenderness and marbling is in the order of 3:1. It was then assumed that, since consumers are prepared to pay a 9% premium for a guaranteed tender carcass, they would then also be prepared to pay a 3% premium for carcasses in the optimum marbling score class. Barwick & Henzell (1999) indicated a lower premium (±30% lower than the optimum class) for the highest marbling score classes.

Truncation points for marbling score classes (L, O, H) representing low, optimum and high respectively, the price per kg carcass weight within each category as well as the probabilities (dependant on population mean level of performance) for carcasses to be in a certain class, are shown in Table 6.5. Truncation points were chosen based on the study by Barwick & Henzell (1999).

Table 6.5 Summary of values/prices (x) in R/kg carcass weight, probabilities before (P) and after a trait change (P*), and marbling score truncation points (t) for different marbling score classes

Marbling score class	Range	x (p_i)	f(x) = P(X = x)	t	P*
L	0, 1	13.50	0.1113	< 2	0.0898
O	2, 3,	13.90	0.7525	2 – 3.9	0.7457
H	4, 5, 6	13.77	0.1362	> 3.9	0.1645

The average value of carcasses in the population or the expected value of a carcass, before any change in marbling score, was computed (equation 2) from the data in Table 6.5 as R13.84 [E(X) = 13.8378]. After a one unit (0.1 score) increase in the mean performance of the trait the expected value of a carcass stayed almost the same on R13.84 [E(X)* = 13.8427). The change in profit due to a one unit increase in the trait is E(X)* – E(X) = R0.0049 / kg carcass weight. At a mean carcass weight of 240 kg (Table 6.1) the uncorrected economic value for marbling would then be R1.18.

To account for the differences in the time and frequency of expression of traits, discounted expressions were calculated with different programs which are based on the discounted gene flow (DGF) techniques of McClintock & Cunningham (1974) and the method of diffusion coefficients (DC) (McArthur & Del Bosque Gonzalez, 1990). The appropriate discount rate was computed by employing the methods discussed by Smith (1978), Weller (1994) and in Chapter 4 from data presented by the S.A Reserve Bank. A discount rate of 8% and an evaluation period of 10 years were used.

6.3 RESULTS AND DISCUSSION

The number of expressions (n) when income and expense are expressed per year (IE = 39), total discounted expressions (TDE = 0.767), cumulative total discounted expressions (CTDE = 29.91) and the diffusion coefficient (DC = 0.878) are the same for all product quality traits since these traits are expressed at the same time and with the same frequency. Uncorrected economic values were multiplied by the CTDE and DC and summarised in Table 6.6 and Table 6.7 respectively.

Table 6.6 Economic values (R / 1 unit change) for product / quality traits corrected with the DGF method and expressed per unit used, per s_P, per s_A and per dG

Trait Method of expression	DP	BF	T	M
Per unit used	17.61	0.45	- 5.03	0.35
Per s_P	33.46	0.59	- 6.54	0.29
Per s_A	20.96	0.39	- 3.52	0.18
Per dG [a]	13.09	0.26	- 1.90	0.11

[a] $dG = i \cdot h \cdot sA$, $i = 1$

DGF corrected economic values were scaled from a herd basis to a per cow-year basis by division by the total number of cows (100) in the herd i.e. to be expressed as per female unit. Although economic values for carcass traits can be expressed per carcass (slaughtered animal) it should be expressed per female if these traits are to be included in the breeding objective together with other traits. The absolute value of the expression ($|EV|$ x s_A) enables the comparison of traits in terms of 'economic–genetic' variation available. This expression is also known as the trait relative economic value (REV) (Barwick & Henzell, 1999). It describes trait importance to the breeding objective by valuing a standard amount of trait change. The expression of economic values per unit of additive genetic and phenotypic standard deviation is important because not all traits are measured in the same unit or have the same variance.

The equation $dG = (r_{A,\hat{A}})\,(i_p)\,(s_A)$ predicts the expected superiority of the selected proportion (p) where selection is based on $\hat{A}$ (Van Vleck *et al*., 1987). Therefore, the absolute value of the latter expression ($|EV|$ x dG) indicates the expected monetary value of the superiority due to selection in one generation. It was assumed that the accuracy of prediction ($r_{A,\hat{A}}$) is equal to the square root of h^2 (h) and the selection intensity factor (i_P) is equal to one (1).

Table 6.7 Economic values (R / 1 unit change) for product / quality traits corrected with the DC method and expressed per unit used, per s_P, per s_A and per dG

Trait Method of expression	DP	BF	T	M
Per unit used	51.68	1.32	-14.75	1.04
Per s_P	98.19	1.72	-19.18	0.85
Per s_A	61.50	1.14	-10.33	0.52
Per dG [a]	38.41	0.76	-5.56	0.32

[a] $dG = i \cdot h \cdot sA$, $i = 1$

Compared with the economic values derived previously for production (growth) traits (Chapter 4) and functional traits (Chapter 5), the economic values for product quality traits are the least important. This is in agreement with the general belief that functional traits are economically the most important followed by production traits. The only exception is dressing percentage (DP) with an economic value similar to the production traits. This is to be expected as DP is not a quality trait as such but can be regarded as a production trait. This higher value for DP is similar to the results obtained by Wolfovà *et al*. (1995). Amongst the three quality traits (BF, T and M) to include in the breeding objective, tenderness (T) is the most important (-R3.52 / -R10.33) followed by backfat thickness (BF) (R0.39 / R1.14) and marbling (M) (R0.18 / R0.52). Although tenderness is economically the most important beef quality trait it is not an optimum trait. Optimum traits have an intermediate optimum value (intermediate mean performance in the population). This is not the case with tenderness were a maximum rather than an intermediate value is currently still ideal. This may change in future as too soft meat can be undesirable to consumers. However, given the current mean and / or expected rate of progress this is not an issue yet.

Since the economic value of optimum traits (e.g. backfat and marbling) depend on the population mean value for these traits, optimum traits may have positive, zero or negative economic values. The low economic values for BF and M may, therefore, indicate that these traits are close to the optimum value (optimum mean performance). To test the possibility of obtaining a negative economic value it was assumed that the mean backfat thickness in the population was 4 mm (µ = 4mm) and that it increased, through selection, to 5 mm (µ* = 5mm). The expected value of a carcass (at 4 mm) was computed as R13.37 [E(X) = 13.37] and after a one unit (1 mm) increase in mean performance (at 5 mm) as R13.20 [E(X)* = 13.20]. The uncorrected economic value at this level of performance in the population is then E(X)* – E(X) = - R0.17 / kg carcass weight. At a mean carcass weight of 240 kg (Table 6.1) the uncorrected economic value would then be –R40.80. This negative economic value confirms the above mentioned phenomenon.

To determine the optimum backfat thickness under the current pricing system, the expected value of a carcass was determined at assumed different mean levels for the trait (BF) by employing the method discussed above. Results are summarised in Figure 6.1.

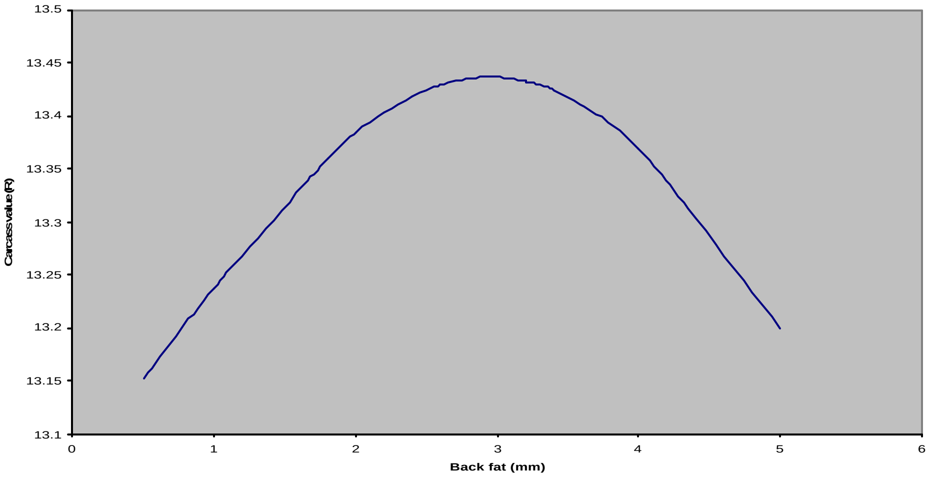

Figure 6.1 Expected values [E(X)] in Rand/kg of carcass at different mean levels (mm backfat thickness) for the trait backfat

Certain conclusions can be drawn from Figure 6.1. The most obvious is the fact that backfat thickness is indeed an optimum trait. From Figure 6.1 it is also clear that the optimum value or optimum mean performance for this trait is 3 mm. At this level of performance the expected value of a carcass or the mean value of carcasses in the breed / population will be R13.44 / kg. At mean values to the left of (less than) 3 mm the trait BF will have a positive economic value whereas to the right of (more than) 3 mm the economic value will be negative. In other words, in populations with a mean BF more than 3 mm, BF should be included in the breeding objective with a negative value and not with a positive value as for the Simmentaler. Mate genotype (mean performance of the breed to be crossed with) should, in crossbreeding programs, be taken into consideration as it may have an influence on the economic value of optimum traits.

These results also emphasise the importance of knowing the correct mean values for traits, especially optimum traits, as not only the magnitude of economic values can change but also the sign. Re-derivation of economic values after a trait change is also of major importance.

Since selecting animals for mature weight or growth rate has the effect of delaying maturity or the onset of the fattening phase, a leaner carcass can be marketed at comparable weight (Casey, 1993). In other words, larger, later-maturity types reach equal fatness at heavier body weight than smaller, early-maturity types. However, excessive weight (size) places the carcass outside the consumer acceptable norm which may then result in a price penalty. The fact that the average Simmentaler carcass is already heavier than the optimum (SAMIC) (with less than optimum fat), again stresses the importance to include mature weight with a negative economic value in the breeding objective.

There are many factors that influence the quality of beef, including, genetics, feeding regime, pre-slaughter management, age at slaughter, post-mortem aging, electrical stimulation and cooking method. Exploiting genetic variation by including meat quality traits in the breeding objective of a beef breeding program is one possibility to improve meat quality.

6.4 CONCLUDING REMARKS

There are, at present, for the majority of carcass traits no consumer driven price differentials in South Africa. This shortcoming prevents the formal derivation of economic values for these traits. Since there is an increasing awareness of and an interest in product quality by breeders and consumers alike, more and better information to include in the model will in future become available. Live animal ultrasound data and gene marker technology in combination with carcass data can be powerful tools to enhance genetic evaluation and selection for carcass quality traits. Assumptions made in this study should, however, in the mean time suffice. Furthermore, inclusion of these traits in the breeding objective may reflect possible future developments in the beef market.

Optimal utilization of genetic evaluations for quality traits, in combination with genetic evaluation for other traits, involves determination of the economic importance of improving quality traits relative to the economic importance of improving other traits. Since the economic values of product quality traits are low (under the current price structure) these traits will only be of interest for selection programs and be included in the selection index, if they are favourably correlated with economically more important traits. The long-term survival and prosperity of the beef industry still depends on its economic viability, which is served by improving its competitiveness, profitability and economic efficiency by focusing on characteristics that customers want.

CHAPTER 7

Proposed economic selection indices for the Simmentaler breed in South Africa

7.1 INTRODUCTION

In practice, several or many traits influence an animal's value, although they do so in varying degrees (Hazel, 1943). Information on several traits can be combined in an index by a special use of Fisher's discriminant function as proposed by Smith (1936) and Hazel (1943). The genetic gain which can be made by selecting for several traits simultaneously within a group of animals is the product of the selection differential, the correlation between the aggregate breeding value (breeding objective) and the selection index, and genetic variability. The greatest opportunity of increasing the progress from selection is by ensuring that the correlation between the breeding objective and selection index is as large as possible. Hazel (1943) presented a multiple correlation method of constructing optimum selection indices. However, to solve the simultaneous equations the economic parameters (relative economic values), genetic parameters (heritability, genetic correlations) and phenotypic parameters (standard deviation, correlations) of/among traits must be known (Hazel, 1943). When these traits differ in variability, heritability, economic importance, and in the correlation among their phenotypes and genotypes, index selection was more effective than independent culling levels or sequential selection (Hazel & Lush, 1943; Young, 1961; Hazel *et al*., 1994).

Conventional selection index theory assumes that the total merit or profitability of animals is a linear function of measurable traits (Hazel, 1943). However, in some cases merit (profit) may be a non-linear function of these traits (Moav & Hill, 1966; Amer *et al*., 1994a). Non-linear profit equations cause difficulty because the economic value of a trait is not constant but changes as the population mean changes (Goddard, 1983) and no uniformly "best" solution exists (Pasternak & Weller, 1993). Wilton *et al*. (1968) developed a quadratic index for net merit which included squares and cross products of the traits. A formal approach to find an optimum linear index given any form of profit function was presented by Pasternak & Weller (1993). However, Goddard (1983) concluded that even for non-linear profit a linear selection index achieves the greatest increase in profit. Furthermore, in a comparison of alternative index procedures for multiple generation selection on non-linear profit, Groen *et al*. (1994) concluded that stepwise (each generation) adjustment of a linear index according to current population averages was satisfactory. A constant linear index using base population averages and a quadratic index were found to be less efficient. Dekkers *et al.* (1995) also showed that the method most commonly used, where economic values are derived as first-order derivatives of the profit function at current population means in the present generation, performed well up to generation four.

Selection indices can also be designed to change some traits while restricting the response in other traits (Kempthorne & Nordskog, 1959; Tallis 1962; Cunningham *et al*. 1970; Mendoza & Slanger 1985). With these indices there are predetermined constraints on genetic response of some traits that partly or completely override the response determined by their economic values. Results from Mortimer & James (1987) suggest that long term restriction may be very difficult without re-estimation of parameters, while Gibson & Kennedy (1990) concluded that constrained indices should be avoided for economic genetic selection.

Elston (1963) developed an index without going through the Smith-Hazel index construction procedures. This index was shown to be in a certain sense weight free. However, the Smith-Hazel index should be preferred if the relative economic values of traits differ (Lin, 1978).

Williams (1962a) labeled the Smith-Hazel index as an estimated index since the phenotypic and genetic parameters required for index construction are never known. The index has to be derived by use of sample estimates (Williams, 1962b). Sampling errors associated with estimation from a small data set could, therefore, affect the reliability of the index. An alternative index (base index), where each trait is weighted according to its relative economic value, was suggested when confidence in the precision of estimates are low. In this case the index coefficients (b) are equal to the relative economic values (a).

Harris (1964) noted that, with earlier methods, it was possible to detect some estimates that are not reasonable (impossible), i.e., where the estimates are outside the possible limits of the true values. Examples are (1) negative estimates of additive genetic variance, (2) estimates of the additive genetic variance that are greater than the estimates of phenotypic variance (heritability estimates greater than 1.0) and (3) estimates of the additive genetic correlation which are greater than 1.0 in absolute magnitude. Sales & Hill (1976a; 1976b) studied the effects of sampling errors on the efficiency of selection indices and concluded that the loss of efficiency is small even for estimates far from the correct value. Methods to improve the estimates of parameters to increase the efficiency of index selection were proposed by Hayes & Hill (1980; 1981) and Tai (1989), while Tai (1986) proposed a method to construct a confidence interval for the expected response to multi-trait selection. Foulley & Ollivier (1986) described a method to test the coherence of variance-covariance matrices. However, on a large data set, the genetic variance-covariance matrix among traits (i.e. variance-covariance matrix among genetic values of the traits) provides a reasonable estimate of the variance-covariance matrix among the estimated genetic values (Lin, 1990). With the use of a small data set, the variance-covariance matrix of true genetic values may be very different from the variance-covariance matrix of genetic estimates, thus affecting the efficiency of the derived index. According to Lin (1990) this is a problem associated with the use of a small data set rather than a problem of theoretical derivation.

A useful modification developed by C. R. Henderson was the separated application of the selection index in two steps (Hazel *et al.*, 1994). The first step is the estimation of individual breeding values, through multitrait analysis, for each trait included in the definition of the aggregate breeding value. The second step is application of the relative economic values. This separation has two important advantages. It permits use of the most complex and accurate BLUP techniques to estimate individual breeding values for each index trait, including adjustment for differing amounts of information. It then allows the economic values applied to vary with differing selection objectives, depending upon how different breeds are used in a breeding system or the particular production and marketing system, without recalculating breeding values. In this approach selection is based on a “genetic index” whereas a conventional selection index is based on a phenotypic index (Lin, 1990). Thompson & Meyer (1986) reviewed the natural links between BLUP and selection indices and noted that multivariate predictors of genetic effects can be interpreted as selection indices. One basic assumption underlying the conventional selection index is that fixed effects are assumed to be known. In practical applications, fixed effects are seldom known and thus need to be estimated from the data. BLUP provides a means of estimating fixed effects and predicting breeding values simultaneously (Meyer, 1989; 1991).

Lin (1990) also drew attention to the computational equivalence of an index of predicted breeding values using BLUP and conventional selection index (for the restricted case), but assumed the variance-covariance matrix among the predicted breeding values to be the same as that among the actual breeding values. This assumption ignores the effect of differing accuracies of prediction of individual breeding values for each animal, particularly when animal models are fitted to large unbalanced field data sets (Schneeberger *et al*. 1992). Furthermore, the traits in the objective can differ from the selection criteria used to predict the breeding values in the index, although some overlap will occur. Formulas presented by Schneeberger *et al*. (1992) take account of this fact as well as the differences in the accuracy of prediction of individual breeding values. Breeding values predicted using multiple-trait animal model BLUP procedures can, therefore, be combined into an index to predict an aggregate breeding objective made up of economically important traits and their associated economic values (Schneeberger *et al*. 1992).

Although the theory of selection indices has been introduced into animal breeding more than 60 years ago and is highly developed in various forms, its application in practical breeding may not be very extensive. This is not due to the selection index theory, but partly due to difficulties in the derivation of relative economic values as well as the paucity of information on the relationships among traits. Economic values have already been derived for the economically important traits for the Simmentaler (Chapters 4, 5, and 6). Therefore, the objectives of this chapter were (1) the construction of economic selection indices for the Simmentaler breed in South Africa and (2) to test the accuracy and efficiency of these indices.

7.2 MATERIALS AND METHODS

Henderson (1963), as quoted by Harris & Newman (1994), noted that in Hazel's (1943) approach, optimum selection toward a breeding objective ($H = ? a_i G_i$) requires selection on an index (I) which correlates best with H. In matrix notation the unrestricted index would be $I = \mathbf{b'X}$, where $\mathbf{X}$ is a n x 1 vector of sources of information, $\mathbf{b}$ is a n x 1 vector of weighing factors to be computed. The elements of $\mathbf{b}$ are chosen as to maximise genetic gain in a total (aggregate) breeding value or breeding objective. Where ($\mathbf{a'g}_i$) is the aggregate measure of merit for individual i, $\mathbf{a}$ is a m x 1 vector of economic values (weights) and $\mathbf{g}$ is a m x 1 vector of breeding values (for animal i) for the traits in the breeding objective. Also, $\mathbf{a} = \mathbf{c'v}$, where $\mathbf{c}$ is a m x 1 vector of cumulative discounted expressions of m breeding objective traits and $\mathbf{v}$ is a m x 1 vector with uncorrected economic values for the m traits. The optimum set of selection index coefficients are those which maximise the correlation (r_{HI}) or minimise the squared deviation between the selection index and the aggregate genotype (breeding objective) (Weller, 1994). Hazel (1943) showed that maximum r_{HI} is achieved when:

$$\mathbf{Pb} = \mathbf{Ga} \qquad (1)$$

Selection index weights are then calculated as :

$$\mathbf{b} = \mathbf{P}^{-1}\,\mathbf{Ga} \qquad (2)$$

where **G** is a nx m genetic variance – covariance matrix for m traits affecting profitability and n correlated indicator traits (criteria) and incorporates the additive genetic relationships between sources of information; **P** is a n x n phenotypic (co)variance matrix of correlated indicator traits; and **a** is a n x 1 vector of relative economic values (Cunningham *et al.*, 1970; James, 1982; Gibson & Kennedy, 1990; Fewson, 1993b; MacNiel *et al.*, 1994).

Since selection is not directly based on phenotypic measures but on predicted breeding values and since multitrait solutions from BLUP take into account environmental effects, the phenotypic variance-covariance matrix (P) is not needed for index construction (Lin, 1990). Although the phenotypic correlations have no effect on the derivation of index weights (coefficients) they are required for the calculations which describe the index (Amer *et al.*, 1998). The only information needed, in addition to the economic values, to allow prediction of the breeding objective, is information on the genetic variances and covariances among selection criteria in the index and on genetic covariances between the selection criteria and the objective traits (Schneeberger *et al.*, 1992). If predicted breeding values instead of observed phenotypic measures are used in an index, solving for the index coefficients is by equation (3) (Schneeberger *et al.*, 1992):

$$\mathbf{b} = \mathbf{G}_{11}^{-1}\,\mathbf{G}_{12}\,\mathbf{a} \qquad (3)$$

where **b** is a vector of index weights (coefficients) for the predicted breeding values for the selection criteria (traits) in the index, $\mathbf{G}_{11}$ is the n x n genetic variance-covariance matrix of the n criteria in the index, $\mathbf{G}_{12}$ is the n x m genetic covariance matrix between the n selection criteria in the index and the m traits in the breeding objective and **a** is the vector of economic values, expressed in Rand per unit of measurement, for the traits in the objective.

The parameters for traits and criteria used in index construction are summarized in Table 7.1. These parameters were provided by Breedplan International for the South African Simmentaler as well as from literature reports (Koots *et al*., 1994a; Gregory *et al*., 1995a, 1995b; Barwick & Henzell, 1999; Meyer & Johnston, 2001; Devitt *et al*., 2002; Martinez-Velazquez *et al*., 2003; Cundiff *et al*., 2004). Economic values were derived in Chapters 4, 5 and 6.

Table 7.1 Economic values in Rand / unit (a), heritabilities (h^2), phenotypic (s_P) and genetic (s_A) standard deviations for the traits and criteria used in index construction

Trait	Symbol	unit	a	h^2	s_P	s_A
Weaning weight –direct	WW_D	kg	2.12	0.21	26.49	12.04
Weaning weight – maternal	WW_M	kg	1.69	0.12	26.49	9.0
Yearling weight (400 days)	YW_S	kg	1.55	0.33	32.07	18.42
Final weight (600 days)	FW_H	kg	-0.65	0.32	38.05	21.47
Mature Cow weight	MCW	kg	-2.00	0.43	52.92	34.64
Calving rate	CR	%	13.27	0.17	3.47	1.43
Days to calving	CD	days	-13.27	0.08	25.0	7.07
Calving ease - direct	CE_D	%	1.48	0.13	2.02	0.73
Calving ease - maternal	CE_M	%	1.64	0.12	2.02	0.70
Dressing percentage	DP	%	17.16	0.39	1.9	1.19
Backfat	BF	mm	0.45	0.44	1.3	0.86
Tenderness	T	WBS kg	-5.03	0.29	1.3	0.70
Marbling	M	score	0.35	0.38	0.82	0.50
Criteria						
Birth weight – direct	BW_D	kg		0.42	4.32	2.80
Birth weight – maternal	BW_M	kg		0.08	4.32	1.23
Scrotal circumference	SC	cm		0.36	2.70	1.62

The economic value (Table 7.1) of a trait was defined by Hazel (1943) as the amount by which profit may be expected to change for each one unit of improvement in the trait concerned, independent of effects from changes in other traits included in the definition of the breeding objective. Therefore, the economic value (a) of a given trait (i) was derived as the partial derivative (d) of the profit equation (p) with respect to the trait concerned whereby all traits (x) are assumed to take their mean (µ) values:

$$a_i = dp / dx_i \,|_{\,x = \mu} \qquad (4)$$

The mean genetic correlations among traits provided by Breedplan for the South African Simmentaler and reported in the literature by Koots *et al*. (1994b), Graser *et al*. (1994b), Nitter *et al*. (1994) and Johnston & Bunter (1996) are summarized in Table 7.2.

Table 7.2 Mean genetic correlations (r_g) among 16 traits

	WW_D	WW_M	YW	FW	MCW	CR	CD	CE_D	CE_M	DP	BF	T	M	BW_D	BW_M	SC
WW_D	*	-0.16	0.75	0.70	0.40	-	-	-0.21	-	-	-0.05	-	-	0.66	-0.05	0.19
WW_M		*	-	-	-	-	-	-	-	-	-	-	-	-0.14	0.39	0.19
YW			*	0.80	0.50	-	-	-0.29	-	-	-0.10	-	-	0.52	-	0.39
FW				*	0.75	-	-	-	-	-	-0.15	-	-	0.55	-	0.15
MCW					*	-	-	-0.23	-	-	-0.15	-	-	0.35	-	0.10
CR						*	-0.97	-	-	-	-	-	-	-	-	0.63
CD							*	-0.10	-0.20	-	-0.20	-	-	-	-	-0.20
CE_D								*	-0.30	-	-	-	-	-0.74	-	-
CE_M									*	-	-	-	-	-	-0.60	-
DP										*	0.30	-	0.25	-	-	-
BF											*	-	0.24	-0.27	-	-
T												*	-0.31	-0.01	-	-
M													*	0.31	-	-
BW_D														*	-0.35	0.04
BW_M															*	-0.07

Criteria (Table 7.1) to include in the index will be all the traits in the breeding objective except CR, SC, CE_D, CE_M and DP. Birth weight direct (BW_D) and birth weight maternal (BW_M) were included as criteria in the index. These criteria were chosen to help predict calving ease in the population.

Since the heritability of a trait is a ratio of variances ($h^2 = s^2_A / s^2_P$), variances are squared deviations, and a correlation between two variables is a simple function of the covariance of the variables and their standard deviations (Equation 6) (Bourdon, 1997), the variances and covariances to include in the matrices ($\mathbf{G}_{11}$ and $\mathbf{G}_{12}$) were computed from the data in Tables 7.1 and 7.2 with the use of Equations 5 and 7.

$$s^2_A = h^2 \cdot s^2_P \qquad (5)$$

$$r_{X,Y} = \mathrm{cov}\,(X,Y) / s_X s_Y \qquad (6)$$

$$\mathrm{cov}\,(X,Y) = r_{X,Y} \cdot s_X s_Y \qquad (7)$$

Where $r_{X,Y}$ = the genetic correlation among variables X and Y; cov (X,Y) = the covariance among variables X and Y and s_X and s_Y are the genetic standard deviations for X and Y respectively.

As stated above, the optimum set of selection index coefficients are those which maximise the correlation (r_{HI}) or minimise the squared deviation between the selection index and the aggregate genotype (breeding objective). Therefore, according to Groen *et al.* (1994), the accuracy of index selection is a function of the correlation (r_{HI}) between the aggregate genotype and the index and is calculated as:

$$r^2_{HI} = s^2_I / s^2_H \qquad (8)$$

Where s^2_I and s^2_H are the variances of the index and the breeding objective, respectively and since $\mathbf{Pb} = \mathbf{Ga}$ (from Equation 1) it follows that these variances are:

$$s^2_I = \mathbf{b'Pb} = \mathbf{b'G}_{12}\,\mathbf{a} \qquad (9)$$

$$s^{2}_{H} = \mathbf{a}'\mathbf{G}_{22}\,\mathbf{a} \qquad (10)$$

Where $\mathbf{G}_{22}$ is the m x m genetic variance-covariance matrix of the m traits in the breeding objective.

According to Amer *et al.* (1998) responses (R) in each breeding objective trait (j) can be calculated using:

$$R_j = i\,ß_{jI}\,s_I = i\,[(\mathbf{b}'\,\mathbf{G}_{12\,j}) / s_I] \qquad (11)$$

Where i is the selection intensity, $ß_{jI}$ is the genetic regression of the j th recorded trait (criterion) on the index, $\mathbf{b}'$ is a row vector of index coefficients, $\mathbf{G}_{12\,j}$ is the j th column of matrix $\mathbf{G}_{12}$ and s_I the standard deviation of the index which is the square root of the variance, $\mathbf{b}'\mathbf{G}_{12}\,\mathbf{a}$ (from Equation 9). Response in profit (Rp_j) due to genetic change in each trait (j) with selection intensity (i) can then be calculated as:

$$Rp_j = R_j \cdot a_j \qquad (12)$$

Where a_j is the economic value of trait j.

7.3 RESULTS AND DISCUSSION

The breeding objective ($H = ?\ a_iG_i$) was defined as:

$$H = 2.12WW_D + 1.69WW_M + 1.55YW - 0.65FW - 2.00MCW - 13.27CD + 1.48CE_D + 1.64CE_M$$
$$+ 17.16DP + 0.45BF - 5.03T + 0.35M$$

Therefore, let the vector of economic values be:

$$\mathbf{a}' = [2.12 \;\; 1.69 \;\; 1.55 \;\; -0.65 \;\; -2.00 \;\; -13.27 \;\; 1.48 \;\; 1.64 \;\; 17.16 \;\; 0.45 \;\; -5.03 \;\; 0.35]$$

The genetic variance-covariance matrix ($\mathbf{G}_{11}$), with variances on diagonal and covariances off-diagonal, of the criteria (WW_D, WW_M, YW, FW, MCW, CD, BF, T, M, BW_D, BW_M) in the index was computed as:

$$\begin{matrix}
144.962 & -17.338 & 166.333 & 180.949 & 166.826 & 0 & -0.518 & 0 & 0 & 22.250 & -0.741 \\
-17.338 & 81.0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3.528 & 4.317 \\
166.333 & 0 & 339.296 & 316.382 & 319.034 & 0 & -1.584 & 0 & 0 & 26.820 & 0 \\
180.949 & 0 & 316.382 & 460.961 & 557.791 & 0 & -2.770 & 0 & 0 & 33.064 & 0 \\
166.826 & 0 & 319.034 & 557.791 & 1199.93 & 0 & -4.469 & 0 & 0 & 33.950 & 0 \\
0 & 0 & 0 & 0 & 0 & 49.985 & -1.216 & 0 & 0 & 0 & 0 \\
-0.518 & 0 & -1.584 & -2.770 & -4.469 & -1.216 & 0.740 & 0 & 0.103 & -0.650 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.49 & -0.109 & -0.020 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0.103 & -0.109 & 0.250 & 0.434 & 0 \\
22.250 & -3.528 & 26.820 & 33.064 & 33.950 & 0 & -0.650 & -0.020 & 0.434 & 7.840 & -1.205 \\
-0.741 & 4.317 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.205 & 1.513
\end{matrix}$$

The inverse ($\mathbf{G}_{11}^{-1}$) of this variance-covariance matrix was computed in MS-Excel. The genetic covariance matrix ($\mathbf{G}_{12}$) between the selection criteria (WW_D, WW_M, YW, FW, MCW, CD, BF, T, M, BW_D, BW_M) in the index and the traits (WW_D, WW_M, YW, FW, MCW, CD, CE_D, CE_M, DP, BF, T, M) in the breeding objective was computed as:

144.962	-17.338	166.333	180.949	166.826	0	-1.846	0	0	-0.518	0	0
-17.338	81.0	0	0	0	0	0	0	0	0	0	0
166.333	0	339.296	316.382	319.034	0	-3.900	0	0	-1.584	0	0
180.949	0	316.382	460.961	557.791	0	0	0	0	-2.770	0	0
166.826	0	319.034	557.791	1199.93	0	-5.816	0	0	-4.469	0	0
0	0	0	0	0	49.985	-0.516	-0.990	0	-1.216	0	0
-0.518	0	-1.584	-2.770	-4.469	-1.216	0	0	0.307	0.740	0	0.103
0	0	0	0	0	0	0	0	0	0	0.49	-0.109
0	0	0	0	0	0	0	0	0.149	0.103	-0.109	0.250
22.250	-3.528	26.820	33.064	33.950	0	-1.513	0	0	-0.650	-0.02	0.434
-0.741	4.317	0	0	0	0	0	-0.517	0	0	0	0

Although it was assumed that parameters were estimated on a large data set, and the genetic variance-covariance matrix among traits (i.e. variance-covariance matrix among genetic values of the traits) will, therefore, provide a reasonable estimate of the variance-covariance matrix among the estimated genetic values (Lin, 1990), these matrices were tested for coherence with the method of Foulley & Ollivier (1986). According to Foulley & Ollivier (1986) matrices will be coherent if:

- for any linear combination of selection objectives H = a'g,

  $s^2_H > 0$

- and for any predictor I = a'g,

  $s^2_I / s^2_H = ?$, $0 = ? = 1$

These matrices satisfy the criteria of coherence since $s^2_H = 13912.29$ and ? = 0.9746.

The vector of index coefficients (**b**) was then computed using Equation 3 ($\mathbf{b} = \mathbf{G}_{11}^{-1}\,\mathbf{G}_{12}\,\mathbf{a}$) as:

$$\mathbf{b'}_T = [2.28 \quad 1.76 \quad 1.48 \quad -0.50 \quad -2.02 \quad -13.21 \quad 4.92 \quad -2.34 \quad 12.77 \quad -1.65 \quad -1.99]$$

These index coefficients can now be multiplied with each EBV and then summed to obtain the index value for an animal. Animals can then be ranked according to these index values and selection based on these rankings. The total merit index (I_T) for an integrated Simmentaler production system is:

$$I_T = -1.65\,BW_D - 1.99\,BW_M + 2.28\,WW_D + 1.76\,WW_M + 1.48YW - 0.50\,FW - 2.02\,MCW$$
$$- 13.21\,CD + 4.92\,BF - 2.34\,T + 12.77\,M$$

The variances of the index (equation 9) and breeding objective (equation 10) were calculated as 13559.31 and 13912.29 respectively. With Equation (8) the accuracy (r^2_{HI}) of the derived economic selection index, in predicting the breeding objective, was computed as 0.9746 or 97.5%. The correlation (r_{HI}) between this index and the breeding objective is then 0.987.

Since there are a limited number of herds with breeding seasons and as a result thereof that have breeding values for CD, an alternative objective that includes CR instead of CD was also defined. The alternative index (I_A) constructed for this objective includes SC and not CD as fertility criterion.

The alternative index (I_A) for an integrated Simmentaler production system is:

$$I_A = 1.20\,BW_D + 2.76\,BW_M + 1.94\,WW_D + 1.19\,WW_M + 0.74\,YW - 0.08\,FW - 2.09\,MCW$$
$$+ 10.89\,SC + 7.54\,BF - 3.69\,T + 6.15\,M$$

The variance of this index was 4878.238 and it was 90.46 % accurate in predicting the alternative (CR) breeding objective. The correlation (r_{HI}) between this index and this breeding objective was 0.951.

To test the effect of individual criteria on the efficiency of the index (I_T), these criteria were deleted one at a time from the index. The efficiency of these sub-indices was then compared to the efficiency of the total index. These results are summarized in Table 7.3.

Table 7.3 Reduction in accuracy of the sub-index, compared to the total index, when individual criteria were dropped from the index

	T_I	Criteria										
		WW_D	WW_M	YW	FW	MCW	CD	BF	T	M	BW_D	BW_M
r^2_{HI}	0.975	0.962	0.960	0.949	0.973	0.835	0.387	0.974	0.974	0.973	0.974	0.974
Reduction		0.013	0.015	0.026	0.002	0.140	0.588	0.001	0.001	0.002	0.001	0.001

From Table 7.3 it is clear that most individual criteria have only a small influence on the efficiency of the index. However, when MCW or CD is dropped from the index the resultant sub-indices are only 83.5 % or 38.7% accurate respectively, compared to the 97.5 % of the total index with these criteria included. Since dropping certain traits have a small influence on the efficiency of the index the possibility to construct the total index without these traits was investigated. However, when criteria were dropped from the index the index weights (coefficients) of the remaining criteria changed. For instance when WW_D was dropped from the index the index weights for BW_D and BW_M changed from negative values to high positive values of 4.31 and 3.06 respectively. These values are even higher than the values assigned (in this sub-index) to WW_M and YW of 1.26 and 2.01 respectively. Although these indices may be just as efficient economically as the total index it may be unacceptable because of the positive weights assigned to birth weight and the decrease in CE_D and CE_M as a result thereof. It was, therefore, decided to keep the total index as it is.

Responses in each breeding objective trait were calculated using Equation (11) and the response in profit due to genetic change in each trait was then calculated with Equation (12). It was assumed that the selection intensity is equal to 1. This can also be seen as the expected economic superiority, over the average progeny, of the progeny from the top 40% of animals selected on their ranking in the total index. Note that i is approximately equal to 1 when 40% of animals are selected (i = 0.966; Falconer & Mackay, 1996). These results are summarized in Table 7.4.

Since there are at present only a limited number of herds/animals with breeding values for scanned traits (backfat, tenderness and marbling) a primary index (I_P) was developed with traits usually measured in a cow-calf production system (based on the results summarized in Table 7.3) to be used until more information on these scanned traits are available. This primary index includes only WW_D, WW_M, MCW and CD with the vector of index coefficients:

$$\mathbf{b}'_P = [3.14 \quad 1.91 \quad -2.04 \quad -13.33]$$

The variance (s^2_I) of this index (I_P) was computed as 13255.29. The accuracy of I_P is 95.28% and correlation with the objective 0.976. The expected responses when selection is based on this index are also summarized in Table 7.4.

Table 7.4 Properties of indices, expected responses (R) in traits (per unit) and expected economic superiority or expected response in profit (Rp in Rand) of the progeny from animals selected on different indices (I_T = total index, I_A = alternative index and I_P = primary index)

Index	I_T		I_A		I_P	
Trait	R	Rp	R	Rp	R	Rp
WW_D	0.695	1.47	1.170	2.48	0.71	1.51
WW_M	0.861	1.46	1.441	2.44	0.87	1.47
YW	0.230	0.36	0.411	0.64	-1.12	-1.74
FW	-4.679	3.04	-7.764	5.05	-4.95	3.22
MCW	-16.566	33.13	-27.573	55.15	-16.71	33.42
CR	-	-	0.228	3.03	-	-
CD	-5.724	75.96	-	-	-5.79	76.83
CE_D	0.095	0.14	0.056	0.08	0.11	0.16
CE_M	0.121	0.20	-0.02	-0.03	0.12	0.20
DP	0.029	0.50	0.046	0.79	0	0
BF	0.249	0.11	0.184	0.08	0.21	0.10
T	-0.022	0.11	-0.036	0.18	0	0
M	0.028	0.01	0.046	0.02	0	0
Accuracy (%)	97.46		90.46		95.28	
r_{HI}	0.987		0.951		0.976	
Total (R)		116.49		69.91		115.17

From Table 7.4 it can be seen that, with selection on I_T, all the traits improved in the desired direction and, therefore made a positive contribution to profit. The largest contribution came from the functional (fertility) traits and mature cow weight. Ponzoni & Newman (1989) also concluded that, under most circumstances the trait making the greatest positive contribution to genetic gain in economic units was calving day (CD). WW_D, on the other hand, will increase with only 0.695 units (kg). The main reason for this small increase is the relative high genetic correlation between WW_D and MCW ($r_G = 0.4$) and the relatively high negative economic value of MCW. In their study, Nitter *et al.* (1994) showed positive economic responses for growth and reproduction whereas the economic response in carcass value, maintenance and calving difficulty were negative. When selection is based on I_P the expected response in total profit will be almost the same as with selection on I_T. There are, however, no changes expected in the quality traits (dressing percentage, marbling and tenderness) with selection on I_P. The alternative index is clearly the least efficient economically. With I_A relatively more emphasis is placed on weight traits than on fertility traits as compared with the other indices. These heavier weights placed on growth resulted in a smaller improvement in calving ease (direct) and a decrease in maternal calving ease. It is furthermore concluded that CD cannot be excluded from either the objective or the index. It is also clear from these results that, the higher the variance of the index the higher is the expected economic response when selection is based on the specific index.

An alternative breeding objective (H_{AO}) was also defined when feed cost, for the derivation of economic values, was based on agistment rates (R0.09 / kg of DM – from Chapter 4). This breeding objective was defined as:

$$H_{AO} = 2.12WW_D + 1.69WW_M + 2.01YW + 0.19FW + 0.37MCW - 13.27CD + 1.48CE_D + 1.64CE_M$$
$$+ 17.16DP + 0.45BF - 5.03T + 0.35M$$

An economic selection index (I_{AOT}) was then constructed for this objective with the vector of index coefficients as:

$$\mathbf{b'}_{\mathbf{AOT}} = [2.28 \quad 1.76 \quad 1.94 \quad 0.34 \quad 0.35 \quad -13.21 \quad 4.92 \quad -2.34 \quad 12.77 \quad -1.65 \quad -1.99]$$

The variances of this objective (s^2_H) and index (s^2_I) were 14201.12 and 13837.64 respectively. This index is 99.5 % accurate in predicting the alternative objective while the correlation (r_{HI}) between the objective and index is 0.997. A primary index (I_{AOP}) was also developed for this alternative objective with traits usually measured in a cow-calf production system. This primary index includes only WW_D, WW_M, MCW and CD with the vector of index coefficients:

$\mathbf{b'}_{\mathbf{AOP}} = [4.35 \quad 2.17 \quad 0.67 \quad -13.33]$

The expected responses when selection is based on these indices are summarized in Table 7.5.

Table 7.5 Expected responses (R) in traits (per unit) and expected economic superiority or expected response in profit (Rp in Rand) of the progeny from animals selected on the alternative objective index (I_{AO})

Trait	R	Rp	R	Rp
WW_D	5.99	12.70	6.14	13.02
WW_M	0.85	1.44	0.87	1.47
YW	10.24	20.58	8.16	16.40
FW	11.14	2.12	10.11	1.92
MCW	13.02	4.82	13.32	4.93
CD	-5.67	75.21	-5.80	76.97
CE_D	-0.04	-0.06	-0.04	-0.06
CE_M	0.12	0.20	0.12	0.20
DP	0.03	0.52	0	0
BF	0.13	0.06	0.10	0.05
T	-0.02	0.10	0	0
M	0.03	0.01	0	0
Accuracy (%)	99.5		94.84	
r_{HI}	0.997		0.974	
Total (R)		117.70		114.90

From Table 7.5 it can be seen that, with selection on these indices, most of the traits improved in the desired direction and, therefore, made a positive contribution to profit. However, due to the emphasis on production traits (weight at different ages) there was a decrease in calving ease direct. No changes were experienced in the product quality (carcass quality) traits with selection on the primary index. The effect of feed value, on both the objective and index, was clearly demonstrated by the results in Table 7.4 and Table 7.5. This is in agreement with the findings of McMorris *et al.* (1986) that optimal cow size depends on economic conditions (e.g. beef-to-feed price ratio) and the production system.

7.4 CONCLUDING REMARKS

The primary index constructed in this study is not the same as a sub-index. Sub-indices can be constructed for sub-systems (e.g. cow-calf system) of the integrated system, by setting the economic values of certain traits to zero (Amer *et al.*, 1998). The primary index is defined for the total breeding objective of an integrated system but include only criteria usually measured in a cow-calf production system. The intention is that this index is to be used as a first index until more information, especially on scanned (product quality) traits, become available.

In this chapter a detailed description of the development of an economic selection index was presented. Although the indices were developed specifically for the Simmentaler breed in South Africa, the methods employed can be used to develop indices for different breeds and/or different production systems within the same breed. Only small changes in the economic values, definition of the breeding objective, and correlation structure between traits and criteria are necessary.

Application of these principles and results is necessary if the beef cattle industry is to maximise the exploitation of genetics and to improve its relative competitive position. This approach will have wide ranging benefits, not only for the beef cattle industry, but for consumers as well.

CHAPTER 8

General conclusions and suggestions

GENESIS 30:37-39

Jacob took to himself rods of fresh poplar, almond, plane tree, peeled white streaks in them, and made the white appear which was in the rods. He set the rods which he had peeled opposite the flocks in the gutters in the water-troughs where the flocks came to drink. They conceived when they came to drink. The flocks conceived before the rods, and the flocks brought forth streaked, speckled, and spotted.

We as animal scientists, animal breeders and farmers have been engaged in the selection and breeding of domestic livestock for a very long time, even though we do not know exactly what we are doing or how to do it. One can argue that, to understand the intricacies of animal breeding to some extent, a good understanding of the principles of animal husbandry, quantitative and molecular genetics, applied mathematical statistics, matrix algebra and even economics is of major importance. Even though we may not know how to apply these principles directly to improve the many economically important traits of interest, we can still use estimated breeding values to change population mean values for these traits. Although results showed that a certain amount of progress has been made in a number of these traits, an important question still remains: Are we doing the correct thing and are we doing it correctly?

Most breeders have, in general, only been concerned with the multiplication of genetic material. On the other hand, some breeders have tried to breed for clearly defined and obtainable goals although without regard as to whether these goals are sustainable or not. These goals were also set arbitrarily based on perceived importance and not based on sound genetic and economic principles. To be sustainable these goals have to satisfy at least the conditions of improved productivity and efficiency, decreased risk and uncertainty, effective conservation and management of resources, economic viability and social acceptance. The important aspect, therefore, is that breeding should be in a balanced way for a number of economically important traits.

Breeders and farmers, being human, still prefer cattle that they consider to be attractive regardless of the effect of these traits or fancy points on economic efficiency. Furthermore, as not all traits are measurable and included in the objective or index, visual appraisal will still form an integral part of livestock improvement. However, a balance should be retained between visual appraisal and the use of breeding values. These arguments do not contradict the need for a clearly defined breeding goal within an economic context, i.e. a breeding objective. One should also remember that selection directed at economically unimportant traits, even though it seems to do no harm, is indirectly harmful by reducing the selection intensity for economically more important traits.

Although the theory of selection indices has been introduced into animal breeding more than 60 years ago and is highly developed in various forms, its application in practical breeding is very limited. This is not due to selection index theory but partly due to difficulties in the derivation of economic values and the paucity of knowledge on traits and trait combinations. If economic values are not known the traditional selection index is of no use in the definition of breeding objectives. In this study the principles and methods for the derivation of economic values and the definition of breeding objectives have been discussed. Economic values for 13 economically important traits, including production (growth) traits, fitness/functional traits and product quality traits have been derived. It was, therefore, possible to define breeding objectives and construct selection indices for the Simmentaler breed, making the Simmentaler the first beef / dual-purpose cattle breed in Southern Africa to employ this technology.

Breeding objectives, expressed as economic weightings that describe the economic impact of a unit trait change, stipulate the animal characteristics to be improved and the desired direction for genetic change. Breeding objectives should, therefore, be defined in a manner which allows them to play an appropriate role, together with parameters such as heritabilities and correlations (for index construction), as part of a genetic evaluation program, in order to facilitate ranking of animals on genetic merit and implementation of effective breeding program design.

A breeding objective can also be seen as the strategy that the breeding industry (breed society) has for positioning the industry in its chosen market arena, for competing successfully, for pleasing customers and for achieving good business / economic performance. Therefore, two compelling needs exist. The first is to define the breeding objective taking into account the competitive position of the breed with regard to strengths and weaknesses of the specific breed. The second need is then to mould the decisions and actions of individual breeders into a coordinated plan for achieving this objective.

Due to differences in environmental conditions, management and marketing practices a need will, however, always exist to adapt this general objective for specific breeders and specific circumstances. Since the principles and methods for the definition of breeding objectives, derivation of economic values and index construction have been established in this study these adaptations or fine tuning will be a relatively simple exercise.

It will also be necessary to re-estimate parameters and re-derive economic values, at least every generation (± 5 years), to ensure that the breeding objective and selection index is optimal. Furthermore, a long term commitment to systematic recording of economic, production and marketing information at producer and consumer level is of utmost importance in the development of breeding objectives.

In terms of the definition of breeding objectives, derivation of economic values and index construction, research should in future also be directed at non-pure breeding systems taking into account different breeds, different breed combinations, different breeding systems (rotational cross, terminal cross, synthetic breeds) and the effects of heterosis.

It seems obvious, from these final remarks that the three key elements of sustainable genetic improvement can be summarized as follows. The first element is definition of a breeding objective which defines the value of genetic change in a range of traits and establishes the direction to breed, in economic terms. Although this has been done intuitively for the Simmentaler breed in the past, a formal approach was used in this study. Application of these results is necessary if the Simmentaler industry is to maximise the exploitation of genetics and to improve its competitive position.

Using information to identify and select animals with superior genetic merit is the second key element. This obviously necessitates an evaluation system which provides the estimates of genetic merit for each animal for all the identified economically important traits. Where important traits are not included in the genetic evaluation program (performance testing scheme), the necessary steps should be taken for these traits to be included. If a lack of parameter information exists (e.g. for functional and product quality traits) this should be rectified with research directed at these traits and criteria. Breeders should also be informed of these new developments and should be educated to adapt technological and management practices that will enable them to measure these traits (e.g. real time ultrasound technology for carcass traits and breeding seasons for days-to-calving). Genetic evaluation enables animals to be ranked on their overall economic-genetic merit, for a particular breeding objective. The breeding objective and genetic evaluations are linked by the selection index which is a formally (for the Simmentaler) or subjectively derived combination of estimated breeding values which has the highest correlation with the breeding objective.

The third key element is breeding program design which establishes the optimum selection and mating structure ensuring most rapid progress without accumulating excessive inbreeding and thereby increasing risk. Technological advances to increase the influence of genetically superior animals would obviously include A.I., MOET, semen and embryo sexing as well as cloning.

Livestock production is and will be an economic enterprise that converts edible and inedible (to humans) plant products into palatable, nutritious human food. The basic objective of animal breeding, which is a function of economic and genetic factors, is to enhance the efficiency of production and the quality of the product for the ultimate consumer. It is now possible to evolve from the performance orientation (to this objective) to a sound economic approach with wide ranging benefits for the beef cattle industry as well as consumers.

One final remark, adapted from ‘The Origin of Species’ by Charles Darwin (1809 – 1882):

There is grandeur in life, with its several powers, having been originally breathed by the Creator and that, from so simple a beginning, endless forms most beautiful and most wonderful have been and are being evolved according to His master plan.

APPENDIX A – SUMMARY

The development of economic selection indices for the Simmentaler breed in South Africa

Keywords: beef cattle, breeding objective, economic value, selection index, Simmentaler

The objectives of this study were the definition of breeding objectives, derivation of economic values and the development of economic selection indices for the Simmentaler breed in South Africa. The definition of breeding objectives should be the primary step in the design of structured breeding programs.

The decision whether or not to include a trait in the breeding objective depends on the relative economic value of the trait, the potential for genetic improvement and the possibility of accurate and cheap measurement. Several traits determine economic efficiency, and the required balance of these traits is likely to differ between different production systems. Income was partitioned between weaners (steers), surplus heifers and cull cows. Expenses were calculated for all classes and include feed cost, husbandry cost and marketing cost.

Economic values were derived as partial derivatives of the profit equation. These values, expressed per genetic standard deviation, in South African Rand per cow, corrected with the discounted gene flow and diffusion coefficient methods (in brackets) are, 25.57 (75.01), 15.21 (47.97), 28.49(83.63), -13.95 (-40.79) and -69.29 (-63.39) for weaning weight (direct), weaning weight (maternal), yearling weight (400 days), final weight (600 days) and mature cow weight respectively.

Economic values for the functional traits calving rate, days-to-calving, calving-ease (direct) and calving-ease (maternal) were also derived. It was assumed, for categorical traits, that there is an unobserved underlying normal distribution of the sum of genetic and environmental values, and that the phenotypic category is defined by threshold values on this distribution. The consequences of a change in fitness include changes in costs, changes in culling rate, number of barren cows and the number of surplus offspring available for sale. Results emphasised the relative importance of fertility. Economic values are 18.98 (15.27),

-93.82 (-75.51), 1.08 (1.31) and 1.15 (1.08) for calving rate, days-to-calving, calving-ease (direct) and calving-ease (maternal), respectively.

Economic values for product quality traits were also derived. A method to derive economic values for these optimum traits was described. The consequences of a change in the mean performance of a trait include changes in the number of animals in different quality classes and as a result thereof, changes in the expected value of a carcass. Economic values are 20.96 (61.50), 0.39 (1.14), -3.52 (-10.33) and 0.18 (0.52) for dressing percentage, backfat thickness, tenderness and marbling respectively.

Criteria included in the total index are birth- and weaning weight (direct and maternal), yearling weight, final weight, mature cow weight, days-to-calving, backfat thickness, tenderness and marbling. The total merit selection index (I_T) for an integrated Simmentaler production system is $I_T = -1.65\ BW_D - 1.99\ BW_M + 2.28\ WW_D + 1.76\ WW_M + 1.48 YW - 0.50\ FW - 2.02\ MCW - 13.21\ CD + 4.92\ BF - 2.34\ T + 12.77\ M$. The correlation between this index and the breeding objective is 0.987. The economic superiority, over the average progeny, of the progeny from the top 40% of animals selected on their ranking in the total index, is expected to be R116.49.

APPENDIX B / AANHANGSEL B – OPSOMMING

Die ontwikkeling van ekonomiese seleksie indekse vir die Simmentaler beesras in Suid-Afrika

Die doel van hierdie studie was om, vir die Simmentaler beesras in Suid Afrika, teeltdoelwitte te definieer, ekonomiese waardes vir produksie- funksionele- en vleiskwaliteitseienskappe te beraam, en om ekonomiese seleksie indekse op te stel. Die definisie van ‘n teeltdoelwit is die primêre stap in die opstel van gestruktureerde seleksie en teeltplanne. Ontwikkeling van ‘n teeltdoelwit kan in terme van die volgende stappe beskryf word: beskrywing van die teelt-, produksie - en bemarkingstelsel; identifiseer die bronne van inkomstes en uitgawes in kommersiële kuddes; bepaal die eienskappe wat inkomstes en uitgawes beinvloed; beraming van ekonomiese waardes; keuse van seleksie kriteria; beraming van fenotipiese en genetiese parameters. Die metodes om ekonomiese waardes te beraam kan opgedeel word in simulasie, dinamiese programmering en winsvergelykings.

Die relatiewe ekonomiese waarde van die eienskap, die potensiaal om die eienskap geneties te verbeter asook die moontlikheid om die eienskap akkuraat en goedkoop te meet, sal bepaal of ‘n spesifieke eienskap in die teeltdoelwit ingesluit moet word of nie. Ekonomiese doeltreffendheid word deur verskeie eienskappe beinvloed en die relatiewe belangrikheid van hierdie eienskappe verskil tussen verskillende produksie stelsels. Vir hierdie studie is aanvaar dat inkomste verkry is uit die verkoop van speenkalwers, surplus verse en uitskot koeie. Voer-, bestuurs- en bemarkingskostes is vir alle klasse beraam.

Ekonomiese waardes is as eerste-orde funksies (parsiele differensiaal) van die winsvergelyking afgelei. Ekonomiese waardes, uitgedruk per genetiese standaard afwyking in Suid Afrikaanse Rand per koei, gekorrigeer met die genevloei- en geendiffusie metodes (tussen hakkies) is 25.57 (75.01), 15.21 (47.97), 28.49 (83.63), -13.95 (-40.79) en -69.29 (-63.39) vir speengewig (direk), speengewig (maternaal), jaargewig (400-dae), 600-dae gewig en volwasse-koei-gewig, respektiewelik.

Ekonomiese waardes is ook vir funksionele eienskappe beraam. Vir hierdie kategoriese eienskappe word aanvaar dat daar onderliggend ‘n normal-verspreiding, wat die resultaat van genetiese en omgewings waardes is, bestaan en dat die fenotipiese kategorie deur drempelwaardes op hierdie verspreiding gedefinieer word. Die gevolg van veranderinge in reproduktiewe fiksheid sluit veranderings in kostes, uitskot tempo, aantal onvrugbare koeie en surplus kalwers, in. Die relatiewe belangrikheid van vrugbaarheid word deur die resultate beklemtoon. Ekonomiese waardes is 18.98 (15.27), -93.82 (-75.51), 1.08 (1.31) en 1.15 (1.08) vir kalftempo, dae-tot-kalwing, kalwingsgemak (direk) en kalwingsgemak (maternaal), respektiewelik.

Ekonomiese waardes is ook vir vleiskwaliteits eienskappe beraam. As gevolg van 'n verandering in die gemiddelde prestasie van die bevolking vir die eienskap, is daar 'n verandering in die relatiewe getal diere/karkasse in die verskillende kwaliteitsklasse. Dit het tot gevolg dat die verwagte waarde van 'n karkas of die gemiddelde waarde van karkasse uit die bevolking verander. Ekonomiese waardes is 20.96 (61.50), 0.39 (1.14), -3.52 (-10.33) en 0.18 (0.52) vir uitslagpersentasie, rugvetdikte, vleissagtheid en marmering, respektiewelik.

Geboorte- en speengewig (direk en maternaal), 400-dae-gewig, 600-dae-gewig, volwasse-koei-gewig, dae-tot-kalwing, rugvetdikte, vleissagtheid en marmering is as kriteria in die indeks ingesluit. Die ekonomiese seleksie indeks vir 'n geïntigreerde Simmentaler produksie stelsel is beraam as $I_T = -1.65\ BW_D - 1.99\ BW_M + 2.28\ WW_D + 1.76\ WW_M + 1.48YW - 0.50\ FW - 2.02\ MCW - 13.21\ CD + 4.92\ BF - 2.34\ T + 12.77\ M$. Hierdie indeks het 'n korrelasie van 0.987 met die teeltdoelwit. Die verwagte ekonomiese meerderwaardigheid van die nageslag van die top 40% diere, geselekteer op grond van hierdie indeks, is R116.49.

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