The Development of Breeding Objectives for Holstein and Jersey Cattle in South Africa

by

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Declaration

I declare that the thesis hereby handed in for the qualification **Philosophiae Doctor** at the University of the Free State, is my own independent work and I have not previously submitted the same work for a qualification at another university/faculty. I furthermore cede copyright of the thesis to the University of the Free State.

Banga

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Bloemfontein
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Abstract

Key words: breeding objective, selection goal, selection criteria, Holstein, Jersey, economic value, bio-economic model

A sound breeding objective is the basis for genetic improvement in overall economic merit of animals. Breeding objectives for Holstein and Jersey dairy cattle breeds in South Africa were developed in the current study, using a systematic approach. First, a logical framework with a profit focus was utilised to develop plausible selection goals for the pasture-based and concentrate-fed dairy production systems in South Africa, leading to an exhaustive list of objective traits influencing these goals and subsequently their possible selection criteria. Next, economic values were calculated for those objective traits for which there was adequate bio-economic data, viz.: milk volume, fat yield, protein yield, live weight, longevity, calving interval and somatic cell score. A bio-economic model, simulating typical South African pasture-based and concentrate-fed herds, was used to calculate economic values by determining changes in profit arising from an independent unit increase in each trait. Alternative payment systems of four major milk buyers in South Africa were used. Relative economic values, standardised to the value of protein, were used to compare the relative importance of traits across breeds, production systems and payment systems. Protein yield, fat yield and longevity consistently had positive economic values and the converse was true for body weight and calving interval. Economic value for volume was positive or negative, depending on whether the payment system paid for it or did not. Economic values were reasonably robust to fluctuations in the cost of feed and price of beef; with the exception of fat, whose value became negative beyond the feed price of ZAR3.50. Protein was, overall, the most important trait, although volume, live weight, longevity and somatic cell score were more important in some situations. Calving interval was the least important trait, its value ranging from 4 to 22% compared to that of protein, probably because the model used underestimated its value. Sire rankings on aggregate EBVs based on these economic values did not differ much across breeds, production systems and payment systems, most rank correlations falling in the range 0.70-0.99. A single breeding objective may therefore be used for both the Holstein and Jersey breeds, across the different production and payment systems. The basis for multiple-trait selection in the major cattle breeds in South Africa has thus been developed. Considerable work, however, needs to be done to enhance this breeding objective as well as facilitate its wide adoption by industry.

Opsomming

‘n Gesonde teeldoelwit is die grondslag vir die genetiese verbetering van die ekonomiese meriete van diere. In hierdie studie is teeldoelwitte vir die Holstein- en Jersey-rasse in Suid Afrika ontwikkel deur gebruik te maak van ‘n sistematiese benadering. ‘n Logiese raamwerk is eerstens gebruik met die fokus op wins om moontlike seleksiedoelwitte te ontwikkel vir weiding en konsentraatvoeding gebaseerde produksiestelsels in Suid Afrika. Dit het tot ‘n ellelange lys van objektiewe eienskappe gelei wat hierdie doelwitte en gevolglik moontlike seleksiekriteria beinvloed. Vervolgens is ekonomiese waardes vir hierdie objektiewe eienskappe bereken in gevalle waar genoegsame bio-ekonomiese inligting beskikbaar was, byvoorbeeld melk volume, bottervet opbrengs, proteien opbrengs, liggaamsgewig, langslewedheid, tussen kalf periode en somatiese sel punting. ‘n Bio-ekonomiese model, wat tipiese Suid Afrikaanse weiding en konsentraatvoeding gebaseerde kuddes simuleer, is gebruik om ekonomiese waardes te bereken. Die ekonomiese waarde is bepaal deur die verandering in wins bereken wanneer daar ‘n eenheidsverandering in ‘n spesifieke eienskap voorkom onafkanklik van die ander eienskappe. Die veskillende betalingstelsels van vier groot melkkopers in Suid Afrika is gebruik om die verandering in wins te bepaal. Relatiewe ekonomiese waardes wat gestandardiseer is tot die waarde van proteien is gebruik om die relatiewe belangrikheid van eienskappe oor rasse, produksie- en betalingstelsels met mekaar te vergelyk. Proteien opbrengs, bottervet opbrengs en langslewendheid het konstant ‘n positiewe ekonomiese waarde gehad terwyl dit die teenoorgestelde was vir liggaamsgewig en tussen kalf periode. Die ekonomiese gewig vir volume melk was positief of negatief afhangende daarvan of die koper daarvoor betaal of nie. Ekonomiese waardes was redelik gebuffer teen vearanderings in die prys van voer, behalwe vir bottervet, waar die waarde negatief geword het wanneer die voerprys bo ZAR3.50 styg. Proteien was oor die algemeen die belangrikste eienskap, alhoewel volume melk, liggaamsgewig, langslewendheid en somatiese sel punting belangriker was in spesifieke gevalle. Die eienskap wat die minste belangrik is, was tussen kalf periode, wat gevariëer het van 4% tot 22% in vergelyking met proteien, waarskynlik omdat die model wat gebruik is die belangrikheid daarvan onderskat. Bulrangordes volgens saamgestelde teelwaardes wat op hierdie ekonomiese gewigte gebaseer is, het nie veel verskil tussen rasse, produksie- en betalingstelsels nie en die rangorde korrelasies was in die omgewing van 0.70 tot 0.99. ‘n Enkele teeldoelwit kan derhalwe gebruik word vir beide die Holstein- en Jersey-rasse en ook oor produksie- en betalingstelsels. Die basis vir veelvuldige-eienskap seleksie vir die belangrikste rasse in Suid Afrika is ontwikkel. Daar moet egter nog baie gedoen word om hierdie teeldoelwit en die aanvaarding daarvan deur die bedryf te bevorder.

Chapter 1

General Introduction

Genetic improvement of dairy cattle should be primarily aimed at improving the economic efficiency of milk production. Such improvement is achieved by selecting animals that will be more profitable than their parents. Dairy cow profitability is influenced by several traits. In addition to yield of milk and milk solids, several other traits affecting income or production costs (e.g. feed costs, longevity, disease resistance and reproduction) are important. A sound dairy cattle breeding objective must therefore, of necessity, incorporate all these traits.

The fact that, in practice, several traits influence the economic value of an animal has long been recognised by animal breeders (Hazel, 1943). Hazel and Lush (1943) compared different methods of multiple trait selection and demonstrated that selection based on a total score or index of net merit was never less efficient than the other two methods studied (independent culling levels and tandem selection). Subsequently, Hazel (1943) developed selection index methodology which is to date considered superior to all other approaches of multiple trait selection (Sölkner and Fuerst, 2002). Recent studies (Philipsson *et al.,* 1994; Van Raden, 2002; Wesseldijk, 2004, Miglior *et al.*, 2005) have indicated that total merit indices have been applied extensively and increasingly in dairy cattle populations around the world. Traditionally, most of these indices only comprised yield traits; however, changes have taken place in the past decade to include functional traits such as longevity, reproduction and health (Miglior *et al.,* 2005).

In South Africa, estimated breeding values (EBVs) of dairy cattle are routinely produced for 5 milk production traits, 17 linear type traits and somatic cell score (B. E. Mostert, 2008, personal communication). Longevity and cow fertility are expected to be added to this list in the near future. Selection in the South African dairy cattle population has been focussed mainly on increased milk yield and, to a lesser extent, on improved type as can be shown by examining genetic trends (National Dairy Animal Improvement Scheme, 2007). Large increases in genetic merit for yield traits and considerable genetic change in linear type traits, particularly in the Holstein breed, have been effected in the past two decades (Theron and Mostert, 2004; National Dairy Animal Improvement Scheme, 2007). It is however not clear whether these genetic trends are in the desirable direction or what the overall value of these changes amounts to.

A recent survey on the use of selection indices in Holstein cattle populations around the world (Wesseldijk, 2004) shows that South Africa has not incorporated new knowledge in the development of more comprehensive multiple-trait selection indices in dairy cattle. Out of the 17 countries surveyed, only South Africa and Japan did not have an index incorporating traits other than production and conformation. The SAINET and Breeding Value Index (BVI) are the selection indices currently used in South Africa for the Jersey and Holstein breeds, respectively. These indices were derived by a consensus approach and are characterised by an almost exclusive focus on income traits as well as high emphasis on traits that are not economically relevant.

Furthermore, serious concern has been raised about the continued decline in traits such as longevity, cow fertility and udder health observed in this population (Banga *et al*., 2002; Makgahlela *et al*., 2008; Dube *et al*., 2008; Dube *et al*., 2009). The widely reported unfavourable genetic relationships between milk yield and fertility (Van Arendonk *et al*., 1989; Frick and Lindhe, 1991; Bagnato and Oltenacu, 1994; Campos *et al*., 1994; Hoekstra *et al*., 1994; De Jong, 1997; Pryce *et al*., 1997; Ojango and Pollot, 2001; Pryce *et al*., 2004; Kadarmideen, 2004; Makgahlela *et al*., 2008) and milk yield and mastitis (Emanuelson *et al*., 1988; Simianer *et al.,* 1991; Uribe *et al*., 1995; Mrode and Swanson, 1996) raise concerns that udder health and reproductive performance in the South African dairy cattle population may be deteriorating as a correlated response to selection for increased yield. It is therefore becoming increasingly imperative to develop broader breeding objectives, incorporating all economically relevant traits, for dairy cattle in South Africa. Such an approach will allow improvement in overall economic merit.

Simultaneous selection for several traits is generally a complex task as the traits are not of equal economic importance and are not independent of each other (St-Onge *et al.,* 2002). Golden *et al*. (2000) suggest that selection to improve overall economic merit should begin by specifying the selection goal, which attempts to characterise the overall aim of the breeding programme. The next step is the development of a selection objective, which comprises those traits that influence the goal. A profit-based goal indicates that all those traits which influence income or costs, also known as economically relevant traits (ERT) (Golden *et al.*, 2000), are candidates for inclusion in the selection objective. The selection index is constructed by defining an aggregate genotype to be improved, that is a function of individual genetic merit weighted by economic values of traits in the selection objective, i.e. their relative economic importance (Hazel, 1943). Breeding goals and objectives for dairy cattle in South Africa have not been defined and there is paucity of knowledge on the traits that should be improved and their relative importance.

Knowledge of the economic values for each trait in the selection objective is a prerequisite to the construction of a total merit index. The economic value of a trait is defined as the increase in profitability resulting from a unit genetic improvement in that trait while all other traits in the breeding objective are kept constant (Hazel, 1943). Since market conditions that influence economic values vary among different environments, economic values need to be estimated for each environment in order to determine if one selection strategy can be adopted. Previous efforts to determine economic values for dairy cattle production traits in South Africa were restricted to the Holstein Friesian breed in the intensive concentrate-fed production system (Du Plessis and Roux, 1998) or included milk production traits only (Tesfa, 2000).

The overall aim of this study is to develop breeding objectives, expressed as overall genetic merit indices, for South African dairy cattle in the concentrate-fed and pasture-based production systems. A systematic approach is followed towards achieving this aim and the structure and specific objectives of the study are as follows:
Chapter 2 presents a review of recent worldwide advances in the definition of national dairy cattle breeding objectives. Selection indices currently used in countries with progressive dairy cattle genetic improvement programmes are discussed and compared with the *status quo* in South Africa.

An outline of the theoretical basis of multiple trait selection index methodology and a description of how the technique has evolved from the classical form of Hazel (1943) are given in Chapter 3.

Chapter 4 aims to build a framework for sound long term genetic improvement programmes for dairy cattle in South Africa. This is carried out systematically by achieving the following objectives, sequentially, using specific tools:

1. Defining selection goals for South African dairy producers in the two major dairy production systems, namely the pastoral system and intensive concentrate-fed environment.
2. Developing an exhaustive list of traits (selection objective traits) influencing the breeding goals defined in 1.
3. Identifying selection criteria for each of the objective traits.

A review of approaches used to derive economic values in livestock is given in Chapter 5, concluding with a suggested practical approach for calculating such economic values for dairy cattle under South African conditions.

Economic values for the breeding objective traits, where adequate information is available, are determined for each of the two major dairy cattle breeds in South Africa (Holstein and Jersey), for each production system, in Chapter 6. An index of aggregate genetic merit, combining objective trait breeding values and their respective economic values, is then defined for the two breeds. Such indices form the basis for long term genetic improvement of overall economic merit of dairy cattle in South Africa.

The major conclusions to be drawn from the study, as well as recommendations on the future application of multiple-trait selection indices and further enhancements of selection for overall economic merit of dairy cattle in South Africa comprise the final Chapter, Chapter 7.

Chapter 2

Literature Review on National Dairy Cattle Breeding Objectives

This Chapter discusses recent worldwide advances in dairy cattle breeding objective definition and the current status of national selection indices in major dairy cattle producing countries. Selection indices currently used in South Africa are described and compared with those from other countries with progressive dairy cattle genetic improvement programmes.

2.1 Introduction

Several researchers (Leitch, 1994; Philipsson *et al*., 1994; VanRaden, 2002; VanRaden, 2004; Wesseldijk, 2004; Miglior *et al.,* 2005) have reviewed national dairy cattle selection indices used in the major dairy cattle producing countries around the world. Indications from these studies are that there has been a dramatic change in total merit indices in most countries during the past decade, with most of the change occurring at the turn of the century. Miglior *et al*. (2005) observe that there has been a general shift in focus from production only to a more balanced breeding objective of improving production, especially protein yield and percentage, as well as longevity, udder health, conformation and reproduction.

Different methods have been used to determine the relative emphasis placed on traits in the index. One approach is to express it as economic value times standard deviation divided by the sum of the absolute values of the products, multiplied by 100 (e.g.

VanRaden, 2002). Miglior *et al.* (2005) use a similar method but divide instead of multiplying economic values by standard deviations. This definition of relative emphasis is criticised by Cunningham and Tauebert (2009) as it makes the wrong assumption that selection on the index produces equal genetic gain (in SD units) in all traits. Cunningham and Tauebert (2009) suggest the use of a new relative emphasis statistic which expresses the contribution that change in each trait makes to the overall economic gain from selection.

2.2 Recent developments and current status

A recent survey of selection indices in sixteen major Holstein countries by Wesseldijk (2004) showed that, in 1996, 50% of the countries surveyed had a production index only, with the rest having a combined production and type index. Only Denmark and Sweden had a genuine total merit index including production, type, management and health traits. At that point in time the “world index” was made up of 79% production with 15% and 6% respectively for type and health and management traits (Wesseldijk, 2004). The turn of the century saw a radical shift in focus to longevity and health, mostly at the cost of production as well as type to a lesser extent. In 2004 the “world index” comprised 57% production, 17% type, and 26% longevity, health and management (Wesseldijk, 2004). According to Miglior *et al.* (2005), the main reasons behind this shift were quota and/or price constraints, together with increasing concerns associated with deterioration of the health and fertility of dairy cows. Many studies have shown that selection for production alone results in deleterious effects on udder health (Emanuelson *et al*., 1988; Simianer *et al.,* 1991; Uribe *et al*., 1995; Mrode and Swanson, 1996; Heringstad *et al*., 2003) and reproductive performance (Van Arendonk *et al*., 1989; Frick and Lindhe, 1991; Bagnato and Oltenacu, 1994; Campos *et al*., 1994; Hoekstra *et al*., 1994; De Jong, 1997; Pryce *et al*., 1997; Ojango and Pollot, 2001; Lucy, 2001; Nilfrorooshan and Edriss, 2004; Pryce *et al*., 2004; Kadarmideen, 2004; VanRaden *et al*., 2004).

The shift in emphasis among the different traits in the 'world index' between 1996 and 2004 is illustrated in Table 2.2.

Table 2.2: Relative emphasis (%) among traits in the 'world index' between 1996 and 2004 (Wesseldijk, 2004)

Trait	**1996**	**1998**	**2001**	**2002**	**2004**
Production	79	72	60	58	57
Type	15	20	18	19	16
Secondary traits[1]	6	8	22	23	27

[1] *Secondary traits include longevity, udder health, fertility, calving ease, milking speed and temperament.*

Figure 2.1 summarises the relative emphasis placed on different traits in different national indices in 2004 (Wesseldijk, 2004). Only South Africa's Breeding Value Index (BVI) and Japan's NTP did not have any secondary traits. These two indices contained only production and type traits, at that point in time.

2.2.1 Production traits

Intense selection for increased yield, especially protein yield, is clearly justified. Thus, for many years, selection for milk production received exclusive focus in most dairy cattle breeding programs worldwide (Miglior *et al.,* 2005). National selection indices were based on improving milk yield and gradually shifted toward improving protein yield and, outside North America, toward increasing fat and especially protein content (Miglior *et al*., 2005).

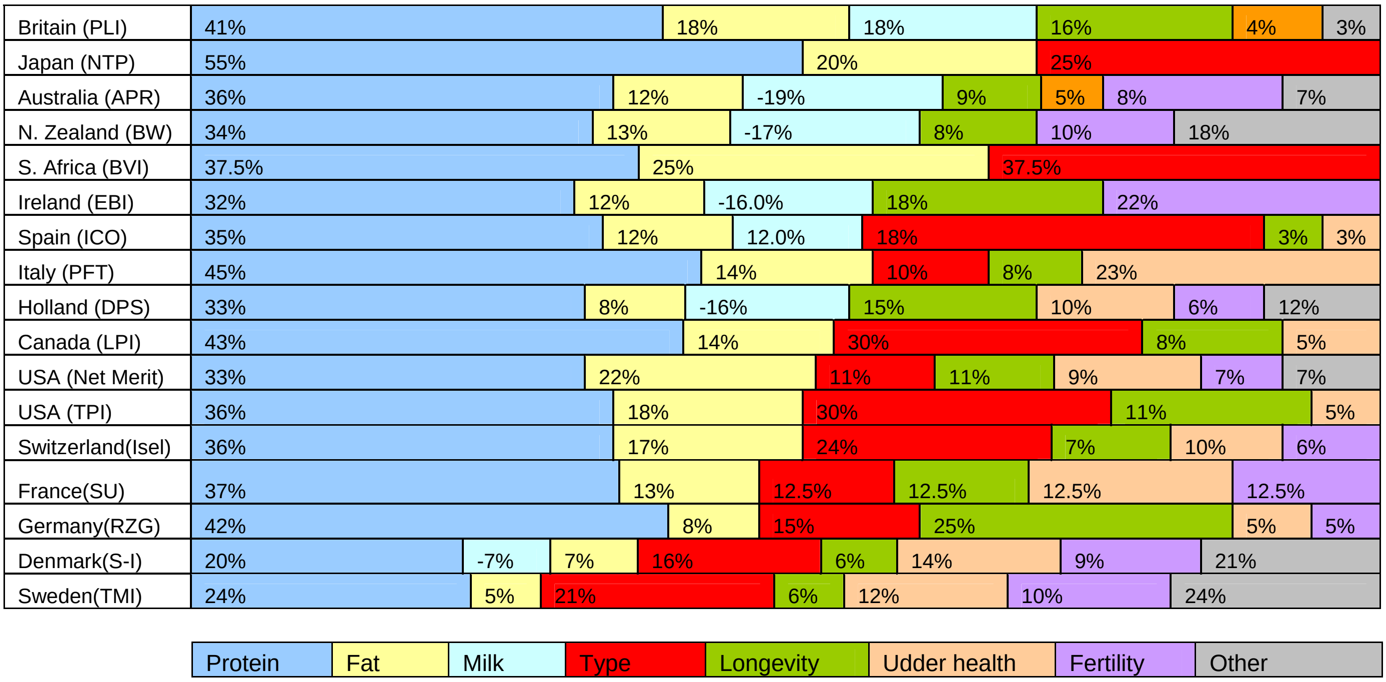


Figure 2.1: Selection indices from 16 top dairying countries showing relative weights among traits. (Source: Wesseldijk, 2004)

Leitch (1994) compared selection indices from ten leading dairying countries and reported that, after accounting for differences in genetic variances of traits included in the indices, protein generally received the highest relative emphasis (18 – 70%). Only five countries (USA, Netherlands, France, Denmark and New Zealand) had more comprehensive indices which considered other non-production traits other than type. In 2004, production had lost considerable emphasis and only two countries (South Africa and Japan) out of seventeen that were surveyed did not have traits other than production and type in their selection indices (Wesseldijk, 2004).

2.2.1.1 Current emphasis in selection indices

Out of 15 countries surveyed by Miglior *et al.* (2005), Israel had the largest emphasis on production (80%) followed by the British PLI and the Japanese NTP (both 75%). The Danish S-Index had the lowest emphasis on production (34%). Save for Denmark, all countries had at least 50% weight on production. The Japanese NTP had the largest emphasis on protein yield (55%) followed by the Israeli PD01 and the British PLI (51% and 49% respectively). The Danish S-Index had the lowest emphasis on protein yield (20.4%) followed by the German RZG (26%) and the Swiss ISEL (27%). The US Net Merit had the highest (22%) and the British TOP the lowest (6%) emphasis on fat yield. All the countries, with the exception of North America and Japan, had positive emphasis on fat or protein percent, either directly or indirectly through negative emphasis on milk yield. The Spanish ICO was an exception as it had positive weight on both milk yield and protein percentage.

Figure 2.2 depicts the relative emphasis of production traits, within the production component, in the 15 national selection indices studied by Miglior *et al.* (2005). Milk mostly has negative emphasis as it is a cost to the system in a predominantly product manufacturing market. It increases energy requirements for lactation and transport and processing costs. (Holmes *et al*., 2000).

2.2.2 Type traits

Cattle breeders worldwide have long held the belief that type or conformation traits have important influence on cattle performance (Gutierrez & Goyache, 2002). Hence type traits have traditionally played an important role and continue to receive considerable attention in most dairy cattle improvement programmes worldwide. The importance of type traits is primarily based on their relationship with traits of economic importance such as resistance to mastitis (Seykora and McDaniel, 1985; Rogers *et al*., 1998; Mrode *et al*., 1998; Sørensen *et al*., 2000), reproductive performance (Dadati *et al.,* 1986; Pryce *et al.,* 2000; Kadarmideen, 2004) and longevity (Hoque and Hodges, 1981; Chauhan *et al*., 1993; Dekkers *et al*., 1994).

Originally, most selection indices such as the US Type-Production Index (VanRaden, 2002), the Canadian Lifetime Profit Index (Lohuis and Sivanadian, 1997), the UK PINII (Leitch, 1994), the Japanese NTP and South African Breeding Value Index (Wesseldijk, 2004) were composed of production and type traits only. Since the turn of the century, however, type traits have marginally lost emphasis in most selection indices (Wesseldijk, 2004). This may partly be due to the fact that economically important traits that they were surrogate traits for (e.g. longevity) have been added to the selection objective.

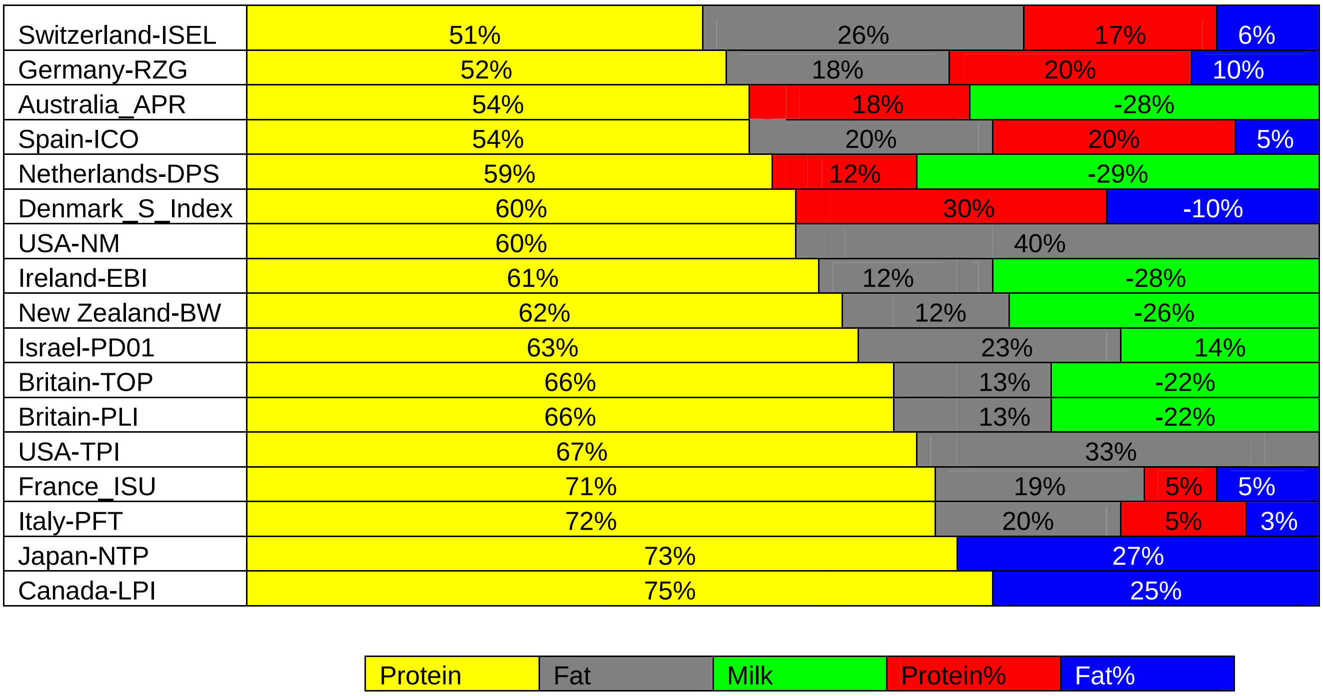


Figure 2.2: Relative emphasis of production traits, within the production component, in national selection indices (Source: Miglior *et al.*, 2005)

Norman and Powell (1999) note that, traditionally, far more emphasis is placed on conformation than is justifiable. For many years, large bulls and cows were favoured by dairy cattle breeders (VanRaden, 2002). Conversely, many studies (Foster *et al.,* 1989; Short and Lawlor, 1992; Norman *et al.,* 1996; Pérez-Cabal and Alenda, 2002) point to the fact that body traits are generally of limited value in determining dairy cow profitability and should be eliminated from breeding objectives. Some researchers (VanRaden, 1988; Funk, 1993; Mulder and Jansen, 2001; St-Onge *et al*., 2002) concluded that cow size should have negative value in an index. Furthermore, certain body traits, such as angularity, have been reported to bear a large negative relationship with cow fertility (Dadati *et al*., 1986; Pryce *et al*., 2000; Kadarmideen, 2004) and health (Rogers *et al*., 1999; Sørensen *et al*., 2000; Hansen *et al*., 2002; Lassen *et al*., 2003). Numerous studies (VanRaden, 1988; Short and Lawlor, 1997; Pérez-Cabal and Alenda, 2002; Pérez-Cabal *et al*., 2006a), on the other hand, have shown that udder and feet and leg traits are correlated with traits (e.g. longevity) that have high economic value and should receive the most emphasis of all type traits in selection indices.

2.2.2.1 Current status

The emphasis placed on type traits varies considerably among countries. In some indices, the scientifically-determined role of type traits as mere predictors of economically relevant traits is recognised and they do not receive direct emphasis. However, where the consensus approach is adopted or the views of pedigree breeders, with a vested interest in the outcome (e.g. South Africa), undue weight is given to type traits, particularly those related to body or frame size.

The importance of udder traits is now widely accepted and most breeding objectives place considerable emphasis on them (Wesseldijk, 2004). Increased importance attached to udder conformation traits is mainly based on indications that they are useful in improving resistance to mastitis (De Jong and Lansbergen, 1996; Gengler and Groen, 1997; Mrode *et al*., 1998). Leitch (1994) observed that mammary system received the highest relative emphasis (37% to 100%) of all the type traits considered. Table 2.3 shows the prominence of udder and leg and feet traits and the insignificance of body traits in current selection indices (Wesseldijk, 2004).

Miglior *et al*. (2005) looked at durability, the component comprising traits contributing to cow herd life, in national selection indices, and observed that conformation traits were the most dominant. The British TOP had the highest weight (40%) on conformation. Overall udder, feet and legs and body size contributed 18%, 14% and 8% respectively, of this proportion. Canada had the second largest emphasis on conformation (30.4%), with 15%, 11.4%, 3.8% coming from overall udder, feet and legs, and, body and legs respectively. Five of the indices had a positive while the other four had negative emphasis on body size. New Zealand's BW had -19% weight on body weight (as an indicator of maintenance feed).

Table 2.3: Type traits in the total merit index per country (Wesseldijk, 2004)

Country	**Traits**			
	Udder	**Feet and Legs**	**Frame/Size**	**Total Type**
Canada	✓	✓	✓	
Denmark	✓	✓	✓	
Germany				✓
France	✓	✓	✓	
Italy	✓			
Japan	✓	✓		
Spain	✓	✓		✓
USA (TPI)	✓	✓		✓
USA (NM)	✓	✓		
South Africa	✓	✓	✓	
Sweden	✓	✓		
Switzerland	✓	✓		

No direct emphasis was placed on type traits in the indices of Australia, Great Britain, Ireland, Netherlands, and New Zealand (Wesseldijk, 2004). Certain type traits are, however, included to predict longevity and certain health traits. For example, besides actual culling data the Australian longevity index largely depends on udder depth, rump angle and total type. Great Britain uses udder and feet and legs as predictors of herd life while Ireland has foot angle, body condition, udder depth, and dairyness as predictors for fertility and longevity. The Netherlands uses a number of type traits to predict secondary traits.

2.2.3 Longevity

The economic importance of longevity is widely acknowledged by animal breeders and has been highlighted in numerous studies (Gill and Allaire, 1976; Dentine *et al*., 1987; Rogers *et al*., 1988; Essl, 1998; Schneider *et al*., 1999; Rizzi *et al*., 2002). Improved longevity results in reduced replacement and veterinary costs, increased proportion of cows in the herd producing at a higher yielding mature level, higher percentage of voluntary culling, and higher potential for selection among replacements.

Selection for longevity is hampered by the time required for cows to complete records, coupled with low heritability (Hoque and Hodges, 1981; Klassen *et al*., 1992; VanRaden and Klaaskate, 1993; Vollema and Groen, 1996). Type traits have been used for many years as indirect selection criteria for longevity because they are recorded early in life, have higher heritability than direct measures of longevity, and have moderately high genetic correlations with longevity (Dentine *et al*., 1987; Boldman *et al*., 1992; Dekkers *et al.*, 1994; Vollema and Groen, 1997). Procedures to combine survival and conformation data to estimate breeding values for longevity (combined longevity) have been developed (Weigel *et al.*, 1995; Jairath *et al.*, 1998) and are currently used in many national genetic evaluation systems (Van der Linde and De Jong, 2002).

Longevity received the highest emphasis among traits other than production and type in the world index in 2004 (Wesseldijk, 2004). All countries, except Japan and South Africa, had longevity in their selection indices. Miglior *et al.* (2005) reported that, within the durability component, the Dutch DPS had the largest emphasis on longevity with 26%, followed by the German RZG (25%), and the Irish EBI (23%). The Israeli PD01 and Japanese NTP did not have direct emphasis for longevity.

2.2.4 Udder health

A healthy udder can be best defined as an udder that is free from infection (mastitis). The economic importance of mastitis is well documented (Gill *et al.*, 1990; Lescourret and Coulon, 1994). Selection for higher resistance to mastitis in dairy cattle has taken place for several years in the Scandinavian countries (Sørensen *et al.*, 2000). Philipsson (1994) noted the exclusion of udder health and other functional traits in the total merit indices of most countries and explained that this was probably due to lack of udder health records required for genetic evaluation or the general neglect of traits with low heritability. The past decade has however seen a growing interest in including udder health in selection indices (Wesseldijk, 2004; Miglior *et al.*, 2005).

Recently, Wesseldijk (2004) reported that udder health comprised 6.2% of the world index. Miglior *et al.* (2005) observed that Canada, the Netherlands and Denmark had udder health indices, comprising SCS and udder conformation traits, as indicators of udder health. The Canadian udder health index was based on SCS (60%), udder depth (30%), and milking speed (10%). The Dutch udder health index was a combination of SCS, udder depth, fore udder attachment, teat length and milking speed. The Danish udder health index was based on clinical mastitis, SCS, udder depth, udder support, and dairy form, with a combined emphasis of 14% on the Danish S-Index. The Danish S-Index also had a 6% emphasis on milking speed and 2% on resistance to other diseases.

2.2.5 Female fertility

Many studies (Van Arendonk *et al.*, 1989; Bagnato and Oltenacu, 1994; Boichard *et al.*, 1997; Esslemont and Kossaibati, 1997; Lucy, 2001; Olori *et al.*, 2002) have stressed the importance of including female fertility in breeding objectives for dairy cattle. In the past, female fertility was left out of most selection programmes, mainly due to its low heritability (Raheja *et al.*, 1989; Grosshans *et al.*, 1997; Pryce *et al.*, 1998; Kadarmideen, 2004). The relatively high additive genetic variation of fertility (Philipsson *et al.* 1981; Hermas *et al.*, 1987; Raheja *et al.*, 1989; Oltenacu *et al.*, 1991; Grosshans *et al.*, 1997; Jong, 1998) however indicates scope for genetic improvement through selection. The increasingly evident antagonistic association between fertility and milk yield (Van Arendonk *et al.*, 1989; Frick and Lindhe, 1991; Bagnato and Oltenacu, 1994; Campos *et al.*, 1994; Hoekstra et al., 1994; De Jong, 1997; Pryce *et al.*, 1997; Ojango and Pollot, 2001; Kadarmideen, 2004; Nilforooshan and Edriss, 2004; Pryce *et al.*, 2004;

VanRaden, 2004) is of major concern. The continual genetic improvement in yield traits taking place in most dairy cattle populations around the world is therefore expected to cause deterioration in fertility.

The importance of female fertility in selection indices around the world has increased significantly in recent years. In 1994, only the Scandinavian countries included fertility in their selection indices (Leitch, 1994; Philipsson *et al*., 1994). Recently, Wesseldijk (2004) reported that fertility contributed 5.2% to the "world index" in 2004. Ireland had increased emphasis on fertility considerably, from 8% to 22%, while the trait was first introduced in the US Net Merit index in 2003. The Irish EBI had the highest emphasis on female fertility (22%), followed by the French ISU (12.5%) and the New Zealand BW and Swedish TMI (both 10%). Although seven of the 17 indices studied recently (Wesseldijk, 2004; Miglior *et al*., 2005) did not have a fertility component, Britain, Canada and Spain were working towards introducing the trait in their indices.

2.3 Use of dairy cattle selection indices in South Africa

2.3.1 Introduction

The South African National Genetic Evaluation Programme has, relatively speaking, kept pace with global advances in genetic evaluation methodologies. Availability of accurate estimated breeding values (EBVs) in the last two decades has resulted in a substantial increase in genetic merit for yield traits (National Dairy Animal Improvement Scheme, 2007) and considerable genetic change in linear type traits (Theron and Mostert, 2004) in the major dairy cattle breeds. The number of traits recorded and receiving genetic evaluations has increased continually and genetic evaluation procedures have improved over time (Banga *et al*., 2007). There is however a need to develop selection objectives for South African dairy cattle and combine the economically relevant traits, using appropriate economic weights, in order to direct improvement in overall economic merit. As a stop gap measure, selection indices have been constructed for the Holstein and Jersey breeds using a general consensus approach. These indices are periodically updated as new traits get EBVs and in keeping with global trends. The relative emphasis given to some of the traits in these indices, particularly type traits, is however not consistent with international trends and certain widely observed research findings.

2.3.2 Traits in national genetic evaluation programme

Historical developments in dairy cattle recording and genetic evaluation in South Africa are described in Loubser (2001), Theron *et al*. (2001) and Banga *et al*. (2007). Official milk recording was initiated in 1919; however progeny testing was only introduced in 1976. The contemporary comparison method was used to estimate sire breeding values until 1987 when it was replaced by the BLUP sire model. In 1992 the BLUP animal model was implemented to estimate breeding values for milk production traits in the four major dairy cattle breeds (Holstein, Jersey, Ayrshire, and Guernsey). Genetic evaluations for linear type traits were introduced in 1994 for the Jerseys and in 1996 for the Holstein (Theron and Mostert, 2004). Recording of somatic cell count was started in 1994 and a fixed regression test-day model for the evaluation of somatic cell score in Holstein and Jersey cattle was implemented in 2004 (Mostert *et al*., 2004). A total of 23 traits are currently measured and receive genetic evaluations in the major dairy cattle breeds, and, EBV for female fertility and longevity are expected in the near future. Table 2.4 contains traits that are currently measured and genetically evaluated in the South African National Genetic Evaluation Programme.

Table 2.4: Traits evaluated under the South African National Genetic Evaluation Programme

Breed(s)	**Trait group**	**Trait(s)**
Ayrshire Guernsey Holstein Jersey	Production	Milk yield (Kg) Fat yield (Kg) Protein yield (Kg) Percent butterfat (%) Percent protein (%)
Holstein Jersey	Linear type	Stature/ Rump height[1] Angularity/ Dairy form[1] Chest/ Chest width[1] Body depth Rump angle Rump width/ Pin width[1] Rear leg set Rear leg side view Foot angle Fore udder attachment Rear udder height Rear udder width[1] Median ligament/Udder cleft[1] Udder depth Front teat placement Rear teat placement[1] Teat length
Holstein Jersey	Udder health	Somatic cell score

[1] Jersey only

2.3.3 Selection indices used in South Africa

2.3.3.1 The Holstein Breeding Value Index

The Holstein Breeding Value Index (BVI) that was adopted by the South African Holstein Society in 1995 (Taurus Holstein, 2002) is shown in Figure 2.3. This is a production-type index, favouring high protein and butterfat producing cows, with large framed and extremely angular bodies, and, tightly attached udders. Many studies (VanRaden, 1988; Metzger *et al.*, 1991; Funk, 1993; Mulder and Jansen, 2001; St-Onge *et al.*, 2002) have however indicated that, due to higher maintenance requirements, large framed animals are less profitable and therefore body size should receive negative emphasis in selection indices. In addition, angularity has been observed to bear a large negative relationship with cow fertility (Dadati *et al.*, 1986; Pryce *et al.*, 2000; Kadarmideen, 2004) and health (Rogers *et al.*, 1999; Sørensen *et al.*, 2000; Hansen *et al.*, 2002; Lassen *et al.*, 2003).

The BVI was revised in 2005 to produce the updated BVI, which is shown in Figure 2.4 (Taurus Holstein, 2007). Major changes implemented were the addition of udder health (somatic cell score and udder depth) and increased emphasis on chest width, rump angle, rump width and rear udder width, at the expense of median ligament, angularity, rear udder height and foot angle. In addition, the emphasis of protein relative to butterfat, in the production index, was reduced contrary to developments worldwide. The broadening of the index to include udder health is consistent with global trends (Wesseldijk, 2004; Miglior *et al.*, 2005); however the continued relatively high positive emphasis on body size traits and angularity is at variance with developments in most other national indices. Table 2.3 (Wesseldijk, 2004) shows that most national indices now exclude traits related to body size.

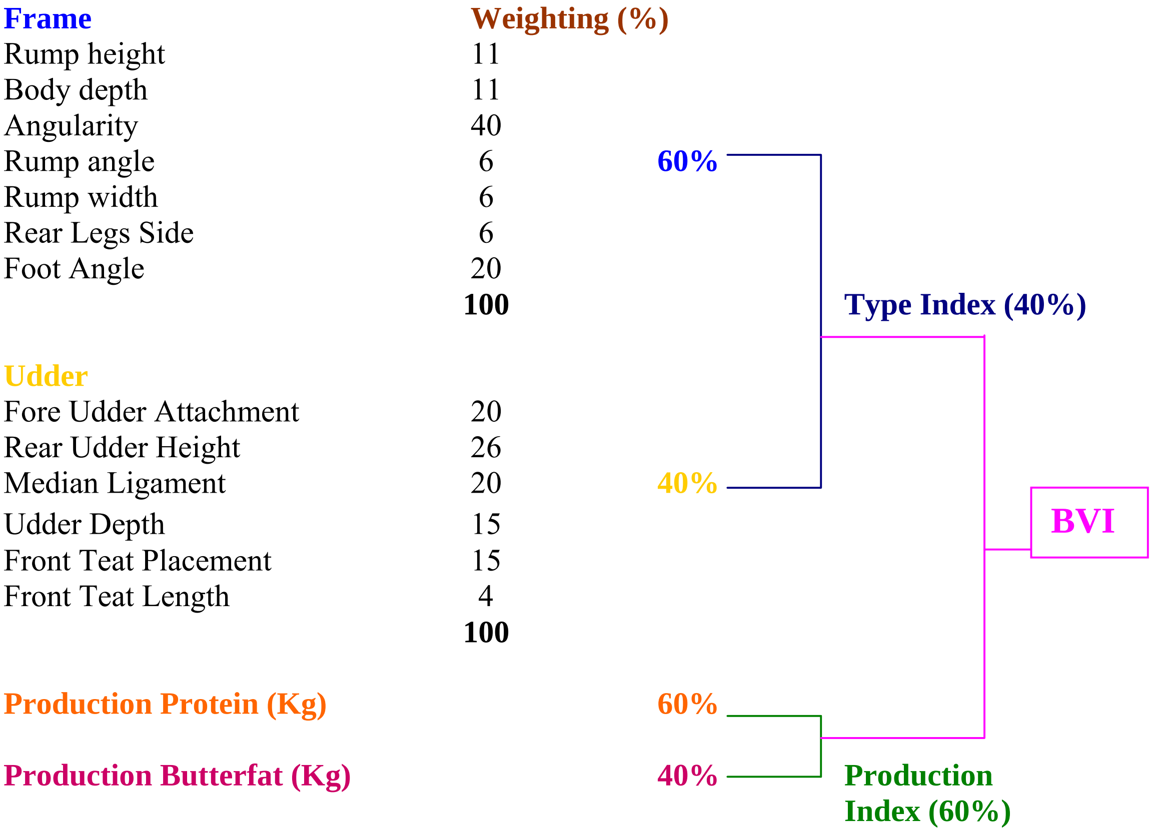
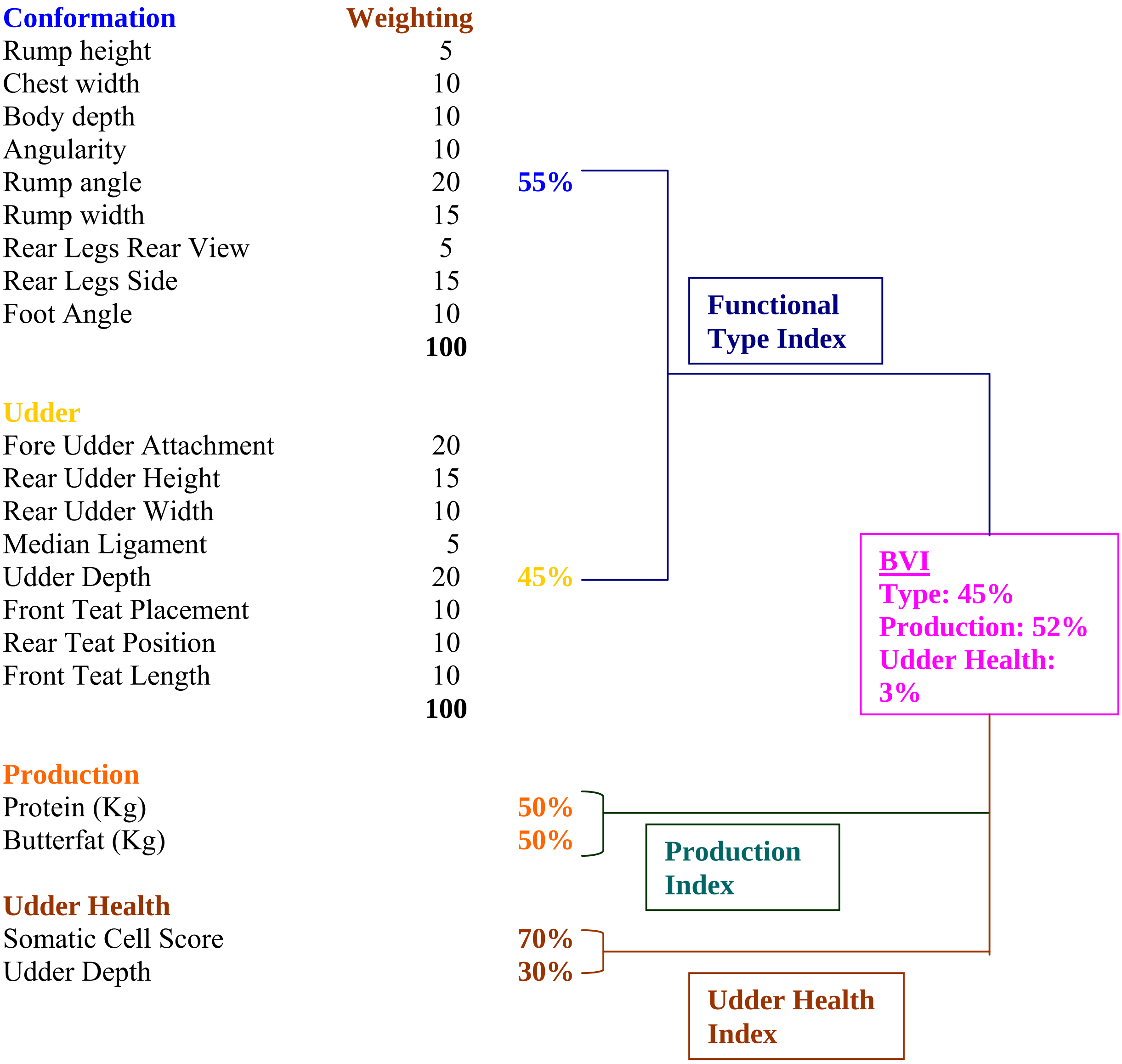


Figure 2.3: Old (1995) Holstein Breeding Value Index (Taurus Holstein, 2004)



Conformation	Weighting
Rump height	5
Chest width	10
Body depth	10
Angularity	10
Rump angle	20
Rump width	15
Rear Legs Rear View	5
Rear Legs Side	15
Foot Angle	10
	100

Udder	
Fore Udder Attachment	20
Rear Udder Height	15
Rear Udder Width	10
Median Ligament	5
Udder Depth	20
Front Teat Placement	10
Rear Teat Position	10
Front Teat Length	10
	100

Production	
Protein (Kg)	50%
Butterfat (Kg)	50%

Udder Health	
Somatic Cell Score	70%
Udder Depth	30%

Figure 2.4: Updated (2005) Holstein Breeding Value Index (Taurus Holstein, 2007)

2.3.3.2 The Jersey SAINET

In its original form, the SAINET was a production index and was calculated as follows (Taurus Jersey, 2002):

$$\textbf{SAINET} = (-0.15 \times \text{EBV-Milk}) + (5 \times \text{EBV-Butterfat}) + (10 \times \text{EBV-Protein}) \qquad [2.1]$$

The SAINET was updated in 2002 to include linear type traits. The contribution of each trait, according to importance to the 2002 SAINET, is set out in Figure 2.5 (production index remained unchanged). This index favours cows with large body capacity, exceptional dairy form, deep and well attached udders, sound feet and legs, and, producing milk of high compositional quality. Similar to the BVI, the high emphasis on capacity and dairy form (angularity) is contrary to worldwide trends (Wesseldijk, 2004).

The SAINET was refined in 2006 to produce the 2006 SAINET which is illustrated in Figure 2.6 (Taurus Jersey, 2007). The 2006 SAINET includes somatic cell score, which was added at the expense of teat placement, udder depth, fore udder attachment, and production. In comparison to most other national selection indices in progressive dairying countries (Wesseldijk, 2004), the 2006 SAINET still maintains too much emphasis on body capacity and dairy form.

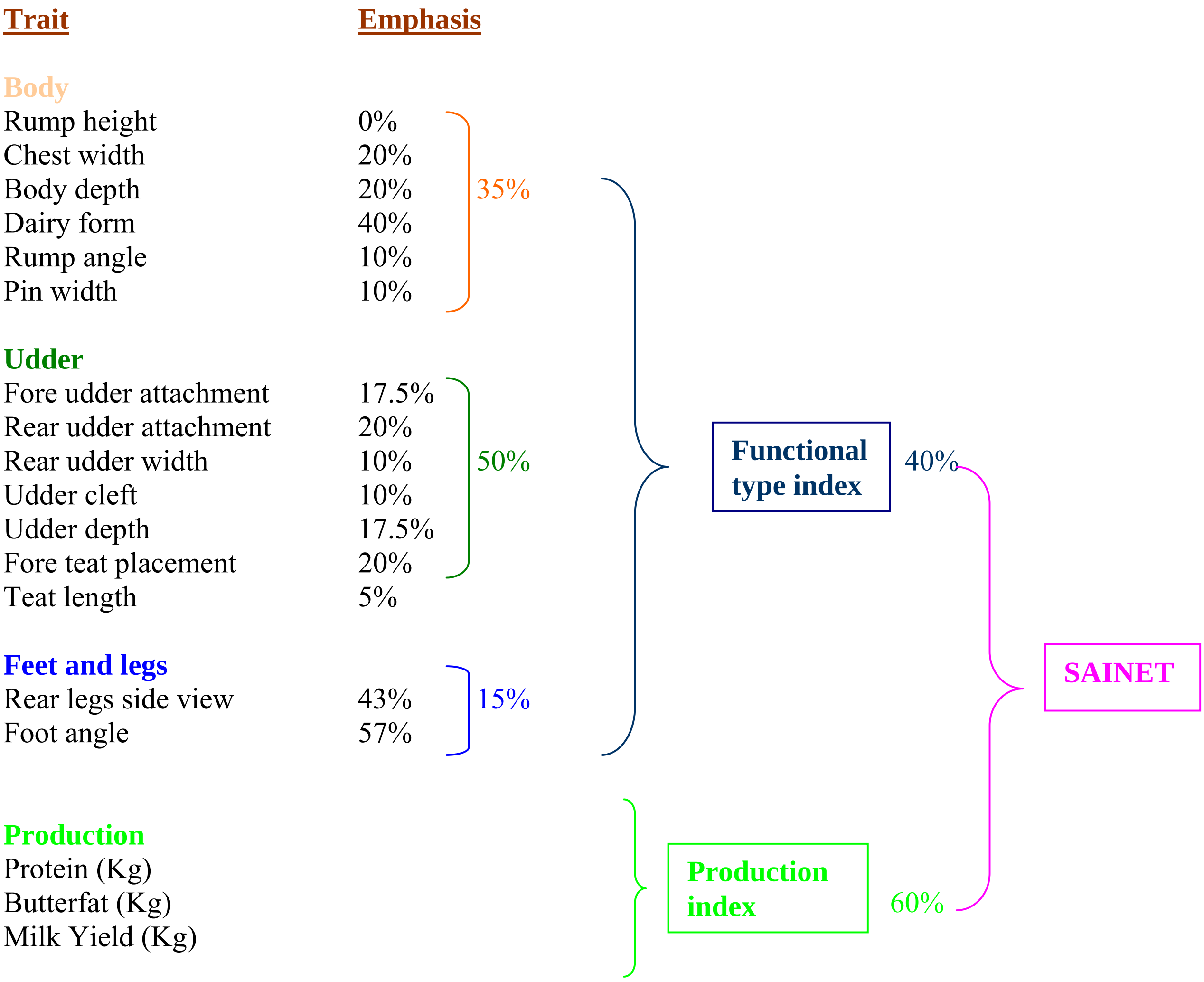
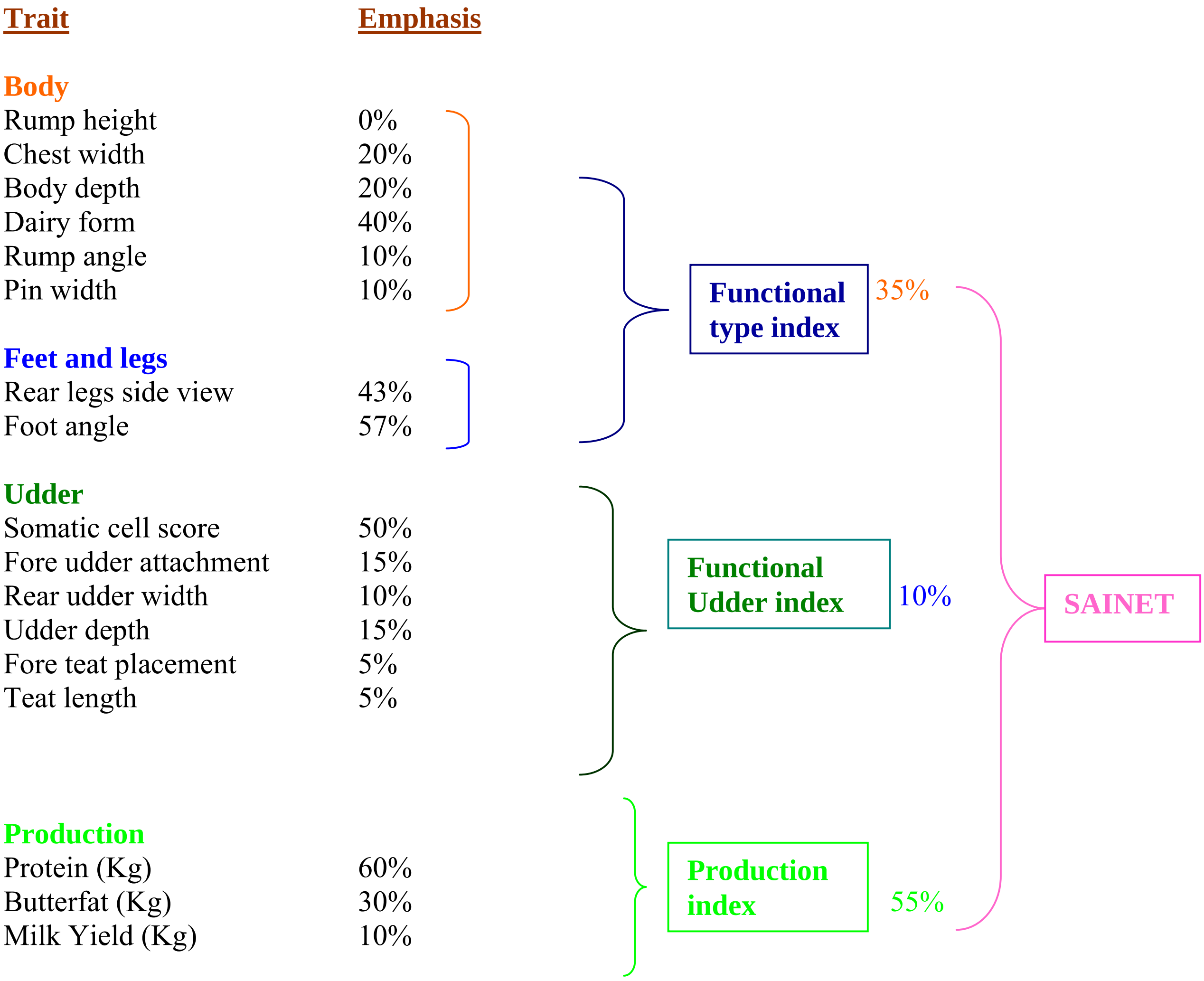


Figure 2.5 Emphasis on different traits in the 2002 Jersey SAINET



Trait	Emphasis
Body	
Rump height	0%
Chest width	20%
Body depth	20%
Dairy form	40%
Rump angle	10%
Pin width	10%
Feet and legs	
Rear legs side view	43%
Foot angle	57%
Udder	
Somatic cell score	50%
Fore udder attachment	15%
Rear udder width	10%
Udder depth	15%
Fore teat placement	5%
Teat length	5%
Production	
Protein (Kg)	60%
Butterfat (Kg)	30%
Milk Yield (Kg)	10%

Figure 2.6 Emphasis on different traits in the 2006 Jersey SAINET

2.4 Conclusions

Traditionally, breeding objectives for dairy cattle in many countries have focussed on production traits. Significant changes have however taken place in recent years, leading to more balanced breeding objectives comprising a wider range of economically important traits. The degree of emphasis placed on the different traits is highly variable among countries. Although efforts have been made to apply multiple trait selection indices in South African dairy cattle, there is a big need to objectively and systematically identify the traits that are desirable to improve, as well as their relative economic importance.

Chapter 3

Literature Review on Selection Index Methodology

A review of methods of selecting for more than one trait (multiple trait selection) and an outline of the theoretical basis of selection index methodology are presented in this Chapter.

3.1 Selection Index Theory

Multiple trait index selection is widely accepted as the method of choice when improvement is desired for more than one trait. The following is an outline of the theoretical basis of selection index methodology and how it has evolved since its development by Hazel (1943).

3.1.1 Selection for more than one trait

In practice several traits influence an animal's economic value, although they do so in varying degrees (Hazel, 1943). Selection applied to the improvement of the economic value of animals is therefore invariably applied to several traits simultaneously. This is usually referred to as multiple trait selection. Hazel and Lush (1943) described three different methods that may be used in multiple trait selection as: (1) selecting in turn for each trait singly in successive generations (*tandem selection*); (2) selecting for all traits at the same time but independently, rejecting all individuals that fail to come to a certain standard for each trait regardless of their values for any other traits (*independent culling* *levels*); (3) applying selection simultaneously to all the component traits together, appropriate weight being given to each trait according to its relative economic importance, its heritability, and the genetic and phenotypic correlations between the different traits (*index selection*). The component characters are combined together into a score or index, in such a way that selection applied to the index, as if the index were a single trait, will yield the most rapid possible improvement of economic value.

Hazel and Lush (1943) compared the three methods of multiple trait selection outlined above and showed that selection for an index which gives proper weight to each trait was never less efficient than tandem selection or independent culling levels. For n traits of the same variability, heritability, and economic importance, combined response from selection on an index was expected to average $\sqrt{n}$ times larger than that from tandem selection, so that response in each of the n traits from index selection would average $1/\sqrt{n}$ of that from selecting for only one trait. Independent culling level selection was never more efficient than index selection which allows superiority in one trait to compensate for inferiority in another trait. The advantage of index selection over independent culling level selection increased sharply with number of traits and with a larger total proportion saved for breeding. Selection index has since been well accepted as the recommended method of selection when more than one trait is considered for improvement (Sivanadian *et al.,* 1998). Increasing use of selection indices and greater scope in number of traits has been observed in dairy cattle populations in the past two decades (Philipsson *et al*., 1994; VanRaden, 2002; Miglior *et al*., 2005).

3.1.2 Optimal index selection

Hazel (1943) remarked that, “The idea of a yardstick or selection index for measuring the net merit of breeding animals is probably almost as old as the art of animal breeding itself.” The big challenge was the need to quantify the influence of differences in economic importance, variability, heritability, and genetic and phenotypic correlations among the traits on the weighting for each trait that would produce maximum genetic change in the economic merit of the selected population. This need formed the basis of the classical work of Hazel (1943) on the development of multiple trait selection indices.

According to Golden *et al*. (2000), the first step in the development of a selection index is the definition of a breeding goal that expresses the overall aim of the breeding programme. This is followed by the establishment of a breeding objective comprising all the traits that influence the breeding goal (i.e. economically relevant traits) and the relative economic importance of each trait. The traits measured (selection criteria) are then used to predict the breeding values of traits in the breeding objective. Finally, the index or aggregate breeding value is calculated as the sum of the selection objective trait breeding values, each weighted by their relative economic importance. Dekkers and Gibson (1998) noted that, although most literature on the development of selection indices focuses on the use of phenotypic records in the index, most indices in practice use breeding values for individual traits as sources of information. A description of the classical approach of Hazel (1943) and how it has evolved to this current form will now be given.

3.2 The classical (Hazel) approach

The classical method of selection index construction developed by Hazel (1943) basically entails the setting up and solving of selection index equations to determine the respective weightings of the measured traits (selection criteria). This procedure may be summarised as follows (Van Vleck, 1993):

If *t* traits have linear economic value, then overall or aggregate economic value for animal *i* can be defined as:

$$T_i = v_1BV_{i1} + v_2BV_{i2} + \ldots\ldots + v_tBV_{it} = \sum_{J=1}^{t} v_jBV_{ij} = \mathbf{v'a}_i \qquad [3.1]$$

where

BV_{ij} = breeding value of animal *i* for trait ***j,***

v_j = the net economic value per unit of trait ***j,*** $j = 1\ldots\ldots t$

$\mathbf{a}_i$ = a vector of breeding values for animal *i* for traits in T (i.e. $BV_{i1}\ldots\ldots BV_{it}$), and

$\mathbf{v}$ = vector of economic values for traits in T (i.e. $v_1\ldots\ldots v_t$**).**

If records are available for *m* traits measured on the animal *i* to be evaluated [X_{i1}, $X_{i2},\ldots X_{im}$], the problem is to weight each record to estimate T_i with an index of the traits, i.e. $\hat{T}_i = I_i = \beta_1X_{i1} + \beta_2X_{i2} + \ldots + \beta_mX_{im} = \mathbf{b'x}_i$ [3.2]

where β_k is the weight for measured trait *k* which will maximise the correlation of I_i with T_i (r_{TI}) (k=1………*m*), **b'** is a vector of selection index weights (i.e. index coefficients $\beta_1\ldots\beta_m$) and $\mathbf{x}_i$ is a vector of phenotypic records on animal *i* (i.e. $X_{i1}\ldots X_{im}$), expressed as deviations from contemporary group means and adjusted for non genetic effects.

The index coefficients are given by solutions to the equation:

$$\mathbf{Pb} = \mathbf{Qv} \tag{3.3}$$

where

P is the *m* x *m* matrix of phenotypic variances and covariances among the measured traits

Q is the *m* x *t* matrix of genetic covariances between the *m* measured traits and the *t* traits in the aggregate genotype

b and **v** are vectors of *m* index weights and *t* economic values respectively, as defined previously.

Rearranging [3.3], solutions for **b** are obtained by

$$\mathbf{b} = \mathbf{P}^{-1}\mathbf{Qv} \tag{3.4}$$

Bourdon (1998) noted that this simple formulation of the selection index has two serious drawbacks. First, it lacks accuracy because it does not contain information on relatives. Second, it is biased because genetic differences among contemporary groups are not accounted for.

3.2.1 Enhancements to the classical approach

Hazel *et al.* (1994) noted that rapid developments in data recording, computer technology and genetic analysis followed the conception of the selection index theory by Hazel (1943), facilitating a number of refinements in methodology. One major modification, which was effected by Henderson (1951), was the separation of selection index construction into two steps. The first step is the estimation of individual breeding values for each trait in the breeding objective. Finally, the breeding values and relative economic weights are combined to calculate the index. The two steps may be summarised as follows (Hazel *et al.*, 1994):

1. Estimation of breeding values (EBV) for breeding objective traits. In practice, observations of many breeding objective traits are not available, due to the fact that they are difficult or too expensive to measure with existing technology. One solution is to predict the breeding objective trait in a multiple trait analysis using measured traits with which it is correlated. Alternatively, Schneeberger *et al.* (1992) showed that EBV for an unobserved trait can be calculated as a linear function of EBV for the selection criteria. Estimated breeding values for the measured traits (selection criteria) are combined to calculate EBV for the objective traits, each selection criteria EBV being weighted by coefficients derived as follows (Schneeberger *et al.*, 1992):

$$\mathbf{b} = \mathbf{G}_{11}^{-1}\mathbf{G}_{12}\mathbf{v} \qquad [3.5]$$

where:

$\mathbf{G}_{11}$ is the genetic variance-covariance matrix of the measured traits

$\mathbf{G}_{12}$ is the genetic covariance matrix between the measured traits and the objective traits.

2. Calculation of the index value (I), which is given by Henderson (1963):

$$I_i = v_1EBV_{i1} + v_2EBV_{i2} + v_3EBV_{i3} + \ldots + v_tEBV_{it} = \mathbf{v}'\hat{\mathbf{a}}_i \qquad [3.6]$$

where:

I_i = estimated aggregate economic merit of an animal, *i*, as a parent,

EBV_{ij} = EBV of animal *i* for breeding objective trait *j*

$\hat{\mathbf{a}}$ = vector of EBV for animal *i* for traits in the objective.

In other words, genetic predictions can simply be substituted for true breeding values in the breeding objective.

In some cases, if an objective trait is not measured, calculation of its EBV may be dispensed with by accounting for the trait when determining the economic values of traits with which it is closely associated. For example, in New Zealand, feed intake is incorporated by accounting for the feed costs associated with higher productivity when the economic value of the milk revenue or beef revenue traits is assessed (Holmes *et al.*, 2000)

The following advantages of the above two-step approach were pointed out by Hazel *et al.* (1994) and Bourdon (1998):

1) It permits use of the most complex and accurate BLUP techniques to estimate individual breeding values for each index trait by including large amounts of pedigree and performance on relatives of candidates into the selection index and adjusting for differing amounts of information (Henderson, 1963; Henderson, 1972).
2) It allows the economic weightings 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.

3.3 Expression of the index

Dekkers and Gibson (1998) stress that implementation of an overall selection index can be facilitated by its expression. Expression includes the name given to the index that must convey the purpose and meaning of the index, the units in which the index is expressed, and an indication of what the index denotes. Table 3.1 shows examples of national dairy cattle selection indices and the different ways in which they are expressed.

Examples in Table 3.1 illustrate how the name given to an index can articulate the meaning and purpose of the index. For total merit indices that are intended to rank animals based on genetic merit of profitability, expression of the index in monetary units as indicated in Table 3.1 facilitates and promotes use of the index (Dekkers and Gibson, 1998).

Table 3.1: Examples of national dairy selection indices and how they are expressed

Selection Index	**Expression**
New Zealand Breeding Worth (BW)	Net lifetime income ($NZ) per 4.5t dry matter required. Indicates estimate of animal's genetic merit for the production of 'dollars of net lifetime income per unit of feed required' (Holmes *et al*., 2000).
Canadian Total Economic Value (TEV)	Expected daughter difference ($CAN) at the farm level. Represents differences between sires in the net present value of cash flow over 10 years from a milking daughter and her descendants (Dekkers, 1995)
USA Net Merit ($NM)	Expected lifetime profit ($US). Measures additional lifetime profit that is expected to be transmitted to an average daughter (VanRaden and Seykora, 2003).
Australian Profit Ranking (APR)	Predicted daughter profitability ($AUS). Shows differences between sires in terms of the profitability of their daughters (ADHIS, 2001).

Standardised index coefficients, which reflect the emphasis put on each trait in relation to the genetic variability that is present in the population, may be obtained by multiplying the economic value by the genetic standard deviation for the trait (Rogers, 1993; Dekkers and Gibson, 1998).

3.4 Conclusions

Index selection is the widely accepted method of multiple trait selection. The classical selection index technique, developed by Hazel (1943), has evolved into a two-step approach comprising: (1) a statistical step involving estimation of breeding values for breeding objective traits and (2) an economic step concerned with weighting objective traits according to their relative economic importance. Sound application of this methodology requires that these steps be preceded by definition of the breeding goal (i.e. articulating the overall aim of the breeding programme), followed by identification of traits influencing the goal (objective traits) and development of their selection criteria.

Chapter 4

Selection goals, objective traits and selection criteria for South African dairy cattle

4.1 Introduction

Genetic improvement of dairy cattle is essentially achieved by the selective mating of the best sires to the best cows and retaining the best of the resulting heifers. The best animals may be described as those that have the highest overall economic value or aggregate genotype. Selection on aggregate economic value will balance all the good and poor characteristics of each individual available for selection, thereby maximising improvement in overall economic merit. Development of the selection objective is a prerequisite to the determination of aggregate economic value of individual animals. A selection objective is a list of all the traits that are desirable to improve and their relative importance.

The following description of how a practical selection objective is developed is given in Holmes *et al*. (2000). “First, the selection goal must be defined and in general terms this goal will be related to satisfaction or utility. In most cases satisfaction relates to economics of production and therefore profitability, because most dairy farmers would be more satisfied with an increase in profit. Second, the list of traits that influence the goal (objective traits) must be identified.” Since the objective traits are usually difficult or expensive to measure, this step should be followed by a determination of the selection criteria; that is those traits that are measured on the animals and used to predict the objective traits (Hazel, 1943). Finally, the relative importance of the objective traits must be decided, and this is typically described in financial terms using relative economic values for each trait.

In order to achieve sustainable genetic progress, national breeding programmes need to be guided by well thought-out and clearly defined breeding objectives. Such breeding objectives are non-existent in the South African dairy industry. Breeding goals for dairy producers have not been defined and there is a lack of consensus on the traits that should be improved. The South African National Dairy Cattle Genetic Evaluation Programme routinely publishes EBVs on 23 traits (B.E. Mostert, 2008, Personal Communication). Selection in the major dairy breeds is mainly based on increased yield and linear type traits (See Chapter 2, Section 2.3). Intense selection for milk yield has resulted in a substantial increase in genetic merit for milk, protein and butterfat yield in the past two decades (National Dairy Animal Improvement Scheme, 2007). Figures 4.1 to 4.6 show the phenotypic and genetic trends in yield traits for the major dairy cattle breeds. Considerable genetic change in some linear type traits, particularly in the Holstein breed, has also taken place (Theron and Mostert, 2004). In the absence of a clearly defined breeding objective, it is however not clear whether these trends are in the desirable direction or what the overall value of these changes amounts to.

Furthermore, recent studies on South African dairy cattle (Banga *et al*., 2002; Dube *et al*., 2008; Makgahlela *et al*., 2008) have indicated deterioration in fitness traits such as longevity, cow fertility and udder health, which may be of high economic value but have not been subject to selection. These undesirable trends are illustrated in Figures 4.7 to 4.9. The widely reported unfavourable genetic relationships between milk yield and fertility (Van Arendonk *et al*., 1989; Frick and Lindhe, 1991; Bagnato and Oltenacu, 1994; Campos *et al*., 1994; Hoekstra *et al*., 1994; De Jong, 1997; Pryce *et al*., 1997; Ojango and Pollot, 2001; Pryce *et al*., 2004; Kadarmideen, 2004; Makgahlela *et al*., 2007) and milk yield and mastitis (Emanuelson *et al*., 1988; Simianer *et al.,* 1991; Uribe *et al*., 1995; Mrode and Swanson, 1996; Dube e*t al*., 2008) raise concerns that the deterioration in udder health and reproductive performance in the South African dairy cattle population may be a correlated response to selection on milk yield *per se*. Depending on the economic values of these non-yield traits, this may negate the economic benefit of increase in yield.

The aim of this Chapter is to build a framework for sound long term breeding programmes for dairy cattle in South Africa. This is achieved by following the first three steps in developing selection objectives outlined above (Holmes *et al*., 2000). Each step is discussed in detail, within the context of the South African dairy industry. In addition to producing a logical means of determining aggregate economic value for individual animals, this framework will form the basis for sustainable genetic improvement of dairy cattle in South Africa. In order to put the concept of selection objective definition into perspective, a systematic approach to the design of a sound breeding programme is discussed first.

Figure 4.1: Phenotypic trends for milk yield

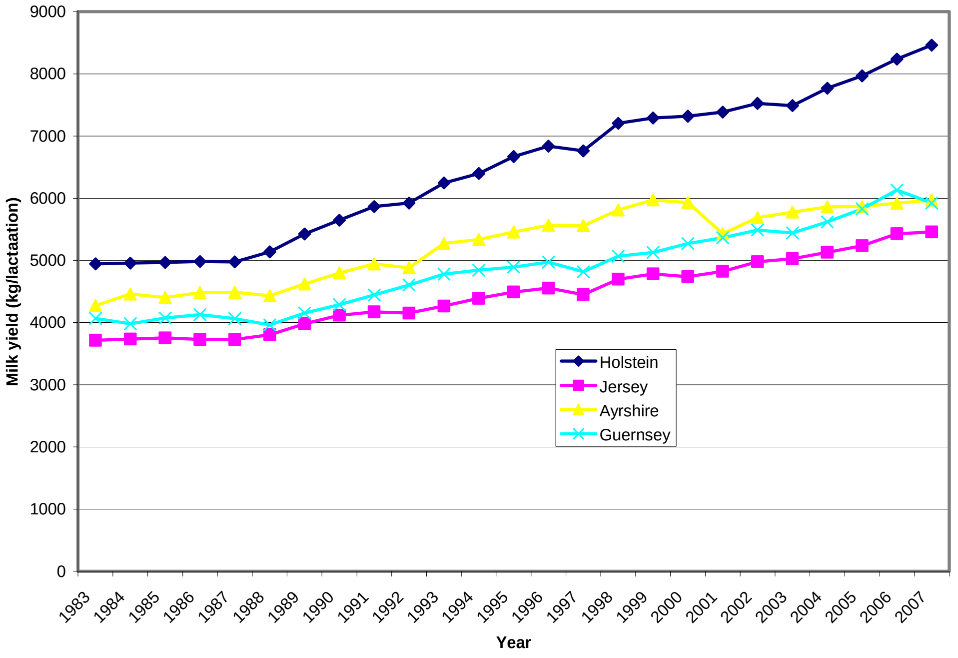


Figure 4.2: Phenotypic trends for lactation fat yield

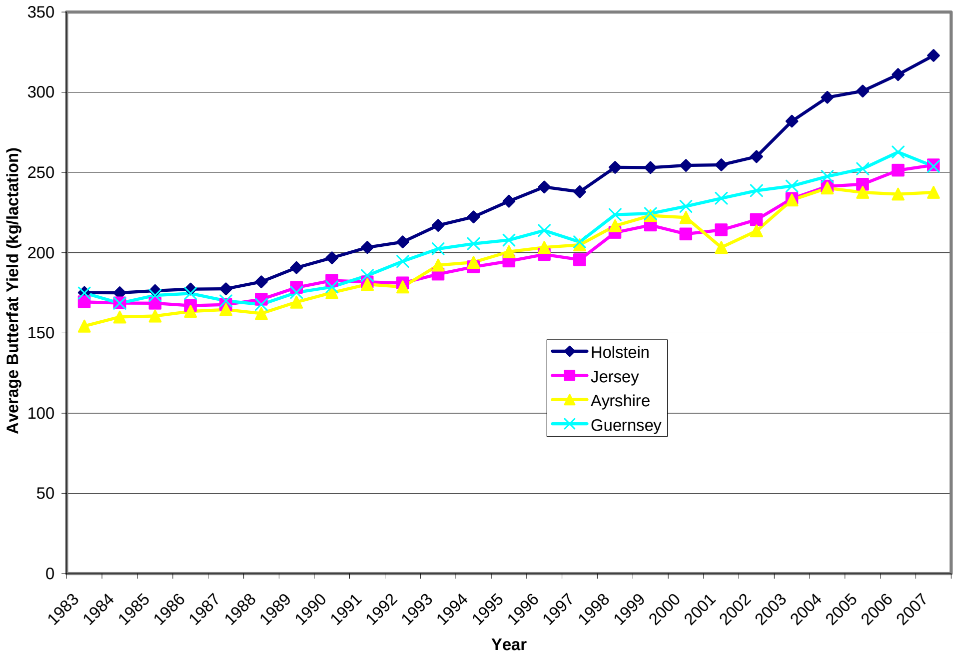


Figure 4.3: Phenotypic trends for protein yield

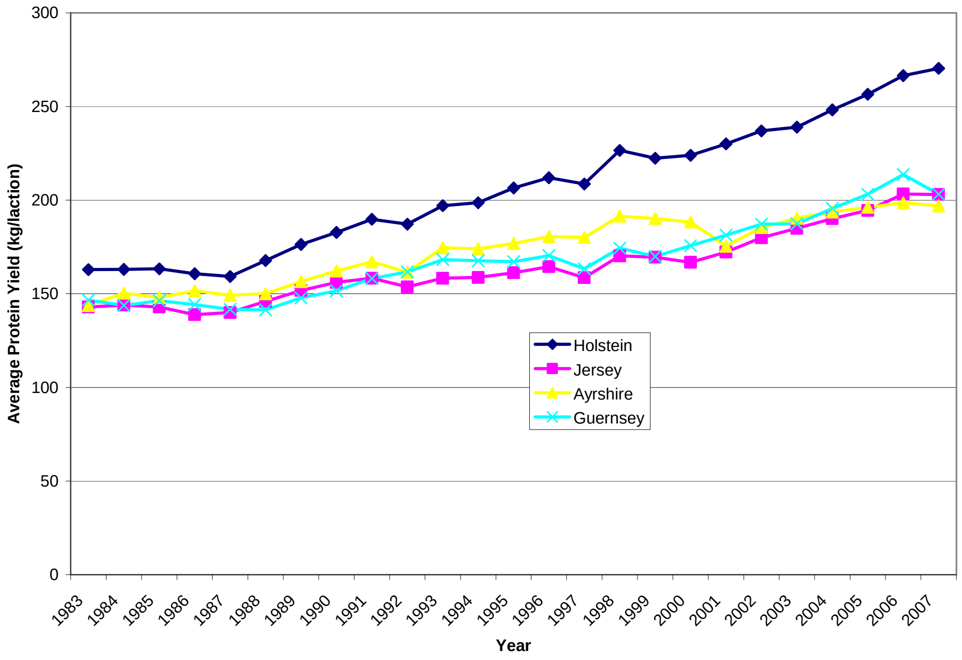


Figure 4.4: Genetic trends for lactation milk yield

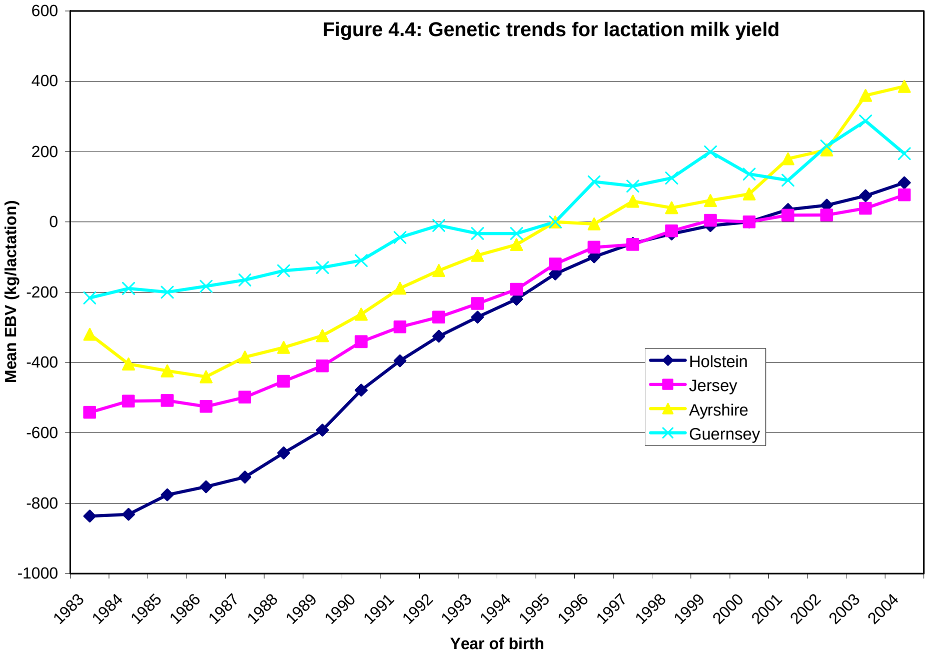


Figure 4.5: Genetic trends for fat yield

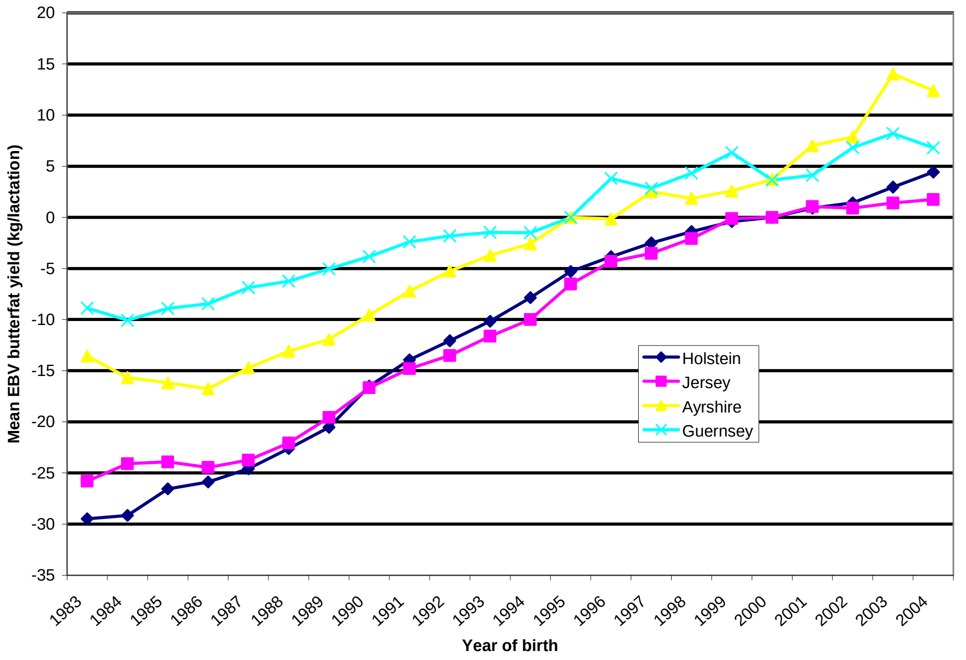
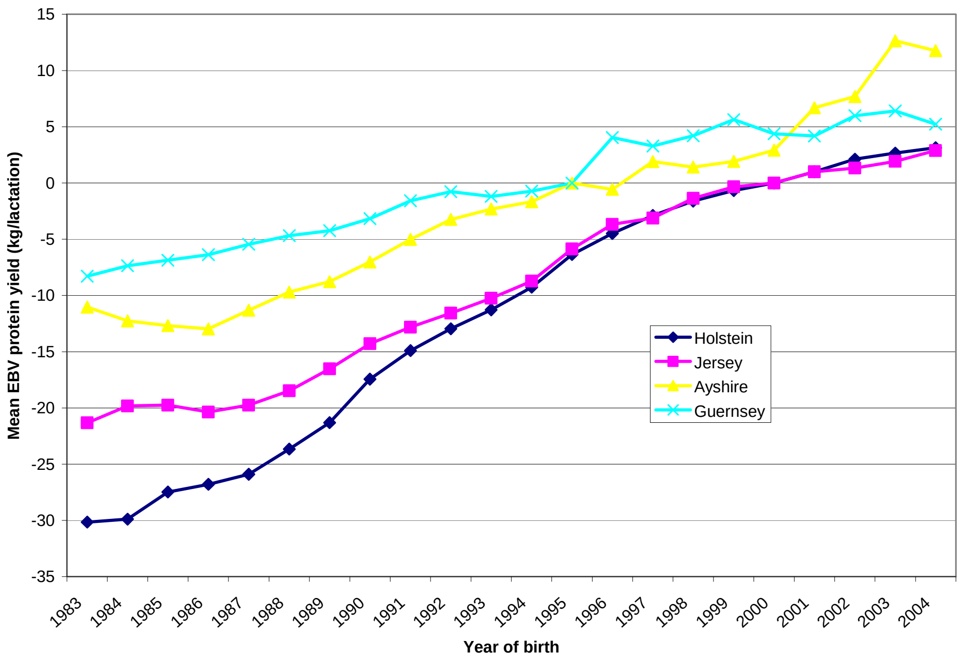


Figure 4.6: Genetic trends for protein yield



Figures 4.1 – 4.6 adapted from National Dairy Animal Improvement Scheme (2007)

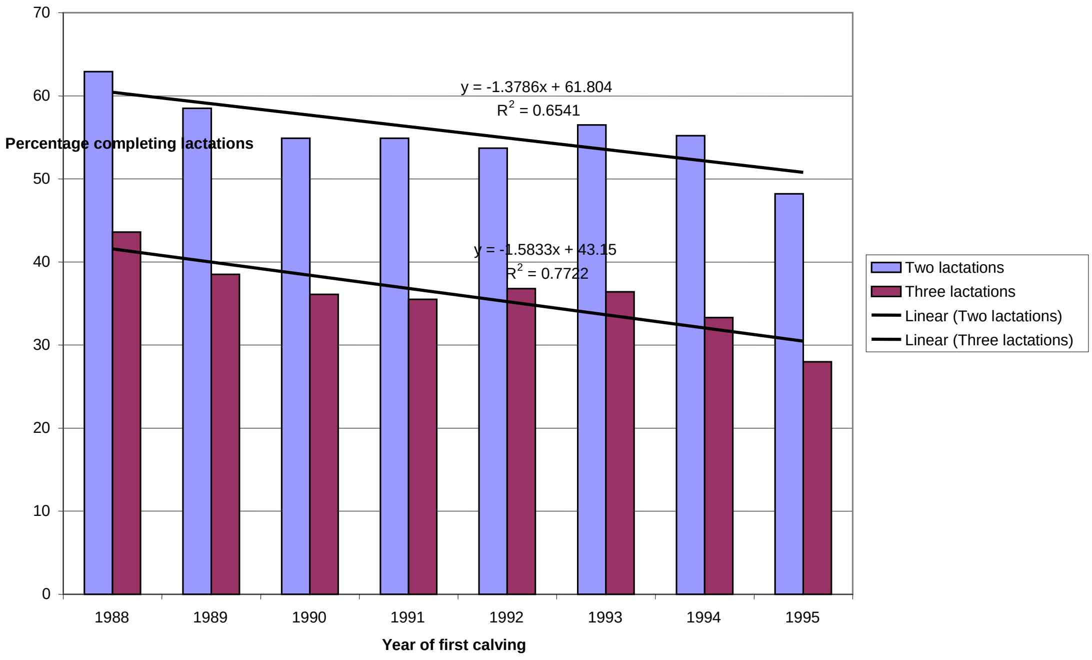


Figure 4.7: Phenotypic trend for longevity in South African Holsteins (Banga *et al*., 2002)

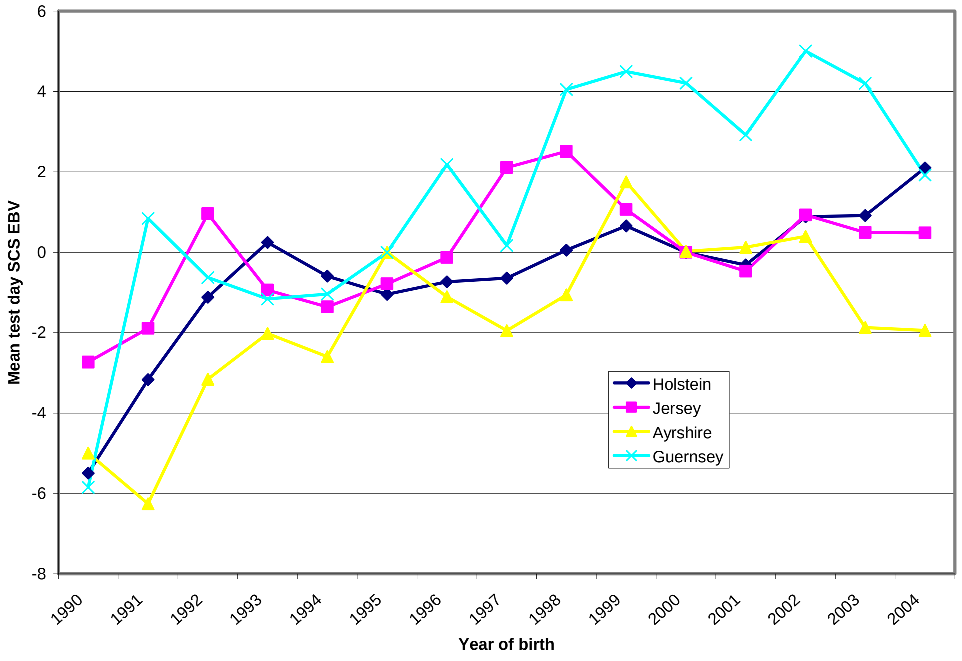
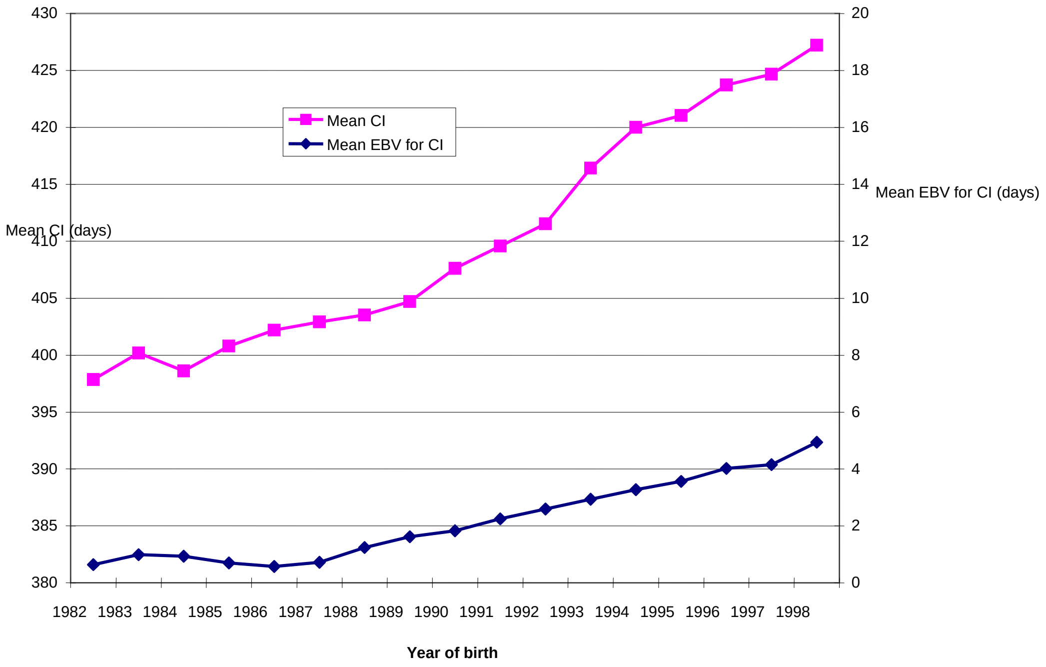


Figure 4.8: Genetic trends for somatic cell score (SCS)

Adapted from Dairy Animal Improvement Scheme (2007)

Figure 4.9: Genetic and phenotypic trends for calving interval (CI) (Makgahlela *et al.*, 2007)



4.2 Breeding programme design

High rates of cost-effective genetic improvement in commercial livestock enterprises rely on well designed and implemented breeding programmes. Figure 4.10 (Lopez-Villalobos and Garrick, 2005) shows a structured approach to the design of such breeding programmes.

First, the selection goal must be defined and in general terms this goal will be related to satisfaction or utility, usually via profit. Second, the breeding objective comprising a list of traits that influence the goal (economically relevant traits) and their relative importance is developed. Traits that are measured on the animals in order to evaluate

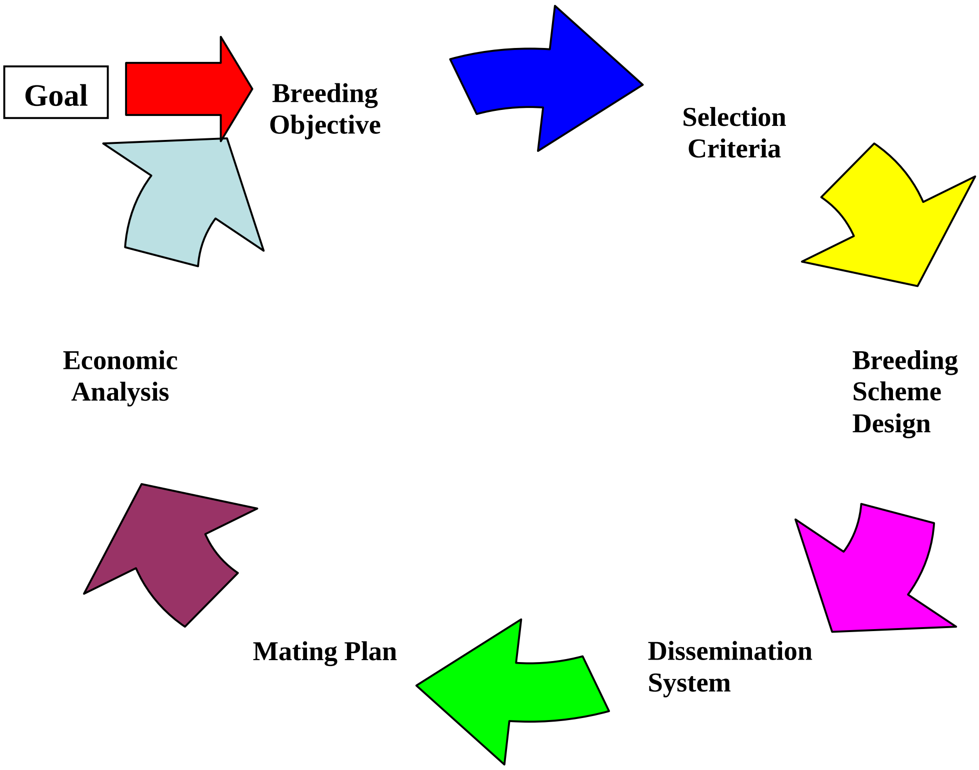


Figure 4.10: Structured approach in breeding programme design and enhancement (Lopez-Villalobos and Garrick, 2005)

animals for the traits in the breeding objective are identified in the following step. Next, a breeding scheme is designed to measure animals in order to select those with the highest genetic merit for the breeding objective. A system for the transfer of genes from high genetic merit animals into the commercial population, such as via artificial insemination, is then required. Subsequently, a mating system allocates cows to bulls under various alternative plans. The final step is economic analysis of the entire breeding programme to ensure that the cumulative value of the benefits is well in excess of the cumulative costs.

4.3 The selection goal

According to a definition in Holmes *et al*. (2000), the selection goal is like a mission statement that attempts to characterise the overall aim of the breeding programme. Weaber (2005) suggests that a verbal description of the goal, rather than a mathematical one, may provide an easy way to initiate the process. Initially describing the production system will help put the definition of the goal in the right perspective (Harris *et. al.*, 1984). Increasing the level of satisfaction, which in the context of dairy production can be achieved by increasing profitability and managing risk, is a usual goal.

It makes good economic sense to express profit per unit of input. According to the Theory of Constraints (TOC) by Goldratt (1990), identifying constraints (e.g. limiting resources) provides the best means of evaluating and continually achieving more of the goal of a system. It is therefore a reasonable approach to express profit per unit of limiting resource. For example, in a pasture production system in a country like New Zealand, where feed is the most limiting resource, it may be appropriate to express the goal as profit per unit of feed than per animal (Holmes *et al*., 2000).

4.3.1 Selection goals for South African dairy producers

Dairy production in South Africa may be classified into two distinct production systems although some systems exhibit elements of both. Farmers along the south-east coastal areas are largely dependent on pasture and practice what is commonly referred to as the New Zealand (pastoral) production system. Most herds are large in size (250 cows on average) and animals graze on pasture throughout the year, with bought-in roughage and concentrate supplements in winter. Both seasonal and year-round calving are practised although there is a growing increase in seasonal calving (F. du Toit, 2007, Personal Communication). The major limiting resource on these farms is pasture. A plausible goal for farmers in this production system is profit per unit area of grazing land or per unit of feed intake.

The other production system, that characterises dairy farms in inland areas, mainly involves intensive housing and concentrate-based feeding of cows, with year round calving. Cows are mainly fed total mixed rations *ad lib*, although some herds practice separate feeding of roughage and restricted quantities of concentrates. Irrigated or dry-land pastures, as well as natural veld, are commonly used to supplement home grown or bought-in fodder. Management capacity, as well as facilities such as milking parlours, animal housing, feeding troughs and feed silos limits the number of animals that can be in a particular herd. The major constraint or limiting factor to output in these herds is thus the capacity of production facilities. A reasonable goal in this production system would be profit per cow place.

Table 4.1 contains a summary of these two production systems and articulation of plausible breeding goals for farmers in the two systems. The following section discusses a framework for focussing on the goal with a view to achieve greater effectiveness and efficiency in identifying traits influencing the goal.

Table 4.1: Dairy production systems and proposed selection goals for dairy cattle in South Africa.

Production System	***Limiting Resource***	***Selection Goal***
Extensive pasture-fed *- dry land pastures all year round* *- dry season supplementation* *- seasonal and year round calving* *- milk price not seasonal*	Feed (grazing)/ha Feed (grazing)/animal	*'To achieve, in a sustainable and environmentally friendly way, continuous improvement in profit from the sale of milk and cull and excess animals produced on extensive dry land pastures.'* **Profit/ha of pasture land** **Profit/kg dry matter**
Intensive concentrate-fed *- intensive feeding of concentrate and bought-in fodder* *- low reliance on pastures* *- all year round calving* *- milk price not seasonal*	Capacity of production facilities (cow space)	*'To achieve, in a sustainable and environmentally friendly way, continuous improvement in profit from the sale of milk and cull and excess animals produced in an intensive concentrate-fed system with year-round calving'* **Profit/cow place**

4.4 Goal focusing framework

In order to effectively and efficiently identify traits influencing the goal, a goal focusing framework (Figure 4.11) will be used. The concept of a focusing framework is described in Timms and Clarke (2007) where a beef profit focussing framework is used to identify key elements affecting profit in a beef enterprise. The most fundamental component of the framework is a clearly defined focus. A focus may be defined as a specific area and target outcomes on which to concentrate attention, thinking and action (Timms and Clarke, 2007). Timms and Clarke (2007) note that besides being an effective tool in identifying critical elements of a system a clear, shared and agreed focus can save time, effort, money and other resources. In the context of developing breeding objectives, the focus is the selection goal. Given a profit-based goal, the primary elements influencing the goal are income and costs. Next, the major factors that determine income and/or costs, each of which is a group of traits, can be identified. Such factors may be termed goal trait groups and each comprises traits of the same nature (e.g. reproduction) that are critical to the attainment of the goal. The individual traits within each goal trait group that influence the goal (i.e. economically relevant traits) are finally identified. Figure 4.12 illustrates the identification of goal trait groups and economically relevant traits for the pastoral and intensive concentrate-fed production system goals, using the goal focusing framework.

4.5 Goal trait groups

The goal trait groups (See Figure 4.12) may be defined as the composite or super traits (Wilmink, 1996) that directly influence the goal through their effect on income or costs. Table 4.2 contains a list of goal trait groups that relate to the achievement of the selection goals defined in Table 4.1. This list is not exhaustive and may change over time or with refinement of goals.

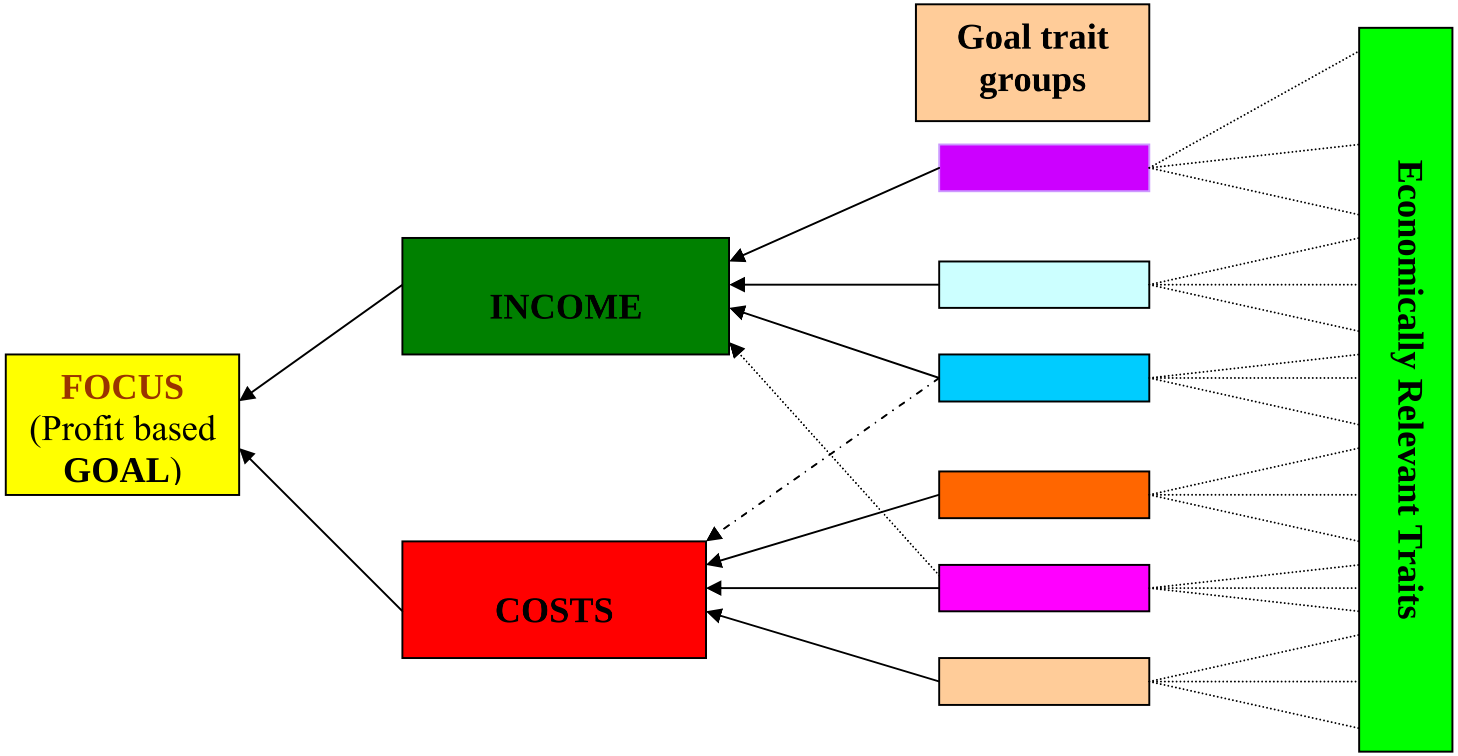


Figure 4.11: Focussing framework for considering key elements affecting the selection goal

Certain goal trait groups (e.g. milk composition, reproduction) are obvious and clearly justified; however goal trait groups such as cow comfort may be regarded as *externalities*. An *externality* is an incidental condition that may affect a course of action. A *negative externality* occurs when undesirable impact or costs of an economic activity are not taken into account in making decisions pertaining to that activity. For example our economic system treats environmental degradation as an *externality*, that is a cost that does not enter into the conventional arithmetic that determines how we best use our resources. A *positive externality* exists when external economic benefits go under-valued by the market. Genetic improvement of animal resistance to parasites may be regarded as a *positive externality* as it results in reduced environmental pollution by parasiticides; a societal benefit that is not normally taken into account in making animal breeding decisions.

In the past, selection in the South African dairy cattle population has mainly focused on yield and type traits and interest has been shown recently in incorporating udder health (See Chapter 2, Section 2.3). There is, however, a growing need to increase the goal trait groups to include all economically important traits. Efforts are under way to implement routine genetic evaluations for reproduction and longevity. Since feed costs are the most expensive input for most South African dairy producers, it is imperative to pay attention to this trait group. Goal trait groups such as cow comfort, milkability and environmental cleanliness may currently be regarded as *externalities* but, in keeping with global trends, are likely to gain prominence in the future. Goal trait groups influencing the goals in Table 4.1 will now be discussed.

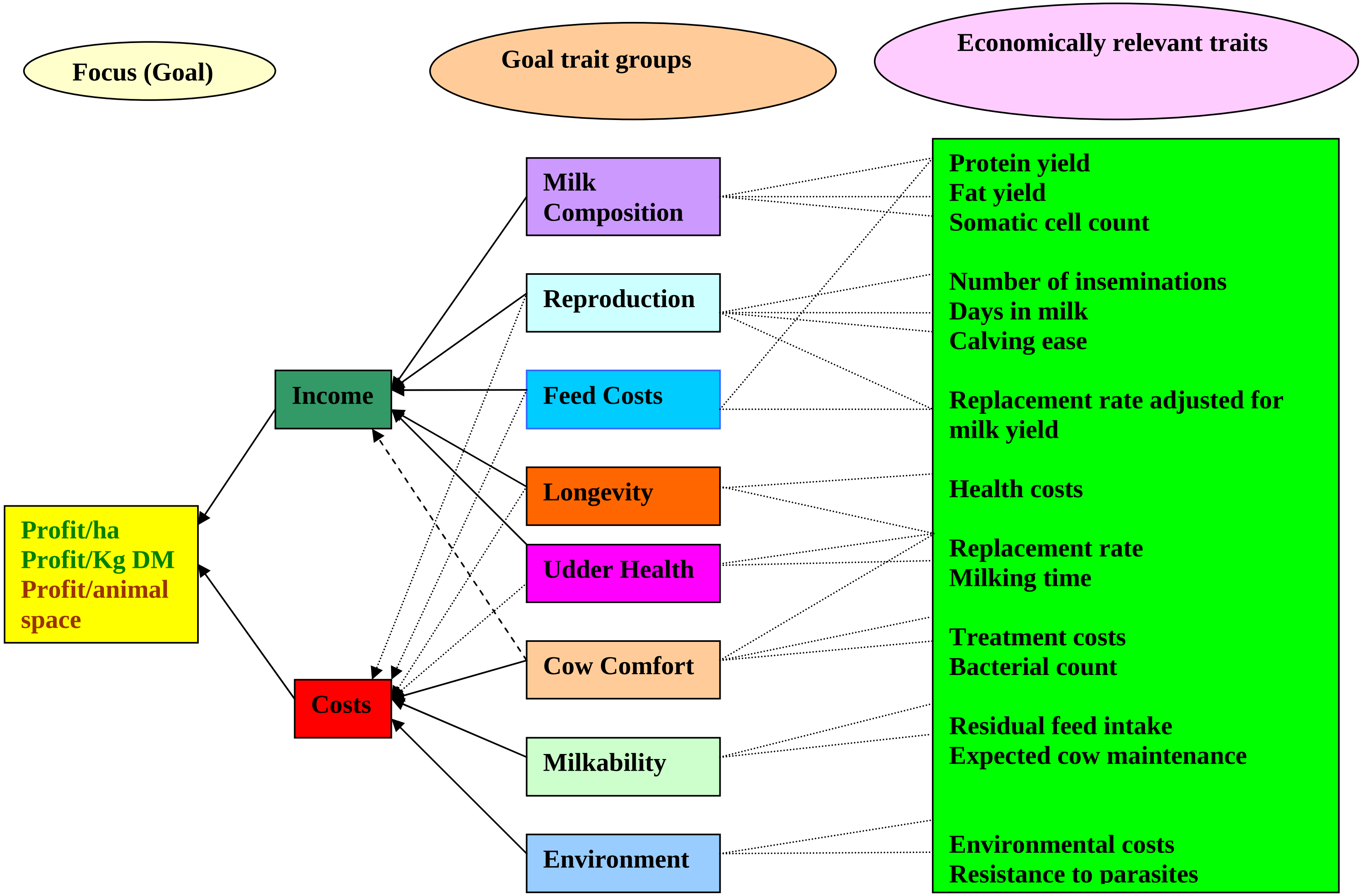


Figure 4.12: Goal focussing framework

4.5.1 Milk composition

The primary source of income from dairy production is the sale of milk. Yields of milk components are therefore traits of paramount importance in dairy cattle. Milk payment systems vary considerably among markets. The value of milk may also depend on the major products manufactured. The major milk processors in South Africa pay producers predominantly on the weight of butterfat and protein (K. Coetzee, 2008, Personal Communication). The current and future importance of the different components of milk and their impact on income from milk, globally and in South Africa, is discussed in section 4.6.1 below.

4.5.2 Reproduction

Reproduction is a critical factor in determining sustainable and profitable dairy farming. Every heifer and cow in the herd must become pregnant before it can give birth to a calf and produce useful quantities of milk. Milk and replacement calves are therefore direct products of reproduction. In pasture-based dairy production systems, cows must get pregnant and calve at the right time of the year (typically spring) so that the start of lactation, which has high nutritional demands, coincides with the start of rapid pasture growth. Economic losses from impaired reproductive performance in dairy cattle are well documented in the literature (Dijkhuizen *et al.*, 1985; Schmidt, 1989; Pecsok *et al.*, 1994; Plaizier *et al.*, 1997).

Reproduction is a complex trait encompassing a host of economically relevant traits that may be measured by a variety of indicator traits (See Table 4.2). Traditionally, reproduction has largely been ignored in most dairy genetic improvement programmes, mainly due to its low heritability (Raheja *et al.*, 1989; Grosshans *et al.*, 1997; Pryce *et al.*, 1997; Kadarmideen, 2004). The relatively large additive genetic variation of fertility (Philipsson *et al.*, 1981; Hermas *et al.*, 1987; Raheja *et al.*, 1989; Oltenacu *et al.*, 1991; Grosshans *et al.*, 1997; De Jong, 1997) however, indicates scope for genetic improvement through selection. The increasingly evident antagonistic association between reproduction and milk yield (Van Arendok *et al.*, 1989; Frick and Lindhe, 1991; Bagnato and Oltenacu, 1994; Campos *et al.*, 1994; Hoekstra *et al.*, 1994; De Jong, 1997; Pryce *et al.*, 1997; Ojango and Pollot, 2001; Kadarmideen, 2004; Nilforooshan and Edriss, 2004; Pryce *et al.*, 2004; VanRaden., 2004; Makgahlela *et al.*, 2007) is of major concern. Recent developments have seen an increased prominence of reproduction in dairy cattle improvement programmes worldwide (Wesseldijk, 2004; Miglior *et al.*, 2005).

In the past, reproduction has largely been regarded as an externality in respect to the valuation of semen from alternative bulls. Global trends have, however, stimulated a paradigm shift and work is now under way to estimate breeding values for some reproductive traits in South African dairy cattle. The future is therefore expected to see a more prominent role for reproduction in selection objectives for dairy cattle in South Africa.

4.5.3 Feed costs

Feed accounts for the highest proportion of production costs in most dairy farms. Improvement of the efficiency of feed utilisation (i.e. reduction of feed costs per unit of product) should therefore form an essential component of dairy cattle breeding programmes. Feed efficiency, which has traditionally been measured as the ratio of feed to yield, is difficult to improve through selection because it is not easy to measure and also because of problems inherent with ratio traits (Gunsett, 1986). Furthermore, Garrick (2006) demonstrates that selection to improve profit will be more effective when based on predicted outputs and predicted inputs than on ratios such as efficiency. Economically relevant traits with a direct bearing on feed costs (Table 4.2) are the logical option. These traits have, however, been generally considered difficult to predict and, as a result, have not been included in most breeding objectives. Research is, however, generating a number of indicator traits that may be used to predict these traits with reasonable accuracy (See Table 4.2 and discussion in Section 4.6.3). Genetic improvement of feed costs is therefore set to feature a prominent role in dairy cattle improvement programmes worldwide and in South Africa.

4.5.4 Longevity

Longevity may be defined as the ability to avoid death or culling. Culling may be voluntary or involuntary. Involuntary culling may result from causes such as reproductive failure, disease or old age and voluntary culling can be due to a variety of reasons relating to poor performance and/or physical appeal (e.g. yield, temperament, milking speed, conformation). Thus longevity is a complex trait primarily comprising of economically relevant traits related with herd replacement (see Table 4.2). A number of traits may be used to measure longevity and these are discussed in detail in section 4.7.4.

The economic importance of longevity in contributing to dairy herd profitability has been stressed in numerous studies (Gill and Allaire, 1976; Dentine *et al*., 1987; Rogers *et al*., 1988; Essl, 1998; Schneider *et al*., 1999; Rizzi *et al*., 2002). Many national dairy cattle selection objectives now incorporate longevity traits (Wesseldijk, 2004; Miglior *et al.*, 2005). Recent work in South Africa (Banga *et al*., 2002) has shown a consistent decline in longevity in dairy cattle over time. Depending on the economic value of the economically relevant longevity traits, this may be adversely affecting the aggregate economic value of South African dairy cattle. Estimated breeding values of South African dairy cattle for longevity traits are expected in the near future and may form an important part of the breeding objectives.

4.5.5 Cow health

Genetic improvement of overall dairy cow health is desirable for various reasons. Diseases (impaired health) cause economic losses through reduced milk yield, milk discarded due to antibiotic treatment, premature loss of animals, reduced salvage value of animals, drugs, veterinary services, labour, reduced genetic gain, and reduced milk quality (Shook, 1989). In addition, increased demand by consumers for animal products of high quality from healthy animals, heightened concerns about animal welfare, increased resistance to antimicrobial drugs, loss of biodiversity in naïve populations, and positive epidemiological feedback due to a decreased disease transmission when the proportion of resistant animals increases in the population highlight the need to include disease resistance in breeding programmes (Detilleux, 2001). Several studies (Emanuelson *et al.*, 1988; Mäntysaari *et al.*, 1991; Simianer *et al.,* 1991; Uribe *et al.*, 1995; Mrode and Swanson, 1996; Pryce *et al.*, 1997; Heringstad *et al.*, 2005; Heringstad *et al.*, 2007) have shown unfavourable genetic correlations between predominant diseases in dairy cattle and milk production. Such correlations indicate that selection for milk yield without regard to health is likely to result in increased susceptibility to disease, thus further justifying the need to include cow health in dairy cattle breeding objectives.

In the past, cow health has not been included in most dairy breeding programmes, primarily due to the low heritability characteristic of fitness traits and a general lack of appropriate disease recording schemes (Shook, 1989). Regardless of their low heritability, most health traits have, however, been shown to exhibit large additive genetic variation (Shook, 1989; Philipsson and Lindhe, 2003); indicating scope for genetic improvement through selection. Experiences in the Scandinavian countries (Philipsson and Lindhe, 2003; Heringstad *et al.*, 2007) demonstrate significant genetic improvement in cow health through selection. Resistance to disease, particularly mastitis, is now included in most national dairy cattle breeding objectives (Miglior *et al.*, 2005).

Cow health cannot continue to be ignored in dairy cattle breeding programmes. The decline in genetic resistance to disease accompanying selection for increased milk production, which has been reported in many populations (Rauw *et al.*, 1998; Castillo-Juarez *et al.*, 2002; Hansen *et al.*, 2002; Koivula *et al.*, 2005; Dube *et al.*, 2008), is cause for concern. Improvements in management *per se* cannot be expected to offset the genetic deterioration in cow health that might occur in many dairy cattle populations as a correlated response to selection for milk yield. In South Africa, steps have been taken to incorporate udder health in dairy breeding objectives (see Chapter 2, Section 2.3); however other aspects of cow health should not be overlooked. Economically relevant traits within the cow health trait group are discussed in section 4.6.5 below. Dairy cattle genetic improvement strategies for South Africa should determine the economic importance of these traits and, if economically justifiable, implement the recording of appropriate selection criteria for cow health.

4.5.6 Udder health

Udder health refers to the infection status of the udder. A healthy udder may thus be defined as one that is free from infection (mastitis). Mastitis is the most prevalent and costly disease in dairy herds worldwide and its economic impact has been highlighted in many studies (e.g. Gill *et al.*, 1990; Schepers and Dijkhuizen, 1991; Lescourret and Coulon, 1994; Hortet and Seegers, 1998). Economically relevant traits that reflect the loss of income or increase in costs as a result of mastitis constitute udder health traits (Table 4.2).

Selection for improved udder health in dairy cattle has taken place for several years in the Scandinavian countries (Sørensen *et al.*, 2000). Most national selection objectives have however, in the past, excluded udder health traits, mainly due to a lack of records required for genetic evaluation of these traits and/or the general neglect of traits with low heritability (Philipsson *et al.*, 1994). Wesseldijk (2004) and Miglior *et al.* (2005) however reported a growing interest in including udder health in national selection objectives over the past decade. A recent study by Banga (2004) underscored the economic impact of poor udder health in South African dairy cattle and genetic evaluation for test-day somatic cell score, as an indicator trait for economic losses due to poor udder health, is now being undertaken for South African dairy cattle (Mostert *et al.*, 2004). Economically relevant traits relating to udder health, which are proposed for inclusion in the breeding objectives for South African dairy cattle, are discussed in section 4.6.5.

4.5.7 Cow Comfort

Cow comfort can be regarded as the degree of stress, or lack of it, relating to the animal's environment. Factors such as heat stress, metabolic stress, physical discomfort, infectious challenge, social confrontation with other cows, or housing facilities may affect cow comfort. Farm animal welfare, which is a reflection of cow comfort, is an increasingly important consideration for consumers, farmers and health authorities, as a criterion for ensuring acceptable standards and conditions of food production. In addition, cow comfort can be important in maintaining high production, optimising herd health and increasing reproductive success and longevity. Economically relevant traits that reflect wastage resulting from stress experienced by the cow therefore typify cow comfort traits (Table 4.2).

Individual cows respond differently to stressors; for example, cows with lower maintenance requirements will cope better with heat stress. Heat stress is one of the most important causes of cow discomfort, especially in tropical and sub-tropical environments. Specialised dairy cattle breeds such as Holstein and Jersey, that were developed in temperate environments, are particularly affected. St-Pierre *et al.* (2003) estimated that dairy herds in the USA annually lose $897 million to summertime heat stress. Long term genetic improvement strategies in South Africa should therefore seriously consider cow comfort traits.

Developments in the dairy industry worldwide have created dairy production units with many cows, total confinement systems, and total mixed rations formulated for high yields and fed to surplus appetite. This, coupled with intense genetic selection for increased yield, has created cows that are more prone to discomfort manifested in metabolic stress and other diseases (Rogers *et al*., 1999; Oltenacu and Algers, 2005). Genetic trends in South Africa (see Figures 4.1 – 4.6) point to intense selection for yield traits. Metabolic stress may therefore be of high importance, particularly in the intensive concentrate-fed production system. Inadequate animal housing in intensive production systems has also been found to be a major source of cow discomfort (Weary and Tucker, 2003). Future genetic improvement of dairy cattle in South Africa should therefore be geared towards breeding animals that are less susceptible to discomfort, or providing environments (e.g. shade) that avoid discomfort.

4.5.8 Milkability

Milkability or ease of milking may be defined as the rate at which milk can be completely drawn from a cow's udder. Both milking machine operation and function and animal effects determine milkability. From the animal perspective, milkability is a trait that expresses the extent to which a cow will let down its milk as well as its adaptation to machine milking. Poor milkability increases milking costs (increased labour, electricity, machine wear and tear); however research has shown that cows that have high genetic merit for milkability are more susceptible to mastitis (Seykora and McDaniel, 1985; Monardes *et al.*, 1990; Lund *et al.*, 1994; Zhang *et al.*, 1994; Boettcher *et al.*, 1998). Depending on the magnitude of the genetic correlation between milkability and mastitis, this may make the genetic improvement of milkability a complex undertaking. The economically relevant traits appertaining to milkability are discussed in section 4.6.7.

Milkability is increasingly gaining importance in dairy genetic improvement programmes worldwide. A number of countries now include milkability traits in their selection objectives (Boettcher *et. al.*, 1998; Dodenoff, 2004). Udder health and milking machine operation costs are both important factors in South African dairies. Milkability traits can therefore not be ignored in selection objectives for South African dairy cattle. The challenge is to incorporate these traits in the selection objectives in a manner that will maximise overall economic merit.

4.5.9 Environmental cleanliness

Environmental pollution and degradation by farm animals, especially dairy cattle, is increasingly becoming a major issue of global concern. Large numbers of animals, requiring huge quantities of feed grown using massive inputs of water, energy, fertilisers and pesticides, produce enormous amounts of waste, causing serious pollution and environmental degradation. In dairy cattle, the situation is exacerbated by the fact that intensive management systems, where large groups of cows are kept and fed in small areas of land to improve efficiency of milk production, are predominant. Intense selection for milk yield has also created dairy cows that have high nutritional demands.

The following facts (Turner, 1999) highlight the seriousness of the problem caused by such developments:

- 200 dairy cows produce as much nitrogen in their manure as 10 000 people.
- Farm animals are major sources of greenhouse gases, methane and nitrous oxide.
- Ammonia released from manure and slurry is a major contributor to acid rain.
- Excess nitrogen from intensive farms may cause groundwater pollution, increasing nitrate levels in drinking water.

- Huge amounts of insecticides are used to control a variety of pests, parasites and diseases affecting dairy cattle. These, in addition to fertilisers and pesticides used in producing animal feeds, are a big threat to biodiversity.

Any serious efforts to achieve sustainable dairy production must therefore take cognisance of the aforementioned facts and the importance of minimising environmental pollution and degradation. In the context of genetic improvement, the challenge is to breed animals that have less negative impact on the environment. This could be achieved in a number of ways, for example:

- Developing animals that are more resistant to diseases and parasites, thereby reducing the use of pesticides and other chemicals.
- Developing animals with decreased excretion of pollutants such as nitrogen, ammonia and greenhouse gases. For example, Wood *et al.* (2003) obtained moderate to high estimates of heritability for milk urea nitrogen, indicating scope for reducing nitrogen excretion through genetic selection.
- Developing more efficient animals so the same amount of food can be produced by fewer animals and less land.

The proposed selection goals for South African dairy farmers (Table 4.1) have an environmental conservation component. National genetic improvement strategies should therefore work towards identifying economically relevant traits relating to this component and incorporate them into selection objectives. Suggestions in Table 4.2 will form the basis of such an initiative.

4.6 The economically relevant traits

After identifying the goal trait groups, the next step is to determine the individual traits, within each goal trait group, that influence the goal (Figure 4.11). Such traits, known as economically relevant traits (ERT), are the traits that directly affect profitability by being associated with a specific cost of production or an income stream (Golden *et al.*, 2000). In dairy cattle, traits that influence milk revenue and income from beef (cull cows, surplus calves, calves reared for beef) are clearly economically relevant. Traits that impact on profitability through their association with costs include those affecting feeding, rearing, health and wastage. Economically relevant traits within each of the goal trait groups, influencing selection goals for South African dairy producers (Table 4.2), now and possibly in the future, will now be discussed.

4.6.1 Milk composition

Identifying economically relevant traits within the milk composition goal trait group is theoretically cut and dried but, practically, can be a complex task. The primary source of income from dairy farming is revenue from the sale of milk. Garrick and Lopez-Villalobos (1999) demonstrate that the true value of milk to the industry depends upon its composition and its end use. In New Zealand, the true value of milk to the dairy industry was shown to vary considerably with composition and the product mix created from the milk (Garrick and Lopez-Villalobos, 1999). The value of milk to the producer depends upon its true value to the industry and the payment system used by the milk processors. Ideally, the payment system should appropriately reward producers according to the true value of their milk to the industry. In such a ‘perfect’ market, price signals to producers would reflect the true value of milk and its components, now and in the future. The list of economically relevant traits would thus be based on the payment system. Garrick, in Holmes *et al.* (2000) points out that few markets are however 'perfect', with the result that market signals do not always reflect the true situation.

Compositional traits such as **yields of protein**, **butterfat**, **lactose** and **casein** are clearly of importance as they affect product quantity. It is important, however, to note that consumers are generally becoming more perceptive and their needs are always changing. A shift from marketing commodity dairy products to the development, manufacture, and marketing of value added dairy foods for specific market segments has created the need to pay attention to traits relating to the quality of milk (Barbano and Lynch, 2006). For example, **milk colour** is important for products such as butter and cheese in certain markets (e.g. Japan) (Holmes *et al.*, 2000). The **hardness of fat** is important in products such as butter as it affects consumer properties such as spreadability. **Milk flavour** may influence the desirability of certain dairy products. For example, milk from breeds such as Guernsey and Ayrshire is known to impart a pleasant flavour to fermented milk (*maas* in South Africa), a widely consumed relish among the indigenous African population.

Milk is increasingly changing from being the raw material for cheese, butter and milk powders, to being a source of a diverse range of **functional bioactive molecules**, often with health promoting attributes (Bauman *et al.*, 2006). These molecules include **conjugated linoleic acid (CLA)** which has been shown to be a potent cancer inhibitor. *Lactium*, a peptide isolated from casein, is used to help people reduce and regulate their response to stress. Advances in filtration and processing have led to the identification and isolation of certain proteins from whey that have useful biological properties. For example, **lactoferrin** has been shown to have antimicrobial and immune stimulating properties. *Glycomacropeptides* (GMP) stimulate an appetite-suppressing hormone, potentially allowing its use to regulate food intake (Chung *et al.*, 2007). Other whey proteins of interest include *β-lactoglobulin* and *α-lactoglobulin* which are important in developing infant formulas that more closely match the composition of human milk. The presence of all these components in milk offers an opportunity to add value to dairy products, thus compounding the list of economically relevant traits.

Hygienic quality of milk is important as it affects product yield and quality. Most milk buyers worldwide therefore routinely test bulk tank samples to determine the quality of milk. Concentration of **somatic cell counts (SCC)** is the most commonly used indicator of raw milk quality. Producers are awarded a premium price for milk quality meeting certain thresholds or penalised for milk falling below minimum quality thresholds, as determined by SCC. This makes SCC important in determining the value of milk.

Economically relevant traits included in most national breeding objectives are based on the payment system used by the milk processors, possibly with adjustment to the values of milk components forecast for the future. Thorough development of a breeding programme should, however, give due regard to the manipulation and marketing of dairy products, considering likely developments in manufacturing technology, milk payment systems and consumer demand (Holmes *et al.*, 2000). Consumer trends will inevitably determine the future value of milk and its components. This means that traits other than yields of the major components should be considered seriously in the development of sound long-term breeding programmes.

Economically relevant traits within the milk composition goal trait group, that are likely to influence the breeding goals for South African dairy producers, now and in the future, are listed in Table 4.2. The South African dairy industry is going through a slump, with widespread shortages of milk and dairy products, caused by a decline in producer viability (Business Day, 9 May 2007; Dairy Mail, 2007a). The country changed from being a net exporter of 11 000 tonnes of dairy products in 2002 to being a net importer of 16 000 tonnes in 2007 (Lactodata, 2007). An upturn in this situation is however highly anticipated and the confidence of South African dairy producers is on an increasing trend (Dairy Mail, 2007b). Although most of the locally-produced milk is consumed on the local market as fluid milk (Lactodata, 2007), there is scope for a significant export market for dairy products in the future (Coetzee, 2007). These trends, in addition to the revolution in consumer demand, point to the importance of non-yield traits (e.g. colour, flavour) in the future. Yield traits that are highlighted in Table 4.2 are currently recorded and can be justifiably included, immediately, in the breeding objectives. The rest of the traits may be kept on the list and get gradually incorporated into the breeding objectives, as and when it becomes necessary and feasible to do so.

4.6.2 Reproduction

Economically relevant traits within the reproduction trait group influence the selection goal in two ways. Firstly, they affect revenue from the sale of milk and excess animals (Van Arendonk *et al.,* 1989; Boichard *et al.*, 1997). Calves and milk are only produced after successful reproduction. Secondly, reproductive performance has a significant bearing on costs related to herd replacement and insemination (Esslemont and Kossaibati, 1997; Plaizier *et al.*, 1997; French and Nebel, 2003).

Reproduction traits may be classified into (1) those relating to cow fertility and (2) those pertaining to calving performance. The following economically relevant traits, contained in Table 4.2, are known to influence dairy herd profitability.

- **Replacement rate:** Poor reproductive performance has been shown to be the single largest cause of culling in many dairy herds (e.g. Colleau and Moreaux, 1999; Esselmont and Kossaibati, 1997). Impaired reproductive performance results in increased culling rates, leading to higher replacement costs. In addition, replacement rate affects the age structure of the herd and therefore average milk yield.
- **Days in milk:** In a pastoral production system, where calving is seasonal and cows are in milk for a restricted period of time, late calving (i.e. poor fertility) will result in fewer days in milk. This results in reduced milk revenue due to decreased lactation yields.

- **Number of inseminations:** The number of inseminations per conception is directly related to conception rate. A high number of inseminations per conception is an indication of reproductive failure and can contribute significantly to herd breeding costs.
- **Calving ease:** Dystocia (calving difficulty) causes high economic losses in dairy herds. The economic costs of dystocia include loss of calf, veterinary fees, farm labour costs, increased risk of subsequent health and fertility problems, increased culling, and reduced production (Meijering, 1984).
- **Stillbirths:** Still born calves result in large economic losses in dairy herds. For example, losses due to stillbirths have been estimated to amount to $125.3 million per year in the USA (Meyer *et al*., 2001).

Although no studies have been done to determine the economic importance of the above listed traits in South African dairy herds, they deserve serious attention and are poised to feature prominently in breeding objectives worldwide, now and in the future. A recent study (Makgahlela *et al*., 2008) shows a consistent deterioration in genetic merit for female fertility in South African Holstein cattle, thus stressing the need to pay attention to this trait. The first two traits (replacement rate and days in milk) can be determined from data currently recorded on the South African national dairy animal recording scheme and, therefore, can be immediately incorporated in breeding objectives. The scheme has provision for the other traits to be determined by recording certain measures, and, efforts should therefore be made to implement this.

4.6.3 Feed costs

Although many dairy breeding objectives exclude them, economically relevant traits within the feed costs goal trait group are highly important as they are among the major determinants of production costs. South Africa has been a net importer of dairy products for the past four consecutive years and is currently experiencing an unprecedented shortage of milk, caused mainly by escalating feed costs (Lactodata, 2007; MPO, 2008). Feed prices doubled in 2006 and this was not adequately compensated by an increase in the farm gate price of milk (Business Day, 9 May 2007). This has led to the erosion of viability of small and medium-sized dairy farmers, particularly those in the concentrate-fed production system, resulting in many of them going out of business. This situation underscores the need to pay serious attention to the following traits relating to feed costs.

Maintenance energy requirement is an economically relevant trait that influences dairy herd profit through its effect on feed costs. The maintenance energy requirement of an animal is the energy required to sustain their body tissues with no net change in body tissue. Maintenance energy, as a proportion of the total energy requirements of a dairy cow, varies according to level of production but represents one of the largest components of feed expenses (Moran, 2005). Considerable genetic variation in maintenance energy requirements has been observed among animals of the same breed (e.g. Hotovy *et al.*, 1991). Some animals have lower energy requirements for maintenance and are able to maintain their body tissues with fewer calories. Thus, there is scope for reducing maintenance requirements through selection.

Residual feed intake, also referred to as **net energy efficiency** or **residual feed efficiency**, is defined as the difference between actual feed intake and that predicted on the basis of requirements for production (e.g. growth, gestation, lactation) and maintenance of body weight (Koch *et al.*, 1963). Variation in residual feed intake reflects differences in efficiency with which animals use feed for production and maintenance of body weight, as well as errors in the prediction (Kennedy *et al.*, 1993). Selection to reduce residual feed intake can result in cows that eat less without sacrificing production performance (Herd *et al.*, 1997). Residual feed intake is receiving increasing attention in breeding programmes worldwide and has been adopted intensively in countries such as Australia and Canada (Sainz and Paulino, 2004). It is therefore justifiable to consider this economically relevant trait in breeding objectives for dairy cattle in South Africa.

The viability problems currently being experienced by South African dairy producers, as a result of increased feed costs, highlight the importance of feed costs as a critical factor in determining herd profitability. This means that the economically relevant traits relating to feed costs discussed above should be given serious consideration in breeding objectives, now and in the future.

4.6.4 Longevity

Replacement rate adjusted for milk yield is a reflection of the ability of cows to avoid involuntary culling, normally referred to as functional longevity, and has a large influence on dairy herd profitability (Gill and Allaire, 1976). This trait has a direct influence on breeding goals for South African dairy farmers through its effect on herd replacement costs (See Table 4.1 and Figure 4.10).

The **lifetime production** of a cow is a major determinant of lifetime profitability. Cows that do not last long in the herd have lower lifetime production and therefore generate less revenue from the sale of milk.

The economic value of cow longevity traits has not be determined in South Africa; however a recent study (Banga *et al.*, 2002) indicates a consistent decline in South African Holstein cow survival in the past few years. This trend may be a correlated response to intense selection for increased yield and may negatively impact on herd profitability. It is therefore imperative to give serious consideration to economically relevant longevity traits in developing breeding objectives for dairy cattle in South Africa.

4.6.5 Cow Health

The importance of cow health in dairy cattle breeding objectives is mainly based on its association with costs of production and animal welfare. Impaired cow health (disease) negatively impacts on dairy herd profitability through: (1) reductions in output levels, and, (2) wastage of resources incurred and the resource costs of disease prevention and treatment (Esslemont and Kossaibati, 1992; Esslemont and Spincer, 1993; Bellows, 2002). Numerous studies (e.g. Enting *et al.*, 1997; Bennet *et al.*, 1999; Warnick *et al.*, 2001; Bellows, 2002) have highlighted the costs attributable to disease in dairy cattle. Economically relevant traits within the cow health trait group can be identified as follows:

- **Disease resistance:** Reduced resistance to disease results in increased incidence of disease, leading to higher economic losses and deterioration in animal welfare. Although there is paucity of research on the economic value of disease resistance, available genetic parameter estimates indicate genetic variation for the trait is large enough to achieve significant genetic improvement through selection (Shook, 1989; Philipsson and Lindhe, 2003).
- **Replacement rate:** Premature disposal of animals is one of the major components of the cost of disease (Shook, 1989). A review by Shook (1989) showed that disease accounts for up to 27.6% of culling in dairy herds. Cow health also influences culling indirectly through its effect on production and reproduction.

- **Therapy and prevention costs:** Cow disease prevention and therapy account for a significant portion of economic losses due to disease in dairy herds. These costs include expenses on drugs, vaccines, veterinary services and labour. Although infectious diseases are the most costly, metabolic and other non-infectious diseases are also important (Shook, 1989).
- **Milk yield:** Decreased production is one of the most important components of economic losses from disease in dairy herds. Most diseases of dairy cattle adversely affect milk production, although they do so to varying degrees. Yield loss may account for up to 80% of total costs of mastitis, the most economically important disease in dairy cattle (Raubertas and Shook, 1982; Gill *et al.*, 1990; Hortet *et al.*, 1999). Lameness, another prevalent disease in dairy cattle, may cause losses in milk yield of up to 2.8 kilograms per cow per day (Rajala-Schultz *et al.*, 1999; Warnick *et al.*, 2001).

Cow health cannot be overlooked in dairy cattle breeding programmes. The significant implications of disease on dairy herd profitability and animal welfare mean that cow health traits should be given serious consideration in the development of dairy cattle breeding objectives. Although udder health is increasingly receiving attention in most national dairy cattle breeding objectives, including South Africa (see Chapter 2 section 2.7.5), overall cow health cannot continue to be ignored. There is a need to determine the economic values of the economically relevant traits pertaining to cow health in order to assess the merit of including them in breeding objectives. Care should however be taken in using some of the economically relevant traits discussed above. Replacement rate and milk yield fall within other goal trait groups (e.g. reproduction, longevity, milk composition) and caution should be taken not to double-count them.

4.6.6 Udder health

Traits reflecting udder health influence dairy herd profitability through reduced production and increased costs and, therefore, should constitute a key component in most dairy cattle breeding objectives. These traits can be distinguished as follows:

- **Replacement rate:** Involuntary culling for udder health is one of the major factors contributing to replacement costs in dairy herds (Osteras, 2000; Yalcin *et al.*, 1999; Seegers *et al.*, 2003). Some studies (e.g. Moore *et al.*, 1991; Shrick, 2001) also indicate that udder health may influence culling rate indirectly through its effect on reproductive performance.
- **Mastitis therapy costs:** Costs attributable to mastitis therapy consist of value of discarded milk, veterinary fees, costs of antibiotics and other therapeutics and extra labour due to therapy (Osteras, 2000). These costs represent a significant proportion of the total cost of mastitis in many dairy industries. For example,
- Osteras (2000) reported that, under Norwegian conditions, treatment costs of clinical mastitis cases accounted for 48% of costs resulting from poor udder health.
- **Milk quality:** High somatic cell counts associated with mastitis cause effects such as unstable and rancid taste of milk, reduced cheese yield, less stable cheese texture and taste, and longer whipping time for cream (Osteras, 2000). These

properties result in dairy products with poor quality and therefore less value. Thus, impaired milk quality due to mastitis normally leads to reductions in payments for milk. In certain markets, where product quality is critical, such reductions in milk prices can result in heavy losses in revenue for farmers.

- **Milk yield:** Infection of the udder causes damage to secretory tissue, resulting in reduced milk secretion. Decreased milk production is by far the single largest component of economic losses due to poor udder health, accounting for up to 80% of total costs of mastitis (Janzen, 1970; Dobbins, 1977; Blosser, 1979; Raubertas and Shook, 1982; Gill *et al*., 1990; Hortet *et al*., 1999). A recent study by Banga (2004) points to heavy losses in milk yield as a result of udder infection in South African dairy herds.

Although their economic values have not yet been determined, the importance of udder health traits in breeding objectives for dairy cattle in South Africa can not be doubted. Udder health, as indicated by levels of somatic cell count, is phenotypically improving but nevertheless genetic trends show that cows are genetically becoming less resistant to mastitis (Dube *et al*., 2008). Any serious efforts to improve dairy herd profitability should at least slow down this deteriorating trend. Care should be taken not to double-count traits such as replacement rate and milk yield which also belong to other goal trait groups (e.g. reproduction, longevity, milk composition, cow health). The fact that premiums are paid for milk meeting certain standards and penalties are imposed on milk falling below certain quality levels also poses a challenge in the determination of the economic value of milk quality. These factors will be dealt with when determining economic values (Chapter 6).

4.6.7 Cow comfort

Traits pertaining to cow comfort are increasingly becoming important, owing to their impact on profitability and animal welfare concerns. Various forms of stress (i.e. lack of cow comfort) have been shown to cause huge economic losses in dairy herds worldwide. For example, heat stress on cattle in the US is estimated to result in losses around US$897 million in dairy herds (St-Pierre, 2003). Lameness has been identified as the third most common disorder, after mastitis and reproductive failure, causing economic losses in dairy herds (Enting *et al.*, 1997). The following may be defined as the economically relevant traits in the cow comfort goal trait group:

- **Replacement rate:** A decline in cow comfort due to intensive housing and concentrate feeding is usually manifested in metabolic diseases such as lameness, mill fever, retained placenta, metritis, milk fever, ketosis, and abomasal replacement. These diseases are among the major causes of involuntary culling in many dairy herds (Kaneene and Hurd, 1990; McDaniel, 1995).

Part of culling for poor reproduction or production may also be due to such diseases. Heat stress has also been widely reported to cause impaired reproductive performance (Fuquay, 1981; Her *et al.*, 1988; Wilson *et al.*, 1998; Ravagnolo and Misztal, 2002), thus indirectly increasing culling rates.

- **Milk yield**: Cow comfort is known to impact heavily on production. Heat stress has been shown to result in reduced feed intake and milk production (Berman *et al.*, 1985; Her *et al.*, 1988; Lough *et al.*, 1990; West, 2003; West *et al.*, 2003). Metabolic diseases such as lameness, milk fever and ketosis have also been observed to cause significant reductions in milk yield (Rajala-Schultz *et al.*, 1999; Warnick *et al.*, 2001; Green *et al.*, 2002).
- **Health costs:** Treatment of animals inflicted with stress-related diseases represents a big cost to dairy herds. For example, lameness has been estimated to cost around €192 per cow per incidence in Danish herds (Ettema and Østergaard, 2006). In addition, construction of facilities that alleviate stress and improve cow comfort, such as better cow housing and bedding, sheds and sprinklers contributes significantly to dairy farm expenses.
- **Cow maintenance requirements:** Lower dry matter intake during hot weather reduces nutrients available for absorption, and absorbed nutrients are used less efficiently (West, 1999). An increase in heat load causes animals to direct energy to eliminate excessive heat in order to maintain internal thermal balance, leading to higher maintenance energy requirements. The maintenance energy requirement may increase by 20-30 % in heat stressed animals (West, 2003).

- **Residual feed intake:** Conditions that interfere with cow comfort are known to reduce the efficiency of feed utilisation and thus increase residual feed intake. Stress raises concentrations of the hormone cortisol which may increase the cow's residual feed intake (Richardson *et al*., 2004).

The foregoing facts indicate that cow comfort may have been an *externality* in the past but cannot continue to be ignored in dairy cattle breeding objectives. Animal welfare is increasingly becoming a topical issue and losses in profitability due to impaired cow comfort cannot be exaggerated. Improving cow comfort through environmental intervention is desirable; however it is expensive. Selection to improve the adaptability of animals to stressful conditions provides a means of achieving permanent cow comfort. There is genetic variation in cattle in, for example, cooling capability which suggests that heat tolerance may be improved genetically (West, 2003). In South Africa, where summer temperatures are generally high and intensive housing and feeding of dairy cows is on the increase, cow comfort is undoubtedly an issue of concern. It is therefore important that cow comfort features significantly in dairy cattle breeding objectives in South Africa, now and in the future. Most of the traits discussed above however appear in other goal trait groups and care should be taken not to double-count them.

4.6.8 Milkability

Good milkability is achieved when milk is removed from the udder gently, quickly and completely. Poor milkability will increase the operational costs of a dairy enterprise through increased milking times (more labour and electricity) and increased wear and tear of milking equipment (Boettcher *et al.*, 1998). Reduced milk yield, as a result of incomplete milking, may also cause loss of revenue. Furthermore, incompleteness of milking has been observed to cause increases in udder infection (O'Shea, 1987). Notwithstanding all these advantages, high milkability has been widely reported to predispose cows to udder infection (Seykora and McDaniel, 1985; Lund *et al.*, 1994; Luttinen and Juga, 1997; Boettcher *et al.*, 1998; Rupp and Boichard, 1999). This implies that genetic improvement of milkability traits should be aimed at achieving intermediate values.

Milkability is an important reason for premature removal of cows from dairy herds (Vicario *et al.*, 2006). Such animals may exhibit poor shed temperament or may not be well adapted to milking equipment, resulting in longer milking times and reduced milk yields. Cows may also be culled for udder infection associated with extremely high levels of milkability. Thus **replacement rate, milk yield** and **milking time** are the economically relevant traits within the milkability goal trait group.

Replacement rate and milk yield form part of other goal trait groups (see Table 4.4) and, therefore, care should be taken not to double-count them. **Milking time** is however likely to be important in most dairy cattle breeding objectives, especially where labour and/or electricity are expensive. In South Africa, there is a need to determine the economic value of this trait in order to assess the value of including it in breeding objectives, now and in the future.

4.6.9 Environmental cleanliness

Traits within the environmental cleanliness goal trait group are particularly important in the concentrate-fed production system where cows are housed and fed intensively, resulting in massive discharge of pollutants. Environmental pollution caused by dairy production is a major cost to the dairy industry and to society at large. This cost has two components. Firstly, it is a manifestation of impaired efficiency of nutrient use and therefore implies increased feed costs (Chandler, 1996). Secondly, livestock production is a source of negative environmental externalities such as air and water pollution, odours and flies (Delgado *et al*., 2003). Dairy farmers in most countries do not bear the costs of these externalities. Local government authorities in many countries are however beginning to take measures to ensure that farmers minimise environmental pollution. Delgado *et al*. (2003) point out that farmers may incur expenses to compensate those who bear the cost, or to prevent the side effects of negative externalities.

Efficiency of feed utilisation is clearly an economically relevant trait relating to environmental cleanliness. The extent of pollution of the environment with excess nutrients, such as nitrogen and phosphorous, bears a relationship to the efficiency with which they are used by animals (Chandler, 1996). Given the inherent difficult of using feed efficiency as a trait (Gunsett, 1986), **residual feed intake** is a reasonable economically relevant trait to use. More efficient animals typically produce the same output with fewer cows; hence less environmental pollution. Thus, selection to improve residual feed intake is likely to reduce feed costs as well as environmental pollution.

The costs of environmental degradation and health resulting from dairy farming units represent an externality as they are not taken into consideration when farmers make profit maximising decisions. Developments taking place in regions such as North America and Europe, however, indicate that regulations or incentive schemes forcing dairy farmers to meet certain environmental quality standards are most likely going to be enforced in many countries (Lally and Riordan, 2001). Such changes would, most probably, impose a substantial cost to dairy farmers. This means that farmers would have to share the costs of maintaining a clean environment. Farmers would therefore have to consider such costs when making their profit maximising decisions in which case these broadly termed **environmental costs** would no longer be an externality and would be an economically relevant trait.

The importance of minimising feed costs in dairy production, in South Africa, is highlighted in Section 4.3. The inclusion of **residual feed intake** in the breeding objectives for South African dairy cattle therefore warrants serious consideration. Lower residual feed intake (improved efficiency of feed utilisation) will reduce feed costs as well as minimise environmental degradation.

Parasites are a serious constraint on livestock production throughout the world. Susceptibility of many breeds, particularly temperate breeds, to parasites in tropical and subtropical environments can cause substantial economic losses (Henshall, 2004). Extensive use of chemicals such as anthelmintics and acaricides to control these parasites is a cause for environmental concern. Results from certain studies (e.g. Baker, 1998; Mandonnet *et al.*, 2001) demonstrate the feasibility of improving **resistance to parasites** through genetic selection. Thus, improved genetic merit of **resistance to parasites** is likely to result in better environmental cleanliness, through reduced use of chemicals.

Concerns about environmental degradation due to widespread use of chemicals to control parasites are no less important in South Africa than in other countries. It is therefore reasonable to consider **resistance to parasites** as an important trait for inclusion in breeding objectives for dairy cattle in South Africa.

[1]Table 4.2: Goal traits, economically relevant traits and selection criteria for dairy cattle in South Africa.

Goal Trait Group	*Economically Relevant Traits*	*Selection Criteria*
Milk Composition	**Daily protein yield** **Daily fat yield** Daily lactose yield Daily casein yield **Daily milk (carrier) yield** **Somatic cell count** Casein yield Milk colour Milk flavour Fat hardness Fat type Lactoferin Conjugated linoleic acid (CLA) Lactium Gylcomacropeptide (GMP) α-lactoglobulin β-lactoglobulin	**Test day yields or** score

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[1] Traits in bold are currently recorded in South Africa

Goal Trait Group	*Economically Relevant Traits*	*Selection Criteria*
Reproduction	**Replacement rate** **Days in milk (pasture)** Number of inseminations Calving ease Rate of stillbirths	Heifer pregnancy rate Age at puberty Lactation length **Age at first calving** Services/conception **Calving interval** Days open Days to first service Body condition score Milk progesterone Milk urea nitrogen Calving ease score Birth weight Gestation length Stillbirth Pelvic measurements Rump angle Rump width
Feed costs	**Expected cow maintenance** **Residual feed intake** **Nitrogen balance**	**Body weight** Body condition score Gut weight **Milk urea nitrogen (MUN)** **Stature** **Rump length** **Rump width** **Body depth** **Feed intake**

Goal Trait Group	*Economically Relevant Traits*	*Selection Criteria*
Longevity	**Replacement rate adjusted for milk yield** **Lifetime production**	**Herd life** **Number of lactations** **Stayability** **Length of productive life** **Survival rate** **Type traits**
Cow Health	Disease resistance Milk yield Replacement rate Health costs	Disease incidence Somatic cell count (SCC) Bovine Lymphocyte Antigens (BoLA) Immune response to antigen injection Serum lysozyme activity Serum haemolytic complement Efficiency of phagocytosis Calcium mobilisation Plasma concentration of glucose, ketones, insulin, thyroxine Tick count Faecal egg count Molecular markers Type traits

Goal Trait Group	***Economically Relevant Traits***	***Selection Criteria***
Udder health	**Replacement rate** Mastitis treatment costs Milk quality **Milk yield**	Incidence of mastitis **Test day Somatic Cell Score (SCS)** Milking speed **Udder type traits** Electrical conductivity Lactose concentration Bovine serum albumin concentration Concentration of chloride, sodium or potassium Markers of immune response
Cow comfort	**Replacement rate** **Milk yield** Health costs Cow maintenance Residual feed intake	Incidence of metabolic diseases Nitrogen balance Rectal temperature Respiration rate Plasma cortisol concentration Whole body ^{40}K counting Grazing time Feed intake Foot & leg conformation Angularity /dairy form

Goal Trait Group	***Economically Relevant Traits***	***Selection Criteria***
Milkability	**Replacement rate** **Milk yield** Milking duration	Milking speed scores Kilograms milk per minute Temperament scores Approachability to humans Flight distance from humans Flinch, step & kick (FSK) behaviour Linear type scores Residual milk Heart rate
Environmental cleanliness	Nitrogen excretion Residual feed intake Resistance to parasites	Milk Urea Nitrogen Nutrient balance Methane/greenhouse gases Tick counts Faecal egg counts

4.7 The Selection Criteria

4.7.1 Introduction

The next step, after identifying the traits in the breeding objective, is to determine the selection criteria. Selection criteria are those traits that can be measured on the animals and can be used as predictors of the traits included in the breeding objective (Hazel, 1943). Traits included in the breeding objective (i.e. economically relevant traits) may be the same or different from the selection criteria. If the objective trait and selection criterion are different, the latter is known as an indicator trait. An indicator trait is a trait that is used to indicate the merit of an animal for another trait (Golden *et al*., 2000). Schneeberger *et al.* (1992) showed that the EBV of an unobserved trait can be readily calculated as a linear function of the EBV for measured traits. Figure 4.13 illustrates how the EBV of an economically relevant trait can be derived from its indicator traits. The value of an indicator trait will depend largely on the magnitude of co-heritability and genetic correlation between the objective trait and the indicator trait (Woolliams and Smith, 1988). Many economically relevant traits in dairy cattle are difficult to measure and therefore need to be predicted by indicator traits.

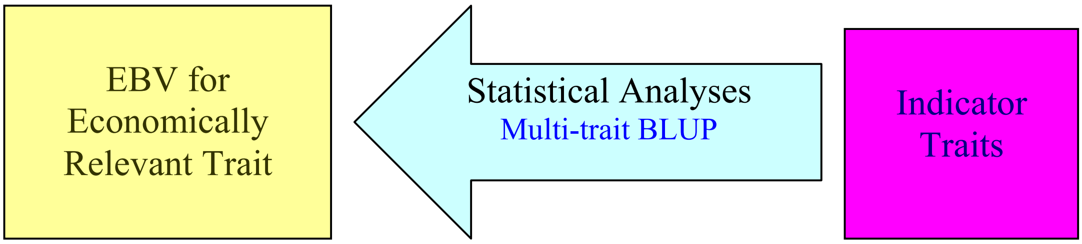

Figure 4.13: Prediction of objective trait EBV from indicator traits

The third column of Table 4.2 contains selection criteria that can be used for the economically relevant traits discussed in Section 4.6. This section looks at these selection criteria, means of measuring them, their utility in predicting objective traits and the feasibility of implementing them in national breeding schemes. Deficiencies in selection criteria that are widely-recorded are highlighted and possible improvements suggested. Selection criteria that are routinely recorded under the South African National Dairy Animal Improvement Scheme (NDAIS), highlighted in bold font in Table 4.2, are reviewed and their adequacy in predicting the objective traits discussed. Finally, recommendations are made on measures that can be taken to ensure the collection of data required to maximise accuracy of prediction of traits in the breeding objectives for South African dairy cattle.

4.7.2 Milk composition

Genetic evaluation of dairy cattle for milk production traits in most countries, including South Africa, is carried out using test-day models to produce EBVs for **test-day yield** (Interbull, 2009). These EBVs give a good prediction of genetic merit for daily yield of these components. Thus test day yields can be used as reliable selection criteria for the yield traits within the milk composition goal trait group. The major solid components (protein, butterfat and lactose) are routinely measured in most national dairy recording schemes using infra-red technology (Interbull, 2009). Casein content may be determined from the crude protein content using a general conversion factor (Sørensen *et al.*, 2003). More accurate techniques for determining casein, such as long wavelength fluorescence detection (Aguilar-Caballos *et al.*, 1998), infrared spectrometry (Sørensen *et al.*, 2003) or optical immunosensor (Muller-Renaud *et al.*, 2004) have also been introduced although they are more expensive. Milk colour can be measured by visual assessment or reflectance colorimetry (Kneifel *et al.*, 1992) and milk flavour can be determined by sensory tests (Baldwin *et al.*, 1982).

Instruments such as the maturometer (Board *et al.*, 1980), oscillating rheometer, butter-measuring instrument or universal testing machine (Strohmaier *et al.*, 1992) may be used to measure fat hardness or spreadability. More sophisticated and expensive analytical techniques such as chromatography are however needed to determine components such as fat type, whey proteins and CLA (Luna *et al*., 2005). Traits that are measured subjectively such as milk colour, milk flavour and butterfat hardness are normally expressed by means of **scores.**

Test day yields of protein, butterfat and lactose are routinely recorded on milk-recorded herds in South Africa and therefore are readily available for use as selection criteria. Infrared analysis equipment, similar to the one used to determine these components, may be used to measure casein as well, provided the extra cost is justifiable. Measurement of the other components of milk as well as indicators of milk quality is generally not carried out in dairy cattle breeding schemes worldwide (Interbull, 2009) and poses a big challenge to animal breeders. The use of panels to subjectively measure traits such as fat hardness, milk flavour and milk colour is both time-consuming and expensive. Such tests may be used on a small scale but their application in extensive routine animal recording schemes is difficult. The techniques used to measure fat type, whey proteins and CLA are also too expensive for large scale routine recording purposes. Economic trends may however justify the recording of some of these traits. There is therefore a need to continually assess the economic values of these difficult-to-measure traits in order to determine the value of recording them. The costs of measuring such traits may be minimised by only recording a subset of industry herds (e.g. progeny test herds), although this compromises accuracy of prediction.

4.7.3 Reproduction

Measures of cow fertility may be classified into two categories: (1) **time intervals** and (2) scores or 'success' traits (ability or **success rate**). Time intervals include traits such as **days open**, **days to first service**, **age at puberty/first calving, calving interval** and **days in milk**. Traits such as **heifer pregnancy rate**, **services per conception** and **non-return rate** are 'success rate' traits. Indicators of cow fertility include correlated traits such as **body condition score (BCS)** (Pryce *et al*., 2000; Dechow *et al*., 2001; Veerkamp *et al*., 2001; Berry *et al*., 2003; Wall *et al*., 2003; Kadarmideen, 2004; Pryce and Harris, 2006), **milk progesterone** (Darwash *et al*., 1997; Royal *et al*., 2002) and **milk urea nitrogen (MUN)** (Melendez *et al*., 2000; Godden *et al*., 2001). Most of the measures of cow fertility require the recording of breeding details such as insemination dates and pregnancy confirmations. In the absence of such data, calving interval can be considered a good indicator of cow fertility because of its high correlation with direct measures of fertility (Campos *et al*., 1994; Grosshans *et al*., 1997; Pryce *et al*., 1997; Olori *et al*., 2002). The use of calving interval as the only indicator trait for cow fertility however delays selection decisions as it requires a record of consecutive calving dates. Furthermore, calving interval is open to management bias (e.g. decisions to extend lactation length of individual high-yielding cows within herds). Sire EBVs for calving interval may also be biased due to the fact that animals that are culled for failure to conceive will not be included in the analysis, if no disposal codes are recorded.

Calving ease score is a selection criterion that is widely used as a direct measure of calving ease. Cows are given scores ranging from 1 (no problem) to 5 (extreme difficulty) by farmers at the time of calving (Wiggans *et al*., 2003; López de Maturana *et al*., 2007). The accuracy of evaluation for calving ease may be increased by indicator traits such as **birth weight** and **gestation length** (review by Meijering, 1984; Golden *et al*., 2000; Lee *et al*., 2002). **Pelvic measurements** such as pelvic width, height and area (Green *et al.,* 1986; Naazie *et al*., 1991; Kriese *et al*., 1994) as well as linear type traits such as **rump angle** and **rump width** (Dadati *et al*., 1985; Cue *et al*., 1990) have also been reported to be good indicators of calving ease.

Most countries define **stillbirth** as those calves born dead or dying within 12 hours of parturition, although some include deaths occurring within 24 hours of birth (Cole *et al*., 2007). Rate of stillbirth is derived from the number of stillbirths as a percentage of the total births (per cent stillbirths).

Although the national animal recording system (IRIS) caters for it, breeding information such as insemination dates, insemination numbers and pregnancy diagnoses is not routinely recorded under the South African NDAIS. A few herd owners with herd management software record such information on their on-farm computers for herd management purposes; however it is not available for national genetic evaluations. This leaves calving interval as the only selection criterion available for predicting cow fertility. Plans are under way to implement routine estimation of breeding values for calving interval. Efforts however need to be made to institute routine recording of breeding information, in order to enable the use of selection criteria that are not subject to selection bias. Research also needs to be carried out to look into the possibility of improving the accuracy of genetic predictions for cow fertility through the use of indicator traits such as BCS and MUN. Milk urea nitrogen is routinely recorded on many herds participating in milk recording; however the NDAIS needs to take initiatives to collect BCS data.

Calving ease score and stillbirth are also not recorded under the South African NDAIS. Efforts also need to be made to record these traits and their indicators (e.g. birth weight, gestation length), in view of the growing importance of the objective traits that they predict (See Section 4.6.2). These traits are cheap and relatively easy to measure; the only challenge being to motivate farmers to routinely record them. Rump angle and rump width, which are routinely evaluated by breed societies, may be considered for use as indicator traits for calving ease in the meantime. Research however needs to be carried out first to determine the suitability of using these traits only, to predict calving ease.

4.7.4 Feed costs

Selection criteria for the economically relevant traits in the feed costs trait group are not widely recorded in most animal recording schemes, despite the importance of feed requirements as an input in dairy production. The expense of measuring individual feed intake has, in the past, hampered efforts to improve genetic merit for efficiency of feed utilisation. Predictors of feed costs that are cheap to measure (e.g. body weight) have however been identified and these are now gradually being incorporated into national breeding schemes.

Measurement of **feed intake, body weight** as well as **milk energy yield** is required to predict residual feed intake (Kennedy *et al*., 1993). The advent of automatic feeding and milking systems, although expensive, has made it relatively easy to obtain such measurements (Halachmi *et al*., 2004). Techniques such as use of n-alkanes and stable C-isotope discrimination (reviewed by Mayes and Dove, 2000) are available for measuring feed intake in grazing animals. These techniques are however too time-consuming and expensive to implement on a large scale.

Several studies (Groen, 1989; Groen and Korver, 1990; Visscher *et al*., 1994; Spelman and Garrick, 1997; review by Veerkamp, 1998; Perez-Cabal *et al*., 2006b) support the use of **body weight (BW)** as a good indicator trait for cow maintenance requirements. Selection indices for countries such as New Zealand, Australia, and Denmark include body size or BW, negatively-weighted, as an indicator trait for maintenance costs (Lopez-Villalobos and Garrick, 2005; Miglior *et al*., 2005). Traits related to body size, such as **stature, body depth, rump width**, **rump height** and **heart girth** are good predictors of BW (Heinrichs *et al*., 1992; Mantysaari, 1996; Veerkamp and Brotherstone, 1997; Koenen and Groen, 1998). These traits are included in most dairy cattle recording schemes and therefore may be used as indicator traits for maintenance requirements where measurements of BW are not available.

Visceral organs such as the gastrointestinal tract and liver have been implicated as a major factor influencing maintenance energy requirements associated with lactation in dairy cattle (Baldwin *et al*., 2004; Reynolds *et al*., 2004). Thus **gut** or **gut component**

weights, determined by ultrasonic or carcass measurements, have been proposed as indicator traits for cow maintenance requirements (Golden *et al*., 2000).

Maintenance energy requirements are known to vary widely and systematically with **body condition score (BCS)**. Animals with more body fat reserves (higher BCS) require more maintenance energy than those with lower body condition (Caldeira *et al*., 2007). Estimated breeding values for BCS can therefore be used to predict the EBV for expected maintenance energy requirements.

Maintenance energy requirement can be estimated from continuous **heat production** measurements during a change from a near maintenance feeding level to far below maintenance for two consecutive days (Derno *et al*., 2005). Such measurement cannot, however, be done on a large scale as it is time-consuming and requires expensive gas chambers. Several studies (reviewed by Brosh, 2007) indicate that **heart rate (HR)** can be used to predict maintenance energy requirements. Soon, when devices for automatic HR monitoring of domestic ruminants become available at a reasonable price, continuous monitoring of HR might provide a sensitive tool for identifying changes in the energy status of animals (Brosh, 2007).

Although not widely recorded in national breeding schemes, BW offers an easy and cheap-to-measure indicator trait for expected maintenance requirements. Countries such as New Zealand have demonstrated the value and practicability of incorporating BW in a dairy cattle breeding scheme. Milk energy yield can also be easily determined from yields of milk components, which are universally recorded in dairy cattle recording schemes. Body size traits (e.g. stature, body depth, rump width, rump height) and BCS, which are commonly-recorded in dairy cattle populations, may be used to improve the genetic predictions for feed cost traits. Traits such as gut weight and HR can be incorporated into these predictions as and when they become affordable to measure and if it turns out to be expedient to do so. The excuse that indicator traits for feed costs are difficult and expensive to measure, which is often given by animal breeders, may therefore be considered unfounded. Furthermore, the cost of not including predictions of feed costs in dairy cattle breeding objectives may be too high to justify any excuse.

Routine measurement of BW in South Africa, using scales, is a possibility on most dairy herds. Feed intake can also be recorded on farms in the intensive concentrate-fed system that are on total mixed rations and use computerised feeders. The reason farmers do not record such information is that, due to lack of knowledge of its importance, they do not see any practical use for it. The fact that feed cost is not included in the breeding objectives for South African dairy cattle (see Section 2.3.3) also dispenses with the need to record its indicator traits. There is therefore a need to educate farmers on the benefits of BW and feed intake data in herd management (e.g. feed budgeting). Incentives could also be provided for farmers to record such data for genetic evaluation purposes. For example, artificial breeding companies could add a price incentive for farmers providing such data on daughters of progeny test sires. Although measurement of feed intake is a challenge to farmers in the pasture-based production system, it should be possible for them to routinely record body weight, provided there is an incentive for them to do so.

Linear type traits are routinely recorded and genetically evaluated in South Africa. Research needs to be conducted to look into the possibility of using some of these traits as surrogate traits for BW in predicting cow maintenance requirements, in the meantime. Milk yield may also be used in addition, through its relationship with maintenance requirements. This could signal a starting point in observing the value of and incorporating traits related to feed costs in the breeding objectives. Such developments could be followed by efforts to improve such predictions by routinely recording traits such as BW and BCS under the South African NDAIS.

4.7.5 Longevity

Selection criteria for longevity traits can be classified into **stayability** or **lifetime** traits (Vollema and Groen, 1996). Stayability traits, as defined by Everett *et al*. (1976), measure the survival rate of cows at a certain age; for example 36, 48, 60 or 72 months. Often, survival times are coded 0 if the cow fails to survive to the specific age or 1 if she survives to that age (Wolynetz and Binns, 1983). The main problem with stayability traits is that, due to their binary nature, they do not give an exact measure of longevity. For example they do not indicate exactly how long a culled cow was in the herd or how much longer a cow that is still alive is going to survive. Records of cows that are still alive are said to be censored. Lifetime traits include traits such as **age at disposal (herdlife), length of productive life** and **number of lactations** initiated or completed. The main disadvantage with lifetime traits is that they are measured after the death of the cow and therefore increase the generation interval.

Ducrocq *et al*. (1988) showed that **survival analysis** using proportional hazard models could be used to improve the analysis of longevity traits and Ducrocq and Solkner (1998) subsequently developed the survival kit for use by animal breeders. Survival analysis combines information on censored and uncensored records, which enables a proper statistical treatment of censored records and accounts for the nonlinear characteristic of longevity data. Many countries have since implemented genetic evaluation for longevity and other fitness traits in dairy cattle using survival analysis (e.g. Vollema *et al*., 2000; Vukasinovic *et al*., 2001; Caraviello *et al*., 2004; Terawaki *et al*., 2006).

Several studies (Hoque and Hodges, 1981; Dentine *et al*., 1987; Ducrocq *et al*., 1988; Rogers *et al*., 1991; Boldman *et al*., 1992; Dekkers *et al*., 1994; Jairath *et al*., 1994; Vollema and Groen, 1996; Vollema and Groen, 1997) have reported relationships between certain **linear type traits** and dairy cow survival. Such linear type traits may therefore be used as indicator traits for objective traits pertaining to longevity. Type traits are considered suitable selection criteria for longevity traits because they are easily recorded early in life and are more heritable than direct measures of cow survival. Caution, however, needs to be exercised in the use of type as an indicator of cow survival. Firstly, a distinction needs to be made between type traits that influence involuntary culling and those that are merely of sentimental value. Breed Societies and seed stock producers in many countries, including South Africa, tend to promote selection on certain type traits without any economic justification. The discussion on selection indices currently used for dairy cattle in South Africa (Chapter 2, Section 2.3.3) illustrates this fact. A profit based goal, however, dictates that, in the context of selection to improve longevity traits, only those type traits bearing a relationship with involuntary culling should be considered as selection criteria. Secondly, it should be noted that EBVs for type traits only serve to improve the prediction of EBVs for longevity traits. Including EBVs for the same type traits in an index where the EBV for a longevity trait is already present constitutes extraneous information and adds prediction error (Golden *et al.*, 2000).

Most national dairy cattle selection objectives include longevity (Miglior *et al.*, 2005). According to a survey by van der Linde and de Jong (2003), a range of selection criteria, models and analytical procedures are used to predict longevity traits by different countries. Most European countries use survival analysis while the rest of the world uses single or multiple trait analysis of traits such as life span, ability to survive in a number of lactations, number of lactations completed and, probability of surviving from one lactation to the next. In most cases, censored records are predicted by survival analysis. Most countries combine direct measures of longevity with predictors such as type traits.

In South Africa, work is in progress to implement genetic predictions for longevity traits. Data collected under the NDAIS is adequate to derive most of the selection criteria for longevity. Estimated breeding values for linear type traits, which are routinely produced for the major dairy cattle breeds, can be used to improve genetic predictions for these longevity traits. Setati *et al.* (2004) estimated genetic parameters among eight linear type traits and longevity (number of lactations initiated) in South African Holstein cattle. This study needs to be extended to the other major dairy cattle breeds and to include more type traits. The information so generated will serve as a useful guide in determining those type traits that may be utilised in predicting EBV for longevity traits.

4.7.6 Cow health

Several Scandinavian countries have a subsidised and legally-enforced system for recording **disease incidence** in dairy cattle. The disease incidence records are used to predict genetic merit for disease resistance. Selection based on such predictions can yield significant genetic progress in disease resistance (Emanuelson *et al*., 1988; Christensen, 1998; Heringstad *et al.*, 2007). Most other countries however do not have systems for routinely or consistently recording disease incidence. Nevertheless, several indicator traits for cow health traits have been developed and are now increasingly being incorporated in national dairy cattle breeding schemes.

Somatic cell count (SCC) has been considered as the most suitable indicator trait for mastitis resistance and is routinely recorded in most animal recording schemes, including South Africa. The use of SCC and other indicator traits for udder health is discussed in detail in section 4.6.6 below.

Molecular markers, particularly the major histocompatibility complex (MHC) genes, may be used as indicators of disease resistance in livestock. In dairy cattle, molecular markers associated with the **Bovine Lymphocyte Antigens (BoLA)** genes have been identified. The BoLA genes are known to be partially responsible for the development and function of the cow's immune system. Associations have been reported between

BoLA genes and several mastitis indicators (Oddgeirsson *et al*., 1988; Weigel *et al*., 1990; Mejdell *et al*., 1994) as well as resistance to ticks (Stear *et al*., 1989), worm infestation (Stear *et al*., 1990) and chronic posterior spinal paresis (Park *et al*., 1993).

A number of **physiological markers** have also been intimated as indicators of disease resistance (Almlid, 1981; Lie *et al*., 1982). Examples of such physiological markers include **measures of immune system function** such as **immune response to injection of antigens**, **serum lysozyme activity**, **serum haemolytic complement**, and **efficiency of phagocytosis**. **Plasma concentrations** of certain components can also be used. Plasma concentrations of **glucose**, **ketones**, **insulin**, and **thyroxine** after 48 hours of fasting have been suggested for ketosis (Almlid, 1981; Lie *et al*., 1982). For milk fever, measures of **calcium mobilisation** following administration of calcium-chelating agents or calcium-deficient diets have been proposed (Almlid, 1981; Lie *et al*., 1982). Indicator traits such as **tick count**, **faecal egg count** and **percentage volume of red blood cells in blood** have been developed for resistance to parasites. These indicator traits are discussed in more detail in section 4.7.9 below.

Certain **linear type traits** may be used to predict disease resistance in dairy cattle. For example, **udder conformation traits** (e.g. **udder depth**, **udder attachment**, **teat placement** and **teat length**) have been suggested as indicator traits for udder health traits (Rogers *et al*., 1991; De Jong and Lansbergen, 1996; Mrode *et al*., 1998; Gengler and Groen, 1997). **Angularity (dairy form)** has been found to be associated with a number of metabolic and infectious diseases of dairy cattle (Rogers *et al*., 1999; Sørensen *et al*., 2000; Hansen *et al*., 2002; Dechow, 2003; Lassen *et al*., 2003). Feet and leg traits have been reported to be good indicators of resistance to laminitis (McDaniel, 1997; van der Waaij *et al*., 2005).

Any serious efforts to improve cow health through breeding require the efficient recording of reliable predictors of cow health traits. Effective use of disease incidence as a selection criterion requires that diseases are consistently recorded on a routine basis across the population. Most countries, save Scandinavia, however do not have recording systems that meet this requirement. Besides, setting up systems similar to the Scandinavian one, where all diagnoses and treatments are undertaken and recorded by veterinarians, would be too expensive or difficult to implement in some countries. In South Africa, for example, there is a shortage of veterinarians and regular veterinary services are not affordable to many farmers. Relying on farmers to record disease incidence may also result in inconsistencies, if proper guidelines are not provided.

Some indicator traits (e.g. SCC, type traits) are routinely recorded in most dairy cattle recording schemes and already widely used to predict disease resistance (Interbull, 2009). Molecular and physiological markers require sampling and laboratory analysis of samples, which may be too expensive or time-consuming to carry out routinely on a large scale. Markers however offer the advantage that they can be measured on bulls, thus eliminating the need for producers to record disease incidence. Furthermore, these markers could allow identification of disease-resistant animals early in life and may provide an indication of resistance to many diseases. Indicators of resistance to parasites are also too time-consuming for large scale routine-recording; however their importance may justify recording them at least in some industry herds.

In South Africa, SCC and linear type traits are routinely recorded in most herds participating in milk recording. A description of how SCC and udder type traits are used to predict resistance to mastitis in South African dairy cattle, as well as suggestions on how such predictions may be improved, are given in section 4.6.6. Many South African dairy farmers have on-farm herd management software that they use to record, among other things, treatments given to cows for various diseases. This, in addition to increasing possibilities of a traceability system being implemented in the country, opens up opportunities for recording disease incidence. There is however a need for stakeholders in disease recording to provide farmers with clear definitions of diseases and standard recording procedures. Research also needs to be conducted to determine efficient ways of recording appropriate predictors of other diseases that may be economically important in South Africa. For example, if lameness turns out to have significant economic value in South African dairy cattle, the utility of traits that are routinely recorded in South Africa, such as feet and legs, as predictors of lameness should be investigated. In future, the use of markers to select for cow health may also become a reality in South Africa as good infrastructure for most of the laboratory analyses required already exists. Recent advances in molecular genetics and the great potential advantages of genome-wide selection (Meuwissen *et al.*, 2001; Schaeffer, 2006) also present high prospects for the application of this technology in many countries, including South Africa.

4.7.7 Udder health

Incidence of mastitis (rate of udder infection) is probably the most appropriate selection criteria for economically relevant traits relating to udder health. Most dairy cattle recording schemes however do not routinely record mastitis incidences, for practical and economic reasons (International Bull Evaluation Service, 1996). Several Scandinavian countries, however, have a legally enforced, well-established and long-standing system of consistently recording disease incidence (LeBlanc *et al*., 2006) and undertake routine genetic evaluation for mastitis incidence (Heringstad *et al*., 2000).

Somatic cell count (SCC) has been considered as the most suitable indicator trait for mastitis resistance in view of its medium to high genetic correlation with and its higher heritability than mastitis (review by Mrode and Swanson, 1996). Somatic cell count is also relatively easy and inexpensive to measure and is routinely recorded in most dairy recording schemes, including South Africa (Interbull, 2009). The distribution of SCC is positively skewed and its variances among groups or herds are heterogeneous (Ali and Shook, 1980); hence SCC is usually transformed logarithmically to **somatic cell score (SCS).**

Tests such as the **California Mastitis Test (CMT)**, **electrical conductivity** of milk and concentrations of **chloride**, **sodium**, **potassium**, **lactose** or **bovine serum albumin** may also be used as indicators of udder health (Fernando *et al*., 1985; Peris *et al*., 1991). These tests are however time-consuming and/or expensive and are therefore seldom used on a routine basis.

Milking speed (MS) has been reported to bear a relationship with udder health, with faster milking cows having higher rates of udder infection (Grindal and Hillerton, 1991; Lacy-Hulbert and Hillerton, 1995; Boettcher *et al*., 1998; Zwald *et al*., 2005). Genetic predictions for udder health traits in many breeding programmes therefore now include information on milking speed (Miglior *et al*., 2005).

The inclusion of **udder conformation traits** (e.g. **udder depth**, **udder attachment**, **teat placement** and **teat length**) as indicator traits has been suggested as a means of improving genetic predictions for udder health traits (Rogers *et al*., 1991; De Jong and Lansbergen, 1996; Mrode *et al*., 1998; Gengler and Groen, 1997). These traits are routinely measured in most animal breeding schemes. In addition, linear type traits are more heritable than mastitis incidence and SCS (Rupp and Boichard, 1999; DeGroot *et al*., 2002; Marie-Etancelin *et al*., 2005).

Somatic cell count is recorded on most milk-recorded herds in South Africa and EBVs for test day SCS are routinely produced under the national genetic evaluation programme. According to the selection indices that are currently used in South Africa, SCS and a host of udder type traits are used as the selection criteria for udder health traits (See Chapter 2, Section 2.3). Estimated breeding values for these traits are given arbitrary relative economic weights and combined into udder health indices. The use of such an *ad hoc* approach to predict udder health traits is likely to result in large prediction errors. Some studies (e.g. Rogers, 1991; Gengler and Groen, 1997) indicate that only a few udder type traits should be utilised in predicting genetic merit for udder health. The inclusion of traits that do not contribute to such predictions constitutes extraneous information and increases prediction error. There is therefore a need to identify and systematically combine all the useful indicator traits in order to develop more accurate genetic predictions for the economically relevant udder health traits. Recently, Dube *et al.* (2008) estimated genetic parameters among SCS and udder type traits in South African Holstein and Jersey cattle. These parameters form the basis for combining information on SCS and udder type into more reliable predictions for the economically relevant traits in the udder health trait group.

4.7.8 Cow comfort

Selection criteria for cow comfort traits are not routinely recorded in most animal recording schemes. Part of the reason could be that cow comfort has in the past been largely regarded as an *externality* in most animal breeding schemes. High rates of involuntary culling due to a deterioration in tolerance to metabolic stress and growing concerns about animal welfare have however put cow comfort to the fore in many countries (Oltenacu and Algers, 2005).

Incidence of metabolic diseases (e.g. lameness, ketosis, udder oedema, metritis, milk fever and displaced abomasums) may be used to predict economically relevant cow comfort traits such as replacement rate and health costs. Recording of these diseases is however seldom practiced in most animal recording schemes (ICAR, 2007). There is also a lack of clear guidelines and consistent standards on the definition and recording of diseases in most countries (International Dairy Federation, 1997). Case definitions of diseases and the definition of new cases versus recurring cases are usually not clear (Valde *et al*., 2004). Larssen *et al*. (2000) reported that calculated disease rates may vary more than 55% depending on the methods used when calculating disease occurrence in the same population. Kelton *et al*. (1998) recommend the use of lactational incidence risk (cumulative incidence) when recording such data for genetic evaluation.

Involuntary culling of cows for reasons related to cow comfort, particularly in confinement and concentrate-fed dairy production systems, has been associated with traits such as **foot and leg conformation** (McDaniel, 1997). **Angularity (dairy form)** has also been reported to influence involuntary culling, through its relationship with incidence of metabolic diseases (Dechow *et al*., 2003; Lassen *et al*., 2003). These type traits can therefore be used to improve the prediction of economically relevant cow comfort traits.

Heat tolerance is a measure of the animal's ability to dissipate heat and maintain its body temperature. In hot weather, animals that are more heat resistant are less susceptible to the adverse effects of high temperatures, such as lower production due to reduced feed intake, and impaired reproduction. Thus heat tolerance may act as a predictor of economically relevant cow comfort traits such as replacement rate and milk yield. Among the many physiological variables that may be used, body temperature is considered the best single indicator of heat tolerance (Bianca, 1961). In animals, body temperature is normally indicated by **rectal temperature**. Other criteria include

respiration rate, **plasma cortisol concentration** (Hammond *et al*., 1996), **whole body ^{40}K counting** and **nitrogen balance** (Kamal and Johnson, 1970).

Since stress has a large influence on **feed intake**, information on feed intake can help to improve the prediction of cow comfort traits. For example, residual feed intake, which increases in stress-afflicted animals (Richardson *et al*., 2004), requires information on feed intake for its prediction. In grazing animals, eating behaviour (e.g. Chacon *et al*., 1976) or **grazing time** (e.g. Chilibroste *et al*., 1997) can be used to indicate feed intake. Recording of selection criteria for cow comfort traits, particularly disease incidence, poses a challenge to animal breeders worldwide. Type traits (feet and legs, angularity) are the only widely-recorded traits that can be used as indicator traits for cow comfort traits. These traits are however limited to the prediction of feet and leg problems. Animal recording organisations need to develop clear guidelines and standards for recording disease incidence. Experiences in the Scandinavian countries, where such recording has largely been successful, provide a reliable source of learning and inspiration. Heat tolerance, measured by body temperature or respiration rate, can be easily and cheaply recorded on a routine basis, especially in intensively housed animals. Recording organisations and artificial breeding companies need to motivate farmers to undertake such recording.

The only selection criteria for cow comfort traits routinely recorded in South Africa are foot and leg conformation and angularity. The use of these traits only is of limited value in predicting the full complement of traits in the cow comfort goal trait group. There is therefore a need to initiate recording of other indicator traits, such as incidence of metabolic diseases. Such recording should be based on guidelines and standards set by the NDAIS. The recording of measures of heat tolerance is a possibility in the intensive concentrate-fed production system, provided farmers are given sufficient motivation to do so. The hot climatic conditions, characteristic of South African summers, justify the need to make serious efforts to record these traits.

4.7.9 Milkability

The most commonly used selection criterion for milkability traits is milking speed. In most countries, each cow is assigned a **milking speed score** by its owner on a scale of 1 (slow) to 5, 8 or 9 (fast), and results are recorded through milk recording or by appraisers (Wiggans *et al*., 2007). In high technology milking systems, the actual time taken to milk out a cow **(milking time), average milk flow rate** and **maximum milk flow rate** can be measured using sensor technology and recorded electronically (Gäde *et al*., 2006). Genetic predictions for milkability traits may be obtained from such records (Zwald *et al*., 2005).

Temperament is generally regarded as a measure of the ease of handling a cow during milking. Ease of handling at milking has been shown to account for up to half of the assessment of the tractability of cattle and of their milking rate (Isogai *et al*., 1989 cited by Uetake *et al*., 2004). Information on temperament can thus be used to improve the genetic prediction of milkability traits. Temperament in dairy cattle has been assessed in many ways including **approachability** to and **flight distance** from humans, **temperament score** and **flinch, step and kick (FSK)** behaviour (Uetake *et al*., 2004).

There are indications from the literature (e.g. Rupp and Boichard, 1999; Zwald *et al*., 2005; Wiggans *et al*., 2007) that **linear type traits** such as **teat length**, **dairy form** and **udder attachment** are genetically associated with milking speed and, therefore, may improve genetic predictions for milkability traits.

The use of electronic recording equipment is likely to make the genetic evaluation of milkability traits, using milking speed as an indicator trait, a relatively easy task. Recording milking speed with such technology and supplementing that information with subjective measures of temperament and, possibly, udder type scores opens up possibilities of obtaining accurate genetic predictions for milkability traits. The use of electronic recording technology is however still very limited in South Africa. Subjective scoring is therefore the only option currently available. There is therefore a need for the NDAIS to set standards for performing such scoring, in order to ensure uniformity. Extensive research also needs to be carried out to determine the best ways of measuring traits such as temperament under South African conditions as well as identify linear type traits that may be useful predictors of milkability traits. Most important of all, the importance of traits such as milking speed and temperament will need to be demonstrated to the farmers in order to motivate them to record them.

4.7.10 Environmental cleanliness

Environmental pollution by dairy cattle worldwide has, in the past, generally been an *externality*; hence limited efforts have been made to record selection criteria for environmental cleanliness traits. Growing concerns about environmental degradation and resultant legislative measures to control it have, however, led to environmental pollution being a cost to dairy farmers in some countries. Efforts have therefore been made to identify suitable indicators of environmental pollution by dairy cattle.

Milk urea nitrogen (MUN) is a simple and non-invasive measurement that is a good predictor of urinary nitrogen excretion by dairy cows (Jonker *et al*., 1998; Kohn *et al*., 2005). Thus reduced MUN means decreased environmental pollution with nitrogen. In order to comply with new European legislation, countries such as the Netherlands will start to use MUN as a tool to monitor mineral efficiencies of dairy herds (Stoop *et al*., 2007). Automatic determination of MUN using infra-red technology is economical and, therefore, is routinely carried out in most dairy animal recording schemes.

Resistance to parasites is the ability of an animal to survive, reproduce and remain productive under risk of parasitic infestation without the aid of anti-parasitic drugs (d'Ieteran and Kimani, 2006). **Incidence of disease** (e.g. theileriosis) may be used as an indicator trait for resistance to parasites. There is, however, a need to have clear guidelines for defining disease incidence as well as standard recording procedures. Other indicator traits for resistance to parasites include percentage volume of red blood cells in blood **(Packed Cell Volume: PCV)** (e.g. d'Ieteran *et al*., 1998), **tick counts** (e.g.

Mwangi *et al*., 1998) and **faecal egg counts** (e.g. de Rond *et al*., 1990). Repeated measurement of tick count is recommended as results are subject to uncontrolled environmental variation, making it difficult to determine when an animal has acquired, or whether it is expressing, its inherent resistance to ticks (Henshall *et al*., 2003).

The prediction of nitrogen excretion can easily be implemented in most dairy cattle breeding schemes, as MUN is both widely recorded and a good predictor of urinary nitrogen. Methods of measuring selection criteria for resistance to parasites are however time-consuming and therefore difficult to implement on a large scale. Routine recording of such traits may therefore only be carried out on a limited scale such as on progeny test herds only.

Milk urea nitrogen is routinely recorded on most herds participating in the South African NDAIS. The MUN results are only used for nutritional management. Plans are under way to look into the possibility of using these data to implement routine genetic evaluation for MUN. The EBVs for MUN, obtained from these genetic evaluations, may be used to calculate genetic predictions for nitrogen excretion, if and when it turns out to be worthwhile to include nitrogen excretion in the breeding objectives for South African dairy cattle.

Recording of indicators of resistance to parasites is generally not done in the South African livestock industry, despite the economic importance of parasites in the tropics. Any serious efforts to minimise the economic impact of parasites as well as reduce environmental pollution by paraciticides must, however, consider developing animals that are resistant to parasites. Thus, animal recording schemes in South Africa should look into ways of recording information that will enable the genetic prediction of resistance to parasites. Clear guidelines and standards on recording such information would need to be developed and incentives provided for farmers to undertake such recording.

4.8 Summary and Conclusions

In this Chapter, a systematic approach was used to: (i) define selection goals for the two distinct dairy production systems in South Africa, namely pastoral system and intensive concentrate-based system; (ii) develop an exhaustive list of traits influencing these goals (i.e. objective traits) and (iii) identify traits measured on the animals that can be used to predict the objective traits (i.e. selection criteria).

Each goal is expressed as profit per unit of limiting factor in the specific production system. In the pastoral system, the goal is profit per hectare and in the concentrate-based system it is profit per animal space. A sound breeding objective should include all the traits influencing the goal. Thus, given a profit based goal, all traits influencing profitability through their effect on income or costs should be included in the breeding objective. A portfolio of objective traits, falling into nine goal trait groups, was developed for South African dairy cattle. Many objective traits appear in more than one goal trait group and care should be taken not to double-count such traits. The list of objective traits developed in this Chapter presents candidate traits for inclusion in dairy cattle breeding objectives in South Africa, now and in the future. Next, the economic values of these traits need to be calculated regularly, in order to determine which traits should be included in the breeding objectives and their relative importance. The first set of these economic values will be determined in Chapter 6, for those traits where there is adequate information to calculate such economic values. Combining these economic values with the respective trait EBVs will result in the first objectively and systematically developed aggregate economic values for dairy cattle in South Africa.

Effective application of breeding objectives is dependent on the accurate prediction of the objective traits. Ideally, all economically relevant traits should be predicted and included in the breeding objective. In order to address this requirement more adequately, the South African national dairy cattle recording scheme needs to be modified to accommodate the routine collection of data on more traits. Many of the selection criteria contained in Table 4.2 are not recorded under the NDAIS, which makes it difficult to accurately predict some objective traits. For example, information such as insemination number and date, birth weight, calving ease, still births, body weight, condition score and milking speed, which is important in predicting traits that may have significant economic values in South Africa, is not routinely recorded. This may indicate deficiencies in data required to achieve accurate genetic prediction of aggregate economic merit, thus hampering national dairy cattle genetic improvement efforts. Most of these traits are easy to measure and are catered for by the (IRIS) animal recording system used in South Africa. The only challenge is to educate farmers on the importance of such information and motivate them to record it. Artificial insemination (AI) companies that run progeny testing schemes in South Africa stand to benefit from the routine recording of such data. Many of the objective traits listed in Table 4.2 are ceasing to be externalities and are getting considered in the valuation of semen. Imported semen, which includes EBV of such traits, may therefore become more attractive to farmers. It is therefore incumbent upon AI companies to at least encourage the recording of more comprehensive data on progeny test daughters by, for example, providing incentives for farmers to do so. In the face of escalating feed costs and in keeping with global trends, feed efficiency traits should particularly receive attention in South Africa.

Indicator traits required to predict certain objective traits are too time-consuming and/or expensive to record on a routine basis. Economic trends may however make it worthwhile to record such traits. For example, the economic value of a milk component such as CLA may increase drastically due to demand. This would add value to the semen of bulls with EBV for CLA, which would prompt AI companies to initiate its recording. The South African dairy industry should therefore keep track of market trends and economic values of the objective traits in Table 4.2 should be calculated regularly, based on predicted future industry developments.

Chapter 5

Literature Review on Derivation of Economic Values

5.1 Introduction

Defining the breeding goal and determining traits in the breeding objective (Chapter 4) forms the basis of developing a sound breeding objective. The next step after this is to derive the economic value, or relative emphasis to be placed on each trait in the objective (Golden *et al*., 2000; Holmes *et al*., 2000). The economic value of a trait may be defined as the amount by which profit is expected to increase for each unit improvement in the genetic merit of that trait while all other traits in the breeding objective are kept constant (Hazel, 1943). Various approaches have been used to determine economic values in livestock (Gibson, 1989; Groen, 1989; Groen *et al*., 1997; Bourdon, 1998). These methods are reviewed in this Chapter. A number of controversial issues relating to the conventional approach to deriving economic values, and the consensus among researchers on these issues, are discussed. Next, efforts that have been made to determine economic values for dairy cattle in South Africa are looked at. The concluding part of the Chapter discusses practical issues that need to be considered in deciding the most appropriate method(s) to be used to derive economic values for breeding objective traits in South African dairy cattle.

5.2 Methods of determining economic values

Methods for deriving economic weights can be broadly classified into objective and non-objective methods (Groen *et al.*, 1997). Objective methods involve the analysis or simulation of data while non-objective methods entail the subjective weighting of traits.

5.2.1 Non-objective methods

A lack of data for analysis or model simulation is often used as the major justification for deriving economic values non-objectively. The complex nature of objective methods and the difficulty in predicting future trends and parameters required for simulation modelling also, at times, make the non-objective approach the often preferred option.

Relative economic weights may be determined by getting a panel of breeders, scientists and other stakeholders to list those traits with EBVs that they consider economically important and then subjectively determine the relative emphasis (usually percentage weighting) to be placed on each trait. This *ad hoc* approach is the method that has been used to derive selection index weights for South African Holstein and Jersey cattle (Taurus Holstein, 2002; D. J. van Niekerk, 2007, Personal Communication). Some researchers suggest that this methodology may be useful as a way to introduce producers to the concept of economic indices using simple technology (Beef Improvement Federation, 1996). Bourdon (1998) points out that, technically, an *ad hoc* index does not qualify as a true selection index, but may have educational value for breeders unfamiliar with indices as a selection tool. Bourdon (1998) also draws attention to the fact that, because they are economically and genetically naïve, such indices could be misleading.

For example, all traits with EBVs are usually assumed to be eligible for inclusion in the breeding objective and no distinction is made between economically relevant and indicator traits. Furthermore, the magnitude and direction of emphasis placed on most traits is primarily based on breeder perception. In South Africa, this has resulted in the emphasis placed on many traits in the Holstein and Jersey indices being questionable (see Section 2.3).

Economic values may also be determined non-objectively in what are known as desired gains selection indices (Brascamp, 1984). These indices assign economic values in order to achieve a desired amount of genetic gain for some traits. The desired gains approach may be used, for example, if the change in two traits is desired to be in a certain ratio. Economic weights for the two traits are chosen in such a way that the desired relative change in the two traits is achieved. Lin and Togashi (2005), for example, investigated the possibility of maximising lactation production in dairy cattle without reducing persistency, by achieving equal genetic gains at different stages of lactation. Economic weights for milk yield at different stages of lactation were thus assigned in such a way as to obtain equal genetic improvement (Lin and Togashi, 2005). The desired gains method may also be useful in commercial pig and poultry breeding because commercial breeders tend to calculate economic values according to the performance of their stock relative to those of competitors (Schultz, 1986).

Economic weights may be assigned in such a way that genetic change in one trait is enhanced while the other trait does not change at all (e.g. James, 1968; Okada and Hardin, 1970; Linamo and Van Arendonk, 1999; Dzama *et al.*, 2001). Such an index is called a restricted index. Brascamp (1984) suggested that restricted indices are essential for situations of traits with optimal values (e.g. teat placement and milking speed in dairy cattle) or when factors other than economics (e.g., ethical reasons) require certain restrictions on the selection programmes (e.g. Nielsen *et al.*, 2005).

Van der Werf (2005) notes that, in general, it is suboptimal to choose for a desired gains approach, since one puts potentially too much emphasis on traits that are difficult to improve (e.g. due to a low heritability). The small 'desired' improvement that is achieved goes to the expense of a large loss of potential genetic gain for another trait that was easier to improve. In addition, Gibson and Kennedy (1990) illustrate the inefficiency of desired gains indices, and highlight the need for multi-disciplinary scientific effort in deriving reliable and objective functions rather than relying on desired gains. Groen *et al.* (1994) compared linear, quadratic and desired gains indices for multiple generation selection response in a non-linear profit function, and concluded that desired gains indices allow stabilisation of base population averages only at the expense of losses in economic selection response. Thus, if economic weights could be derived without too much uncertainty, objective derivation of economic values is a more efficient approach (Groen *et al.*, 1994).

5.2.2 Objective methods

The objective approach principally derives economic values through the use of mathematical models, also known as systems analysis (Cartwright, 1979). Systems analysis can be carried out by two distinct approaches: (1) data evaluation or the positive approach and (2) data simulation or the normative approach (Van Arendonk, 1991; Groen *et al*., 1997; Forabosco *et al*., 2005). The positive approach entails the analysis of observed economic and technical data to derive the relationship between trait values and profit. On the other hand, the normative approach simulates models that describe relationships among different components of a system to determine the effect of changes in trait values on profit, given the model parameters.

The positive or empirical approach has been used to determine economic values in beef cattle (Groen, 1990; Forabosco *et al*., 2005) and dairy cattle (Mulder and Jansen, 2001; St-Onge *et al*., 2002). Essentially, this method uses multiple regression analysis to estimate economic values as the partial regression coefficients of profit on trait values (change in profit per unit change of a trait). This approach typically does not distinguish between economically relevant traits and indicator traits and therefore negates the concept of breeding objectives. For example, by regressing profit on rump angle (e.g. Mulder and Jansen, 2001), the method presupposes that rump angle *per se* directly affects profitability by being associated with a specific cost of production or an income stream. Groen *et al*. (1997) criticise data evaluation for the fact that it uses current or historical economic data, while breeding is future oriented.

Data simulation employs the use of profit equations or more complicated bio-economic models. A profit equation is a single function designed to represent the relationship between the performance of animals for economically important traits and firm-level profit (Bourdon, 1998). MacNeil (1996) describes a profit equation as a "highly, if informally, aggregated simulation model."

Bio-economic models have been used to derive economic values in pigs (Stewart *et al.*, 1990; Skorupski *et al.*, 1995), sheep (Conington *et al.*, 2001), beef cattle (Koots and Gibson, 1998; Albera *et al.*, 2004) and dairy cattle (Dekkers, 1991; Harris and Freeman, 1993; Koenen *et al.*, 2000; Vargas *et al.*, 2002; Veerkamp *et al.*, 2002; Shook, 2006). A bio-economic simulation model is a collection of equations that describe the biological and economic aspects of livestock production systems. Bourdon (1998) grouped these equations as (1) those that simulate biological relationships, (2) those that simulate management, and, (3) those that determine profitability or some other measure of economic efficiency.

According to Bourdon (1998), the chief advantage of bio-economic simulation is precision. They include much more biological detail than profit equations because they contain large numbers of equations to represent basic biological relationships and can, therefore, more accurately track the sometimes convoluted effects that a change in a genetic component of animal performance has on overall profitability. If simulation models are well designed from a user's standpoint, they may also be more flexible than profit equations (Bourdon, 1998). Disadvantages of bio-economic models include their complexity, which makes them prone to error, and the cost in time and money to develop them (Bourdon, 1998). Besides, the large amounts of input information required to describe physical environment, management, historical production, and economic factors in these models may be difficult to obtain from the farmers. MacNeil (1996) questiones the appropriateness of these models for calculating economic values, arguing that a simulated change in a genetic component for performance in one trait invariably causes changes in performance in other traits in the breeding objective; implying that economic weights determined from simulation do not represent the effects of independent changes in each trait.

Economic values can be derived from profit functions as the partial derivatives of profit with respect to the trait considered, keeping all other traits constant at the mean value (e.g. Gibson, 1989; Ponzoni and Newman, 1989; Gibson *et al*., 1992; Bekman and Van Arendonk, 1993; Visscher *et al*., 1994; Pieters *et al*., 1997). Alternatively, partial budgeting, which entails accounting for unit changes in marginal returns and costs arising from a unit increase in the level of the trait of interest, is used (e.g. Holmes *et al*., 2000; Kahi and Nitter, 2004; Rewe *et al*., 2006).

5.2.2.1 Profit functions

The use of profit equations or functions to integrate the costs and returns of a production system was pioneered by Moav and Moav (1966) in a study to compare the profitability of poultry lines and crosses. Goddard (1998) gave a general description of a profit function as "a procedure or rule that takes genetic values of various traits as input and produces profit as output." Traits may affect profit by influencing enterprise revenue (income traits) or costs (cost traits). In a dairy enterprise, income traits include milk returns (usually determined by milk component yields and quality) and beef returns (salvage values of cull cows and surplus calves). The cost traits include feed costs, animal health costs, breeding and reproduction costs.

Profit may be expressed as a function of revenue (R) and costs (C) in the following different ways (Harris, 1970):

3.2.1. Profit (P) = R – C

3.2.2. Return on investment (Φ) = R/C

3.2.3. Cost per unit production (Q) = C/R

Some researchers (e.g. Smith *et al.,* 1986) contend that the ratios (Φ and Q) are a more appropriate basis for the determination of economic values than the difference (P). Dickerson (1978) and Brascamp *et al.* (1985) showed that all three parameters give the same result, if P is set to zero by including reasonable business returns (i.e. normal profit) as a cost. Smith *et al.* (1986) however note that, in practice, not much difference in economic values is likely to be observed between the use of ratios and the difference between revenue and costs. Furthermore, Ponzoni (1988) compared economic values derived for the Australian Merino sheep, using the three different basis of expressing profit, and concluded that the way in which revenue and costs are combined will have negligible effect on selection decisions.

In most animal breeding studies, profit is calculated per animal per year and expressed as the difference between revenue and costs. In a dairy enterprise, there are normally four sources of revenue (milk, bull calves, cull cows, cull heifers) and total revenue (R_T) can be calculated as follows (Harris and Freeman, 1993):

$$R_T = \sum_{i=1}^{4} R_i \tag{5.1}$$

where R_i denotes revenue derived from the i^{th} source.

Total costs (C_T), excluding fixed costs, are determined using the equation (Harris and Freeman, 1993):

$$C_T = \sum_{j=1}^{k} C_j \tag{5.2}$$

where C_j refers to costs attributable to the j^{th} factor (i.e. feed, reproduction, health, labour,………factor *k*).

The profit equation can be presented succinctly in the following general form (Visscher *et al.*, 1994):

$$\mathrm{P} = \mathrm{P}(\mathbf{x},\mathbf{m}) \tag{5.3}$$

where P is farm profit, **x** is a vector of mean genetic values of the herd, and **m** is a vector of variables controlled by management. Equation 5.3 is generally considered to be linear or slightly non-linear in relation to any single trait (Dekkers and Gibson, 1998).

Profit functions have been used in numerous studies to determine the relative economic importance of traits (e.g. Gibson, 1989; Van Arendonk, 1991; Gibson *et al*., 1992; Bekman and Van Arendonk, 1993; Visscher *et al*., 1994; Kahi and Nitter, 2004; Rewe *et al*., 2006). The use of profit functions to calculate economic values has, over the years, generated considerable debate, relating mainly to the parameterisation of the management variables. The main features of this debate and the consensus on the issues raised are discussed in the following sections.

5.2.2.1.1 Constraining variables in the profit function

The most widely accepted approach to deriving the economic value of a trait (v) is to fix management variables at the values which are optimum for the current genotype (m_o) and examining the effect on profit (P) of a small change in x about the current mean ($\bar{x}$), that is (Visscher *et al*., 1994):

$$v = \frac{\partial P}{\partial x}(\bar{x}, m_o) \tag{5.4}$$

where

$$\frac{\partial P}{\partial m}(\bar{x}, m_o) = 0 \tag{5.5}$$

In practice, an arbitrary rather than optimum value for one management variable is chosen. Different constraints may however result in different economic values and it is also difficult to decide which variable to arbitrarily constrain.

The profit function usually contains a variable such as herd size that indicates the scale of the enterprise. The effect on economic values of the levels at which such variables are fixed has been the subject of considerable debate among researchers. Brascamp *et al.* (1985) showed that the same economic weights are obtained regardless of the constraint used if returns to management and capital (so called *normal profit*) are included as costs in the profit function so that profit is set to zero. It was further demonstrated that economic weights are identical if profit from genetic change is discounted for change in scale of enterprise (Smith *et. al*., 1986). This is equivalent to calculating profit under the constraint that total costs or total returns remain constant. Smith *et al*. (1986) also argue that, in the long term, all costs are variable (i.e. there are no fixed costs) and dependent on the scale of the enterprise; implying that there is no optimum value for the scale variable. Since economic values are simply proportional to the scale variable, the choice of value for the scale variable is therefore arbitrary (Brascamp *et al*., 1985; Smith *et al*., 1986).

Visscher *et al*. (1994) point out that a practical difficulty with the methods advanced by Brascamp *et al*. (1985) and Smith *et al.* (1986) is that all costs, not just marginal costs, must be accounted for and some costs may be difficult to quantify. Amer and Fox (1992) argue that the method of determining economic weights by rescaling the production enterprise to a fixed input, output or profit makes unreasonable assumptions about the behaviour of farm firms. Modification of economic weights to account for scale was shown to be unjustified and unnecessary when economic weights were estimated using a model based on the neoclassical theory (Amer and Fox, 1992). In addition, by assuming that farm firms would always be expected to increase production (rescale) to maximise profits, the conventional model of deriving economic weights implicitly suggests that one would expect to see profit-maximising farms of infinite size; an assumption that is inconsistent with the observed behaviour of farms (Amer and Fox, 1992).

McArthur (1987) and Amer and Fox (1992) suggest that profit from genetic change should be calculated while simultaneously optimising all variables controlled by management including scale of enterprise. McArthur (1987) argues that, in the long run, managers tend to be maximisers and therefore, it is sensible to assume that they will alter managerial decisions to make the most profitable use of improved genetic material. This implies that economic values should be calculated under optimum management. Further, Amer and Fox (1992) point out that if variables in the profit function are not continuously optimised, some bias may appear in the economic values, particularly for large changes over time. Goddard (1998) went on to show that if the scale variable is optimised, economic weights are equivalent with different parameterisation, which concurs with the reasoning of Amer and Fox (1992) that the scale of the enterprise is a management variable and no increase in profit is obtained if it is optimised.

Amer and Fox (1992) criticised the conventional approach to determining economic values and proposed the use of a model based on the neoclassical theory of the firm. In the context of animal production, the neoclassical theory postulates that the goals of farm managers are profit maximisation or cost minimisation. The following farm production function was defined for a farm producing a single output (γ) using both genetic and non-genetic inputs (Amer and Fox, 1992):

$$\gamma = f(\mathbf{x},\mathbf{m}) \tag{5.6}$$

where **x** is a vector of animal traits and **m** is a vector of non-genetic inputs or factors of production. Using the neoclassical approach, the economic weight of a trait is calculated as the difference between profit at the profit maximizing level of production before genetic improvement (γ_0) and the profit level at the profit maximising level after genetic improvement (γ_n). Thus the economic weight is derived as the amount by which net benefit of the optimal policy may be expected to increase for a unit of improvement in that trait.

Goddard (1983) however demonstrated that, provided small changes in traits are considered, the economic weight with re-optimisation of *m* is the same as the economic weight with *m* held constant at the optimum value for the current genotype and also questioned whether the difficulties in modelling optimum farm scale would be justified by significantly better economic weights.

Visscher *et al.* (1994) suggest that, in practice, it may be more useful to have economic values which are appropriate for the range of enterprise sizes actually occurring than for a vaguely defined and unrealistic optimum size.

Goddard (1998) concludes that, “An attempt should be made to account for all costs and to assign them correctly to the variables that determine them in the long term. This procedure also allows a check to be made that profit is zero.” To account for costs that are difficult to apportion, Goddard (1998) recommended that, the scale variable should be chosen so that these costs can be assumed to remain constant while the scale variable is held constant. For instance, in a pasture-based production system, it is difficult to account for feed costs and choosing the land area as the scale variable tends to fix such costs (e.g. Visscher *et al.*, 1994; Kahi and Nitter, 2004; Rewe *et al.*, 2006). Garrick (2002) however demonstrated that, in grazing circumstances, the cost of feed required to meet demands resulting from genetic improvement could be determined as the average revenue per kg DM consumed in the base situation. Assuming that the extra feed is purchased at opportunity cost, defined as average revenue in the base situation, will result in equivalent economic values for a model with a fixed number of animals as with one that uses land area as the scale variable (Garrick, 2002).

5.2.2.1.2 Perspective used to derive economic values

One of the dilemmas that have been encountered in the use of profit functions to determine economic values is on whose perspective profit should be defined. The question is whether the profit function should be defined from the viewpoint of a seed-stock company, individual producer, the industry as a whole or the consumer. A selection objective based on a producer goal may not necessarily lead to changes that are beneficial to other sectors of the industry, or even the industry as a whole. For example, genetic improvement of dairy cattle may lead to an increased supply of milk and, consequently, a depression in the price of dairy products. Early work (Dickerson, 1973; Moav, 1973) indicated that the economic values depended on whether the profit function was based on a unit of product (industry perspective), the producer or production unit (producer perspective), the investor (e.g. seed-stock company perspective) or consumer (national) interest. Amer and Fox (1992) used the Ontario, Canada, cow-calf sector to illustrate the fact that economic weights calculated from the perspective of all producers could be different from those calculated from the perspective of an individual farmer or industry as a whole. The way in which benefits were split between consumers and producers was shown to depend on elasticities of supply and demand (Amer and Fox, 1992). Goddard (1998), however, observes that a profit function for a vertically integrated firm with optimised management and that cannot gain by increasing the scale of the enterprise is widely applicable.

5.2.2.1.3 Discounting economic values

In most cases, traits in the breeding objective are not expressed at the same time or with the same frequency. Traits such as age at puberty, for example, are expressed early in life whereas others (e.g. longevity) are expressed late in life. Benefits from selection that come earlier may be more valuable than benefits that are realised later. Furthermore, genes relating to the expression of traits like carcass composition will be expressed only once at the end of any one animal's lifetime, whereas genes relating to milk production will be expressed in every lactation over an animal's entire lifetime.

It is generally agreed among researchers that, in determining the relative importance of traits in the selection objective, the timing as well as number of expressions of the traits should be accounted for. This is normally done by discounting the value of genetic change in future years to a net present value (Dekkers and Gibson, 1998). The discounted gene flow method of McClintock and Cunningham (1974), gene flow (or Markov chain) methodology (Hill, 1974) or diffusion coefficients (McArthur *et al.*, 1990) can be used to achieve this. Alternatively, the feed and cash forecast budgets are calculated on an annual basis to account for the frequency of expression of traits (e.g. Ponzoni and Newman, 1989). The discounted gene flow is normally the preferred method, especially in animal species with a long life span such as dairy cattle; as it takes into account both the frequency and time of expression of traits (Ponzoni and Newman, 1989). The annual income and expense budget forecast method can be refined by following the consequences of genetic change for at least the lifetime of an average animal (Holmes *et al.*, 2000).

Goddard (1998) notes that, although discounting is very important to assess the total value of genetic change, it does not seem to substantially alter economic weights. The discounted gene flow method was also observed to have a small effect on economic values for Merino sheep, compared to the income and expense per year approach (Ponzoni, 1986). Ponzoni and Newman (1989) however found that, in beef cattle, discounting increased the importance of traits expressed early in the life of animals and postulated that the contrast with the finding of Ponzoni (1986) was due to shorter life assumed for the Merino sheep.

5.3 Determination of economic weights in South African dairy cattle

Breeding objectives for dairy cattle in South Africa are expressed in two indices, the Breeding Value Index (BVI) and SAINET, for the Holstein and Jersey breeds respectively (see Chapter 2, Section 2.3.3). The efficacy of these indices is hamstrung by the fact that no breeding goals for dairy cattle in South Africa have been clearly defined. Consequently, decisions as to which traits to include in the selection indices and their relative economic weights have not been determined as objectively as possible. Additionally, limited efforts (du Plessis and Roux, 1999; Tesfa, 2001) have been made to obtain objective economic weights for dairy cattle traits in South Africa. The *ad hoc* approach has been used to determine the relative emphasis of traits in the BVI and SAINET (G du Preez, 2005, Personal Communication; D. J. van Niekerk, 2007, Personal Communication).

The relative importance of traits in both the BVI and SAINET was determined by a panel of breeders, breed society representatives and scientists. The methodology used to achieve this is described as follows (D. J. van Niekerk, 2007, Personal communication). The panel looks at a list of all the traits with EBV and starts by classifying them into trait groups (i.e. production, body conformation, feet and legs, udder health). Each member of the panel suggests the relative emphasis (as a percentage) of each trait within a group and debate ensues until consensus is reached. The same process is repeated to assign relative weights to the trait groups. All traits with EBV are included in the index and new traits are added as they get EBV. This approach has the following shortcomings:

3. No distinction is made between economically relevant traits and selection criteria and there is no clear definition of the traits that are desirable to improve in order to address the breeding goal. By assuming that every trait with EBV should be included in the index, the method defeats the idea of improving only those traits that have a direct influence on the breeding goal. For example, many type traits, which receive considerable emphasis in these indices (see section 2.3.3) clearly have no direct effect on income or costs. As indicated by Golden *et al.* (2000), the inclusion of such extraneous EBVs is likely to reduce the effectiveness of these indices by adding to the prediction error of the aggregate prediction of merit. Besides, a breeding objective that is not based on economically relevant traits is likely to be inaccurate and misleading.
4. The relative importance of traits in the index is subjective and primarily determined by the perception of the panel (mainly the breeders). Many traits, particularly type traits, are weighted purely on the basis of sentimental value rather than economic value. A close look at the BVI and SAINET shows that this approach has led to questionable emphasis being placed on certain traits. For example, angularity has been widely observed to bear a negative relationship with health (Rogers *et al.*, 1999; SØrensen *et al.*, 2000; Hansen *et. al.*, 2002, Dechow, 2003; Lassen *et al.*, 2003) and cow fertility (Dadati *et al.*, 1986; Pryce *et al.*, 2000; Kadarmideen, 2004). This trait, however, receives considerable positive emphasis in the BVI and SAINET (see section 2.3.3).

Du Plessis and Roux (1999) used simulation modelling to calculate relative economic weights for low, medium and high producing concentrate-fed Holstein herds in South Africa. A farm model with a fixed herd size (100 lactating cows) on a total mixed ration (TMR) feeding system was used. Two milk pricing systems, one based on fresh milk and yoghurt production and the other on butter and cheese processing were used. Economic weights were estimated for milk, fat, protein and lactose yields, survival, feed efficiency and calving interval. Feed efficiency generally had the highest economic weight, followed by production traits. The economic weights of survival, calving interval and body weight were exceptionally small, that of body weight being the only negative one. Unfortunately, no other estimates with which to compare the results of du Plessis and Roux (1999) are available in South Africa.

The work of du Plessis and Roux (1999) was, according to information that could be gathered, the first serious effort towards the objective determination of economic values for dairy cattle traits in South Africa. The study was however not based on a clearly defined breeding goal and description of traits that are desirable to improve. For example, a trait such as udder health, which is clearly economically relevant in South Africa (see Chapter 4, Section 4.5), was excluded from the breeding objective. In addition, the inclusion of feed efficiency in a breeding objective is not recommendable, due to the problems associated with ratio traits (see Chapter 4, section 3.5.3). The study was also based solely on one breed (Holstein) in one production system. Studies have shown that economic values may vary considerably between breeds and production systems. It has been shown, for example, that the economic value of body weight may vary substantially among different production systems (Koenen *et al*., 2000). South Africa has diverse dairy cattle production systems (see section 3.2) and Bourdon (1998) questioned the usefulness of a one-size-fits-all index for such situations where operations differ widely in physical environment, mating system, management, and marketing. There is therefore a need to broaden as well as refine the work of du Plessis and Roux (1999).

Tesfa (2002) estimated economic weights for milk production traits (volume, butterfat yield and protein yield) in South African Holstein cattle for producers selling their milk to three different milk buyers. Unit prices of the three milk components were assumed to represent the relative economic values of the traits. This approach assumes a perfect pricing system, where producers are appropriately rewarded on the basis of the value of their milk. The value of milk under the different marketing systems in South Africa has however not been determined. Additionally, as Tesfa (2001) acknowledges, the costs of producing an extra unit of output (milk component) should have been accounted for and other dairy cattle breeds need to be studied.

5.4 Conclusions

Objective and accurate determination of relative economic weights is critical to the development of sound breeding objectives. The *ad hoc* method of deriving economic values, which has been used in South Africa, is generally considered inappropriate as it lacks economic basis. Most studies on the determination of economic values in dairy cattle have been based on herd simulation models, with constraints on and optimisation of some production scale variables. Although discounting of economic values is widely accepted as important, indications are that such discounting may not be important if feed and cash forecast budgets are calculated on an annual basis to account for the frequency of expression of traits.

Previous efforts to objectively estimate economic values for dairy cattle in South Africa were limited in scope. In order to develop sound and widely applicable breeding objectives for South African dairy cattle, it is imperative to determine economic values for the objective traits described in Chapter 4. This step is performed in the next Chapter.

Chapter 6

Economic values of traits in the breeding objectives for South African Holstein and Jersey cattle breeds

6.1 Introduction

Ideally, economic values should be determined and updated regularly for all traits in the breeding objective. In practice however, there usually is insufficient information to calculate economic values of some objective traits in the population. Many objective traits are not readily observed and, in some cases, their indicators are also not recorded. This makes it difficult to predict such traits as well as determine their current levels. Lack of requisite economic data also makes it difficult to calculate economic values of some objective traits.

This Chapter focuses on calculating economic values of breeding objective traits for South African dairy cattle, listed in Table 4.2 (Chapter 4), for those traits where adequate information is available. The appropriateness of a one-size-fits-all selection index, applied across breeds and diverse production and marketing systems, is questionable (Bourdon, 1998). Economic values are therefore determined separately for the two major dairy cattle breeds (Holstein and Jersey) in each of the two major dairy production systems in South Africa. There are numerous milk buyers, using different milk payment systems, in South Africa. Economic values are calculated using the payment systems of four major milk buyers, who comprise about 60% of the milk buyer market (Koos Coetzee, 2008, personal communication).

6.2 Materials and Methods

6.2.1 Data and General Methodology

A bio-economic herd model simulating an average farm, for each breed in each production system, was developed. Data collected through the National Dairy Animal Improvement Scheme (NDAIS) were used to derive base herd parameters. Farm economic data and information on milk pricing were obtained from the Milk Producers' Organisation (MPO) of South Africa (Lactodata, 2007; MPO, 2007; MPO, 2008; Koos Coetzee, 2008, personal communication; Dawie Maree, 2008, personal communication). Two of the milk buyers, Parmalat SA and Clover SA, also provided information on their milk payment schemes (Berlo Cotsee, 2008, personal communication; Pieter van Zyl, 2008, personal communication).

The partial budget approach was used to compute economic values by simulating the marginal change in profit resulting from a unit increase in the trait of interest, while all other traits remained constant. Profit was expressed per cow in the herd per year and its marginal change was calculated as the difference between marginal change in revenue and marginal change in costs. Economic values obtained this way can be converted so that they are expressed according to selection goals such as those proposed in Table 4.1, following consultation with industry. This is, for example, the approach that has been used in New Zealand where profit is expressed on a base of 4.5 t dry matter (Holmes *et al.*, 2000).

6.2.2 The Herd Model

The herd model simulated typical breeding and management practices in the two major production systems in South Africa (pasture and concentrate-based system). Breeding and calving took place all year round, with constant herd size being assumed. Replacement rate was therefore equal to death plus culling rate. All replacement heifers were raised on the farm. It was assumed that 55 % of calves born were male and they were all sold at a fixed price, within one week of birth. All heifer calves were retained until culling took place at 12 months of age and 3 months after reaching breeding age (for failure to conceive). Conception rate and mortality rate were assumed to be 85% and 5% respectively, across breed and production system. Surplus heifers were sold for slaughter, with the price per animal being based on carcase weight. Culled cows were disposed of at the end of a 305-day lactation and their slaughter price was determined by carcase weight. Carcase weight was calculated as 49% of live weight for both heifers and cows.

Calf rearing was the same in both production systems. After receiving 3 or 4 litres of colostrum a day (respectively for Jersey or Holstein) in the first 3 days of life, Jersey calves were fed 3 litres and Holstein calves 4 litres of whole milk a day until weaning at 8 weeks of age. In addition, Jersey and Holstein calves were given, respectively, 2 kg and 3 kg of calf meal a day from day 3 of age. Average weaning weight was 50 kg and 60 kg respectively for the Jersey and Holstein.

Cows in the pasture-based production system were grazed on pasture, comprising predominantly Kikuyu grass, and given 6 to 10 kg (as fed) of concentrate per cow per day during lactation. In winter (June-July), 10 kg (as fed) of maize silage were provided per cow per day as supplementary feed. Cows in the concentrate based production system were fed a total mixed ration (TMR), with quantities being based on production. The average energy content of feed (MJ ME/kg DM) was 9.0, 9.5, 11.0 and 14.0 respectively for pasture, silage, TMR and concentrate (Dugmore, 1995).

6.2.3 Base herd parameters

Base herd parameters used to simulate the average performance level of each breed in each production system are shown in Table 6.1. These values were derived from data recorded under the NDAIS on cows that calved between 1 January and 31 December 2006. It was assumed that all Jersey cows remaining in the herd were culled after completing their tenth lactation. There were however extremely few (less than 1%) Holstein cows calving after the eighth lactation, therefore it was assumed that all Holstein cows were only allowed to last in the herd for up to 8 lactations. Details of base herd structure, production by lactation group and survival in each lactation, for each breed and production system, are presented in Appendix A1 – A4.

6.2.4 Live weight prediction

Live weight (LW) of animals at each month of age was predicted from the first month after weaning (month 3), using the von Bertalanffy growth function as given by Bakker and Koops (1978):

$$LW = M\{1 - (1 - (w_0/M)^{1/3})e^{-kt}\}^3 \qquad [6.1]$$

where:

M = mature weight (kg),
w_0 = birth weight (kg),
k = growth rate parameter,
t = age (months).

Table 6.1: Base herd parameters for each breed in each production system

Parameter[1]	**Concentrate**		**Pasture**	
	Holstein	**Jersey**	**Holstein**	**Jersey**
Milk volume (l/cow)	9 746	6 252	7 049	5 152
Fat yield (kg/cow)	383	303	277	248
Protein yield (kg/cow)	319	237	233	198
SCC (x1000 cells/ml)	332	308	262	237
Age at first calving (months)	26	25	28	27
Calving interval (days)	413	395	399	390
Productive lifetime (lactations)	2.4	2.7	2.9	3.0
Productive lifetime (months)	45.3	47.8	52.8	53.3
Cows culled (%)	34.6	31.9	26.1	26.6

[1] *Yields standardised to 305 day lactation*

Table 6.2 contains parameter values that were used to calculate live weight for each breed and production system. Values for birth and mature weight were obtained from a survey on herds that regularly weigh animals. Estimates of growth rate parameters were not available for South Africa, therefore literature estimates for the same breeds under similar production systems elsewhere were used (Keller and Allaire, 1990; Visscher *et al*., 1994; Garcia-Muniz *et al*., 1998).

Table 6.2: Parameters used to predict live weight for each breed and production system

	Concentrate		**Pasture**	
Parameter	**Holstein**	**Jersey**	**Holstein**	**Jersey**
Birth weight (kg)	40	30	40	30
Mature weight (kg)	650	500	600	450
Growth rate (k)	0.0885	0.0915	0.07625	0.089

6.2.5 Feed requirements

Feed requirements (kg DM per cow per year) were determined from the total feed energy required for growth, maintenance, milk production and pregnancy. Total energy requirements were divided by the energy content of feed (MJ ME/kg DM) to give the amount of feed required. It was assumed that requirements for protein and other nutrients were adequately met by the available feeds.

6.2.6 Energy requirements

The metabolisable energy (ME) system (ARC, 1965) was used to calculate energy requirements and the following general equation was applied (AFRC, 1993):

$$ME_{mp}\ (MJ/d) = E_m/k_m + E_l/k_l + E_g/k_g + E_c/k_c \qquad [6.2]$$

where:

ME_{mp} = ME requirement for maintenance and production,

E_m, E_l, E_g and E_c = net energy values for maintenance, lactation, growth and conceptus, respectively,

k_m, k_l, k_g and k_c = efficiencies of utilisation of ME for maintenance, lactation, growth and pregnancy, respectively.

Efficiencies of utilisation of metabolisable energy (k-values) were calculated as follows (AFRC, 1993):

$$k_m = 0.35q_m + 0.503 \qquad [6.3]$$

$$k_l = 0.35q_m + 0.420 \qquad [6.4]$$

$$k_c = 0.78q_m + 0.006 \qquad [6.5]$$

$$k_g = 0.95k_l \qquad [6.6]$$

where:

q_m = metabolisability of gross energy at maintenance.

A value of 0.6 was assumed for q_m, giving the k-values presented in Table 6.3.

Table 6.3: Efficiencies of utilisation of ME (k-values) used to calculate ME requirements

ME requirement	**Coefficient (k)**	***k* value**
Maintenance	k_m	0.70
Lactation	k_l	0.62
Cow growth	k_g	0.59
Heifer growth	k_f	0.45
Pregnancy[1]	k_c	0.133

[1] *k-value assigned constant value, with no influence of q_m implied*

6.2.6.1 Maintenance requirements

Maintenance ME requirements (ME_m) were calculated per month of age, for each lactation group, using the following equation (AFRC, 1993):

$$ME_m \text{ (MJ/d)} = (F + A)/k_m \qquad [6.7]$$

Where:

F = fasting metabolism,

A = activity allowance.

Fasting metabolism is given by ARC (1980) as:

$$F \text{ (MJ/d)} = 0.53(LW/1.08)^{0.67} \qquad [6.8]$$

The average predicted LW for the respective lactation group and month of age was used. Activity allowance was 0.0095LW and 0.011LW respectively for concentrate and pasture systems, following the recommendations by AFRC (1993).

6.2.6.2 Requirements for production

Total ME requirement for milk production (ME_l) was calculated per lactation, for each lactation group, using the following formula (AFRC, 1993):

$$ME_l\ (MJ) = (y \times EV_l)/k_l \qquad [6.9]$$

where:

y = lactation milk yield (kg),

EV_l = energy value of milk (MJ/kg).

The energy value of milk was calculated using the following equation (adapted from Tyrell and Reid, 1965):

$$EV_l\ (MJ) = 37.6F + 20.9P + 0.948y \qquad [6.10]$$

where:

F = fat yield (kg),

P = protein yield (kg).

It was assumed that energy content of milk components was 56.1 MJ ME per kg milk fat, 31.8 MJ ME per kg protein and 1.84 MJ ME per litre milk, following Holmes *et al.* (2000).

6.2.6.3 Requirements for replacements

Requirements for growth and maintenance of replacements (ME_r) were calculated for each month of age according to AFRC (1993) as follows:

$$ME_r\ (MJ) = (E_m/k) \times \ln\{B/(B - R - 1)\} \qquad [6.11]$$

where:

E_m = sum of fasting metabolism (F) and activity allowance (A),

$B = k_m/(k_m - k_c)$, [6.12]

$k = k_m \times \ln(k_m/k_c)$. [6.13]

Scaled energy retention (R) is given by:

$R = E_f/E_m$ [6.14]

E_f is calculated from:

E_f (MJ/d) = $1.10(EV_g \times \Delta W)$ [6.15]

where:

ΔW = weight gain.

EV_g = energy value of gain and is given by:

$$EV_g = \frac{1.30(4.1 + 0.0332LW - 0.000009LW^2)}{(1 - 0.1475\Delta W)} \quad [6.16]$$

6.2.6.4 Requirements for cow growth

Requirements of ME for cow growth (ME_g) were calculated for each month of age, within each parity group, as follows:

$ME_g = (EV_g \times \Delta W)/k_g$ [6.17]

6.2.6.4 Requirements for pregnancy

Requirements of ME for supporting pregnancy (ME_c) were predicted for each week of pregnancy, up to and including week 40, using the following equations (AFRC, 1993):

$ME_c = E_c/k_c$ [6.18]

where:

E_c = energy retained for foetal growth (MJ/day)

Ec was obtained by:

E_c (MJ) = $0.025w_0(E_t \times 0.0201e^{-0.0000576t})$

where E_t (MJ) is energy retention at time *t* (days) in the gravid foetus and is given by:

$$\log_{10}(E_t) = 151.665 - 151.64e^{-0.00000576t} \quad [6.19]$$

6.2.7 Milk payment systems

There are well over 400 milk buyers, using a variety of payment systems, in South Africa (MPO, 2008). Most of these buyers are regionally based; however the major companies have a nationwide customer base and account for most of the market. The payment systems of four of these companies, which buy approximately 60% of the national milk output (MPO, 2008), were used to calculate milk revenue. Somatic cell count premium schemes of the two largest buyers were used to estimate the economic value of somatic cell count (SCC). It was not possible to use any information other than payment system because there is no transparency of product returns to milk values in South Africa. Furthermore, information could only be obtained on the four payment systems considered, which made it difficult to determine a general result of economic values across the whole industry. Due to the sensitivity of producer milk pricing in South Africa, milk buyers are not referred to by their names but as A, B, C and D and their payment systems as PS_A, PS_B, PS_C and PS_D, respectively.

6.2.7.1 Milk components

Table 6.4 contains the milk component prices of the four payment systems used. The main difference among the four payment systems is the relative prices of fat and protein and the fact that some buyers pay for volume while others do not.

Table 6.4: Milk component prices of four major payment systems

	Payment System			
Component	**A**	**B**	**C**	**D**
Fat (ZAR/kg)	16.00	20.60	17.26	19.00
Protein (ZAR/kg)	16.00	30.26	28.26	28.50
Volume (ZAR/l)	0.77	0.00	0.00	0.77

6.2.7.2 Somatic cell count

Most of the large milk buyers give a premium or impose a penalty on milk falling below or exceeding certain SCC thresholds. Somatic cell count premium schemes of the two major milk buyers, A and B, were used to simulate the effect of changes in SCC on revenue from the sale of milk. The two premium schemes are summarized in Table 6.5.

6.2.8 Beef prices

Prices that were used to calculate revenue from the sale of beef were obtained from the South African Meat Industry Company (SAMIC, 2008) and are contained in Table 6.6.

Table 6.5: Somatic cell count premium schemes for payment systems PS_A and PS_B

PS_A	
SCC Band (x1000 cells/ml)	**Penalty/Premium (c/l)**
<400	+0.4 for every 10 000 reduction in SCC up to maximum of +4
400 - 500	0.00
>500	-0.1 for every 10 000 increase in SCC up to maximum of -4
PS_B	
<350	+0.4 for every 10 000 reduction in SCC up to a maximum of +4
350 - 400	0.00
>400	-0.4 for every 10 000 increase in SCC up to a maximum of -10

Table 6.6: Beef price by class of stock

Class	**Price (ZAR)**[1]
Bull calves	250.00
Surplus heifers	21.46
Cull cows	18.89

[1] *Price per animal for bull calves and per kg of carcase for other classes*

6.2.9 Farm costs

Farm costs, excluding feed costs, were obtained for the pasture-based production system from the Milk Producers' Organisation (MPO, 2008) and results of surveys carried out by a private consulting company (*www.tammac.co.za*). These costs are presented in Table

6.7. The price of the total mixed ration (TMR) used in the concentrate-fed production system was ZAR2.90 per kg DM and was obtained from the Agricultural Research Council, Irene, dairy farm (Claude Mukengeleya, 2008, personal communication).

6.2.10 Traits

There was sufficient information to determine economic values for seven objective traits. These traits were milk yield (volume), fat yield, protein yield, live weight (as an indicator of expected cow maintenance), somatic cell score (SCS), longevity (productive life time) and calving interval. The base herd levels of these traits, for each breed and production system, are contained in Table 6.1.

6.2.11 Calculation of economic values

Economic values were calculated by first considering incomes and expenses for alternative herds, each herd differing from the base herd in only one trait. Incomes and expenses were expressed per cow in the herd per year. Six alternative herds differing from the base herd by 10 kg fat, 10 kg protein, 500 l milk, 50 kg live weight, 30 days calving interval and 10 days productive life time, respectively, were considered.

Differences from the base herd were greater than one unit, to reduce the chance of rounding errors. Results were scaled back to the effect on profit of a one unit change in the trait. It was assumed that costs per cow per year, excluding feed costs, remained constant. Further, it was assumed that increased feed requirements were met by buying in extra feed, in both production systems. In the context of the pasture-based system,

Table 6.7: Farm costs for the pasture-based production system

Item	Cost
Farm Expenses	
Interest rate (%)	15.00
Animal health (ZAR/cow)	455.04
Breeding & testing (ZAR/cow)	268.92
Farm dairy expenses (ZAR/cow)	390.24
Seed (ZAR/ha)	523.44
Fertiliser (ZAR/ha)	2469.00
Weeds & pest control (ZAR/ha)	319.08
Other/transport (ZAR/ha)	685.68
Mechanical costs	
Fuel & oils (ZAR/ha)	943.68
Tractor R&M (ZAR/ha)	399.60
Implement R&M (ZAR/ha)	221.76
Other mechanical costs (ZAR/ha)	429.00
Other fixed costs	
Insurance (ZAR/ha)	264.24
Electricity (ZAR/ha)	649.56
R&M fixed implements (ZAR/ha)	533.88
Other costs (ZAR/ha)	330.60
Sundry costs (ZAR/ha)	446.16

Source: www.tammac.co.za (Accessed 28 July 2009)

extra feed could be in the form of concentrate, silage, nitrogen or phosphate fertiliser, improved drainage or pasture cultivars, hay or more land. The actual price of feed (total mixed ration) was used to determine the cost of extra feed in the concentrate-fed system. In the pasture-based production system, it was assumed that purchased feed is obtained at opportunity cost defined as average revenue in the base situation, following Garrick (2002). Economic value was calculated as the change in profit (income less costs) per unit change in the trait. The methodology used for SCS was somewhat different and is described below. The model was validated by applying New Zealand data to the model in this study and comparing the results with those obtained by Livestock Improvement Corporation (LIC) of New Zealand (as published by Holmes *et al*., 2000).

Standardised relative economic values were determined to enable comparison of the relative importance of traits among the different milk payment systems. These were expressed in genetic standard deviation units relative to the standardised value for protein yield, as in, among others, Visscher *et al.* (1994) and Veerkamp *et al.* (2002). Genetic standard deviations used are given in Table 6.8 and were calculated from heritabilities and phenotypic variances. Phenotypic variances were determined from the data used to calculate base herd parameters. Heritability estimates for production traits, calving interval and SCS were obtained from the national genetic evaluation programme (B. E. Mostert, 2008, personal communication). The heritability estimate obtained recently for the Jersey breed by Du Toit *et al*. (2009) was used for longevity, for both breeds. Live weight is not routinely recorded in South Africa; therefore parameters used by Visscher *et al.* (1994) were assumed.

6.2.12 Calculation of economic value of SCS

Milk quality payment schemes in South Africa are based on herd-bulk-tank somatic cell count (SCC). Premiums or penalties (Table 6.4) are determined from a three-month rolling geometric mean for SCC. Bulk tank SCC were not available; hence they were calculated as the average of individual cow test-day SCC weighted by milk yield.

Table 6.8: Genetic standard deviations for traits by breed and production system

Trait	Concentrate		Pasture	
	Jersey	**Holstein**	**Jersey**	**Holstein**
Milk yield (l)	843.0	1 476.0	645.8	1 049.4
Fat yield (kg)	36.2	52.2	27.7	33.6
Protein yield (kg)	30.3	44.5	23.2	30.3
Live weight (kg)	34.2	49.3	37.9	45.5
Calving interval (days)	12.6	12.7	11.8	11.7
Longevity (days)	121.1	99.1	128.8	117.7
SCS (score)	0.35	0.42	0.41	0.37

Veerkamp *et al*. (2002) found that, when used to predict payment scheme penalties, calculated bulk tank samples are representative of real bulk tank samples. Each herd-test-day had a minimum of 10 cows. Additionally, each herd was tested for at least 5 times, with not more than 45 days between consecutive tests. The number of herds and bulk tank SCC tests by breed and production system are given in Table 6.9. The impact of SCC on milk revenue was calculated by first deviating each bulk tank SCC by -10% and +10%, to simulate low and high SCC situations. Next, the average gain or loss in revenue due to SCC level in each situation was calculated as follows:

i. Three-month rolling bulk tank SCC means were calculated for each herd.

ii. Penalty/premium (ZAR/litre) was determined for each rolling bulk tank mean.

iii. Average penalty/premium (ZAR/litre) of all rolling bulk tank means was calculated.

iv. Total penalty/premium (ZAR/cow/year) was calculated as the product of *iii* and milk yield (litres) per cow per year.

Table 6.9: Somatic Cell Count rolling averages by production system and breed

	Concentrate		**Pasture**	
	Jersey	**Holstein**	**Jersey**	**Holstein**
Number of Herds	40	95	143	114
Number of SCC rolling averages	858	2 154	3 110	2 538
SCC rolling average (x1000 cells/ml)	298	397	192	252

Economic value was calculated as the change in profit per percentage increase in SCC, per cow per year (i.e. difference in gain/loss of revenue between low and high SCC situations, scaled to 1% increase in SCC). Breeding values are calculated using $\log_e$ transformed SCC (somatic cell score, SCS); therefore the final economic value was expressed in ZAR per SCS.

6.2.13 Sensitivity analysis

There may be increases in dairy production input costs, particularly the price of feed, without corresponding adjustments in milk price. The sensitivity of economic values to such changes was assessed by gradually incrementing the price of feed in the concentrate-fed production system from ZAR2.90/Kg DM to ZAR4.00/Kg DM (40%

increase) and determining the effect on economic values. The effect on economic values of an increase in the price of beef was also examined by steadily raising the price of beef by up to 46.2 %. Economic values of the Jersey breed, averaged across payment systems, were used. Similar results would be expected in the Holstein as economic values are the same for milk composition traits and comparable for the other traits, between the two breeds.

6.2.14 Sire rankings

The existence of diverse markets (milk buyers) raises the question whether the same breeding objective can be used across the different payment systems. Furthermore, it is pertinent to know whether different breeding objectives, customised for each breed and production system, should be used or a single common objective will suffice. These questions were addressed by first obtaining the latest national EBVs of all sires with reliabilities for all objective traits of at least 40% and 50%, respectively, for the Jersey and Holstein breeds. There was a total of 105 Jersey and 264 Holstein sires. Next, aggregate EBVs of these sires, based on milk components (fat, protein and volume) and calving interval, were computed for each payment system in each production system. Aggregate EBVs including SCS were also determined for payment systems PS_A and PS_B. The aggregate EBV of animal *i* was calculated as:

$$AEBV_i = v_1EBV_{i1} + v_2EBV_{i2} + \ldots\ldots + v_tEBV_{it} \qquad [6.19]$$

where:

$AEBV_i$ = aggregate estimated breeding value of animal i,

EBV_{ij} = estimated breeding value of animal i for trait j,

v_j = the economic value of trait j, $j = 1 \ldots\ldots 5$.

Live weight and longevity could not be included in the aggregate EBVs as no EBVs were available for these traits. Economic values of these traits, however, did not differ much among production and payment systems; therefore, including them is not expected to cause a significant change in variation of aggregate EBVs among production and payment systems. Spearman's rank correlation was used to compare sire rankings among different payment systems, within and across production systems. In order to find out if different breeding objectives should be used for the Jersey and Holstein breeds, aggregate EBVs were calculated using economic values of the other breed, for each payment system in both production systems. Spearman's rank correlations were then computed between these aggregate EBVs and those based on the breed's own economic values.

6.3 Results

Economic values (ZAR per unit) by breed and payment system are presented in Table 6.10 for the concentrate-fed system and Table 6.13 for the pasture-based system. Standardised economic values, expressed in genetic standard deviation units relative to the standardised value for protein, are shown in Tables 6.10 and 6.13 respectively for the concentrate-fed and pasture based systems. Figures 6.1 and 6.2 depict the relative importance of traits graphically.

Economic values and standardized economic values for the two production systems are discussed in detail, separately, in the following sections.

6.3.1 Concentrate-fed system

Economic values of milk components (fat, protein and volume) in the concentrate-fed system were the same for both breeds; hence they are only presented for the Jersey breed in Table 6.10. Breed has no effect on economic values, under this production system, because change in profit per unit increase of a milk component is determined only by the payment price per unit of that component and the cost of the extra feed required to produce it. Economic values are therefore dependent only on the payment system and cost of feed. In this production system, the cost of feed is the same across breeds and payment systems.

Volume had negative economic value (-ZAR0.49 per litre) under those payment systems not paying for it (PS_B and PS_C). This is due to the fact that no revenue is received for producing any extra volume of milk; however it costs energy (feed) to produce the milk. Where volume is paid for (PS_A and PS_D) an increase in volume by 1 litre resulted in an increase in profit of ZAR0.28 per cow per year.

Payment system PS_B gave the largest economic values for both fat and protein. This is not unexpected as this payment system offers the highest price per kg of fat and per kg of protein. On the other hand payment system PS_A, which has the lowest fat and protein prices, resulted in the lowest economic values for the two traits. The fact that it is more costly (i.e. more energy is required) to produce a kg of fat than of protein is reflected in the much higher economic value of protein (ZAR7.62) compared to fat (ZAR1.21), even under a payment system where both components are equally priced (PS_A).

Economic values of live weight and calving interval were only affected by the difference in maintenance energy costs and beef revenue (for live weight) between the base and alternative herds. They were therefore constant across payment systems feeding concentrates. Increases in live weight or calving interval resulted in a decrease in profit. A one kg increase in live weight resulted in a larger decrease in profit in the Jersey (ZAR7.49 per cow per year) compared to the Holstein (ZAR6.62 per cow per year). This is partly due to the higher culling rate for the Holstein, which results in a larger increase in beef revenue in the alternative (higher live weight) herd, compared to the Jersey (see Appendix B). The converse was however true for calving interval (decreases of ZAR4.19 per cow per year in Jersey and ZAR5.75 per cow per year in Holstein). This is explained by the fact that it is more costly to maintain the bigger-sized Holstein than the Jersey. Economic value of longevity varied slightly among payment systems and this was due to the change in milk revenue resulting from the difference in herd structure between the base herd and the increased longevity herd. The increased longevity herd had a bigger proportion of higher producing (older) cows and therefore had more milk revenue per cow than the base herd. The magnitude of such increase in revenue is dependent on the payment system.

An increase in SCS by 1 score resulted in about double the reduction in profit under payment system PS_B compared to PS_A, for both breeds. This is due to the fact that buyer B has a more strict SCC payment scheme (lower SCC threshold for bonus and higher penalties for high SCC milk). The economic value of SCS was approximately double in the Holstein than in the Jersey, probably due to the fact that the mean SCC is higher for the Holstein than the Jersey. The economic value of SCS is known to be sensitive to the population mean (e.g. Dekkers *et al*., 1996; Veerkamp *et al*., 2002). The higher milk yield of the Holstein also results in a more pronounced loss in revenue per cow per year. A unit reduction in SCS will thus result in better marginal returns in the Holstein than in the Jersey.

Standardised economic values indicate the relative importance of the traits. In both breeds, protein is the most important trait under all except one payment system (PS_A). The values of live weight in the Jersey and volume, longevity and SCS in the Holstein exceed that of protein under this payment system. The importance of fat is low to moderate (15 – 32 % as important as protein) and similar in the Jersey and Holstein breeds. Where fat and protein are equally priced (PS_A), the value of fat is only19 % compared to that of protein, in both breeds. Volume has its largest value under payment system PS_A and is more important in the Holstein than in the Jersey.

Table 6.10: Economic values[1] (ZAR per unit) for concentrate-fed production system

Breed	**Trait**	**Payment System**			
		A	**B**	**C**	**D**
Jersey &	Fat (kg)	1.21	5.81	2.47	4.21
Holstein	Protein (kg)	7.62	21.88	19.88	20.21
	Milk (l)	0.28	-0.49	-0.49	0.28
Jersey	Longevity (days)	1.15	1.11	1.09	1.23
	Live weight (kg)	-7.49	-7.49	-7.49	-7.49
	Calving interval (days)	-4.19	-4.19	-4.19	-4.19
	Somatic cell score	-433.87	-912.90		
Holstein	Longevity (days)	3.68	3.59	3.59	3.67
	Live weight (kg)	-6.62	-6.62	-6.62	-6.62
	Calving interval (days)	-5.75	-5.75	-5.75	-5.75
	Somatic cell score	-949.26	-1795.57		

[1] *Economic values of milk production traits (fat, protein and volume) the same for both breeds.*

Table 6.11: Relative economic values for concentrate-fed production system standardised to protein

Breed	Trait[1]	Payment System			
		A	B	C	D
Jersey	Fat (kg)	0.19	0.32	0.15	0.25
	Protein (kg)	1.00	1.00	1.00	1.00
	Milk (l)	1.02	-0.62	-0.69	0.39
	Longevity (days)	0.60	0.58	0.22	0.24
	Live weight (kg)	-1.11	-0.39	-0.43	-0.42
	Calving interval (days)	-0.23	-0.08	-0.09	-0.09
	Somatic cell score	-0.65	-0.48		
Holstein	Fat (kg)	0.19	0.31	0.15	0.24
	Protein (kg)	1.00	1.00	1.00	1.00
	Milk (l)	1.22	-0.74	-0.82	0.46
	Longevity (days)	1.08	0.37	0.40	0.40
	Live weight (kg)	-0.89	-0.31	-0.34	-0.34
	Calving interval (days)	-0.22	-0.08	-0.08	-0.08
	Somatic cell score	-1.18	-0.78		

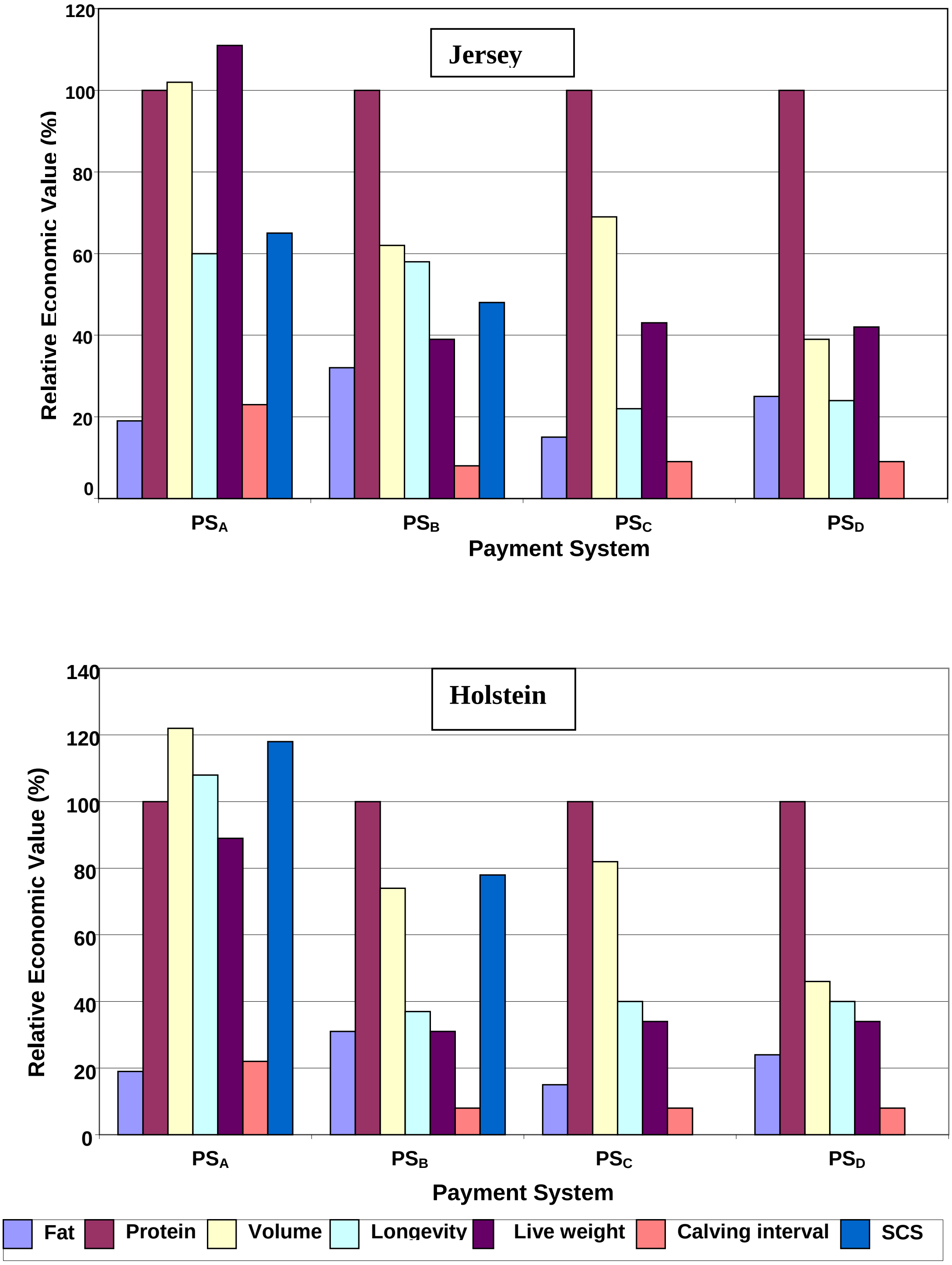

Figure 6.1: Relative importance of traits (%) for concentrate-fed system standardised to protein

Based on payment system PS_A, the value of volume is equal to that of protein in the Jersey whereas in the Holstein it is 22 % more important than protein. Longevity and SCS have higher relative value in the Holstein than in the Jersey while the converse is true for live weight. In the Holstein, longevity is 8 % more important than protein whereas in the Jersey it is 60 per as valuable as protein, under payment system PS_A. In the remainder of the payment systems, the value of longevity is in the range 22 – 58 % of protein. Live weight is 11 % more valuable than protein in the Jersey and 89 % as important as protein in the Holstein, under payment system PS_A. It is however much less important under the rest of the payment systems (31-43 % of protein). SCS is an important trait, ranging in value from 48 % of protein under payment system PS_B in the Jersey to 18 % more than protein in the Holstein under PS_A. Calving interval is the least important trait, with its value in both breeds being nearly the same and ranging from 8 to 23 % of that of protein.

6.3.2 Pasture-based system

Feed costs for the pasture-based system were calculated as average revenue per kg DM consumed in the base situation. Garrick (2002) demonstrated that, in grazing circumstances, the cost of feed required to meet demands resulting from genetic improvement could be determined this way. Table 6.12 shows that, under this production system, feed costs vary with breed and payment system. Under all payment systems, feed costs were higher in the Jersey than in the Holstein. Payment system PS_D gave the highest feed cost while PS_C had the lowest, in both breeds. Thus, unlike in the

Table 6.12: Net income per cow and average revenue per kg DM consumed (feed cost) by breed and milk buyer for pasture-based system.

Breed	**Payment System**	**Net Income[1] (ZAR/cow/year)**	**Average Revenue[2] (ZAR/kg DM)**
Jersey	A	11 221	1.91
	B	11 068	1.88
	C	9 992	1.70
	D	14 439	2.45
Holstein	A	15 256	1.90
	B	14 422	1.78
	C	13 030	1.60
	D	18 998	2.40

[1] *Calculated as milk revenue plus beef revenue less cow costs (excluding feed costs).*
[2] *Net income divided by dry matter intake per cow.*

concentrate-fed system, economic values of milk components differed between breeds and those of the rest of the traits varied across payment systems.

Trends for economic values were generally similar to those in the concentrate-fed production system. Due to the fact that feed costs were lower compared to the ZAR2.90 for the concentrate-fed system, economic values of milk components were higher. In addition, the difference between economic values of fat and protein was less than in the concentrate-based system. Economic values of volume were nearly the same across breeds and ranged from –ZAR0.27 (PS_C) to ZAR0.45 (PS_A). In accordance with feed costs, payment system PS_C gave the lowest economic values for longevity, live weight and calving interval while PS_D had the highest.

A unit increase in SCS caused lower decreases in profit compared to the concentrate-fed system (ZAR178.65 and ZAR 367.37 for the Jersey and ZAR491.48 and ZAR938 for the Holstein, respectively, for payment systems PS_A and PS_B). This may also be attributed to the lower SCS means in the pasture-based system.

Table 6.13: Economic values (ZAR per unit) for pasture-based production system

Breed	**Trait**	**Payment System**			
		A	**B**	**C**	**D**
Jersey	Fat (kg)	6.26	10.91	8.59	6.51
	Protein (kg)	10.48	24.77	23.35	21.42
	Milk (l)	0.45	-0.32	-0.28	0.36
	Longevity (days)	1.77	1.73	1.54	2.29
	Live weight (kg)	-4.63	-4.60	-3.93	-6.46
	Calving interval (days)	-2.47	-2.45	-2.19	-3.18
	Somatic cell score	-178.65	-367.37		
Holstein	Fat (kg)	6.36	11.52	9.10	6.76
	Protein (kg)	10.54	25.11	23.63	21.56
	Milk (l)	0.45	-0.30	-0.27	0.37
	Longevity (days)	3.68	3.59	3.59	3.67
	Live weight (kg)	-4.12	-3.78	-3.22	-5.71
	Calving interval (days)	-3.19	-3.00	-2.68	-4.05
	Somatic cell score	-491.48	-938.00		

Relative importance of traits also followed similar trends as in the concentrate-fed system; however there were marked differences in magnitude of the relative economic values of some traits. Protein is the most important trait but, under payment system PS_A, its value is exceeded by those of volume and longevity. The relative importance of fat differs marginally between the breeds and ranges from moderate to high (35-71 % of the value of protein). Volume is more important in the Holstein than in the Jersey and its relative economic value varies from 33 % of protein (Jersey and PS_C) to 48 % more than protein (Holstein and PS_A). Longevity is important for both breeds and under all payment systems, although its relative economic value varies widely (37 % of protein to 36 % more valuable than protein). Live weight also varies considerably in importance, ranging from 22 % of protein (Holstein and PS_C) to 72 % of protein (Jersey and PS_A).

Similar to the concentrate-fed system, calving interval is the least important trait; its relative economic value is not influenced by breed and shows little variation (5-12 % of protein) across payment systems. Relative economic values of SCS are less than in the concentrate-fed system and higher in the Holstein than in the Jersey.

Table 6.14: Relative economic values for pasture-based production systems standardised to protein

Breed	Trait	Payment System			
		A	**B**	**C**	**D**
Jersey	Fat (kg)	0.71	0.52	0.44	0.36
	Protein (kg)	1.00	1.00	1.00	1.00
	Milk (l)	1.19	-0.36	-0.33	0.47
	Longevity (days)	0.94	0.39	0.37	0.59
	Live weight (kg)	-0.72	-0.30	-0.28	-0.49
	Calving interval (days)	-0.12	-0.05	-0.05	-0.08
	Somatic cell score	-0.30	-0.26		
Holstein	Fat (kg)	0.67	0.51	0.43	0.35
	Protein (kg)	1.00	1.00	1.00	1.00
	Milk (l)	1.48	-0.41	-0.40	0.59
	Longevity (days)	1.36	0.56	0.59	0.66
	Live weight (kg)	-0.64	-0.25	-0.22	-0.43
	Calving interval (days)	-0.12	-0.05	-0.04	-0.07
	Somatic cell score	-0.57	-0.45		

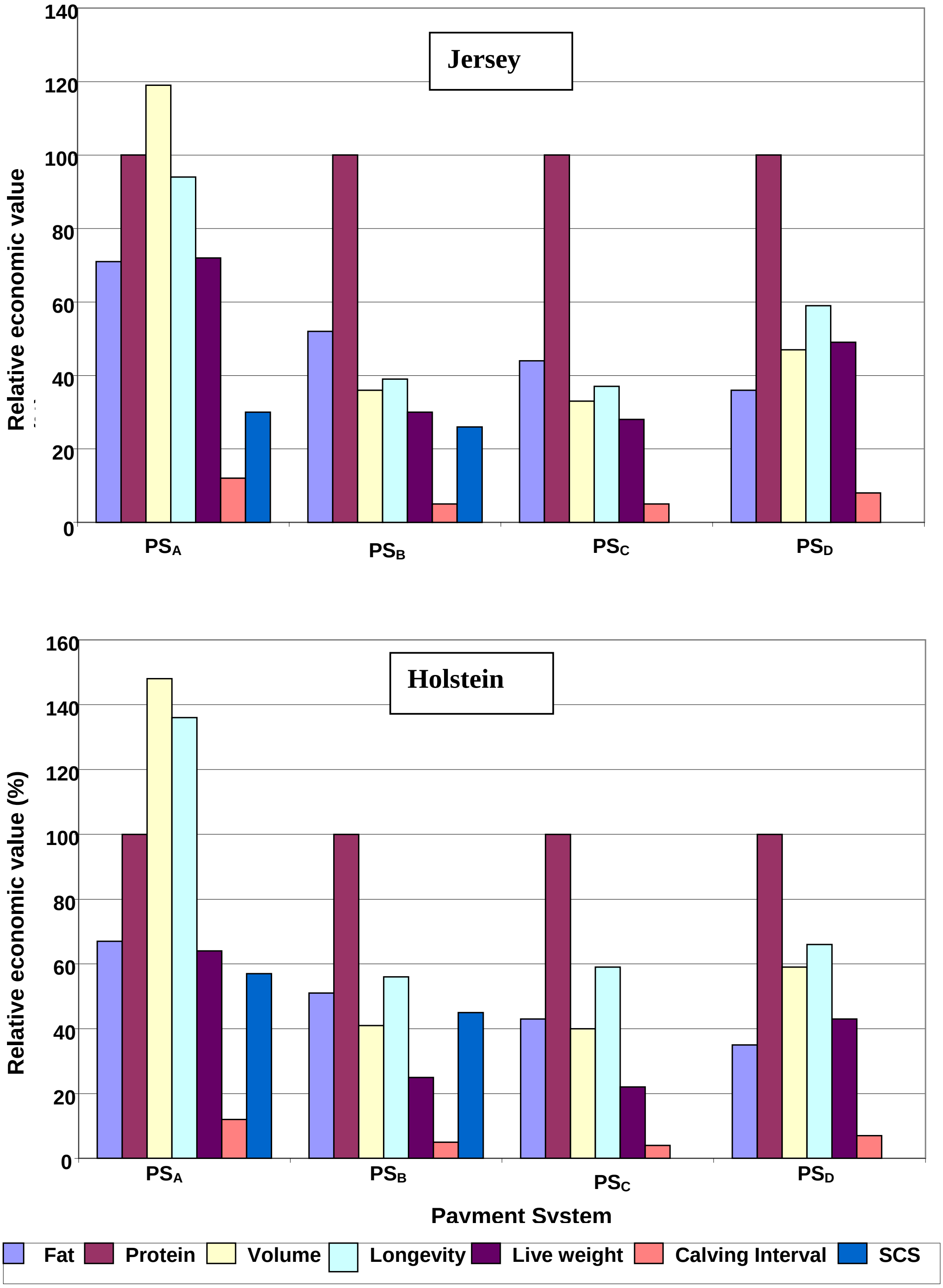

Figure 6.2: Relative importance of traits (%) for pasture based system standardised to protein

6.3.3 Sensitivity analysis

The linear response of economic values to increasing feed price is illustrated in Figure 6.3. On the whole, the change in economic values is marginal. Fat shows the largest sensitivity, its economic value becoming negative as the feed price exceeds ZAR3.50/Kg DM. Economic values for longevity and volume are the most robust. Figure 6.4 shows the effect of increasing the price of beef on economic values. Economic values for production traits are not influenced by the price of beef; hence they are not included in this Figure. Higher beef prices do not cause a significant change in economic values for longevity and calving interval. The economic value of live weight, however, decreases marginally from –ZAR7.49 to –ZAR6.50 following a 46.2% rise in the price of beef.

6.3.4 Sire rankings

Table 6.15 shows means and standard deviations of aggregate EBVs for the different payment systems, for each breed in each production system. Means and standard deviations are invariably greater for the Jersey than the Holstein breed as well as the pasture compared to the concentrate-fed production system. Payment system PS_D consistently has the highest and PS_C the lowest mean and standard deviation.

Comparisons of sire rankings on aggregate EBVs among the different payment systems, within and across production system, are illustrated by correlation coefficients in Table 6.16. All correlations are significant ($P<0.001$) and, overall, considerably high. Trends are similar between the Jersey and Holstein breeds. Correlations are exceptionally strong (nearly 1.00) between PS_A and PS_D, indicating that sire rankings are basically identical

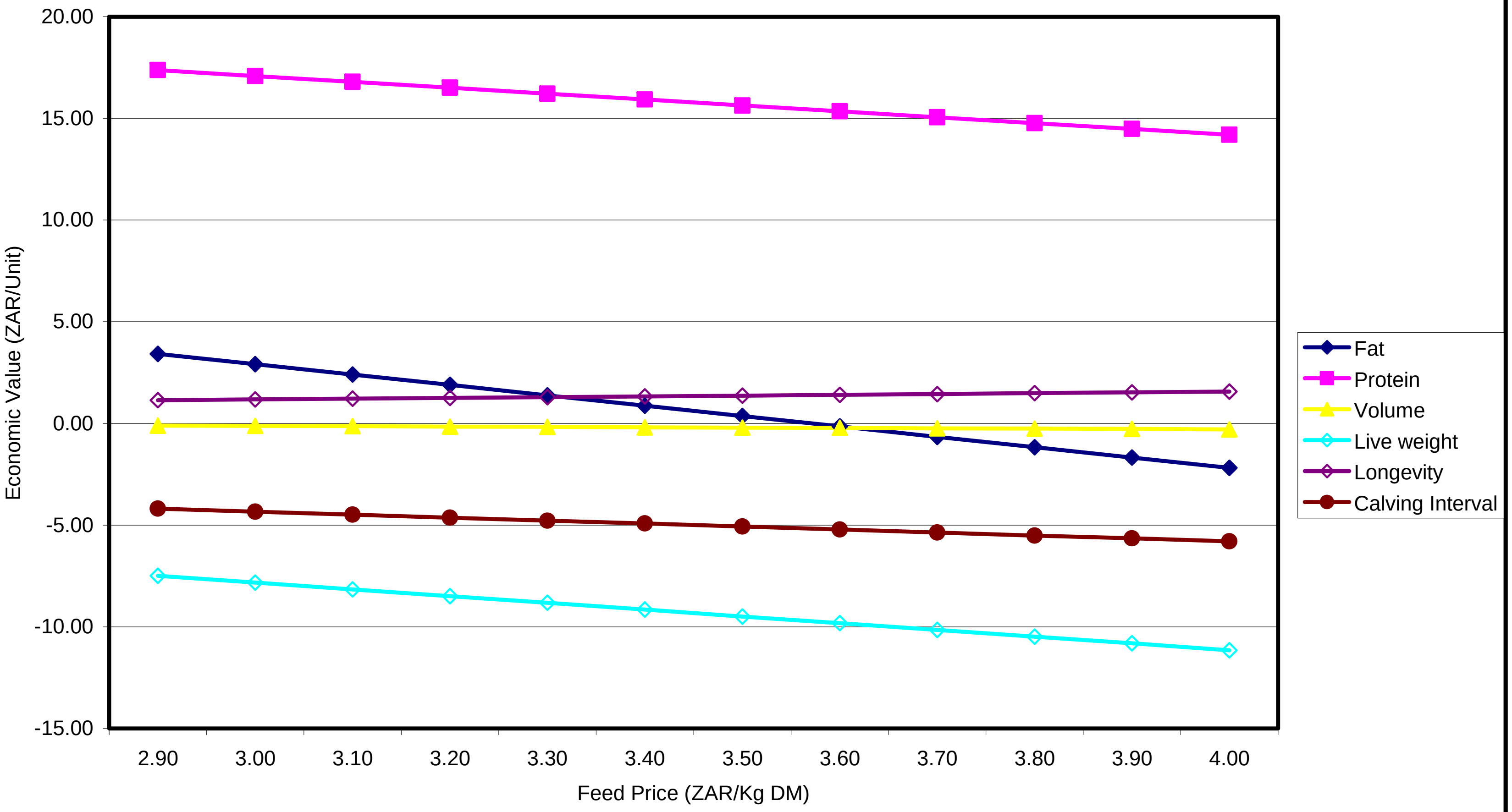

Figure 6.3: Sensitivity of economic values to feed price

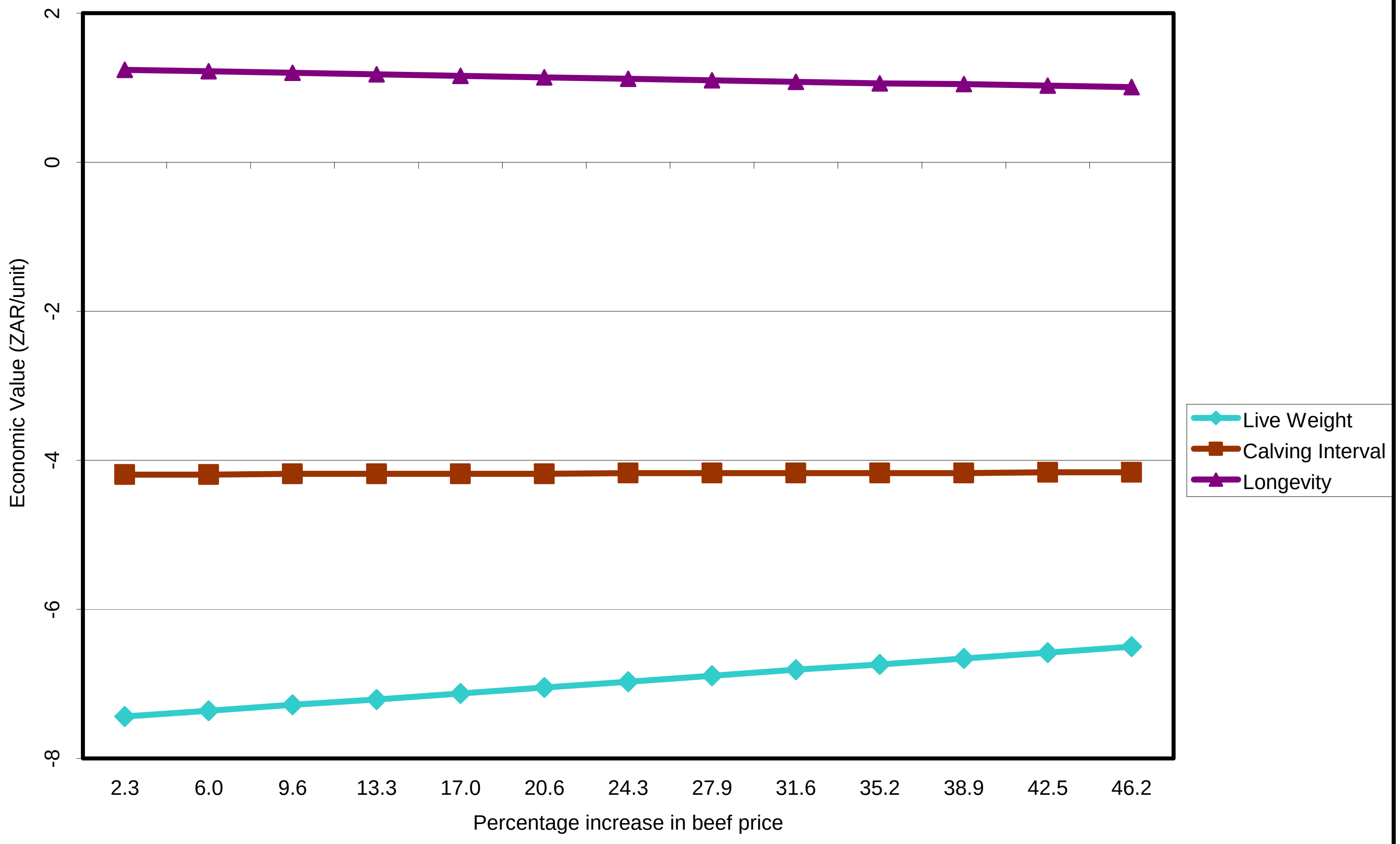

Figure 6.4: Sensitivity of economic values to beef price

Table 6.15: Means and standard deviations (in brackets) of aggregate EBVs (ZAR) for the different payment systems, within breed and production system.

Payment System	Concentrate		Pasture	
	Holstein	Jersey	Holstein	Jersey
A	97.37(166.31) 70.02(262.64)	111.73(173.37) 113.07(184.09)	206.98(306.60) 192.81(324.25)	217.23(309.46) 217.78(309.44)
B	67.90(172.96) 16.17(420.45)	100.26(177.34) 103.08(245.43)	189.31(294.43) 162.28(355.58)	206.48(288.61) 207.62(297.59)
C	27.15(139.39)	55.33(131.03)	167.43(262.76)	183.80(256.46)
D	208.98(322.89)	229.41(329.11)	265.76(396.01)	277.89(391.79)

Values in blue are for aggregate EBVs including SCS

Table 6.16: Spearman's rank correlation coefficients among aggregate EBVs of Jersey (above diagonal) and Holstein (below diagonal) sires, based on economic values for the different production and payment systems.

		Concentrate				**Pasture**			
		PS_A	**PS_B**	**PS_C**	**PS_D**	**PS_A**	**PS_B**	**PS_C**	**PS_D**
Concentrate	**PS_A**		0.56 0.62	0.38	0.99	0.98 0.94	0.80 0.82	0.82	0.98
	PS_B	0.50 0.84		0.97	0.66	0.61 0.47	0.92 0.82	0.91	0.67
	PS_C	0.32	0.95		0.49	0.40	0.77	0.76	0.47
	PS_D	0.97	0.62	0.42		0.99	0.88	0.90	1.00
Pasture	**PS_A**	0.96 0.83	0.50 0.50	0.28	0.98		0.85 0.86	0.87	0.99
	PS_B	0.76 0.85	0.87 0.80	0.70	0.88	0.83		0.99	0.88
	PS_C	0.77	0.87	0.70	0.89	0.83	0.99		0.90
	PS_D	0.96	0.60	0.38	0.99	0.99	0.88	0.89	

Coefficients in blue are for aggregate EBVs including SCS. All coefficients significant ($P<0.001$)

between the two payment systems. Sire rankings are also closely similar (correlations mostly greater than 0.90) between PS_B and PS_C. The weakest correlations are between PS_A and PS_C; these go below 0.50 in a few cases. Most correlations of the same payment system, between the concentrate and pasture-based production systems, are close to 1.00. This means that, for a particular payment system, economic values based on either production system result in practically the same sire rankings. Inclusion of SCS in the aggregate EBV generally does not cause much change in the magnitude of correlations. All correlations between aggregate EBVs calculated on the breed's own and the other breed's economic values (not shown) are practically 1.00, implying no breed effect.

6.4 Discussion

The current study follows two known earlier attempts to determine economic values for dairy production traits in South Africa (Du Plessis and Roux, 1998; Tesfa, 2002). Both previous studies were, however, limited to the Holstein breed. Keller and Allaire (1990) showed that economic values may vary significantly among breeds. Furthermore, the work of Du Plessis and Roux (1998) was based only on the concentrate-fed production system and Tesfa (2002) did not consider any particular feeding system.

Du Plessis and Roux (1998) calculated economic weights, expressed as percentage change in economic efficiency, under a fluid (fresh milk and yoghurt) and a manufacturing (cheese and butter) market. It is not clear if the milk component prices they used for these markets represent any of the payment systems used in the current study. Tesfa (2002), on the other hand, only calculated economic values for milk production traits (volume, fat yield and protein yield) and assumed the milk component prices to represent the economic values. Thus, Tesfa (2002) assumed a perfect pricing system where producers are appropriately rewarded for the value of their milk and also did not account for the cost of producing milk components. The milk component prices used by Tesfa (2002) do not correspond to any of the payment systems used in this study. Due to all these inconsistencies in methodology, it is difficult to compare the results of Du Plessis and Roux (1998) and Tesfa (2002) with those of the current study.

6.4.1 Milk components

The observation that protein is the most important trait is largely consistent with trends in manufacturing markets with multiple-component pricing systems (Gibson, 1989; Bekman and Van Arendonk, 1993; Visscher *et al*., 1994; Pieters *et al*., 1997; Holmes *et al*., 2000; St-Onge *et al*., 2002; Veerkamp *et al*., 2002). In such markets, increased protein yield typically results in positive marginal returns and the value of protein is usually higher than that of the other milk components. In fluid markets, where it has no value, protein may however have negative economic value (Gibson, 1989; Keller and Allaire, 1990; Harris and Freeman, 1993; St-Onge *et al*., 2002). Fat is less important than protein under most payment systems and may have negative economic value in fluid milk markets or under production quotas (Harris and Freeman, 1993; Pieters *et al*., 1997; Kahi and Nitter, 2004; Wolfová *et al*., 2007). In the current study, the value of fat is much lower than that of protein under all payment systems, particularly in the concentrate-fed system where it ranges from 15 to 32 % as important as protein. This generally concurs with values reported elsewhere under multiple-component pricing systems (Visscher *et al*., 1994;

Pieters *et al*., 1997; Holmes *et al*., 2000; Veerkamp *et al*., 2002). The current selection index for the South African Holstein breed (BVI) however gives equal weight to fat and protein, while the Jersey SAINET gives double the emphasis to protein relative to fat. This implies that, given the parameters used in the current study, fat is over-valued in these two indices, especially in the concentrate-fed system. In the pasture-based system, however, the relative emphasis of fat to protein appears reasonable in the SAINET as it falls within the 36 – 71 % range obtained in the current study.

Volume should have negative economic value in a predominantly product manufacturing market as it is a cost to the system. Hence volume is negatively priced in markets where most of the milk is processed into products, such as the US cheese market (Keller and Allaire, 1990), Australia (Visscher *et al*., 1994), New Zealand (Holmes *et al*., 2000) and Ireland (Veerkamp *et al*., 2002). Negative economic values for volume under payment systems where it has no value (PS_B and PS_C) are consistent with expectations and have been reported in other markets where volume is either not paid for or is negatively priced (Gibson, 1989; Bekman and Van Arendonk, 1992; Gibson *et al*., 1992; Visscher *et al*., 1994; Pieters *et al*., 1997; Holmes *et al*., 2000; Vargas *et al*., 2002; Veerkamp *et al*., 2002). Under a fluid milk market with a volume based payment system, however, volume has been found to have positive economic value (Harris and Freeman, 1993; Du Plessis and Roux, 1998; Kahi and Nitter, 2004). The relative economic importance of volume obtained in this study, particularly under payment system PS_A, is higher than values reported in other studies (Keller and Allaire, 1990; Visscher *et al*., 1994; Veerkamp *et al*., 2002). This may be explained by the relatively high rewards for volume compared to protein under this payment system. Results of the current study suggest that at least 33 % emphasis, relative to protein, should be placed on volume in breeding objectives for dairy cattle in South Africa. Either positive or negative emphasis should be made, depending on the payment system used. On the other hand, the Holstein BVI has zero weight while the Jersey SAINET places about 17 % positive emphasis on volume, relative to protein. This implies that the importance of volume is understated in both indices. Cognisance is also not taken of the fact that the direction of selection for volume should be aligned with the payment system.

6.4.2 Live weight

The current study highlights the importance of live weight and indicates that increased live weight is associated with a decrease in profit. This is a widely observed phenomenon (Visscher *et al*., 1994; Du Plessis and Roux, 1998; Holmes *et al*., 2000; Koenen *et al*., 2000; Nielsen *et al*., 2004; Nielson *et al*., 2006; Pérez-Cabal *et al*., 2006; Wolfová *et al*., 2007) and can be explained by the fact that marginal costs associated with increased energy requirements for raising heifers and higher maintenance requirements for lactating cows exceed marginal revenues from increased live weight of disposed stock (Groen, 1989). Contrary to these results, however, Vargas *et al*. (2002) and Kahi and Nitter (2004) reported positive economic values for live weight. Such results may theoretically be possible in a market where the price of beef relative to feed is such that marginal revenue from increased live weight is more than marginal costs of raising larger heifers and maintaining heavier lactating cows.

Despite its importance as an indicator of feed costs, live weight is generally ignored in dairy cattle selection programmes. Only a few countries, such as Finland (Hietanen and Ojala (1995), New Zealand (Holmes *et al.*, 2000) and Australia (Hayes *et al.*, 2009) include live weight in their selection criteria. In South Africa, the Holstein BVI places positive emphasis while the Jersey SAINET has zero weight on rump height and rump width, traits that are known to bear strong and positive correlations with live weight (Heinrichs *et al.*, 1992; Veerkamp and Brotherstone, 1997; Koenen and Groen, 1998). Results obtained in the current study point out the need to revise these perspectives.

6.4.3 Longevity

According to the herd model used in this study, increased longevity affects profit by: (i) increasing milk yield through an increase in the proportion of older (higher producing) cows, (ii) reducing energy requirements for cow growth by lowering the proportion of younger cows, (iii) reducing the number of replacement heifers, thus decreasing replacement costs and increasing the number of cull heifers for sale and (iv) reducing revenue from cull cows. Cumulatively, these factors amount to an increase in profit, in agreement with several other studies (Harris and Freeman, 1993; Visscher *et al.*, 1994; Du Plessis and Roux, 1998; Veerkamp *et al.*, 2002; Kahi and Nitter, 2004; Nielsen *et al.*, 2004; Wolfolvá *et al.*, 2007). Since the increase in milk revenue through (i) is dependent on payment system, the economic value of longevity varies slightly among payment systems in the concentrate-fed production system. In the pasture-based production system, the variation is more pronounced as feed costs differ among payment systems, resulting in further variation due to (ii).

Longevity shows up in the current study as one of the most important traits in breeding objectives for dairy cattle in South Africa, exceeding the value of protein in the Holstein breed under payment system PS_A. Its value relative to protein, under the rest of the payment systems, compares well with values reported by Visscher *et al*. (1994) and Veerkamp *et al*. (2002). Du Plessis and Roux (1998) however found longevity to rank low in South African Holsteins. This disparity may partly be attributable to differences in models, definition of traits, payment systems and other parameters used.

The fact that longevity is more important in the Holstein than Jersey breed may be explained, in part, by the difference in population means. Economic values are known to be sensitive to the population mean, for non-production traits. Jersey cows have longer productive life than the Holsteins. Improvement in longevity in the Holstein population therefore results in a higher increase in profit than in the Jersey.

6.4.4 Calving interval

Calving interval is an indicator of cow fertility, with long calving interval signifying poor fertility. According to the model used, the economic value of calving interval reflects maintenance costs associated with extended inter-calving periods. Other costs related to cow fertility such as replacement and insemination costs are not accounted for. The economic value of calving interval is therefore probably underestimated.

The economic value of calving interval is negative because of marginal costs arising from higher maintenance requirements of cows with longer inter-calving periods. Although not accounted for by the model used in the current study, extended calving interval is also associated with costs related to impaired reproductive performance such as herd replacement and insemination costs (Esslemont and Kossaibati, 1997; Plaizier *et al*., 1997; French and Nebel, 2003). Negative economic values for calving interval have also been reported by Plaizier *et al*. (1997), Stott *et al*. (1999) and Veerkamp *et al*. (2002). On the contrary, Du Plessis and Roux (1998) and Kahi and Nitter (2004) observed positive marginal returns from extended calving interval. Such discrepancies may, in part, be explained by differences in elements contained in the models as well as parameters used. For example, under the model of Du Plessis and Roux (1998), increased calving interval was also associated with an increase in income from the sale of livestock. This element is however not included in the model used in the current study; a simulated increase in calving interval does not result in a change in culling rate. The big difference between the weight of calving interval under payment system PS_A and the rest of the payment systems shows that milk pricing may also be a factor contributing to disparity among results from different studies.

Although they used a rather different model, Du Plessis and Roux (1999) also found calving interval to be the least important objective trait in South African Holsteins. Veerkamp *et al.* (2002) reported a relative economic value of -0.21 for calving interval, compared to protein. This compares well with the -0.22 obtained in this study for the Holstein breed under payment system PS_A. Further work should, however, attempt to develop a more comprehensive model for calving interval that incorporates other factors related to reproductive performance, such as replacement and insemination costs.

6.4.5 Somatic cell score

The economic value of SCS represents the marginal loss in revenue attributable to penalties/reduced premiums resulting from marginal increases in SCC. It does not include losses related to mastitis, such as increased labour and therapy costs, discarded milk, and premature culling of cows. Winkelman *et al.* (2003) calculated the economic value of SCC in New Zealand dairy cattle based on the costs of dry cow therapy, incidence of clinical mastitis, penalty for high SCC milk, lost days in milk and inhibitory substances. Other researchers (Sender *et al.*, 1992; Dekkers *et al.*, 1996; Veerkamp *et al.*, 1998) however used the approach of the present study. Sender *et al.* (1992) and Colleau and Le Bihan-Duval (1995) determined relative economic values for SCC and resistance to mastitis separately and Sender *et al.* (1992) noted that such an approach was better in improving resistance to mastitis and milk quality than using only either of the traits. Furthermore, Veerkamp *et al*. (1998) suggest that other benefits related to a decrease in SCC (i.e. resistance to mastitis) may be included in the breeding objective in their own right. In South Africa, available data do not allow these other benefits to be quantified. Resistance to mastitis may therefore be added to the breeding objectives as and when data to determine its economic value become available.

Milk quality premium schemes vary among and within countries. In addition, the economic value of SCS is strongly dependent on the population mean (Dekkers *et al.*, 1996; Veerkamp *et al.*, 1998). These factors result in considerable variation in the economic value of SCS among different studies. The current work shows SCS to be of high relative value (26 – 118 % as important as protein). Colleau and Le Bihan-Duval

(1992), however, reported an economic value of SCS relative to production of only 0.07 under French conditions. The sensitivity of the economic value of SCS to the mean is reflected in its variation between breeds and production systems, in the present study. Mean SCS is lower in the pasture-based than in the concentrate-fed production system and the Holstein breed has a higher mean SCS compared to the Jersey. These differences correspond to the trends in economic values and highlight the need to determine economic values for each population and production system. Since mean SCS is likely to change with time, this also means that it is important to calculate economic values regularly.

6.4.6 Sensitivity analysis

Economic values are, in general, reasonably robust to increases in the price of feed or beef. Due to the relatively high cost (energy requirements) of producing fat, its value declines faster compared to the other traits, as the price of feed increases. Beyond the feed price of ZAR3.50/Kg DM the economic value of fat becomes negative, indicating that it turns into a cost to the system. The relatively high positive emphasis that is placed on fat in the Holstein BVI and Jersey SAINET is therefore questionable, particularly under the current and projected future environment of escalating feed costs.

6.4.7 Sire rankings

Selection on aggregate EBVs based on economic values for payment system PS_D is expected to result in the largest response, as these have the highest means and standard deviations. The same is true for the Jersey relative to the Holstein breed and the pasture *versus* the concentrate-fed production system.

Predominantly strong correlations among aggregate EBVs indicate that, notwithstanding considerable variation in relative importance of traits, sire rankings do not differ significantly across the different production and payment systems. This is particularly true for payment systems PS_A *versus* PS_D and PS_B relative to PS_C. Correlations between payment systems PS_A and PS_D are exceptionally high because they both reward milk volume. Similarly, volume has no value under PS_B and PS_C, and sire rankings between the two payment systems are notably alike. Relatively weak correlations between payment systems PS_A and PS_C imply that there may be considerable re-ranking of sires between the two payment systems. Thus, there is no compelling basis for customising breeding objectives for the different payment systems; however the relatively low correlations between PS_A and PS_C should be noted. Strong correlations for the same payment system, compared across production systems and between breeds, imply that a common breeding objective is adequate for the Holstein and Jersey breeds as well as the concentrate-fed and pasture-based production systems.

6.5 Conclusions

The final step in developing breeding objectives, that is determination of the relative importance of objective traits, was carried out in this Chapter. Traits in the breeding objectives were milk composition (fat, protein, volume), live weight, longevity, calving interval and somatic cell score. Economic values of these traits were computed for South

African Holstein and Jersey cattle in concentrate-fed and pasture-based production systems, using four alternative major milk payment systems. The resulting economic values are reasonably robust to changes in the price of feed, although the value of fat deteriorates to being a cost to the system, at high feed prices. Relative importance of most traits varies considerably among breeds, production systems and payment systems. Ranking of sires on aggregate EBVs, however, does not differ much across breeds, production systems and most payment systems. A single breeding objective may therefore be used across breeds, production systems and payment systems. The complexity of implementing and educating industry about numerous breeding objectives, customized for the different breeds, production systems and payment systems would, in any case, be prohibitive. A breeding objective based on economic values of payment system PS_D is recommended for implementation as it will result in the largest response to selection.

Chapter 7

Overall Conclusions and Recommendations

7.1 Overall Conclusions

This study followed a systematic approach to develop breeding objectives for Holstein and Jersey dairy cattle breeds in South Africa. The first step involved the application of a logical framework with a profit focus to develop plausible selection goals for pasture-based and concentrate-fed dairy production systems in South Africa, leading to a list of objective traits influencing these goals and subsequently their possible selection criteria. Economic values were calculated for those objective traits for which there was adequate bio-economic data, *viz* milk volume, fat yield, protein yield, live weight, longevity, calving interval and somatic cell score (SCS). A sensitivity analysis showed that these economic values are generally robust to fluctuations in feed cost. Although there was considerable variation in the relative importance of traits across milk payment systems, breeds and production systems, this did not translate to a significant re-ranking of sires on aggregate estimated breeding value. A single breeding objective can, therefore, be practically implemented and used for both the Holstein and Jersey breeds, across the different production and payment systems. The basis for multiple-trait selection of the major dairy cattle breeds in South Africa has thus been developed. Considerable work needs to be done to enhance this breeding objective as well as facilitate its wide adoption by industry, as discussed in the following recommendations.

7.2 Recommendations

7.2.1 Enhancing the Breeding Objective

A breeding objective should ideally include all economically relevant traits. Although their economic values have been determined, live weight and longevity cannot presently be included in the breeding objective, as they are not routinely evaluated under the national genetic evaluation programme. This is despite indications from the current study that these traits are of high importance. Efforts are underway to routinely produce EBVs for longevity; however live weight is not even routinely recorded. Several other traits identified as economically relevant in South African dairy cattle (Table 4.2) or their indicator traits are also not recorded under the national dairy recording scheme. The South African dairy industry therefore needs to initiate efforts to build on the work of this study by developing the means to collect relevant data, and evaluate the traits in order that they might be incorporated in the breeding objective. This will entail collecting more data under the national dairy cattle recording scheme, coupled with appropriate research. For example, live weights could be collected on progeny test daughters, probably through some incentives to the farmers. The possibilities of using indicator traits, such as stature or rump height, as surrogate traits for live weight also need to be investigated. These indicator traits are already routinely recorded and genetically evaluated in South Africa and have been shown to be good predictors of live weight (Heinrichs *et al.*, 1992; Mantysaari, 1996; Veerkamp and Brotherstone, 1997; Koenen and Groen, 1998). The utility of several other traits that are routinely recorded under the national dairy recording scheme (e.g. milk urea nitrogen, linear type traits) in improving the prediction of breeding objective traits also needs to be investigated.

In addition to incorporating other economically relevant traits into the objective, economic values will need to be updated regularly, in order to account for changes in management, production and economic parameters and to exploit any improvements in the bio-economic models developed as part of the research reported in this thesis. For example, the economic value of calving interval calculated in this study is probably underestimated because costs related to cow fertility such as replacement and insemination costs are not taken into account by the model used. Improvements to this model will also entail the collection of more data, over and above what is currently recorded under the national dairy recording scheme.

The breeding goals defined in Chapter 4 are expressed per unit of limiting factor in the respective production system. Hence, it is important that the breeding objective be expressed accordingly. Further work needs to be done, in consultation with industry, to determine the most effective way of expressing the objective and investigate whether this will justify different breeding objectives for the different production systems. The effect of discounting economic values to account for different times and numbers of expression of traits also needs to be studied in the same context.

7.2.2 Promoting use of the Breeding Objective

A breeding objective is practically worthless unless it is widely adopted by industry. To this end, there is a need for concerted extension efforts to communicate the concept and promote the use of the breeding objective. The industry needs to be enlightened about a number of fundamental issues relating to the principles and functions of the breeding objective. In the South African dairy industry, there is a need to prompt a paradigm shift with regard to the roles of different traits in improving total economic merit. The current notion is that any trait that is routinely recorded and genetically evaluated is economically relevant. This is demonstrated by the portfolio of traits in the Holstein BVI and Jersey SAINET. A clear understanding of the difference between traits that are economically relevant and those that only serve to predict other traits therefore needs to be promoted. A Particularly challenging issue will be to convince the industry that type traits are not economically relevant; their role is to predict traits in the breeding objective. It needs to be explained that type traits will not be dispensed with but they will contribute to the breeding objective through their use in predicting traits such as longevity, somatic cell count, health and fertility. They will thus still form an integral part of the multiple trait selection process. There is a pressing need to carry out research to develop such predictions.

Implementation of an index denoting a breeding objective can be facilitated by its expression (Dekkers and Gibson, 1998). There is therefore a need to give the index a name that aptly describes its purpose and meaning. Expressing it in monetary units (ZAR) may also facilitate its adoption (Dekkers and Gibson, 1998). These decisions would need to be made with active industry engagement, in order to facilitate easier acceptance. Online publication of sire aggregate EBVs, supported by concise and clear explanatory materials, may help to expedite industry adoption. In addition, providing such easy access of net genetic merit of South African sires may help to market them, both locally and globally.

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Appendix A1: Age structure and survival and production per age group for an average concentrate-fed Jersey herd

Age group (parity)	Age (months)	Number/100 herd	Survival	Number culled/100 herd	Milk yield/cow/year (kg)	Milk yield/cow/year (l)	Fat yield/cow/year (kg)	Protein yield/cow/year (kg)	Live wt (kg)
1	25	31.9	0.715	9.1	5750	5583	272	211	398
2	38	22.8	0.785	4.9	6574	6383	311	244	434
3	51	17.9	0.631	6.6	6905	6704	326	257	445
4	65	11.3	0.646	4.0	7043	6838	328	259	448
5	77	7.3	0.562	3.2	6880	6680	322	253	450
6	91	4.1	0.634	1.5	6742	6546	316	248	450
7	104	2.6	0.500	1.3	6458	6270	298	234	450
8	117	1.3	0.462	0.7	6188	6008	283	223	450
9	130	0.6	0.333	0.4	5945	5772	272	215	450
10	143	0.2	0.000	0.2	5930	5757	258	206	450
Average	**47.8**			**31.9**	**6440**	**6252**	**303**	**238**	**432**

Appendix A2: Age structure and survival and production per age group for an average pasture-based Jersey herd

Age group (parity)	Age (months)	Number/100 herd	Survival	Number culled/100 herd	Milk yield/cow/year (kg)	Milk yield/cow/year (l)	Fat yield/cow/year (kg)	Protein yield/cow/year (kg)	Live wt (kg)
1	26	26.6	0.808	5.1	4691	4554	219	174	402
2	40	21.5	0.823	3.8	5280	5126	250	199	435
3	53	17.7	0.746	4.5	5574	5412	263	209	445
4	66	13.2	0.689	4.1	5715	5549	267	213	449
5	79	9.1	0.582	3.8	5696	5530	265	211	450
6	92	5.3	0.623	2.0	5741	5574	264	212	450
7	105	3.3	0.545	1.5	5566	5404	254	205	450
8	118	1.8	0.556	0.8	5466	5307	249	200	450
9	130	1.0	0.500	0.5	5252	5099	240	192	450
10	141	0.5	0.000	0.5	5036	4889	232	185	450
Average	**53.3**			**26.6**	**5306**	**5152**	**248**	**198**	**438**

Appendix A3: Age structure and survival and production per age group for an average concentrate-fed Holstein herd

Age group (parity)	Age (months)	Number/100 herd	Survival	Number culled/100 herd	Milk yield/cow/year (kg)	Milk yield/cow/year (l)	Fat yield/cow/year (kg)	Protein yield/cow/cow (kg)	Live wt (kg)
1	26	34.6	0.801	6.9	9222	8945	352	294	569
2	41	27.8	0.647	9.8	10495	10180	403	336	628
3	55	18.0	0.587	7.4	10630	10311	406	337	644
4	67	10.5	0.522	5.0	10567	10250	401	333	648
5	80	5.5	0.421	3.2	10069	9767	385	318	649
6	93	2.3	0.396	1.4	10048	9747	377	312	650
7	105	0.9	0.429	0.5	9640	9351	361	298	650
8	116	0.4	0.000	0.4	9157	8882	343	282	650
Average	**45.3**			**34.6**	**10039**	**9738**	**383**	**319**	**626**

Appendix A4: Age structure and survival and production per age group for an average pasture-based Holstein herd

Age group (parity)	Age (months)	Number/100 herd	Survival	Number culled/100 herd	Milk yield/cow/year (kg)	Milk yield/cow/year (l)	Fat yield/cow/year (kg)	Protein yield/cow/year (kg)	Live wt (kg)
1	28	26.3	0.906	2.5	6333	6149	244	205	591
2	42	23.8	0.785	5.1	7277	7065	280	236	630
3	55	18.7	0.713	5.4	7704	7480	294	247	644
4	68	13.3	0.696	4.1	7836	7608	297	248	648
5	81	9.3	0.517	4.5	7799	7572	296	246	649
6	93	4.8	0.558	2.1	7758	7532	293	243	650
7	105	2.7	0.446	1.5	7441	7224	281	233	650
8	117	1.2	0.000	1.2	7519	7300	283	234	650
Average	**52.8**			**26.3**	**7262**	**7050**	**278**	**233**	**639**