NOVELTY TRAITS TO IMPROVE COW-CALF EFFICIENCY IN CLIMATE SMART BEEF PRODUCTION SYSTEMS

BY:

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Declaration

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M.C Mokolobate

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CHAPTER 1

GENERAL INTRODUCTION

1.1 INTRODUCTION TO COW EFFICIENCY

The search for efficiency dates back as early as 1911 when Armsby & Fries (1911) indicated that the ability of an animal to convert feed to weight is influenced by its "type". Kleiber (1936) was the first to identify potential approaches to describe the efficiency of feed utilization by animals when he suggested that the ratio growth rate/weight$^{0.75}$ as an indirect measure of efficiency. At a symposium on the relationship between size and efficiency, Robertson (1973) suggested that efficiency must be considered as a function of the production unit. Dickerson (1978) proposed that the components of the production cycle should be aggregated to define efficiency in a systems concept. It is therefore somewhat surprizing that until today most measurements to improve production efficiency in livestock are still per individual animal (milk production, weaning weight, calving interval, growth rate, etc.). The chances are that selection for these traits may increase production, but not necessarily efficiency of production.

The relationship between cow weights and calf weaning weights has been investigated as far back as the 1950's. Knox (1957) reported that calf weaning weight per 454 kg cow weight (the equivalent of an Animal Unit in the USA) tend to favour smaller cows. Cartwright *et al.* (1967) reported that calf weaning weight will increase as dam weight increased up to a dam weight of 544 kg, where after it will slightly decrease. Likewise Cartwright *et al.* (1967) reported that in respect of calf weight gain the optimum cow weights for Angus and Hereford cows were 570 kg and 600 kg respectively. Urick *et al.* (1971) reported a small but positive, although not significant, relationship between calf weight and cow weight in Angus, Charolais and Hereford cattle. This increase amounted to 1.93 kg increase in calf weight for every 45.5 kg (100 pounds) increase in cow weight. Urick *et al.* (1971) also reported that the relationship of cow weight$^{0.73}$ and cow weight with the weight of the calf is essentially the same. Large parts of the cost in cow-calf production systems are related to the weight of the cow and since calf weight is the principle output from such as system, Vanmiddlesworth *et al.* (1977) recommended further research on this "gross efficiency ratio".

For some reason the research on cow efficiency faded. A possible explanation is that with the developments in the estimation of breeding values and selection indices the focus shifted to the component traits associated with production and that efficiency of production was neglected.

However, in beef cattle the search for the optimum cow is still ongoing (Greiner, 2009) and has become a "holy grail" for the seed stock industry (Tedeschi *et al.,* 2004). The ideal beef cow should be the one that use less resources to produce the same output in a sustainable environment (Tedeschi *et al.,* 2004). This will be a reflection of biological efficiency. The historic definition of biological efficiency has been defined as the kilogram of calf weaned per cow exposed, but this is changing with the realization that it is important to have some input-output relationship (Jenkins & Ferrell, 2002; Greiner, 2009).

There are numerous factors that can affect cow efficiency. They include, but are not limited to, cow maintenance, gestation and lactation feed requirements, calf maintenance and growth requirements, and calf weight; and perhaps the most important one – reproductive performance (Jenkins & Ferrell, 2002; Greiner, 2009). Cow efficiency can be profoundly affected by differences in reproduction, irrespective of other factors such as feed consumption and calf weight. Efficient cows are those that produce calves regularly and reproduction is the constant variable defining cow efficiency, while the relative importance of other variables may change with fluctuations in production environments and prevailing market conditions (Notter, 2002). Selection for days to calving has been proposed some time ago as a trait and it seems to be an effective way to improve fertility in beef cattle (Johnston & Bunter, 1996). However, its application is still limited in developing countries, such as South Africa, since adequate data is not recorded by farmers. Reproduction is not part of the current study and this aspect will not be discussed further.

1.2 UNDERSTANDING COW EFFICIENCY

Although biological and economic efficiency may be related they are not necessarily the same. For example a cow with a low biological efficiency due to high feeding requirements relative to the weaning weight of her calf, may have a relatively high economic efficiency if feed costs are low (Greiner, 2009).

Optimal and sustainable production efficiency should be the goal of any beef production system (Schiemiester, 2014). Cow efficiency is normally a complex, multi-trait measure that is variable depending on differences in production environments and management systems (Greiner, 2009). Hence, the most efficient cow may not be the same for different production environments, such as the difference between northern hemisphere (temperate environments) and southern hemisphere (tropical and subtropical environments) countries.

Efficiency is generally regarded as the attainment of a sustainable, but desired level of production with the optimal use of available resources (Maddock & Lamb, 2010). In beef production, cow-calf production efficiency can be expressed as the ratio of kilogram of calf weaned per unit of forage consumed. Utilization of feed has long been recognized as one of the most essential factors in determining profitability in the case of beef cattle production. Efficiency basically measure the inputs needed to create a desired output. However, measuring efficiency may differ and be complicated due to the various variables that contribute to the efficiency and effectiveness of the breeding herd (Maddock & Lamb, 2010). Measures of efficiency can also differ from one production system to the other.

1.3 MEASURES OF COW EFFICIENCY

There are basically only two measures of cow efficiency, namely calf weaning weight/cow weight ratio (MacNeil, 2007) and calf weaning weight/cow weight$^{0.75}$ ratio (Rasby, 2010). The use of these ratio traits as selection criteria has theoretical defects, since it places inconsistent emphasis on the component traits. This will result in variable responses to selection (MacNeil, 2007). In spite of this the use of calf/cow weight ratios is still common practice.

Another alternative was to develop Breeding Values for cow maintenance energy requirements (Evans *et al.,* 2002). The motivation for this initiative was that feed energy consumption during the cow-calf production cycle represents approximately 72% of the energy consumed from conception to slaughter (Ferrell & Jenkins, 1982). If cow maintenance requirements can be reduced, the feed energy requirements will be less and this should reduce the input cost of the cow and thus improve cow efficiency. However, the implementation and interpretation of such a breeding program seems to be a challenge (Evans *et al.,* 2002).

An interesting measurement of "mother-offspring" efficiency was reported by Olivier *et al.* (2001), where reproductive performance of ewes was defined as total weight of lamb weaned per ewe joined (TWW), which also demonstrated that TWW can be genetically improved by either direct or indirect selection. Following a study on Dormer sheep, van Wyk *et al.* (2003) recommended that the total weight of lamb weaned should be considered as a selection criteria, since it is a composite trait that incorporates elements of both the lamb and ewe. These results obtained on sheep proposes a similar initiative in beef cattle, which would be selection for weight of calf weaned per large stock unit (LSU) and this possibility should be explored as a means of improving cow efficiency. These results of Olivier *et al.* (2001); van Wyk *et al.* (2003) thus stimulated the idea to investigate possibilities to improve cow-calf efficiency as will be discussed in paragraph 2.3.

It will become more important to develop breeding objectives and selection criteria to ensure that beef cattle breeding is effective and sustainable in the era of changing environments and production systems. In contrast to production systems in the northern hemisphere temperate countries, maximum production might not be feasible or recommended in southern hemisphere countries such as South Africa (Scholtz, *et al.,* 2013). It is therefore important to investigate candidate traits that can improve cow-calf efficiency in climate smart beef production systems of these countries.

1.4 GENERAL BACKGROUND

Climate change is an issue of global significance and is potentially the defining issue of the current era (Ridoutt *et al.*, 2011). Since 1980 scientific evidence of human interference on the climate placed the question of climatic change and its environmental consequences on the world's political agenda. In response, at various levels, governments, business and individuals are taking actions to mitigate greenhouse gas (GHG) emissions (Ridoutt *et al.,* 2011). These are guided by the Kyoto Protocol, which was adopted in December 1997 in Japan after various discussions and officially established goals for emission of greenhouse gases (GHG) for industrialized nations (UNFCCC, 2014). Up to June 2013 a total of 192 countries and regional economic integrated organization states had signed and ratified the protocol.

In December 2009, the United Nations Climate Change Conference, commonly known as the Copenhagen Summit, took place where a framework for climate change mitigation beyond 2012 was to be agreed on. At this conference, the Copenhagen Accord was drafted by the US, China, India, Brazil and South Africa, but was not passed unanimously. The document recognized that climate change is one of the greatest challenges of the present day and that actions should be taken to keep temperature increases to below 2°C. The document is not legally binding and does not contain any legally binding commitments for reducing CO_2 emissions (http://news.bbc.co. uk/2/hi/science/nature/8422307.stm).

The uncontrolled anthropogenic (man–made) release of GHG into the atmosphere is thought to be the primary cause of a systematic and unprecedented increase in sea and earth surface temperatures. A survey by the American Association for the Advancement of Science (AAAS) indicates that 97% of climate scientists have concluded that anthropogenic climate change is happening (AAAS, 2014).

The two major GHG's are carbon dioxide (CO_2) and methane (CH_4). Of the two, CO_2 is by far the most abundant with an atmospheric concentration of 49% compared to 18% for CH_4. Despite the highest concentration being carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have heating potentials 23 and 296 times higher than CO_2, respectively, due to the higher atmospheric warming activity of these compounds (Clark *et al.,* 2001), resulting in it being a significant role player in the GHG emission family.

Human-related activities producing CH_4 include fossil fuel utilization, animal husbandry (enteric fermentation in livestock and manure management), rice cultivation, biomass burning, and waste management. Natural sources of CH_4 include wetlands, gas hydrates, permafrost, termites, oceans, fresh water bodies, non-wetland soils, wild ruminants (game) and other sources such as wild fires. It is estimated that more than 60 percent of global CH_4 emissions are related to human activities (IPCC, 2007).

Whereas CO_2 releases result mostly from non-agricultural activities (power plants, deforestation, transport, oil and gas production and manufacturing), CH_4 results primarily from agricultural sources. Enteric fermentation (animal digestive tract) is the main source of CH_4 and is responsible for 28% of global CH_4 emissions, followed by natural gas (15%), waste management (13%) and rice cultivation (11%) Factors that influence enteric CH_4 production in livestock are level of feed intake, diet composition, digestibility and quality of roughage, forage species, C3 versus C4 grasses, cultivar and variation between animals (Clark *et al.*, 2001; US-EPA, 2006; IPCC, 2007; Biotech Ltd, 2009).

From all CH_4 emissions sources, agriculture is by far the most important source in South Africa and enteric fermentation in ruminants accounts for 90% of the agricultural sectors CH_4 emissions (Blignaut *et al.*, 2005). CH_4 emission is therefore a concern and it is the responsibility of agriculture as a whole and livestock farming in particular, to reduce these emissions.

Ruminants are important to mankind since most of the world's vegetation biomass is rich in fibre (Moss, 2000). Only ruminants can convert this rich in fibre vegetation into high quality protein sources (i.e. meat and milk) for human consumption and this will need to be balanced against the concomitant production of CH_4.

In spite of the important role of livestock, it is being specifically targeted and singled out as having a high carbon footprint that contribute to climate change. The popular press is fuelling these sentiments with slogans telling consumers to eat less meat. This may result in some consumers deciding to reduce their consumption of red meat.

The Department of Environmental Affairs and Tourism of South Africa (DEAT, 2007) predicted a quadruple increase in CO_2-equivalent emissions by 2050 from 440

Megatonne (Mt) to 1600 Mt. According to the DEAT (2007) the South African government has set a reduction target of between 30 and 40% from the 2003 levels by 2050. This is in line with the requirements of the Kyoto protocol of which South Africa is a signatory.

GHG emission from livestock is measured either in terms of kg CO_2 equivalent per kg of meat or milk available for consumption, or per area of land used. In the case of ruminants extensive systems are usually found to have a lower per-area carbon footprint than intensive grain-fed systems but a higher footprint if expressed in terms of kg/product (Garnett, 2010). Breeding objectives to reduce enteric methane production from beef cattle under extensive production systems can therefore play a significant role in addressing climate change.

1.5 EXTENSIVE COW-CALF PRODUCTION SYSTEMS

Approximately 84% of South Africa's surface area is available for farming. However, a large part of this is not suitable for crop production, with approximately 13% that is arable. The greater part of South Africa (approximately 70%) is therefore only suitable for extensive livestock farming (RMRD SA, 2012). South Africa's beef cow-calf production systems are thus mainly extensive, based on mostly natural pastures which means that cattle utilize the natural vegetation that monogastric animals are unable to digest.

This cow-calf portion of the production cycle, that is conducted in the extensive parts of South Africa accounts for 72% of the nutrient requirements from conception to harvest (Ferrell & Jenkins, 1982). In spite of primary beef cattle farming (cow-calf production) being extensive, most of the calves in the formal sector is finished in feedlots on maize and its by-products (RMRD SA, 2012).

CHAPTER 2

MOTIVATION FOR THE STUDY

2.1 INTRODUCTION

It is important that climate smart beef production systems are developed and put in place to reduce the GHG production from beef and to mitigate the effects of climate change on beef production. An effective way to reduce the carbon (and water) footprint from beef is to reduce the animal numbers and increase the production per animal, thereby improving their productivity. Increased productivity generates less GHG emissions per unit of livestock product (Scholtz *et al.*, 2013). Production efficiency can be improved through breeding, feeding, management and alternative production systems. There should be sufficient genetic variation in South Africa's beef cattle genetic resources to facilitate breeding for improved production efficiency.

One way of improving cow efficiency is by increasing the weaning weight of calves in relation to a cow Large Stock Unit (LSU) in extensive beef cow-calf production systems. Meissner *et al.* (1983) noted the need for suitable animal production "standardization units" and through a comprehensive study of the available literature and research results, developed an official definition of LSU for South Africa; i.e. the equivalent of an ox with a live weight of 450 kg which gains 500 g per day on grass pasture having a mean digestible energy of 55% and to maintain this 75MJ per day is required. This is similar to the Animal Unit used in North America (Thorne & Stevenson, 2007).

2.2 BREEDING OBJECTIVES

Ponzoni (1986) suggested that maximizing the return on investment must be the aim of genetic improvement programs, and that selection and breeding objectives must be set accordingly. This means that the breeding objectives should be directed at improving the traits that will have an effect on production and revenue of product sales (Ponzoni, 1992; Holst, 1999). Normally both observable and measurable traits are included in the traditional ruminant breeding systems, however some may not be easily measurable (Kosgey & Okeyo, 2007). Some observable traits would be size, body shape, colour, etc.; whereas measurable traits would be, weaning weight, dam weight, lactation length, etc. (Bourdon, 2000).

Clear definition of breeding objectives and the implementation of efficient breeding systems should form the basis for optimal utilization of genetic resources as recommended by the Food and Agriculture Organization (FAO) of the United Nations (FAO, 1998). Most animal breeding programs lack basic definition of breeding objectives.

In a breeding objective, the trait under consideration is the final product or goal to select for (Harris, 1970) – what should be achieved. Decisions about such a goal (in this case trait) is based purely on the end product, not on whether it is difficult or easy to measure or whether there may be problems in selecting for it. The next phase is to identify the selection criteria, which are the traits that should be used in selecting animals. Traits in the selection criteria should be both correlated with the traits in the breeding objective and easily measurable as well as heritable.

Until now most measurements for beef improvement in South Africa is per individual animal such as weaning weight, calving interval, growth rate, etc. A measurement is thus required that expresses performance per constant (standardized) unit such as LSU. Selection for productivity and efficiency, for instance, will have a permanent mitigating effect on the production of GHG's, as higher productivity will lead to higher gross efficiency as a result of diluting the maintenance cost of animals (Wall *et al.*, 2010; Scholtz *et al.*, 2011). Proper trait definition is therefore imperative.

2.3 AIM OF THE STUDY

The aim of the study is to identify novelty traits as possible selection criteria to improve cow-calf efficiency and to describe cow efficiency in extensive systems that will support climate smart beef production. The traits to be investigated are briefly described below.

2.3.1 Kilogram calf weaned per LSU

A measure (value) that expresses performance (calf weaning weight) per constant unit, viz. per LSU may be a useful breeding objective/goal to increase production efficiency, which may reduce the carbon footprint of extensive cow-calf production systems. Since a LSU is linked to specific metabolizable energy requirements it should be possible to eventually "link" this breeding objective with the carbon footprint of weaner calf production.

2.3.2 Calf weaning weight as trait of the dam

Conventionally maternal weaning weight; and in some cases a combination of maternal and direct weaning weight breeding values (ARC, 2012), is used as indication of the dam's contribution to the weaning weight of her calf. In this study it was decided to investigate calf weaning weight as a trait of the dam.

2.3 CONCLUSION

No reference could be found in the literature where kilogram calf weaned per Large Stock Unit or weaning weight as trait of the dam were considered as breeding objectives. Therefore it was decided to investigate the novelty traits proposed above as measures of cow-calf efficiency.

CHAPTER 3

REPORT ON A BREEDING OBJECTIVE THAT MAY REDUCE THE CARBON FOOTPRINT OF EXTENSIVE COW-CALF PRODUCTION SYSTEMS

3.1 INTRODUCTION

The general perception that livestock is a major contributor to global warming mainly resulted from the FAO publication "Livestock's Long Shadow" which indicated that livestock is responsible for 18% of the world's greenhouse gas emissions (GHG). This initial calculation of the contribution of livestock to global warming has since been drastically scaled down from the figure initially quoted in this FAO publication (Steinfeld *et al.*, 2006). The initial figure has been proven to be an overestimation (Pitesky *et al.*, 2009) and the most recent figure for the contribution of livestock to GHG is in the order of 5% - 10%. This also applies for South Africa. Livestock contributes about 65% of total agricultural GHG (CO_2 equivalent) of which enteric fermentation (animal digestive tract) accounts for 90% (Meissner *et al.*, 2012), and mitigation strategies are essential if climate change is to be contained within certain limits.

The atmospheric lifetime of methane (CH_4) is 12 years, compared to 100 to 200 years of carbon dioxide (IPCC, 2007). Furthermore the heating potential of methane is 23 times that of carbon dioxide (Clark *et al.*, 2001). Reduction in CH_4 levels will thus have a significant effect on the targets set by governments in terms of the Kyoto protocol, since its impact will be quicker due to the shorter lifetime and bigger due to the higher heating potential, compared to CO_2. More emphasis on the reduction of CH_4 emissions can thus be expected in the immediate future if reduction targets are to be met.

Livestock on extensive rangelands/pastures produce more methane than livestock on intensive production systems, since the lower quality feed (mainly pastures that they are consuming) produce more GHG per kilogram feed intake than the higher quality feed used in intensive systems. Since the cow-calf production system in South Africa is largely extensive, it is important to find a measurement of cow efficiency.

This Chapter (originally published as an article) describes a pilot study in which a possible breeding objective/goal that may reduce the carbon footprint of extensive cow-calf production systems is reported. A trait that expresses performance (calf weaning weight) per constant unit, viz. kilogram calf weaned per Large Stock Unit (KgC/LSU) may be useful as such a breeding objective.

3.2 MATERIALS AND METHODS

For the purposes of this study the information from performance recording of beef and dual purpose breeds in South Africa over a 10 year period was used (Scholtz, 2010). The data that was extracted were cow weight at birth of the calf and the 205 day corrected weaning weight of the calf and this was used to calculate the calf/cow weight ratio (205 day weaning weight/cow weight) and KgC/LSU. The breeds, breed types and number of cow weights per breed, are presented in Table 3.1. The breeds were classified as Sanga, Sanga derived, Zebu, Zebu derived, European and British.

In South Africa a LSU is defined as the equivalent of an ox with a weight of 450 kg and a weight gain of 500 g per day on grass pasture with a mean Digestible Energy (DE) concentration of 55%. To maintain this, 75 MJ Metabolizable Energy (ME) is required (Meissner *et al.*, 1983). This is similar to the Animal Unit used in North America Thorne & Stevenson (2007). Meissner *et al.* (1983) developed tables in which the LSU units have been linked to the weights of lactating beef cows. For example a 500 kg lactating cow is equal to 1.43 LSU units. These cow weights and their respective LSU's were used to develop an equation to calculate the LSU for different weights of lactating beef cows (Neser, 2012).

The equation is:

$Y= 2.13 - 0.0054*x + 0.000008x^2$

Where y = LSU units and x = cow weight.

The Spearman correlations of cow weight, cow LSU unit and calf weaning weight with the calf/cow weight ratio and KgC/LSU were also estimated to investigate the nature of relationship between the traits.

Table 3.1. Breeds, breed types and number of cow weights per breed.

Breed type					
Sanga*	**Sanga derived**	**Zebu**	**Zebu derived**	**British**	**European**
Breed					
Afrikaner	Afrigus	Boran	Santa Gertrudis	Angus	Braunvieh
(19 450)	(115)	(458)	(28 160)	(28 670)	(2 290)
Drakensberger	Afrisim	Brahman	Brangus	Red Poll	Charolais
(33 060)	(78)	(39 700)	(21 927)	(1 440)	(12 920)
Nguni	Bonsmara		Simbra	SA Hereford	Romagnola
(15 280)	(266 880)		(46 240	(13 660)	(350)
Sanganer	Hugenoot			Dexter	Gelbvieh
(408)	(2 080)			(85)	(405)
Tuli	Senepol			Sussex	Limousin
(6 780)	(97)			(16 570)	(12 350)
	SA Beefmaster			Shorthorn	Pinzgauer
	(35 850)			(864)	(1 110)
				South Devon	Simmentaler
				(3 100)	(56 870)

*Refers to the indigenous breeds from Southern Africa. ( ) Number of cow weights per breed

3.3 RESULTS AND DISCUSSION

In Table 3.2 the breed type weighted averages for cow weight at birth of calf, LSU units, corrected 205 day weaning weight (205 WW), KgC/LSU and the total number of weaning records are summarized. As expected the Sanga breed types had the lowest- and the European breed types the heaviest cow weights.

Table 3.2. An illustration of weighted average cow weights, Large Stock Unit (LSU) units, 205 day weight, Kilogram Calf Weaned per LSU (KgC/LSU), standard error of means and the total number of weaning records by breed type.

Breed Type	Trait				Total number of weaning records
	Cow weight (Kg)	LSU units	WW (Kg)	KgC/LSU	
Sanga*	462±24	1.34±0.04	188±8.0	136±3.1	74 978
Sanga derive	501±8.2	1.43±0.02	218±2.9	156±2.9	305 122
Zebu	519±5.0	1.48±0.11	200±0.1	146±1.1	40 158
Zebu derived	527±17.1	1.50±0.05	223±10.8	148±2.5	96 327
British	533±32.4	1.52±0.05	217±10.0	143±5.2	64 389
European	575±18.7	1.67±0.07	238±5.1	138±5.3	89 940

*Indigenous breeds of Southern Africa

In Table 3.3 the Spearman correlations of cow weight, cow LSU unit and calf weaning weight with the calf/cow weight ratio and KgC/LSU are presented. The relationship between cow weight and KgC/LSU is also presented in Figure 3.1. Both the results from Table 3.2 and Figure 3.1 indicate that KgC/LSU is independent of cow weight between breeds.

Table 3.3. Spearman correlations between cow weight, cow, Large Stock Unit (LSU) unit and calf weaning weight with the calf/cow weight ratio and Kilogram Calf Weaned per LSU (KgC/LSU).

Trait	Cow Weight	LSU unit	Calf Weaning Weight
Calf/Cow Weight Ratio	-0.65*	-0.64*	-0.12
KgC/LSU	-0.09	-0.036	0.42

*Significant correlation (P < 0.10)

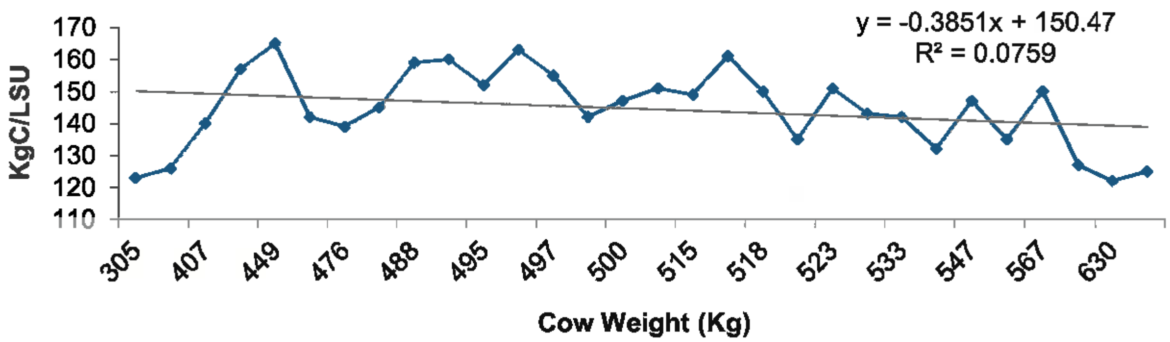

Figure 3.1. The relationship between kilogram calf weaned/LSU (KgC/LSU) and cow weight.

The relationship between cow weight and the calf/cow weight ratio is presented in Figure 3.2. Both Table 3.3 and Figure 3.2 demonstrate that there is a negative relationship between cow weight and the calf/cow weight ratio, indicating that the calf/cow weight ratio that is currently being used in South Africa (and other countries) may favour smaller cows.

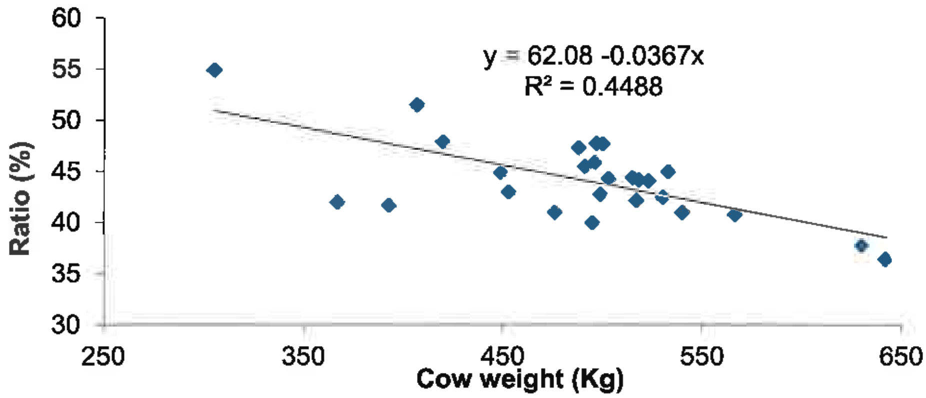

Figure 3.2. The relationship between the calf to cow weight ratio and cow weight.

The KgC/LSU per breed type as listed in Table 3.2, is also illustrated in Figure 3.3. From Table 3.2 and Figure 3.3, it can be noted that the Sanga and European breed types produce the least KgC/LSU (possibly a higher carbon footprint) and the Sanga derived breed types the most (possibly a lower carbon footprint). This is probably due to retained heterosis.

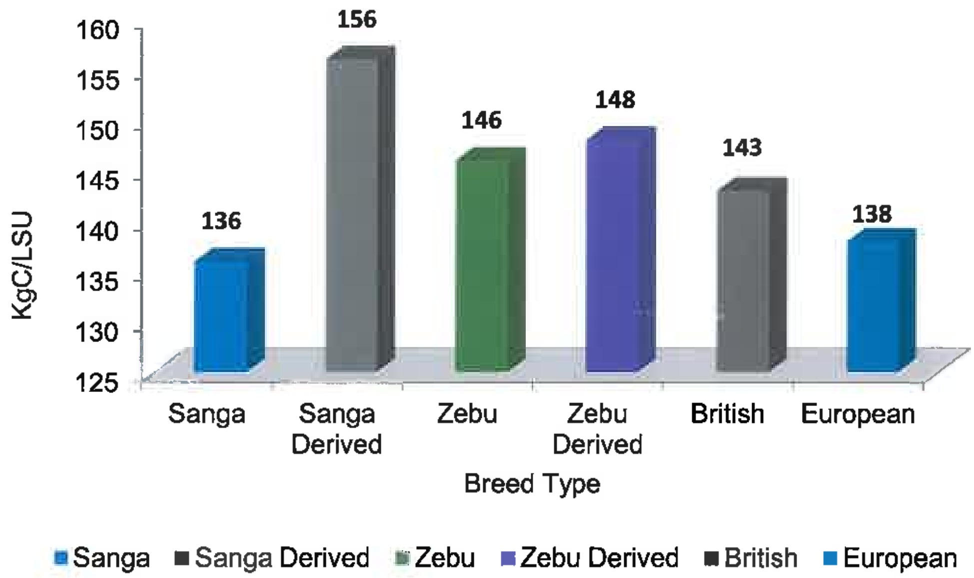

Figure 3.3. KgC/LSU summarized per breed type.

In this study it was found that KgC/LSU is independent of cow weight based on breed averages, which is contrary to the calf/cow weight ratio also based on breed averages, which favours smaller cows. For a trait to be considered as a selection criterion to improve the trait in the breeding objective, it should be correlated to the trait in the breeding objective. It is important to note that these calculations were only done on breed averages. The next step (Chapters 5 and 7) will be to do a genetic analysis on a breed level to estimate genetic parameters for the trait KgC/LSU, and its genetic correlations with other traits of relevance (e.g. weaning weight, cow weight, cow LSU) before a decision can be taken whether selection for it will be feasible.

The use of ratios to adjust one correlated trait for another is fairly commonplace, albeit that there are statistical arguments that restrict the appropriate use of ratios to certain circumstances (Weil, 1962). For example, the use of the ratio of calf weaning weight to cow weight as a selection criterion has theoretical defects and places inconsistent emphasis on the component traits resulting in variable responses to selection (MacNeil, 2007). However, the fact that KgC/LSU is independent of cow weight when calculated on breed averages, warrants further investigations before a final decision is taken in this regard.

Note: This chapter has been previously published in Natural Science (Mokolobate *et al.*, 2013).

CHAPTER 4

APPROXIMATION OF LIVESTOCK FORAGE DEMAND FOR DIFFERENT FRAME SIZES: THE LARGE STOCK UNIT

4.1 INTRODUCTION

Meissner *et al.* (1983) developed tables in which LSU's have been linked to the weights of for example, lactating beef cows. The definition of LSU's in South Africa is given in the previous chapters (1 and 3). It is important to note that the LSU equivalent of cows with the same body weight but different frame sizes is different. Furthermore, the relationship between cow weight and LSU is not linear.

For example, the LSU unit of a small frame cow of 450 kg is 1.32, whereas that of a large frame cow of 450 kg is 1.6 LSU. Similarly the 450 kg small frame cow will require 12 kg of grass per day and the 450 kg large frame cow 15 kg of grass per day, a difference of 25%. Likewise, the feed requirements of animals at different physiological stages are different, even if they have the same body weight.

The differences in LSU units between animals of the same body weight, but with different frame sizes is based on the principle that there are differences in the voluntary feed intake between such animals, although they have the same body weight (Meissner *et al.,* 1983). An example of these differences (from Meissner *et al.,* 1983) in the feed intake of lactating cows with the same body weight, but of different frame sizes, is illustrated in Table 4.1.

The aim of this study was to develop regression equations for lactating cows of different frame sizes (small, medium, large) and at different body weights that can be used to calculate individual cow LSU's. These frame size specific equations will also be compared to the general equation developed by Neser (2012).

4.2 MATERIALS AND METHODS

The requirements of forage intake in kilogram Dry Matter (DM) by cows with calves of small, medium and large mature size have been published by Meissner *et al.* (1983) and are listed in Table 4.1. This information was used to develop the frame size specific prediction equations for the estimation of LSU units. The general equation developed by Neser (2012) was also used to estimate LSU units.

Since breeds differ in DM intake, metabolism and in size they should be classified accordingly and Meissner *et al.* (1983) have grouped the different breeds according to their frame sizes as indicated in Table 4.2.

Table 4.1.* Cow weights and daily feed intake DM (Kg) of lactating beef cows of different frame sizes

Breed type								
Small Frame			**Medium Frame**			**Large Frame**		
Cow Weight	**Voluntary Feed Intake**	**LSU**	**Cow Weight**	**Voluntary Feed Intake**	**LSU**	**Cow Weight**	**Voluntary Feed Intake**	**LSU**
350	10.0	1.11	350	10.6	1.17	350	12.8	1.42
400	11.0	1.22	400	11.7	1.29	400	13.9	1.55
450	11.9	1.32	450	12.6	1.40	450	15.0	1.66
500	12.8	1.42	500	13.6	1.50	500	16.0	1.78
550	13.7	1.52	550	14.5	1.60	550	16.8	1.88
			600	15.3	1.69	600	17.8	1.98

*Table details are extracted from Meissner *et al.* (1983).

Table 4.2. Breeds classified according to frame size according to Meissner *et al.* (1983)

Small framed breeds	Medium framed breeds	Large framed breeds
Aberdeen Angus	Bonsmara	Charolais
Afrikaner	Brahman	Simmentaler
Galloway	Brown Swiss	South Devon
Hereford	Drakensberger	
North Devon	Pinzgauer	
Beef Shorthorn	Red Poll	
	Sussex	

4.3 RESULTS AND DISCUSSION

The information in Table 4.1 was used to derive the following frame size regression equations:

a) Small frame $Y = 0.2871428571 + 0.0025542857*x - 0.0000005714*x^2$
b) Medium frame $Y = 0.220714286 + 0.0030978571*x - 0.0000010714*x^2$
c) Large Frame $Y = 0.3239285714 + 0.0036535717*x - 0.0000015*x^2$

The generalized equation of Neser (2012) is also given below.

d) Generalized equation $Y = 2.13 - 0.0054*x + 0.000008*x^2$

Where Y = LSU and x = cow weight

The different regression equations are graphically presented in Figure 4.1. From Figure 4.1 it is clear that the LSU units of cows of different frame sizes differ, even if they are of the same body weight, especially between large framed cows and the rest. It is also evident that there is not a big difference between the small and medium frame equations. Similarly the generalized LSU equation seems to be almost a precise predictor of feed requirements of small and medium, with an under estimation of the LSU units of large framed animals. These results imply that the generalized equation can be used as a fair prediction of the LSU for small and medium frame animals, but not for large frame animals.

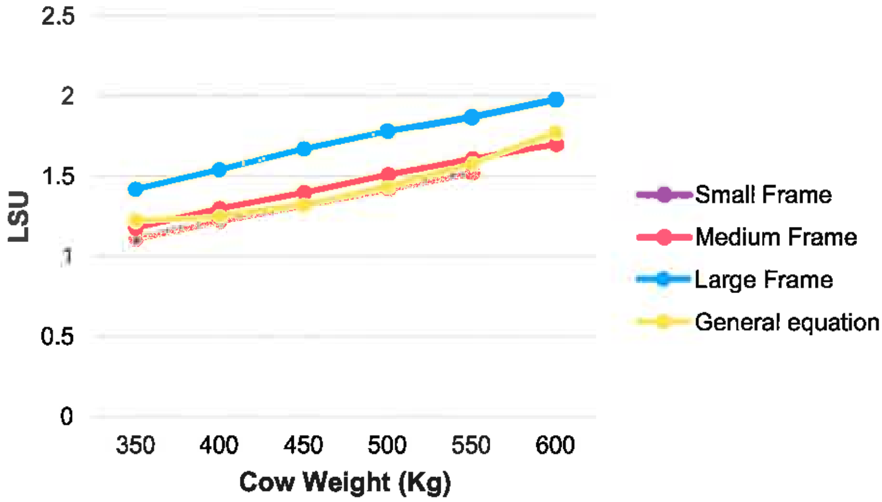

Figure 4.1 LSU regression equations for various frame sizes

4.4 RECOMMENDATIONS

Meissner *et al.* (1983) estimated the LSU's for livestock more than 30 years ago. In the case of beef cattle the body weights of some of the breeds may have changed. It is therefore recommended that the categorization of breeds into the different frame sizes be re-evaluated.

In the publications of MacNeil *et al.* (2013) & Hendriks *et al.* (2014) the equations for calculating phenotypic Residual Feed Intake (RFI) and Residual Daily Gain (RDG) for the Bonsmara and Angus breeds respectively, are quite different for bulls tested at the ARC's bull testing stations where conditions are standardized. One possibility for this difference is differences in basal metabolism. There should be sufficient data available to develop equations for calculating RFI and RDG for most beef breeds in South Africa. Depending on the results from such investigation, it might be possible to also group breeds according to their basal metabolisms in breed groups, in addition to frame size. It is recommended that this be investigated.

CHAPTER 5

INVESTIGATION OF NOVELTY TRAITS TO IMPROVE COW-CALF EFFICIENCY IN BONSMARA COWS

5.1 INTRODUCTION

In Chapter 3 it was found that kilogram calf weaned per Large Stock Unit (KgC/LSU) is independent of cow weight when breed averages are compared, which is contrary to the calf/cow weight ratio which favours smaller cows. This stimulated an investigation into the use of KgC/LSU and calf weaning weight (K205), both as traits of the dam, as breeding objectives to improve efficiency in extensive cow-calf production systems. The use of the trait KgC/LSU and weaning weight as traits of the dam as breeding objectives could not be found in any literature and are therefore regarded as innovative traits worth investigating. Such breeding objectives, in the era of climate smart beef production, should be a significant consideration in extensive cow-calf production systems where direct measurement of feed intake is almost impossible.

As already pointed out in Chapter 1, improved cow productivity and efficiency will have a permanent mitigating effect on the production of GHG's, as higher productivity will lead to higher gross efficiency. (Wall *et al.,* 2010; Scholtz *et al.,* 2011).

The Bonsmara breed is the most numerous seed stock beef breed in South Africa with more than 50 000 cows (Scholtz, 2010) and is also dominating the commercial cow herd. Feedlots are an important segment of beef production in South Africa supplying about 75% of beef to the formal market and the breed has the highest percentage intake in feedlots of all breeds in South Africa (Scholtz *et al.,* 2008). Performance recording was compulsory since the inception of the breed. It is thus obvious why the Bonsmara was used in this investigation.

The Bonsmara is a composite breed that was developed in South Africa. The development of the Bonsmara started in the late 1930's and the first pure Bonsmara calves were produced in 1943. It was based on 5/8 Afrikaner (an indigenous Sanga breed) and 3/8 Exotic (Shorthorn/Hereford) breeding admixture. The Bonsmara has established itself as an easy care breed with favourable attributes such as the ability to adapt to most climatic conditions, good mothering ability, high fertility, good feed efficiency and quality carcasses. It is a red, smooth coated medium sized, animal with a slightly sloping rump which is common for sub-tropical breeds. Scholtz, (2010).

5.2 MATERIALS AND METHODS

The edited dataset, as used by the Agricultural Research Council (ARC) for routine genetic evaluations, was used for this study. The final dataset used comprised of complete calf-cow records for parities 1, 2 and 3 from cows born between 1962 and 1999, with the latest calves born in 2005. The descriptive statistics are shown in Table 5.1. Only the first three parities were used as the data set was significantly reduced after three parities, which may be as a result of sequential culling.

Herds with less than three years of recording as well as contemporary groups with less than 10 cow records and two service sires in the first parity, as well as animals with unknown parents were removed from the final dataset used for the analysis. The initial data set consisted of about 900 000 records which was finally reduced to 34 884 records for parities 1, 2 and 3 from 13 579 cows after the above mentioned editing was done.

To assess the influence of non-genetic factors on the different weights for inclusion in the model, an analysis of variance was done using SAS's proc GLM program (SAS, 2009). A stringent significant level of $P<0.01$ was used as criteria for inclusion. Fixed effects fitted were sex (male, female) and a concatenation of breeder (herd), year and season (HYS). Age of dam was fitted as a linear covariate, Sex effect was fitted to calf traits. All weaning weights were pre-adjusted to 205 days to simplify the analysis.

Taking into consideration both the distribution of records over a twelve month period as well as the weaning weights of the calves, two distinct seasons were identified. The months from September to March were classified as season one, while April to August were classified as season two. The weights extracted from the dataset were cow weight at weaning (DW) and pre-adjusted 205 day weaning weight (WW205). The trait "kilogram calf weaned per Large Stock Unit" (KgC/LSU) was calculated using WW205 and DW for the respective parities.

Table 5.1. Descriptive Statistics of the traits analyzed (34 884 complete records).

Trait	Minimum	Mean	Maximum	SD
DW	190	475	875	67
KgC/LSU	36	90	193	14
K205	100	213	375	36

Pedigree	Number of Animals
Sires	2 774
Dams	11 973
Sires of Dam	804
Dams of Dam	1 561

Dam Weight (DW), Kilogram Calf Weaned per LSU (KgC/LSU) and Weaning Weight as trait of the Dam (K205)

The following equation developed in Chapter 4 for medium frame breeds was used to estimate LSU:

$y = 0.220714286 + 0.003978571*x - 0.0000010714*x^2$

Where Y = LSU and x = dam weight

A number of different models were tested for the traits investigated to estimate the (co)variance components for the traits DW, KgC/LSU and calf weaning weight as trait of the dam (K205), the latter two as traits of the dam, using repeatability models in ASReml 3.0 (Gilmour *et al.,* 2009). The most suitable model for each trait was selected based on the log likelihood values following the same approach as Neser *et al.* (1996) and Mohammadi *et al.* (2013). The simplest model with improved (smaller) log likelihood values was chosen, since fitting other models did not change the log likelihood values favorably.

Four models, including the one with service sire, and the other three models that were the most suitable are presented below.

Model 1, Service sire included as additional random effect.

$Y = X\beta + Z_1a + Z_2s + \varepsilon$

Where: -

Y = vector of observations (DW, KgC/LSU and K205)

β = vector of fixed effects (HYS, Sex) influencing KgC/LSU, K205, and DW

a = vector of direct additive effects,

s = vector of additive effects related to Service Sire

ε = vector of residuals and where

X, Z_1 and Z_2 were incidence matrices relating observations to their respective fixed and random effects.

<u>Model 2, used for single trait analysis:</u>

$$Y = X\beta + Z_1a + Z_2c+\varepsilon$$

Where: -

Y = vector of observations, (K205, KgC/LSU and DW)

β = vector of fixed effects (HYS, Sex, Damage, Parity) influencing KgC/LSU, K205, and DW

a = vector of direct additive effects,

c = vector of additional random permanent environmental effects (Animal),

ε = vector of residuals and where

X, Z_1 and Z_2 were incidence matrices relating observations to their respective fixed and random effects

<u>Model 3, used for single trait analysis:</u>

$$Y = X\beta + Z_1a +\varepsilon$$

Where: -

Y = vector of observations KgC/LSU, K205, and DW,

β = vector of fixed effects (HYS, Sex) influencing KgC/LSU, K205, and DW

a = vector of direct additive effects,

ε = vector of residuals and where

X and Z_1 were incidence matrices relating observations to their respective fixed and random effects (Animal).

<u>Model 4, used for the bivariate analysis:</u>

$Y = X\beta + Z_1a + Z_2c + \varepsilon$

Where: -

Y = vector of observations KgC/LSU, K205, and DW,

β = vector of fixed effects (HYS and Sex) influencing KgC/LSU, K205, and DW

a = vector of direct additive effects,

c = vector of additional random permanent environmental effects (Animal),

ε = vector of residuals and where

X and Z_1 were incidence matrices relating observations to their respective fixed and random effects (Animal).

5.3 RESULTS AND DISCUSSION

Some of the models showed singularities and gave negative residual error variance. Model 1 included service sire as an additional random effect, but since service sire was not significant it was omitted from the final model used and the results are not reported. Van Wyk *et al.* (2003) reported a similar finding. In the case of their study on Dormer sheep it was found that the contribution of including service sire as an additional effect was only marginal for the traits birth and weaning weights. It is somewhat surprising that service sire had no effect on KgC/LSU and K205 and the reason for this might be attributed to the dam effect over shadowing all other effects, a speculation that calls for further investigation.

Since Model 1, with service sire as an additional random effect was not significant, it was not used and only the results of Models 2, 3 and 4 are presented.

The (co)variance component estimates, genetic parameters and log likelihoods for K205, KgC\LSU and DW for the three models are presented in Table 5.2. The log likelihood obtained for Model 3 indicates that it is the most suitable model to use for the estimation of variance components and heritabilities because for all traits analyzed the log likelihoods values were the least (improved). Model 4 was used in the bivariate analyses to estimate the genetic correlations between the different traits.

Dam variance for the weaning weight of her calf consist of additive genetic variances, both direct and maternal, and variance of the permanent environment (Assan & Masache, 2012). Results from Wright *et al.* (1987) revealed that the contribution of the dam to the variation in the weaning weight of the calf is almost seven times that of the sire. The foremost contribution of dam's maternal environment to its growing calf was also recently documented by van der Westhuizen (2014). This supports the speculation in Paragraph 5.2 that the fact that the model in which service sire was not significant may be attributed to the dam effect over shadowing all other effects.

The permanent environmental variance (δ^2_{PE}) as percentage of the phenotypic variance (δ^2_{P}) was calculated from Model 3 for the three traits using the information in Table 5.2. The δ^2_{PE} represented 18%, 10% and 22% of the phenotypic variance for the traits KgC/LSU, K205 and DW respectively. From this result it is clear that δ^2_{PE} forms a larger percentage of δ^2_{P} in traits that include cow weight, e. g. 18% for KgC/LSU and 22% for DW. This probably indicates a large carry over effect on cow weights from one parity to the next. Wright *et al.* (1987) reported that δ^2_{PE} represents 7.4% of δ^2_{P} for weaning weight, which is in line with the 10% for weaning weight reported in this study.

Table 5.2. (Co)variance components estimates genetic parameters and Log likelihoods for K205, KgC\LSU and DW with the "best" model in bold

	KgC/LSU			K205			DW		
	Model 2	**Model 3**	Model 4	Model 2	**Model 3**	Model 4	Model 2	**Model 3**	Model 4
h^2	0.44±0.007	**0.26±0.02**	0.20±0.007	0.20±0.008	**0.11±0.01**	0.26±0.005	0.69±0.005	**0.45±0.02**	0.66±0.006
δ^2_A	188	**35**	124	124	**67**	127	1541	**950**	12
δ^2_P	140	**136**	621	616	**610**	493	2246	**2124**	2201
δ^2_e	78	**77**	39	492	**483**	60	705	**697**	1459
δ^2_{PE}		**24**	21		**61**	21		**476**	56
Ratio PE		**0.18±0.02**	0.15±0.02		**0.1±0.01**	0.15±0.008		**0.22±0.02**	0.03±0.004
Log likelihood value	-7 274	**-7 223**	-7 908	-734	**-710**	-6 689	-3 667	**-3 600**	-3 890

Heritability estimate (h^2), phenotypic variance (δ^2_A), error variance (δ^2_e), additive variance (δ^2_A), permanent environmental variance (δ^2_{PE}), permanent environmental variance, Ratio (Ratio PE) and Log likelihood value.

The heritability estimates from Model 3 (on the diagonal) and the genetic correlations from Model 4 (above the diagonal) between the different traits are presented in Table 5.3.

Table 5.3. Heritabilies (on the diagonal) and genetic correlations (above the diagonal) (± SE) as obtained in the bivariate analysis

Trait	K205	KgC/LSU	DW
K205	**0.11**±0.01	0.39±0.03	0.17±0.02
KgC/LSU		**0.26**±0.01	-0.83±0.01
DW			**0.45**±0.01

Kilogram Calf Weaned per LSU (KgC/LSU), Weaning Weight as trait of dam (K205) and Dam Weight (DW).

The heritability estimates reported in Table 5.3 for K205 was relatively low (0.11) while the estimates for KgC/LSU was moderate (0.26) and that for DW high (0.45). Van der Westhuizen *et al.* (2010) reported heritability estimates of 0.12, 0.22 and 0.32 for weaning weight maternal, weaning weight direct and mature cow weight respectively for the Bonsmara breed. Assan & Masache (2012) however reported similar direct and maternal heritability estimates within a range of 013-0.25 and 0.04-0.17 respectively when using different models. A reduction in heritability estimates is observed when permanent environmental effect is included in the univariate model which was expected and concurs with other findings (Neser *et al.,* 1996; Koots *et al.,* 1994; Dadi *et al.*, 2002). The heritability estimate for DW (which is not the same as mature cow weight) obtained in this study using a repeatability model is somewhat higher than that obtained for mature cow weight by Van der Westhuizen *et al.* (2010).

The repeatability of consecutive weaning weights in the American Simmentaler (Wright *et al.*, 1987), Hereford and Angus (Vanmiddlesworth *et al.,* 1977) breeds are reported to be 0.21, 0.35 and 0.25 respectively. This low repeatability may partly explain the relative low heritability of K205 (0.11), since K205 is weaning weight as trait of the dam in a repeatability model and not weaning weight per sé. It is furthermore in line with heritability estimate by Van der Westhuizen *et al.* (2010) for weaning weight maternal of 0.12. The cow efficiency trait KgC/LSU has a moderate heritability of 0.26, which was slightly higher than the estimate of 0.20 for the direct calf-cow weight ratio of MacNeil (2005) and 0.22 and 0.19 for the calf-cow weight ratio and the calf-metabolic cow weight ratio respectively as reported by Boligon *et al.* (2013). More discussion on the difficulties in selecting for composite traits will follow later.

The very high negative genetic correlation (-0.83) between KgC/LSU and DW suggests that direct selection for KgC/LSU will decrease dam weight. On the contrary selection for K205 will result in a slight increase in DW, since the correlation between the two is only +0.17. Of interest is the moderate positive correlation between K205 and KgC/LSU of +0.38, indicating that selection for weaning weight as trait of the dam may increase cow efficiency, albeit that cow weight will possibly show a small increase as well.

The results demonstrate that although the use of ratios to adjust one correlated trait for another has been fairly commonplace, it may not be the most feasible approach to use to select for efficient animals. The statistical arguments that restrict the use of ratios to certain circumstances are well documented (Weil, 1962).

5.5 CONCLUSION

A trait that expresses performance (calf weaning weight) per constant unit, viz. per Large Stock Unit (KgC/LSU) would be a useful breeding objective/goal to increase production efficiency, which may reduce the carbon footprint of extensive cow-calf production systems. Since a LSU unit is linked to specific metabolisable energy requirements, and thus daily feed consumption, it should be possible to eventually "link" this breeding objective with the carbon footprint of weaner calf production. However, the use of the ratio of calf weaning weight to cow weight as a selection criterion, for example, has theoretical defects and places inconsistent emphasis on the component traits resulting in variable responses to selection (MacNeil, 2007). It seems that selection on KgC/LSU will have the same defects. A "Cow Efficiency index" could therefore be a more effective alternative, with minimal to no defects. Such a "cow efficiency index" should include DW and K205 but with a restriction on DW. A restricted selection index will therefore restrict increases in DW (and implicitly LSU) which will happen as a consequence of improving K205, thus limiting or restricting the increase in DW which is also associated with high maintenance cost (Burrow *et al.,* 1991; Schoeman & Jordaan, 1999).

CHAPTER 6

RELATIONSHIP BETWEEN THE NOVEL COW-CALF EFFICIENCY TRAITS AND CONVENTIONAL PRE-WEANING TRAITS IN BONSMARA COWS

6.1 INTRODUCTION

Until now, most measurements to improve production in developing countries, and many other parts of the world, are per individual (milk production, fibre production, weaning weight, calving interval, growth rate, etc.). Selection for these traits will increase production, but not necessarily productivity or efficiency of production (Scholtz *et al.,* 2013). In the case of beef cattle these traits are largely limited to breeding values for direct weaning weight and/or maternal weaning weight, or combinations thereof (Rust *et al.,* 2010).

It is therefore important to understand the correlations between the novel cow-calf efficiency traits described in Chapter 5 and the conventional pre-weaning trait, which is calf weaning weight. The aim of this study is therefore to investigate the relationship between K205 and KgC/LSU as traits of the cow with the dam's own weaning weight.

6.2 MATERIALS AND METHODS

The edited dataset, as used by the Agricultural Research Council (ARC) for routine genetic evaluations, as described in Chapter 5 was also used for this study. Since it was not possible to run a repeatability and normal model within the same analyses, it was decided to take the averages of the three weaning weights of the cow's calves, corrected for parity and sex, as an approximation of K205 in the case of this study.

The traits in this study were therefore weaning weight of the dam (DWW) and average weaning weight of her three calves (ACWW) obtained from the dataset described in Chapter 5. Model 2 (Chapter 5) was used to estimate the heritabilities and Estimated Breeding Values (EBV's) and Model 3 to estimate the genetic correlation and covariance components to establish the relationship between DWW and ACWW. The

EBV's for K205 and KgC/LSU EBV's were also already available from the analyses described in Chapter 5.

SAS's proc GLM program (SAS, 2009) was used to calculate Pearson correlations between the novel cow-calf efficiency traits (K205 and KgC/LSU) and DWW and ACWW. Such correlation between traits can be regarded as approximating genetic correlations (Joaquim *et al.*, 2006) and this correlation was regarded as a genetic correlation for the purposes of this study.

The descriptive statistics of the EBV's of the traits K205, KgC/LSU, ACWW and DWW are given in a Table 6.1

Table 6.1. Descriptive statistics of the EBV's of the traits K205, KgC/LSU, ACWW and DWW

Variable	N	Mean	SD	Min	Max
K205	26 707	0.07	5.4	-30.4	29.1
KgC/LSU	26 707	-0.05	3.3	-17.6	77.1
ACWW	26 707	0.5	18.6	-85.7	101.5
DWW	26 707	0.08	4.0	-21.4	22.5

Weaning Weight as trait of the Dam (K205), Kilogram Calf Weaned per LSU (KgC/LSU), Weaning Weight of her three calves (ACWW) and Weaning Weight of the Dam (DWW).

6.3 RESULTS AND DISCUSSION

Variance component estimates and genetic parameters of ACWW and DWW are shown in Table 6.2.

The heritability estimates of ACWW and DWW are 0.81 and 0.26, with the ACWW showing to be highly heritable while DWW is moderately heritable. The heritability of ACWW tend to be substantially higher than those stated by in previous studies (Meyer, 1992; Koots *et al.*, 1994), however the latter were not the average weaning weight of a dam's calves. Models tend to inflate direct heritabilities when the maternal additive effects are excluded in the analysis (Dadi *et al.*, 2002; Koots *et al.*, 1994) which could be an explanation of the substantially high heritability estimates of ACWW. The heritability estimate for DWW was in line with most other estimates from literature as already quoted in Chapter 5. The genetic correlation between ACWW and DWW is moderately positive at 0.52, indicating that selection for cow weaning weight will have a moderate increase in the weaning weights of her calves.

Table 6.2. Variance components estimates (Kg^2) and genetic parameters of ACWW and DWW

	Trait	
Parameter	**ACWW**	**DWW**
h^2	0.81±0.02	0.26±0.03
δ^2_A	567	98
δ^2_P	684	237
δ^2_e	62	62
δ^2_{PE}		34
$r_{ACWW.DWW}$	0.52±0.05	

Heritability estimate (h^2), phenotypic variance (δ^2_A), error variance (δ^2_e), permanent environmental variance (δ^2_{PE}) and correlation between Weaning Weight of her three calves (ACWW) and Weaning Weight of the Dam (DWW) ($r_{ACWW.DWW}$).

Pearson correlations between the novel cow-calf efficiency traits (K205, and KgC/LSU) and ACWW and DWW are presented in Table 6.3. The first point to note is that the Pearson correlation between K205 and KgC/LSU is 0.42, compared to the genetic correlation of 0.39 from Chapter 5. Similarly the genetic correlation between ACWW and DWW is 0.52 (Table 6.2) compared to the Pearson correlation of 0.54. This is some confirmation that the Pearson correlation is a fair approximation of the genetic correlation.

The Pearson correlation between KgC/LSU and ACWW is 0.24 and between KgC/LSU and DWW it is 0.08. In contrast to these fairly low correlations, that of K205 with ACWW and DWW is moderate at 0.52 and 0.42 respectively. The correlation between DWW and ACWW is moderately positive 0.54, which is expected.

A very low correlation of 0.08, which indicates almost totally independency, was obtained between DWW and KgC/LSU indicating that KgC/LSU is independent of the weaning weight of the dam. This is also similar to the previous findings in Chapter 3 where KgC/LSU was shown to be independent of CW. A possible explanation for this apparent low correlation may lie in the fact that weaning weight and cow weight are positively correlated (genetic correlation of +0.94) in Brangus (Neser *et al.*, 2012) and (genetic correlation of +0.44) in Bonsmara (van der Westhuizen *et al.*, 2010). It is possible that the concomitant increase in cow weight (and therefore LSU) as a result of selection for weaning weight (DWW) outweighs the increase in weaning weight and therefore has a negligible effect on cow efficiency.

Table 6.3. Pearson Correlations of Estimated Breeding Values of K205, KgC/LSU, ACWW and DWW.

	Trait			
	K205	**KgC/LSU**	**ACWW**	**DWW**
K205	x	0.42	0.52	0.42
KgC/LSU		x	0.24	0.08
ACWW			x	0.54
				x

Weaning Weight as trait of the Dam (K205), Kilogram Calf Weaned per LSU (KgC/LSU), Weaning Weight of her three calves (ACWW) and Weaning Weight of the Dam (DWW).

This study is suggesting that an alternative approach to selection or selection practices may be needed to increase the efficiency of beef cattle in climate smart agriculture as also indicated in Chapter 5. A profitable and climate smart future for the beef industry will become more and more dependent on the ability to become more efficient (Marshall *et al.*, 1976) and therefore also sustainable.

6.4. CONCLUSION

Weaning weight is regarded as an imperative trait of a beef production enterprise as the end product (calf) and almost the total output of the cow-calf production system (Christian e*t al.,* 1965; Szabò *et al.,* 2012). Clearly defined breeding objectives that increase calf weight in comparison to input costs (cow weight or LSU units) are therefore imperative.

CHAPTER 7

INVESTIGATION OF NOVELTY TRAITS TO IMPROVE COW-CALF EFFICIENCY IN COWS FROM THREE OTHER BREEDS

7.1 INTRODUCTION

It is relevant that the results on the Bonsmara in respect of the novel cow-calf efficiency traits from Chapter 5 be compared with that of other breeds. It was decided to use diverse breed types for this comparison and the breeds selected were the Afrikaner (indigenous *Bos taurus africanis*), Angus (British *Bos taurus*) and Charolais (European *Bos taurus*).

The Afrikaner breed is among the oldest indigenous breeds in South Africa and since its history dates back to the end of the 14th century, it is closely associated with the history of the country and its people. The Breeder's Society was one of the first societies to be founded in 1912. Over the last two decades the Afrikaner breeders have focused strongly on economically important traits in the modern beef production environment, and performance recording was made compulsory, although it is not enforced. (Scholtz *et al.*, 2010). The small to medium frame size of the Afrikaner cow makes it the ideal dam line in crossbreeding for the production of heavy weaner calves (Theunissen, 2011; Mokolobate *et al.,* 2014).

The Angus breed originated in Scotland in the 16th century and the first Angus cattle were introduced in South Africa in 1895. The Angus Society of South Africa is one of the older breeders' societies and was founded in 1917. The Angus is the most numerous British beef breed in South Africa. Performance recording is not compulsory. (Scholtz, 2010).

The Charolais had its origin in the Bresse-Plateau Region in the Jura Mountains of Eastern France. The first Charolais cattle were imported to South Africa in 1955 and again in 1956, followed by a substantial import in 1962 (Bosman, 1994). In 1966, four years after the first substantial import of Charolais cattle into South Africa, the Charolais Cattle Breeders' Society of South Africa was founded. Performance recording is not compulsory. (Scholtz, 2010)

7.2 MATERIALS AND METHODS

The same materials and methods described in Chapter 5, including the models, were used in this chapter. The datasets comprised of 6 104, 7 581 and 2 291 complete calf-cow records for parities 1, 2 and 3, for the Afrikaner, Angus and Charolais breeds, respectively. The description of the various data sets are given in Table 7.1. Charolais had the least number of records followed by the Afrikaner and the Angus with the most records in this case. The relatively low number of records may be attributable to insufficient data provided to the national database (INTERGIS) or discontinued recording.

Table 7.1. Description of the data sets (number of animals)

	Breed		
Animal	**Afrikaner**	**Angus**	**Charolais**
Sires	299	871	262
Dams	1 243	4 527	694
Sires of Dam	150	431	87
Dams of Dam	386	1 459	154

The descriptive statistics for DW, K205, and KgC/LSU of the Afrikaner, Angus and Charolais are given in Table 7.2. As expected Charolais had the highest mean DW. The Angus had the highest mean KgC/LSU followed by the Afrikaner. If KgC/LSU is taken as a definition of cow efficiency, then the cow efficiency of the Angus is 31% higher than that of the Charolais (156/119 x 100%).

7.3. RESULTS AND DISCUSSION

The variance components for the traits K205, DW and KgC/LSU of the different breeds are presented in Table 7.3 and the heritability estimates (h^2) in the same table for the different single trait analyses.

Table 7.2. Descriptive statistics of DW, K205, and KgC/LSU of Afrikaner, Angus and Charolais

	Trait	Min	Mean	Max	SD
	DW	265	444	639	53.9
Afrikaner	**KgC/LSU**	73	140	246	22.9
	K205	103	191	312	27.9
	DW	265	494	884	71.5
Angus	**KgC/LSU**	63	156	258	23.3
	K205	99	232	389	33.4
	DW	391	612	900	84
Charolais	**KgC/LSU**	56	119	191	20
	K205	110	235	365	43

Kilogram Calf Weaned per LSU (KgC/LSU), Weaning Weight as trait of dam (K205) and Dam Weight (DW).

There is a vast difference in the heritability estimates between the breeds for the same trait as is evident from Table 7.3. Heritability estimates of weaning weight as trait of the dam (K205) for the three breeds ranged from 0.13 to 0.40. Since no similar trait could be found in the literature these values had to be compared with the heritabilities of related traits. Wright *et al.,* 1987*)* reported heritabilities of 0.12 and 0.09 for direct and maternal weaning weight respectively, while van der Westhuizen *et al.* (2010) reported heritabilities of 0.22 and 0.12 and Neser *et al*. (1996) reported heritabilities of 0.13-0.28 and 0.14-0.29 for the same traits, respectively.

Table 7.3. Variance components and ratios of the single trait analysis for K205, KgC\LSU and DW of the other three breeds.

Breed	Parameters	Trait		
		K205	DW	KgC/LSU
Afrikaner	h^2	0.40±0.05	0.48±0.05	0.52±0.06
	Ratio PE	0.32±0.05	0.39±0.05	0.32±0.05
	δ^2_A	136.2	682.7	169.3
	δ^2_e	99.3	193.1	53.2
	δ^2_{PE}	108.8	558.7	105.4
	δ^2_P	344.2	1435.3	327.2
Angus	h^2	0.17±0.03	0.56±0.03	0.24±0.03
	Ratio PE	0.19±0.03	0.16±0.03	0.28±0.03
	δ^2_A	94.3	1330.4	81.8
	δ^2_e	352.7	667.8	169.9
	δ^2_{PE}	105.7	378.3	95.4
	δ^2_P	552.7	2378.5±59.5	347.2
Charolais	h^2	0.13±0.08	0.67±0.02	0.21±0.04
	Ratio PE	0.16±0.08	0.22±0.1	0.17±0.08
	δ^2_A	79.3	2505.7	48.7
	δ^2_e	447.1	1202.4	186.9
	δ^2_{PE}	101.7	764	38.3
	δ^2_P	628.1	3708.	235

Heritability estimate (h^2), phenotypic variance (δ^2_A), error variance (δ^2_e), permanent environmental variance (δ^2_{PE}).

The heritability estimates for DW from Table 7.3 varies between 0.48 and 0.67, which are extremely high if compared to the 0.50 of Koots *et al.* (1994), 0.38 of Boligon *et al.* (2009), 0.32 of van der Westhuizen *et al.* (2010), 0.32 of Caetanoa, *et al.* (2013) and 0.43 of Regatieri *et al.* (2012). However there are also other studies reporting very high heritabilities for mature cow weight. Phillips (2001) reported that mature cow weight is a very highly heritable trait in Australia's northern territory, with it being 50% heritable in *Bos Taurus* cattle and even higher in *Bos indicus* cattle, with most estimates ranging from 55 to 85%.

With respect to KgC/LSU the heritabilies range from 0.52 in the case of the Afrikaner to 0.21 in the case of the Charolais. The trend is similar to that of K205, where the heritability was highest for the Afrikaner and lowest for the Charolais.

The permanent environmental variance as percentage of the phenotypic variance is summarized and presented in Table 7.4, since this may be an indication of the carry over effect from one parity to the other in the repeatability model.

Table 7.4. The permanent environmental variance as a percentage of the phenotypic variance

Breed	Trait		
	K205	DW	KgC/LSU
Afrikaner	31.6	38.9	32.1
Angus	19.1	15.9	27.5
Charolais	16.2	20.6	16.3

Kilogram Calf Weaned per LSU (KgC/LSU), Weaning Weight as trait of dam (K205) and Dam Weight (DW).

The permanent environmental values are summarized above to be accessible for discussion. From Table 7.4 it can be seen that the permanent animal effect as percentage of the phenotypic variance is much larger in the Afrikaner breed, which may be an indication of a larger carry over effect from one parity to the other in the case of the Afrikaner. It can only be speculated that since the Afrikaner is kept under more extensive (severe) conditions than the other two breeds, it might be the cause of the larger effect.

An attempt was also made to estimate the genetic correlations between the traits in question for the three breeds using the bivariate model as described in Chapter 5. In the case of the Afrikaner the analyses did not converge and therefore genetic correlations could not be estimated. The genetic correlations in respect of the Angus and Charolais are presented in Tables 7.5 and 7.6 respectively. The genetic correlations between DW and KgC/LSU could also not be estimated in the case of the Charolais. This is possibly due to the high interdependency between the two traits and the low number of records available.

Table 7.5. Genetic correlation (± SE) as obtained in the bivariate analysis for the Angus.

Trait	K205	KgC/LSU
DW	0.43±0.05	-0.75±0.03
KgC/LSU	0.84±0.01	

Kilogram Calf Weaned per LSU (KgC/LSU), Weaning Weight as trait of dam (K205) and Dam Weight (DW).

Table 7.6. Genetic correlations (± SE) as obtained in the bivariate analysis for the Charolais.

Trait	K205	KgC/LSU
DW	0.43±0.24	Not estimable
KgC/LSU	-0.75±0.01	

Kilogram Calf Weaned per LSU (KgC/LSU), Weaning Weight as trait of dam (K205) and Dam Weight (DW).

Table 7.5 and 7.6 demonstrate a moderate but positive relationship between dam weight (DW) and K205 of 0.43 in both breeds. However in the case of the Charolais it is not significant due to the large SE. Since K205 is a novel trait it could not be compared with any estimates from the literature, but it is similar to those between cow weight and weaning weight that are reported by Koots *et al.* (1994) and the 0.44 reported by van der Westhuizen *et al.* (2010) between mature weight and weaning weight direct.

There is however, a major difference in the nature of the relationship between KgC/LSU and K205 between the Angus and the Charolais, the latter indicated a strong negative relationship (-0.75) and the Angus a strong positive relationship (+0.84), compared to that of the Bonsmara (+0.39) from Chapter 5. At this stage it is not clear to what this difference can be attributed to, possibly due to the small number of records. The genetic correlation between KgC/LSU and DW was not estimable in the case of the Charolais and was -0.75 in the case of the Angus, which is of the same magnitude as the -0.83 in the case of the Bonsmara.

7.4 CONCLUSION

The heritability estimate for KgC/LSU in much higher for the Afrikaner (0.52) compared to the Angus (0.24), Charolais (0.21) and the Bonsmara (0.26) indicating that it might be possible to drastically increase the cow efficiency in the case of the Afrikaner. This is in line with the findings of Jordaan *et al.* (2014) where cow efficiency increased by 12.0% in the Afrikaner over a period of 25 years, whereas it increased by only 2.7% in the Bonsmara.

The results in this chapter support the findings of Chapter 5 in respect of the complexities when selecting for a ratio such as KgC/LSU and these complexities seems to be similar to the use of other ratio's such as calf-to-cow ratio (not exclusive), which demonstrates discrepancies when using such a trait (van der Westhuizen, 2014). It is becoming more evident that inclusion and combination of contributing traits in some kind of a selection index is the more feasible and most appropriate option. A "cow efficiency index" could therefore be a more effective alternative, with minimal to no shortcomings.

CHAPTER 8

COW EFFICIENCY IN CROSSBREEDING SYSTEMS AS DEFINED BY KILOGRAM CALF WEANED PER LARGE STOCK UNIT

8.1 INTRODUCTION

As already discussed in Chapter 1, livestock accounts for about 65% of the total agricultural GHG (CO_2 equivalent) of which enteric fermentation (animal digestive tract) accounts for 90%. Mitigation and adaptation strategies therefore need to be put in place if climate change that is related to animal production is to be contained within certain limits (Scholtz *et al.*, 2013). An effective way to reduce the carbon footprint of beef cattle is to reduce the numbers and increase the production per animal, thereby improving their production efficiency. One way to improve production efficiency is through effective crossbreeding systems. The benefits of effective crossbreeding have been reported in a number of studies (Koch *et al.*, 1978; Cundiff *et al.*, 1991; Gregory *et al.*, 1992; Williams *et al.*, 2010). The purpose of this study was to quantify the improved cow efficiency, defined as kilogram calf weaned per Large Stock Unit (KgC/LSU), from the results of an extensive crossbreeding experiment in South Africa.

8.2 MATERIALS AND METHODS

The least square means of cow weight (CW) and weaning weight (WW) from a crossbreeding program using 29 calf and 9 cow genotypes as reported by Theunissen (2011) were used to estimate cow productivity.

These genotypes were formed by crossing Afrikaner (A) cows with Brahman (B), Charolais (C), Hereford (H) and Simmentaler (S) bulls and by back-crossing the F1 cows to the sire line breeds. Cow productivity was defined as KgC/LSU as described in previous chapters. In this case however the weaning rate (number of calves weaned per cow mated) was also included. The latter was obtained from Theunissen *et al.* (2014).

The information of Meissner *et al.* (1983) on the frame sizes of the different breeds as summarized in Table 4.2 was used to categorize the different breeds into frame sizes as indicated below:

Small frame: Afrikaner (A), Hereford (H) and AxH

Medium frame: Brahman (B), AxB, AxC, AxS

Large frame: Charolais (C) and Simmentaler (S)

The regression equations from Chapter 4 were then used to calculate the LSU equivalents for cows of the different frame sizes and cow weights.

Cow productivity was then estimated as follows:

Cow productivity = KgC/LSU x weaning rate (WR)

The weaning weights and cow weights for the 29 different calf genotypes and 9 cow genotypes are set out in Tables 8.1 and 8.2 respectively.

8.3 RESULTS AND DISCUSSION

The results obtained by crossing the Brahman (B), Charolais (C), Hereford (H) and Simmentaler (S) as sire line breeds on the Afrikaner (A) and F1 the genotypes as dam lines (Theunissen, 2011), were used to estimate cow productivity as described in Paragraph 8.2. Table 8.3 illustrates the various LSU's for the different genotypes, as well as the Weaning Rate (WR). Weaning Rate is defined as the number of calves weaned as a percentage of cows mated. Afrikaner F1 cows showed an increased WR of as high as 0.91 compared to the other genotypes.

Table 8.1. Least square means for weaning weights (kg) of calves, combined in the different sire and dam breed groups.

	Sire Breed				
Dam breed	**Afrikaner (A)**	**Brahman (B)**	**Charolais (C)**	**Hereford (H)**	**Simmentaler (S)**
A	184 (41)	206 (29)	212 (24)	195 (31)	210 (32)
B		199 (24)			
C			222 (40)		
H				179 (44)	
S					234 (31)
BA	200 (23)	207 (17)	238 (20)	224 (21)	237 (19)
CA	216 (29)	244 (22)	235 (23)	233 (24)	241 (26)
HA	202 (21)	221 (19)	228 (16)	210 (16)	230 (26)
SA	220 (20)	237 (28)	245 (25)	230 (20)	229 (28)

( ) Number of calves in brackets

The estimated cow productivity for the different genotypes is set out in Table 8.4, with the percentage deviation from the Afrikaner genotype in brackets.

Table 8.4 indicates that crossbreeding with the A as dam line with the B, C, H, and S increased the KgC/LSU on average by 12.8 kg (11.6 %), with the CA F1 cow producing on average the most KgC/LSU (an increase of 15.5%)

Table 8.2. Least square means for cow weights (kg) for the different sire and dam breed groups

	Sire Breed				
Dam breed	**Afrikaner (A)**	**Brahman (B)**	**Charolais (C)**	**Hereford (H)**	**Simmentaler (S)**
A	435	488	497	438	481
B		449			
C			502		
H				407	
S					459

Table 8.3 LSU for the different genotypes above the diagonal, with the Weaning Rate (WR) in italics below the diagonal.

Dam	Sire Breed				
breed	**Afrikaner (A)**	**Brahman (B)**	**Charolais (C)**	**Hereford (H)**	**Simmentaler (S)**
A	1.29 *0.77*	1.48	1.50	1.30	1.46
B	*0.83*	1.32 *0.76*			
C	*0.91*		1.78 *0.74*		
H	*0.91*			1.23 *0.82*	
S	*0.85*				1.34 *0.83*

Table 8.4. Cow productivity (KgC/LSU) for the different genotypes, when calving percentage is included.

Dam breed	Sire Breed Afrikaner (A)	Brahman (B)	Charolais (C)	Hereford (H)	Simmentaler (S)	Average (%)
A	110	123(11.8%)	127 (15.5%)	116 (5.5%)	125 (13.6%)	11.6%
B		115 (4.5%)				
C			92 (-16.3%)			
H				119 (8.2%)		
S					145 (31.8%)	
BA	112 (1.8%)	116 (5.5%)	133 (20.9%)	126 (14.5%)	133 (20.9%)	12.7%
CA	131 (19.1%)	148 (34.5%)	143 (30%)	141 (28.1%)	146 (32.7%)	28.9%
HA	141(28.1%)	155 (40.9%)	160 (45.5%)	147 (33.6%)	161 (46.4%)	38.9%
SA	128 (16.4%)	138 (25.5%)	143 (30%)	134 (28.8%)	133 (20.9%)	22.9%

The AB dam in crosses with the A, B, C, H and S, increased KgC/LSU on average by 14 kg (+12.7%), above that of the AA dam with the C x BA and S x BA and cross producing the most KgC/LSU, an increase of 23 Kg (+20.9%) (Table 8.4). These results are of a similar trend (increased productivity relative to the pure breed A) to the results of the HA, CA and SA dams, with average increases of 42.8 Kg (+38.9%), 31 Kg (+28.9%) and 25.2 Kg (+22.9%) respectively. The S x HA and C x HA had an exceptionally high cow productivity of 44% and 45.5% above that of the pure A respectively.

The improvement demonstrated in this study, concurs with that of Schoeman (2010), which indicates that crossbreeding improves cow/calf efficiency when measured as energy requirements or input costs per kg of steer equivalent weight, as well as the results obtained by Moyo *et al.* (1996). Although the effect of heterosis on individual traits is relatively small, the cumulative effect on composite traits, such as weight of calf weaned per cow exposed are normally large (Gregory & Cundiff, 1980; Schoeman, 2010), which explains the superiority in KgC/LSU as a composite trait.

Effective crossbreeding also makes use of breed complementarity. Complementarity refers to the advantage of a specific crossbred over that of other crossbreds, such as that demonstrated by the HA cow. It is caused by the way in which two or more traits combine or complement each other to express the net merit of the animal. Breed differences in direct and maternal effects can be used to complement each other if appropriate crosses are made (Schoeman, 2010).

A wealth of literature indicates that production efficiency can be improved through improved reproductive performance in beef cattle (Bourdon & Brinks, 1987). When including weaning rate (reflection of pregnancy percentage, calving percentage, and survival rate), the KgC/LSU presented in Table 8.4 demonstrates the importance of improved reproductive performance and survival to improve cow efficiency and indicates that crossbreeding is a good method to improve cow efficiency.

8.4 CONCLUSION

From this study it is clear that cow productivity can be increased by up to 46% without additional herd costs to the farmer through properly designed crossbreeding systems, thereby promoting climate smart beef production systems and reducing the carbon footprint of beef production. The fact that there are large differences in the KgC/LSU between certain genotypes, points to genetic differences and holds the potential for improvement through selection and the use of complementarity between breeds.

CHAPTER 9

CONCLUSION AND RECOMMENDATIONS

9.1 WHY THIS STUDY?

An effective way to reduce the carbon footprint from beef production and to support climate smart production, is to reduce the cattle numbers and increase the production per animal. Increased productivity generates less greenhouse gas emission per unit of product. It therefore becomes increasingly important to define breeding objectives and to develop appropriate selection criteria and crossbreeding strategies to ensure that beef production is effective and aimed at sustainable production (climate smart production) in changing environments. Maximum production might not be the most feasible or appropriate goal for the southern African situation, which is in contrast to production systems in northern hemisphere temperate zone countries. It is therefore important that optimal production that are in harmony with the environment and which utilize appropriate genotypes (including crossbreeding) are developed or implemented. This study was an attempt to investigate such development and implementation and the findings indicate that crossbreeding can increase the performance in a herd without additional costs to the farmer.

The objective of the study was therefore to identify novelty traits as possible selection criteria to improve cow-calf efficiency in extensive systems, as well as the quantification of crossbreeding results to demonstrate the effect of appropriate crossbreeding on cow efficiency.

9.2 NOVEL COW EFFICIENCY TRAITS

The study investigated the use of kilogram calf weaned per Large stock Unit (KgC/LSU) and weaning weight of the calf (K205), both as traits of the dam, as breeding objectives to improve efficiency in extensive cow-calf production systems. The results showed a high negative genetic correlation (-0.83) between KgC/LSU and dam weight (DW) in the case of the Bonsmara, suggesting that direct selection for KgC/LSU will decrease dam weight. Unfortunately this correlation could not be estimated for the other breeds. On the contrary selection for K205 will result in variable increase in DW, since the genetic correlation between the two is +0.17±0.02 in the case of the Bonsmara, 0.43±0.005 in the case of the Angus and not significant in the case of the Charolais.

Of interest is the moderate to high positive genetic correlation between K205 and KgC/LSU of +0.39±0.03 in the case of the Bonsmara and +0.84 in the case of Angus, indicating that selection for weaning weight as trait of the dam might increase cow efficiency, albeit that cow weight will possibly also show an increase. In contrast to this, the genetic correlation between K205 and KgC/LSU in the case of the Charolais is negative -0.75±0.03. If this correlation is to be accepted it implies that selection for K205 will decrease cow efficiency.

From this study it is recommended that possible selection criteria to increase the weaning weight of calves in relation to a cow LSU unit in extensive beef production systems should be investigated. The combination of calf weight as a trait of the dam and dam weight in a selection index might be a feasible option. Another alternative could be to use the relationship between weight of calf produced and the estimated feed inputs (specific regression to estimate LSU as proposed in Chapter 4 will be used) required to sustain the cow and allowing her to provide for the calf. It should be feasible to evaluate the genetic components for milk production (maternal component) and cow size in a multi-trait evaluation system (MacNeil personal communication).

9.2.1 Recommendations

The specific recommendations are to:

1. Do a retrospect analyses of selection applied to kilogram calf weaned per Large Stock Unit using data of a specific timeframe, similar to what was done by MacNeil (2007). This may give an indication as to whether the negative correlation with cow size (in the Bonsmara) is a result of cows being too big already or whether the statistical arguments that restrict its use are valid here (Weil, 1962).
2. Develop alternative selection indexes that will optimize genetic improvement in cow efficiency that include both calf weight and cow weight (including Large Stock Units).

3. Evaluate alternative selection indexes that will optimize genetic improvement in cow efficiency.
4. Compare selection indexes where weights were linked to carbon footprints or credits (sequestration) and those with economic weights.
5. Evaluate trade-offs among strategies that improve productivity and sustainability of beef production.
6. Attempt to develop and evaluate alternative selection indexes that will facilitate maximum genetic improvement in cow efficiency. Normally, the traits in a selection index are weighed with their economic value. However, in this case the traits can even be assigned weights that can be linked to carbon footprints or credits (sequestration) and not only economic weights. It will now be possible to link the annual carbon footprint with an LSU, following the recent publication of Du Toit *et al.* (2013).

9.3 CROSSBREEDING

In South Africa most livestock production is restricted to marginal, natural grazing areas and extensive cattle farming dominate cow-calf production systems. This is in sharp contrast to the intensive systems in large parts of Europe and North America. On the other hand more than 75% of all beef cattle slaughtered in the formal sector in South Africa originate from commercial feedlots (RMRD SA, 2012). A total of 67% of feedlot animals are crossbreds (Scholtz *et al.* 2008), indicating that crossbreeding is playing a significant role in the commercial industry in South Africa. However, it is not clear how effectively this is being done. The results of this study has demonstrated that if the correct crossbred cow is used in crosses with specific terminal sire breeds, cow efficiency can be improved by as much as 45%.

The commercial beef producers in South Africa face the problem of choosing a breeding bull from bulls of different breeds, without having a tool to compare the breeding potential of these bulls directly. Within breed EBV's are available, but cannot be used by commercial breeders to compare bulls across breeds.

In the USA factors to adjust the EBV's of 18 breeds to the base of Angus EBV's are estimated by the USDA-Agricultural Research Service and reported annually to the

Beef Improvement Federation for birth weight, weaning weight, yearling weight, maternal milk, marbling score, ribeye area, and fat thickness, respectively (BIF, 2014).

The EBV of any bull from these breeds can thus be adjusted to the Angus base by adding the corresponding across-breed adjustment factor to its EBV. This provides a platform for national evaluations where different breeds are evaluated together and for whom breed adjustment factors will be available so that EBV's of bulls from different breeds are directly comparable.

9.3.1 Recommendations

It is recommended that a national (multi-breed) evaluation system be developed for South Africa which will allow the proper estimation of heterosis and the development of breed adjustment tables. Across-breed EBV's can be used to compare EBV's of animals from different breeds on the same scale and are especially useful to commercial producers purchasing bulls of two or more breeds for use in systematic crossbreeding programs.

This recommendation will lead to the development of a multi-breed database for South Africa. Breeding objectives can then include crossbred animals in order to create an equitable and enabling environment that allows producers to be highly competitive and market responsive. Across-breed EBV's can be used by commercial producers as a tool to optimize performance and or efficiency of production.

9.4 THE FUTURE

Breeding strategies and production systems to improve the production efficiency of beef cattle can play a significant role in reducing the carbon footprint from beef production, as mentioned many times in this study. This will also enhance climate smart beef production and support the South African government's commitment to reduce GHG emissions.

If the recommendations from this study are implemented, which will still require significant additional research, it has the potential to change the face of beef cattle breeding and production systems in South Africa. The emphasis will then move from increased production to increased efficiency of production.

Improving beef cattle productivity/efficiency will have positive sustainability implications as it will reduce resource use and greenhouse gas emissions whilst improving economic viability. Environmental stewardship is an area for which beef production is under scrutiny, as many consumers perceive that beef has an unacceptable environmental cost. Efforts to address this perception is therefore important.

NOVELTY TRAITS TO IMPROVE COW-CALF EFFICIENCY IN CLIMATE SMART BEEF PRODUCTION SYSTEMS

by

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ABSTRACT

The objective of this study was to identify novelty traits as possible selection criteria to improve cow-calf efficiency and to describe cow efficiency in extensive systems that will support climate smart beef production. The traits investigated were calf weaning weight as trait of the dam and kilogram calf weaned per Large Stock Unit (KgC/LSU); the latter trait being a measure (value) that expresses performance (calf weaning weight) per constant unit, viz. per LSU. This may be a useful breeding objective/goal to increase production efficiency, which may reduce the carbon footprint of extensive cow-calf production systems. No reference could be found in the literature where KgC/LSU or weaning weight as trait of the dam were considered as breeding objectives. Therefore it was decided to investigate the novelty traits proposed above as measures of cow- calf efficiency.

The investigation using breed averages of 30 beef and dual purpose breeds found that KgC/LSU was independent of cow weight and the next step was to do a genetic

analyses on breed level to estimate the genetic parameters for this trait and its genetic correlations with other traits of relevance.

For the purpose of the studies reported later, breed frame size specific equations were developed to estimate LSU units, using published information. The differences in LSU units between animals of the same body weight, but with different frame sizes is based on the principle that there are differences in the voluntary feed intake between such animals, although they have the same body weight.

A Bonsmara (most numerous breed in South Africa) dataset, comprising of 34 884 complete cow-calf records for the first three parities was used to investigate KgC/LSU and calf weaning weight (K205), both as traits of the dam, as breeding objectives to improve efficiency in extensive cow-calf production systems. A number of models were evaluated and the simplest models with improved (smaller) log likelihood values was used. Heritability estimates of KgC/LSU, K205 and dam weight (DW) were 0.26±0.02, 0.11±0.01 and 0.45±0.02 respectively. Genetic correlations of 0.39±0.03 between KgC/LSU and K205, 0.17±0.02 between DW and K205 and -0.83±0.01 between DW and KgC/LSU were found. The very high negative genetic correlation (-0.83) between KgC/LSU and DW suggests that direct selection for KgC/LSU will decrease dam weight. On the contrary selection for K205 will result in a slight increase in DW, since the correlation between the two is only +0.17. Of interest is the moderate positive correlation between K205 and KgC/LSU of +0.38, indicating that selection for weaning weight as trait of the dam may increase cow efficiency, albeit that cow weight will possibly show a small increase as well. It therefore seems that selection or KgC/LSU will have the same defects as other ratio traits. A more effective alternative will be a "cow efficiency index" which include DW and K205 but with a restriction on DW. A restricted selection index will therefore restrict increases in DW (and implicitly LSU).

The relationship between the novel traits and conventional pre-weaning traits were also investigated, where the conventional traits were the weaning weight of the dam (DWW) and the average weaning weight of her three calves (ACWW). The Estimated Breeding Values (EBV's) for the different traits were used to run a Pearson correlation analysis and this correlation was used as approximation of the genetic correlation. Heritability estimates for ACWW and DWW were 0.81±0.02 and 0.26±0.03 respectively. The correlations between K205 and KgC/LSU; ACWW and DWW are

0.42, 0.52 and 0.42 respectively; that between KgC/LSU and ACWW and DWW are 0.24 and 0.08 respectively; whereas that between ACWW and DWW is 0.54. The low correlation of 0.08 between DWW and KgC/LSU indicates that KgC/LSU is independent of the weaning weight of the dam. This result suggests that an alternative approach to selection or selection practices may be needed to increase the efficiency of beef cattle in climate smart agriculture.

The investigation on the novel traits were extended to three diverse breeds namely the Afrikaner (indigenous *Bos taurus* africanis), Angus (British *Bos taurus*) and Charolais (European *Bos taurus*), with 6 104, 7 581 and 2 291 complete cow-calf records respectively, using the same approach as with the Bonsmara. The heritabilities for KgC/LSU were 0.52, 0.24 and 0.21 for the Afrikaner, Angus and Charolais respectively and that for K205 0.40, 0.17 and 0.13 respectively. In many cases the genetic correlations could not be estimated. There were major differences in the nature of the relationship between KgC/LSU and K205 between the Angus and the Charolais, the latter indicated a strong negative correlation (-0.75) and the Angus a strong positive correlation (+0.84). These results support the findings on the Bonsmara, namely that a “cow efficiency index” may be a more effective alternative, with minimal to no defects.

The cow efficiency in crossbreeding systems as defined by KgC/LSU was also investigated, using the results of an extensive crossbreeding experiment. The results was obtained by crossing the Brahman (B), Charolais (C), Hereford (H) and Simmentaler (S) as sire line breeds on the Afrikaner (A) and F1 the genotypes as dam lines. Crossbreeding with the A as dam line increased the KgC/LSU on average by 12.8 kg (11.6 %), with the CA calf producing on average the most KgC/LSU (an increase of 15.5%). In the case of F1 cows, cow productivity of as high as 46% above that of the pure A was achieved. From this study it is clear that cow productivity can be increased without additional herd costs to the farmer through properly designed crossbreeding systems, thereby promoting climate smart beef production systems and reducing the carbon footprint of beef production. The fact that there are large differences in the KgC/LSU between certain genotypes, points to genetic differences and holds the potential for improvement through selection and the use of complementarity between breeds.

An effective way to reduce the carbon footprint from beef production and to support climate smart production, is to reduce the cattle numbers and increase the production per animal. This study attempted to identify novelty traits as possible selection criteria to improve cow-calf efficiency in extensive systems, as well as the quantification of crossbreeding results to demonstrate the effect of appropriate crossbreeding on cow efficiency.

The first recommendation is to investigate possible selection criteria to increase the weaning weight of calves in relation to a cow LSU unit in extensive beef production systems. The combination of calf weight as a trait of the dam and dam weight in a selection index might be a feasible option. Another alternative could be to use the relationship between weight of calf produced and the estimated feed inputs required to sustain the cow and allowing her to provide for the calf. Normally, the traits in a selection index are weighed with their economic value. However, in this case the traits can even be assigned weights that can be linked to carbon footprints or credits (sequestration) and not only economic weights.

This study demonstrated that the correct use of crossbreeding can improve cow efficiency substantially. However, the commercial beef producers in South Africa face the problem of choosing a breeding bull from bulls of different breeds, without having a tool to compare the breeding potential of these bulls directly. Within breed EBV's are available, but cannot be used by commercial breeders to compare bulls across breeds. The second recommendation is therefore to consider the development of breed conversion factors that can be used to convert EBV's between breeds to the same scale.

REFERENCES

AAAS, 2014. American Association for the Advancement of Science, Climate Change Panel. WCGALP, 2014.

ARC, 2012. Agricultural Research Council. Guide to the use of breeding values in cattle breeding. ISBN-13:978-1-86849-412-5.

Armsby, H.P. & Fries, J.A., 1911. The influence of type and of age upon the utilization of feed by cattle. 128. US Department of Agriculture, Bureau of Animal Industry.

Assan, N. & Masache, A., 2012. Genetic parameters for weaning weight of Zimbabwean Nguni cattle accounting for direct-maternal genetic covariances. J. Sci.1, 53-60.

BIF, 2014. Beef Improvement Federation Press Release. http://beefimprovement. org/content/uploads2014/ 09/2014-ABEPD-press-release.pdf.

Biotech LTD, 2009. Agribusiness and Climate Change Seminar: Nutrition and low methane diet. Figures obtained from IPCC 1996 National Emissions. June 16th, 2009. Available at: www.neembiotech.comAccessed: 25 May 2013.

Blignaut, J.N., Mabugu, R.M. & Chitiga-Mabugu, M.R., 2005. Constructing a greenhouse gas emissions inventory using energy balances: The case of South Africa: 1998. J. Envir. S. Afr. 16,105-116.

Boligon, A.A., V Sala, V.E., Mercadante, M.E.Z., Ribeiro, G. E., Cyrillo, J.N. dos S., & de Albuquerque, L.G., 2013. Genetic parameters for different birth and weaning weight ratios in Nelore cows. Cienc. Rural. 43 (4), 676-681.

Bosman, D.J., 1994. National Beef Cattle Performance and Progeny Testing Scheme. 1980-1992 Results.

Bourdon, R.M. & Brinks, J.S., 1987. Simulated efficiency of range beef production. 1. Growth and milk. J. Anim. Sci. 65, 943-955.

Bourdon, R.M., 2000. Understanding animal Breeding. 2nd Edition. Pretice Hall, Inc. New Jersey.

Burrow, H.M., Seifert, G.W. & Hetzel, D.J.S., 1991. Consequences of selection for weaning weight in Zebu, Bos Taurus and Zebu x Bos Taurus cattle in the tropics. Aust. J. Agric. Res. 42, 295-307.

Caetanoa, S.L., Savegnagoa, R.P., Boligona, A.A., Ramosa, S.B., Chuda, T.C.S., Lôbob, R.B. & Munari, D.P., 2013. Estimates of genetic parameters for carcass, growth and reproductive traits in Nellore cattle. Livest. Sci.155, 1-7.

Cartwright, T.C., Melton, A.A., Nelson, L.A., & Riggs, J.K., 1967. Milk Production, Composition and Calf Gains of Angus, Charolais and Hereford Cows. J. Anim. Sci. 26, 804-809.

Christian, L.L., Hauser, E.R. & Chapman, A.B., 1965. Association of preweaning and postweaning traits with weaning weight in cattle. J. Anim. Sci. 24, 652-659.

Clark, H., Klein, C. & Newton, P., 2001. Potential management practices and technologies to reduce nitrous oxide, methane and carbon dioxide emissions from New Zealand agriculture. Ngaherehere: Ministry of Agriculture and Forestry.http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/climate/green-house-gas-migration/ghg-mitigation.htm

Cundiff, L.V., Gregory, K.E. & Koch, R.M., 1991. Breed effects and heterosis in advanced generations of composite populations for preweaning traits of beef cattle. J. Anim. Sci. 69, 947-960.

Dadi, H., Schoeman, S.J., van der Westhuizen, J. & Jordaan, G.F., 2002. The effect of Charolais and Hereford sires and straightbred and crossbred dams on pre-weaning growth of calves. S. Afri. J. Anim. 32, 38-43.

DEAT, 2007. Scenario building team 2007. Long term mitigation scenarios: Technical summary. Department of Environmental affairs and tourism. Pretoria. October 2007.

Dickerson, G.E., 1978. Animal size and efficiency: basic concepts. Anim. Prod. 27, 367-379.

Du Toit, C.J.L., Meissner, H.H. & van Niekerk, W.A., 2013. Direct greenhouse gas emissions of the game industry in South Africa. S. Afr. J. Anim. Sci. 43, 376-393.

Evans, J.L., Golden, B.L. & Hough, B.L., 2002. A new genetic prediction for cow maintenance energy requirements. www.beefimprovement.org/proceedings/ .../Evans_02BIF.pdf

Ferrell, C.L. & Jenkins, T.G., 1982. Efficiency of cows of different size and milk production potential. RLHUSMARC Germ Plasm Evaluation Report 10, 12.

FAO, 1998. Food and Agricultural Organization, Carbohydrates in Human Nutrition. Report of a Joint FAO/WHO Expert Consultation (FAO Food and Nutrition Paper 66) Food and Agriculture Organization: Rome.

Garnett, T., 2010. Intensive versus extensive livestock systems and greenhouse gas emissions. Food Climate Research Network Briefing Paper. http://www.fcrn.org.uk/sites/default/files/FCRN_int_vs_ext_livestock.pdf

Gilmour, A.R., Cullis, B.R. & Welham, S.J., 2009. ASREML Reference Manual.

Gregory, K.E. & Cundiff, L.V., 1980. Crossbreeding in beef cattle: evaluation of systems. J. Anim. Sci. 54, 1224-1242.

Gregory, K.E., Cundiff, L.V. & Koch, R.M., 1992. Effects of breed and retained heterosis on milk yield and 200-day weight in advanced generations of composite populations of beef cattle. J. Anim. Sci. 70, 2366-2372.

Greiner, S.P., 2009. Beef cow size, efficiency, and profit. http://pubs.ext.vt. edu/news/ livestock/old/aps-200904_Greiner.html

Harris, L.D., 1970. Breeding for Efficiency in Livestock Production: Defining the Economic Objectives. J. Anim. Sci. 30, 860-865.

Hendriks, J., Scholtz, M.M., Neser, F.W.C. & Van Wyk, J.B., 2014. Preliminary investigation into genetic parameters for feedlot traits of Angus cattle in South Africa. Proc. 10th Wrld Cong. Genet Appl. Livest. Prod. https://asas.org /docs/default-source/wcgalp-posters/570_paper_9310_manuscript_550_0. pdf?sfvrsn=2

Holst, P.J., 1999. Recording and on-farm evaluations and monitoring: breeding and selection. Small Rumin. Res. 34, 197-202.

IPCC, 2007. Climate change 2007: Synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change [Core writing team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

Jenkins, T.G. & Ferrell, C.L., 2002. Beef cow efficiency revisited. Proceedings Beef Improvement Federation. Omaha, NE.

Joaquim, T., Jesús, P. & Vincent, D., 2006. Validation of an approximate approach to compute genetic correlations between longevity and linear traits. Genet. Sel. Evol, 38, 65-83.

Johnston, D.J. & Bunter, K.L., 1996. Days to calving in Angus cattle: genetic and environmental effects, and covariances with other traits. Livest. Prod. Sci. 45, 13-22.

Jordaan, F.J., Scholtz, M.M., Neser, F.W.C., Maiwashe, A. & King, Z., 2014. Did genetic change improve production efficiency in three landrace breeds of South Africa? Proceedings, 10th World Cong. Genet. Appl. Livest. Prod. source/wcgalpposters/391_paper_8712_manuscript_218_0.pdf?sfvrsn=2

Kleiber, M., 1936. Problems involved in breeding for efficiency of food utilization. Proc. Amer. Soc. Anim. Prod. Pg. 236.

Knox, J.H., 1957. The interrelations of type, performance and carcass characteristics. J. Anim. Sci.16, 240-248.

Koch, R.M., Gregory, K.E., Crouse, J.D., Laster, D.B., Cundiff, L.V. & Smith, G.M., 1978. Heterosis and Breed Maternal and Transmitted Effects in Beef Cattle IV. Carcass Traits of Steers. J. Anim. Sci. 47, 1063-1079.

Koots, K.R., Gibson, J.P., Smith, C. & Wilton, J.W., 1994. Analyses of published genetic parameter estimates for beef production traits. 1. Heritability. Anim. Breed. Abstr. 62, 309-338.

Kosgey, I.S. & Okeyo, A.M., 2007. Genetic improvement of small ruminants in low-input, smallholder production systems: Technical and infrastructural issues. Small Ruminant Research. 70, 76-88.

MacNeil, M.D., 2005. Genetic evaluation of the ratio of calf weaning weight to cow weight. J. Anim. Sci. 83, 794-802

MacNeil, M.D., 2007. Retrospective analysis of selection applied to a ratio. Amer. Soc. Anim. Sci. 58, 85-88.

MacNeil, M.D., Scholtz, M.M. & Maiwashe, A., 2013. Estimates of variance components for postweaning feed intake and growth in Bonsmara bulls and evaluation of alternative measures of feed efficiency. S. Afri. J. Anim Sci. 43, 18-24.

Maddock, T.D. & Lamb, G.C., 2010. Managing beef cow efficiency. University of Florida. IFAS, Florida Coop. Ext. Serv., Animal Science Dept., EDIS Publication AN233.

Marshall, D.A., Parker, W.R. & Dinkel, C.A., 1976. Factors affecting efficiency to weaning in Angus, Charolais and reciprocal cross cows. J. Anim. Sci. 43, 1176-1187.

Meissner, H.H., Hofmeyr, H.S., Van Rensburg, W.J.J. & Pienaar, J.P., 1983. Classification of livestock for realistic prediction of substitution values in terms of a biologically defined Large Stock Unit. Tech.Comm. No. 175. Department of Agriculture, Pretoria.

Meissner, H.H., Scholtz, M.M. & Schönfeldt, H.C., 2012. The status, socio-economic and environmental impact, and challenges of livestock agriculture in South Africa. www.rmrdsa.co.za

Meyer, K., 1992. Variance components due to direct and maternal effects for growth traits of Australian beef cattle. Livest. Prod. Sci. 31, 179-204.

Mohammadi, H., Shahrebabak, M.M., Vatankhah, M. & Shahrebabak, H.M., 2013. Direct and maternal (co)variance components, genetic parameters, and annual trends for growth traits of Makooei sheep in Iran. Trop. Anim. Health. Prod. 45, 185-191.

Mokolobate, M.C., Scholtz, M.M., Mulugeta, S. & Neser, F.W.C., 2013. Report on a breeding objective that may reduce the carbon footprint of extensive cow-calf production systems. Nat. Sci. 5, 167-171.

Mokolobate, M.C., Theunissen, A., Scholtz, M.M., & Neser, F.W.C., 2014. Sustainable crossbreeding systems of beef cattle in the era of climate change. S. Afr. J. Anim. Sci. 44, S8-S11.

Moss, R. A., 2000. Methane: Global warming and production by animals. Canterbury: Chalcombe Publications, 1993. Pg.105.

Moyo, S., Swanepoel, F.J.C. & Rege, J.E.O., 1996. Evaluation of indigenous, exotic and crossbred cattle for beef production in a semi-arid environment: reproductive performance and cow productivity. Proc. Aust. Soc. Anim. Prod. 21, 204-206.

Neser, F.W.C., Konstantinov, K.V. & Erasmus, G.J., 1996. The inclusion of herd-year-season by sire interaction in the estimation of genetic parameters in Bonsmara cattle. S. Afr. J. Anim. Sci. 26, 75-78.

Neser, F.W.C., van Wyk, J.B., Fair, M.D., Lubout, P. & Crook, B.J., 2012. Estimation of genetic parameters for growth traits in Brangus cattle. S. Afr. J. Anim. Sci. 42, 469-473.

Neser, F.W.C., 2012. http://www.rpo.co.za/documents/pptrpo/proffrikkieneser.pdf

Notter, D.R., 2002. Defining biological efficiency of beef production. Proceedings Beef Improvement Federation. Omaha, NE.

Olivier, W.J., Snyman, M.A., Olivier, J.J., Van Wyk, J.B. & Erasmus, G.J., 2001. Direct and correlated responses to selection for total weight of lamb weaned in Merino sheep. S. Afr. J. Anim. Sci. 31, 115-121.

Phillips, A., 2001. Beef cattle genetics applied to extensive herd. Northern Territory Department of Primary Industry, Fisheries and Mines. Incidental Publication No. 8. ISBN 0 7245 3086.

Pitesky, M.E., Stackhouse, K.R. & Mitloehner, F.M., 2009. Clearing the air: Livestock's contribution to climate change. Advances in Agronomy. 103, 1-40.

Ponzoni, R.W., 1986. A profit equation for the definition of the breeding objective of Australian merino sheep. J. Anim. Breed. Gen. 103, 342-357.

Ponzoni, R.W., 1992. Genetic improvement of hair sheep in the tropics. FAO Animal Production and Health Paper. 101, 178.

Rasby, R., 2010. Relationship between Cow Weight, Milk Production, and Nutrient Needs University of Nebraska - Lincoln. Ext. Animal science Dept.

Regatieri, I.C., Boligon, A.A., Baldi, F. & Albuquerque, L.G., 2012. Genetic correlations between mature cow weight and productive and reproductive traits in Nellore cattle. Genet. Mol. Res. 11, 2979-2986.

Ridoutt, B.G., Sanguansri, S. & Harper, S.G., 2011. Comparing carbon and water footprints for beef cattle production in Southern Australia. Sus. 3, 2443-2455.

RMRD, S.A., 2012. Research and development plan for the large and small stock meat industries in South Africa. 2012-2013. www.rmrdsa.co.za

Robertson, A., 1973. Size of animal in relation to productivity and special reference to the ruminant. Proc. British Soc. Anim. Prod. 2, 9-14.

Rust, T., Theron, H.E., Scholtz, M.M. & Bergh, L., 2010. The practical use of breeding values in beef cattle breeding. In: Beef Breeding in South Africa. (2nd Ed.). Ed: Scholtz, M.M., ARC. Pretoria. 115-137.

SAS, 2009. SAS Institute Inc. SAS® Procedures Guide, Cary, NC.

Schiemiester, L.N., 2014. Estimation of breed-specific heterosis effects for birth, weaning and yearling weight in cattle. M.Sc. Thesis. University of Nebraska-Lincoln. United States of America.

Schoeman, S.J. & Jordaan, G.F., 1999. Multi-trait estimation of direct and maternal (co)variances for growth and efficiency traits in a multibreed beef cattle herd. S. Afr. J. Anim. Sci. 29, 124-136.

Schoeman, S.J., 2010. Crossbreeding in beef cattle. In: Scholtz, M., Ed., Beef Breeding in South Africa. 2nd Edition. ARC. Pretoria, 21-32.

Scholtz, M.M., Bester J. & Mamabolo, J.M., 2008. Results of the national cattle survey undertaken in South Africa, with emphasis on beef. Appl. Anim. Hus. & Rur. Dev. 1, 1-9.

Scholtz M.M., Furstenburg, D., Maiwashe, A., Makgahlela, M.L., Theron, H.E. & van der Westhuizen, J., 2010. Environmental-genotype responses in livestock to global warming: a southern African perspective. S. Afri. J. Anim. Sci. 40, 408-413.

Scholtz, M.M., 2010. Beef Breeding in South Africa, 2nd Edition. Ed. Scholtz, M.M, Agricultural Research Council, Pretoria.

Scholtz, M.M., McManus, C., Okeyo, A.M. & Theunissen, A., 2011. Opportunities for beef production in developing countries of the southern hemisphere. Livest. Sci. 142, 195-202.

Scholtz, M.M., Maiwashe, A., Neser, F.W.C., Theunissen, A., Olivier, W.J., Mokolobate, M.C. & Hendriks, J., 2013. Livestock breeding for sustainability to mitigate global warming, with the emphasis on developing countries. S. Afr. J. Anim. Sci. 43, 269-281.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M. & de Haan, C. 2006. Livestock's long shadow: Environmental issues and options. FAO. Rome, Pg. 390.

Szabó, F., Szabó, E. & Szabolcs. B., 2012. Static and genetic parameters of 205-day weaning weight of beef calves. Archiv. Tierzucht. 55, 552-561.

Tedeschi, L.O., Fox, D.G. & Baker, M.J., 2004. Unveiling the production efficiency of the beef cow: A systematic approach using nutrition models. Animal Science Mimeograph Series No. 224. Cornell Cooperative Extension, Corning, NY.

Theunissen, A., 2011. Characterization of breed additive and heterosis effects in beef cattle using experimental results. M.Sc. Dissertation. University of the Free State. South Africa.

Theunissen, A., Scholtz, M.M., Neser, F.W.C. & MacNeil, M.D., 2014. Crossbreeding to increase beef production: Additive and non-additive effects on fitness trait. S. Afr. J. Anim. Sci. 4, 44-51.

Thorne, M.S. & Stevenson, M.H., 2007. Stocking rate: The most important tool in the toolbox. College of Tropical Agriculture and Human Resources. University of Hawaii, Manoa. http://www.ctahr.hawaii.edu/oc/freepubs/pdf/PRM-4.pdf

UNFCCC, 2014. United Nation Framework Convention on Climate Change 2007. Available in:<http://unfccc.int/kyoto_protocol/items/2830.php> Acesso em: 03 abril 2009.

U.S. Environmental Protection Agency (EPA), 2006. Global Anthropogenic Emissions of Non- CO_2 Greenhouse Gases, 1990-2020.

Urick, J.J., Knapp, B.W., Brinks, J.S., Pahnish, O.F. & Riley, T.M., 1971. Relationships between cow weights and calf weaning weights in Angus, Charolais and Hereford breeds. J. Anim. Sci. 33, 343-348.

Van der Westhuizen, R.R., Theron, H.E., Van der Westhuizen, J., Maiwaishe, A. & Jordaan, F., 2010. Newsletter Nat. Beef Record. Impr. Scheme, 99: 39.

Van der Westhuizen, 2014. South African Stud Breeder/ Stoetteler. Incorporating South African Horseman. 24-27.

Van Wyk, J.B., Fair, M.D. & Cloete, S.W.P., 2003. Revised models and parameter estimates for production and reproduction traits in the Elsenburg Dorper sheep stud. J. Anim. Sci. 33, 213-220.

Vanmiddlesworth, C.J., Brown & Johnson, Z.B., 1977. Repeatability of calf weight and ratio of calf weight to cow weight in Hereford and Angus. J. Anim. Sci. 45, 1247-1253.

Wall, E., Simm, G. & Moran, D., 2010. Developing breeding schemes to assist mitigation of greenhouse gas emissions. Animal 4, 366-376.

Weil Jr., W.B., 1962. Adjustment for size—A possible misuse of ratios. A. J. Clin. Nut. 11, 49.

Williams, J.L., Aguilar, I., Rekaya, R.R. & Bertrand, J.K., 2010. Estimation of breed and heterosis effects for growth and carcass trait in cattle using published crossbreeding studies. J. Anim. Sci. 88, 460-46.

Wright, H.B., Pollak, E.J. & Quaas, R.L., 1987. Estimation of variance and covariance components to determine heritabilities and repeatability of weaning weight in American Simmental cattle. J. Anim. Sci. 65, 975-981.