SUSTAINABLE APPLICATION OF LIVESTOCK WATERFOOTPRINTS IN DIFFERENT PRODUCTION SYSTEMS AND REGIONS OF SOUTH AFRICA

Report to the

Water Research Commission

by

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The publication of this report emanates from a project entitled Sustainable Application of Livestock Waterfootprints in Different Production Systems and Regions of South Africa (WRC Project No. K5/2964//4).

EXECUTIVE SUMMARY

This document presents a final report for the project on the "*Sustainable Application of Livestock Waterfootprints in Different Production Systems and Regions of South Africa*" focusing on the intensive production system. The intensive production system (feedlot) is characterized by high stocking densities per hectare. Typically, it has fairly efficient and comparatively high animal productivity. In contrast to mixed and pastoral livestock production systems, feedlots are almost exclusively dedicated to food production, as a response to the growing demand for beef in urban areas. The operations are usually large in size, fully mechanized and vertically integrated. There is thus a greater uniformity of technology and practices than in mixed and grazing systems. Today, about 2% of the global cattle population is estimated to be held in feedlots and produces about 7% of the world's beef. Feedlots are well established in countries like the US and Canada and are rapidly growing in other regions, such as South America, Asia and Africa, driven by rising demand for meat in urban areas (Gerber et al., 2013). Feedlots provide the kind of standardized carcasses required by the retail sector and make use of relatively abundant crop products and co-products as well as by-products such as soybean cakes and Dried Distillers Grains with Solubles (DDGS). Feedlots usually have high animal performance levels in terms of daily weight gain and feed conversion ratio. This often results in relatively high levels of natural resource use efficiency (Capper et al. 2020; Pelletier et al., 2010), although typically lower than industrial poultry and pig operations.

Feedlot operations are nevertheless associated with relatively high impacts on water resources and air quality, mostly due to the geographical concentration of production units. Water constitutes above 70% of the animal's live weight. To maintain this enormous pool of water, animals acquire water through drinking, food consumed and metabolic water. However, not all this water is assimilated into the animal's body. To date, no water footprint assessments have been conducted in South Africa. It is important to provide producers, policy makers and consumers with these figures so that they can make properly informed decisions when considering practices to decrease environmental impact. Therefore, due to rising concerns about water availability in the near future, amid climate change, it is critical to recognize the relationship between water intake and economically important traits such as post-weaning growth performance and meat characteristics. In this study, productivity is defined as meat yield per litre of water.

The overall aim of this study was to evaluate water footprints of beef cattle of South Africa under intensive production system. The study was guided by the following specific objectives:

i. To determine water footprints for different body frame sizes of beef cattle under intensive production system in South Africa.
ii. To assess the degree of variations in the volumetric water footprint indicator for post-weaning growth performance of beef cattle under intensive production system.
iii. To determine the relationship between the volumetric water footprint and carcass characteristics of beef cattle under intensive production system.
iv. To determine the amount of water consumed per kilogram feed intake per breed.

Thirty-three (33) beef cattle weaners representing three different body frame sizes (Small, Medium and Large) from three different breeds of similar age and body weight groups were used in this research. Nguni (n=11), Bonsmara (n=11) and Simmental (n=11) breeds were selected as representatives of small, medium and large frame size beef cattle breeds, respectively. The animals were randomly assigned to treatments in a Completely Randomised Design, i.e. eleven (11) animals per body frame size and each animal as a replicate unit. Animals were allowed an adaptation period of 28 days, followed by data collection for 84 days. A total mixed ration and water were provided *ad libitum* to each animal. Data were analysed using the repeated measures technique of the MiniTab 17 (2017) in PROC MIXED considering the covariance structure of the observed data.

The WCE for the medium frame (0.09 kg/L) cattle was comparable ($p>0.05$) to large frame (0.08 kg/L), whilst that of the small frame (0.11 kg/L) cattle was higher ($p<0.05$) than that of the other frame sizes. The WIE of the small (10.56 L/kg) and medium (10.84 L/kg) frame sizes were not significantly ($p>0.05$) different, however, lower than that of the large frame size (12.04 L/kg). The service water was significantly higher ($p<0.05$) for the large framed beef breed (3.55 l) than that of the small frame (2.45 l) and medium frame (2.64 l) beef breeds. Interestingly, the water footprint for the medium-framed beef breed (8.86 L/kg) was significantly lower ($p<0.05$) than that of the small-framed beef breed (9.88 L/kg) but similar ($p>0.05$) to that of the large-framed beef breed (9.02 L/kg). The eye muscle area was significantly higher ($p<0.05$) for medium (50.36 mm) and large (46.70 mm) framed breeds compared to the small frame (40.24 mm).

The following conclusions and recommendations were made from the results of the study:

- From the literature review, it is evident that South Africa is at risk of water scarcity, and that blue water resources are dry for most months of the year, with agriculture being a major contributor by using largely blue water for the production of both crops and animal food products.
- A notable outcome of this study is the realisation of the effect of frame size on the use of water as a limiting natural resource, an effect that has not been quantified previously.
- In view of water scarcity problems, and amid accelerated global warming (climate change), livestock breeding programmes should consider breeds or frame sizes that efficiently utilize water resources.
- The low fat-based RTU scans, post-slaughter measurements and favourable water use-efficiency indicators (WIE and WCE) suggest that medium frame size breeds have greater water use efficiency.
- The medium frame-size beef breeds are recommended for use in intensive production systems in view of their better water use-efficiency.
- There is a need to develop awareness and educational materials on water use efficiency for farmers and the public, as South Africa is a water-scarce country, and promotion of water use efficient beef breeds.

Below are some of the recommendations for future study.

- Since this research focused only on the intensive production system, it would be worthwhile to assess water use efficiency in extensive livestock production system.
- The current study was conducted and completed in one season, future studies should compare results and trends across seasons.
- The current research was based on only three breeds as representatives of frame sizes, thus future research is needed to focus on identifying more efficient livestock production methods across breeds in order to reduce water footprint without compromising production.
- Previous studies conducted elsewhere reported that the two indicator traits for water use efficiency considered in the current study are under genetic control, therefore, future studies to validate these findings are required under the South African livestock production conditions.
- Studies on the genetic basis underlying water use efficiency mechanisms and the possible genetic markers influencing water use efficiency are recommended.

The outcomes of this study contribute new knowledge and innovation toward the development of indicator traits of water footprints for sustainable utilization of water in livestock production in South Africa. Currently, there are no indicator traits for livestock water footprints in livestock genetic improvement programmes in South Africa and many countries of the world. This research also produced baseline information on the potential indicators traits (Water Intake Efficiency & Water Consumption Efficiency) to assess the livestock water footprints for the intensive production system in South Africa. Furthermore, this study contributes toward global action to mitigate the impact of climate change (Goal 13: Climate Action – United Nations Sustainable Development Goals) and Goal 2 to “End hunger, achieve food security and improved nutrition and promote sustainable agriculture”. The outcomes also align well with the Africa Union Agenda 2063 as well as the National Development Plan (NDP) Vision 2030 Chapter 5 on Climate Change, and Chapter 6 on Modern Agriculture.

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ACRONYMS AND ABBREVIATIONS

ADG	Average daily gain
AOAC	Association of Official Analytical Chemists
ARC-AP	Agricultural Research Council-Animal Production
BF	Backfat
BSC	Balanced Scorecard
CCW	Cold Carcass Weight
DAFF	Department of Agriculture, Forestry and Fisheries
DDGS	Dried Distiller Grains
EMA	Eye Muscle Area
FCE	Feed conversion efficiency
FCR	Feed Conversion Ration
FI	Feed Intake
GLM	General Linear Model
ILO	International Labour Office
Kg	Kilogram
KZN	KwaZulu-Natal Province
L	litre
LCA	Life Cycle Assessment
LSM	Least Square Means
Max	Maximum
Min	Minimum
NDP	South Africa National Development Plan
NRC	National Research Council
PIMF	Percent Intra-Muscular Fat
REA	Rib Eye Area
RF	Rump Fat
RTU	Real-Time Ultrasound
SA	South Africa

SD	Standard Deviation
TMR	Total Mixed Rations
WCE	Water Consumption Efficiency
WCW	Warm Carcass Weight
WF	Water Footprint
WFA	Water Footprint Assessment
WFR	Water-to-Feed Ratio
WFTN	Water Footprint Network
WG	Weight Gain
WI	Water Intake
WIE	Water Intake Efficiency

CHAPTER 1: GENERAL INTRODUCTION

This chapter lays the study foundation by presenting a brief background to the research, purpose, aims and objectives of the study as well as study limitations.

1.1. Background

Food security is a challenge in rural and peri-urban areas of South Africa and in many developing countries. The escalation of the high unemployment rate in rural areas further exacerbates the food security challenge (International Labour Office (ILO), 2012). The increasing demand for agricultural products is connected to the increasing demand for global food. Incidents of drought resulting from climate change have severely impacted water-available resources (Mwendera and Atyosi, 2018). The anticipated growth in the world population assumes intensification of water-availability concerns as food demand escalates, particularly the demand for food of animal origin. This results in a shift from extensive animal production towards semi- and intensive production systems in an attempt to meet this escalating demand (Mpandeli et al., 2018). The expected environmental impacts of increased consumption of animal products (Pelletier and Tyedmers, 2010; Sutton et al., 2011; Godfray et al., 2018; Enahoro et al., 2019), and the pros and cons of intensive and extensive production systems (Porcel et al., 2018; Zura et al., 2019) have been researched extensively. There is an undeniable impact on an increase in pressure exerted on water resources due to the intensification of animal production systems.

There are several other factors associated with this increase in water consumption from the intensive production system, such as the low efficiency of rations (Adduci et al., 2015). Animals kept under the traditional extensive system generally utilize land that would not be suitable for either human settlement or other crop production purposes. Therefore, they largely utilize the green water which forms part of the water footprint assimilated in pastures (Zhao et al., 2019). A water footprint is an indicator of the degree of sustainability in which freshwater is drawn to maintain economic activities, such as food production (Hoekstra et al., 2011). It provides information on two facets of water use: (1) the total amounts of freshwater utilized to produce the required quantities of food product and to deliver it to the end-consumer, measured along the entire supply chain of a commodity, and (2) the degree of sustainability with which freshwater was used. The volume of water used to produce the required quantities of a food product – for example, the litres of water used to produce 1 kg of beef – is referred to as the volumetric water footprint indicator (Chapagain and Hoekstra, 2004; Chapagain and Hoekstra, 2011; Hoekstra et al., 2011;).

Undoubtedly, water is the most important nutrient required in the animal body, constituting above 70% of the animal's live weight (NRC, 1996). To maintain this enormous pool of water, animals acquire water through drinking, water from the food consumed and metabolic water. However, not all this water is assimilated into the animal’s body (Meyer et al., 2004; Khelil-Arfa et al., 2012). Therefore, water use efficiency is defined as the ratio of the water assimilated into the animal’s body to the actual water consumed. Noticeably, water restriction reduces the water and dry matter intakes, body weight at slaughter and hot and cold carcass yields of animals (dos Santos et al., 2019) and carcass traits. There is a paucity of information on the water use efficiency of beef cattle in both intensive and extensive production systems in South Africa.

The outcome of this research supports United Nations' Sustainable Development Goals (SDGs) on Climate Action (Goal 13) and Goal 2 to "End hunger, achieve food security and improved nutrition and promote sustainable agriculture". This also aligns well with Africa Union Agenda 2063 as well as the National Development Plan (NDP) Vision 2030 Chapter 5 on Climate Change, and Chapter 6 on Modern Agriculture.

1.2. Purpose of the Study

1.2.1. Aim

The overall aim of this study was to evaluate the water footprints for beef cattle of South Africa under an intensive production system.

1.2.2. Specific objectives

The objectives were:

i. To determine water footprints of different body frame sizes of beef cattle under intensive production system in South Africa
ii. To assess the degree of variations in the volumetric water footprint indicator for post-weaning growth performance of beef cattle under intensive production system.
iii. To determine the relationship between the volumetric water footprint and carcass characteristics of beef cattle under intensive production system.
iv. To determine the amount of water consumed per kilogram feed intake per breed.

1.3. Study Limitations

The COVID-19 pandemic affected the way that this research was conducted. In this research, the researchers delayed the data collection and/or re-designed the data collection activities and observed national COVID-19 regulations when required. Moreover, the study only used three different breeds as representatives of frame sizes under one season. More breeds may be required in future studies and data should be collected across all seasons. Due to the higher costs associated with evaluating some meat quality traits, only a few carcass and meat traits were considered.

1.4. Structure of the Report

The research was conducted to evaluate the water footprints of South African beef cattle under intensive production system. This analysis considered water use, growth performance, and carcass and meat quality traits from animals finished under a feedlot system. This report is divided into five chapters, consisting of the general introduction of the study, a review of the literature, two chapters of the research findings and, a chapter on conclusions and recommendations.

In Chapter 1, the background and justification, problem, and the purpose of the study were highlighted.

In Chapter 2, the literature review critically examines the historical and current literature on water footprint in beef cattle. This chapter aimed to identify key issues associated with water usage in beef production. These include contributing factors to the water footprint of beef production and the effects it has on various aspects of the environment and social wellbeing. This Chapter further explores the various methods for assessing the water footprint of a product.

In Chapter 3, objectives 1 and 2 of the study were addressed. The water footprints and degree of variations in the volumetric water footprint indicator for post-weaning growth performance of beef cattle under intensive production system were assessed. This was made possible by using the post-weaning growth performance traits and volumetric water usage measurements on beef cattle of different frame sizes.

In Chapter 4, objective 3 and 4 of the study was addressed. The relationship of volumetric water footprint and carcass characteristics of beef cattle under intensive production system, as well as the amount of water consumed per kilogram feed intake per breed, were determined. This was achieved by the use of carcass characteristics and volumetric water usage measurements on beef cattle of different frame sizes in an intensive system.

Chapter 5 presents general conclusions and recommendations from this research and outlined future work.

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CHAPTER 2: SUSTAINABLE APPLICATION OF LIVESTOCK WATER FOOTPRINTS IN DIFFERENT BEEF PRODUCTION SYSTEMS OF SOUTH AFRICA – LITERATURE REVIEW

Abstract

There is an increase in requirement and competition for water, while water resources are decreasing at an accelerating rate. Agriculture is the biggest consumer of water and therefore has the largest water footprint, which is not yet known. The largest portion is acknowledged to be for producing animal products. Water footprints account for the amounts of water used to produce a commodity for consumption, measured along the commodity life cycle. Water withdrawals from surface and groundwater are accounted for when assessing the water footprint. The three identified major determinants of the water footprint of meat include feed conversion efficiency (FCE), feed composition, and feed origin, with the first two being influenced greatly by the animal production system. In South Africa (SA), the two distinct production systems are intensive and extensive. Intensifying beef animals improves FCE due to faster growths per kg of feed consumed, reduced activity, and therefore reduced water footprint. Beef cattle in the extensive system consume a large component of roughage, while the intensive system has a high concentrate to roughage ratio. This theoretically increases the water footprint in the intensive system. The literature indicates large amounts of volumetric water footprint indicators of boneless beef in SA. Water footprint assessment is critical for enabling consumers to make well-informed and sound decisions when considering changes in their behaviour due to the effect this has on social, economic, and environmental wellbeing. This paper aims to postulate the various issues associated with water usage in beef production. These include factors affecting the water footprint of beef production and the effects it has on various aspects of both the environment and social wellbeing. It further explores the various methods to assess the water footprint of a product.

Keywords: Water use; production system; animal feed; drinking water

2.1 Introduction

Incidents of drought resulting from climate change have severely impacted water-available resources (Mwendera and Atyosi, 2018). The anticipated growth in the world population assumes intensification of water-availability concerns as food demand escalates, particularly the demand for food of animal origin. This results in a shift from extensive animal production towards semi- and intensive production systems in an attempt to meet this escalating demand (Mpandeli et al., 2018). The expected environmental impacts of increased consumption of animal products (Pelletier and Tyedmers, 2010; Sutton et al., 2011; Godfray et al., 2018; Enahoro et al., 2019), and the pros and cons of intensive and extensive production systems (Porcel et al., 2018; Zura et al., 2019) have been researched extensively. There is an undeniable impact on an increase in pressure exerted on water resources due to the intensification of animal production systems.

There are several other factors associated with this increase in water consumption from the intensive production system, such as the low efficiency of rations (Adduci et al., 2015). Animals kept under the traditional extensive system generally utilize land that would not be suitable for either human settlement or other crop production purposes. Therefore, they largely utilize the green water which forms part of the water footprint assimilated in pastures (Zhao et al., 2019). A water footprint is an indicator of the degree of sustainability in which freshwater is drawn to maintain economic activities, such as food production (Hoekstra et al., 2011). It provides information on two facets of water use: (1) the total amounts of freshwater utilized to produce the required quantities of food product and to deliver it to the end-consumer, measured along the entire supply chain of a commodity, and (2) the degree of sustainability with which freshwater was used. The volume of water used to produce the required quantities of a food product – for example, the litres of water used to produce 1 kg of beef – is referred to as the volumetric water footprint indicator (Hoekstra et al., 2011; Chapagain and Hoekstra, 2004; Chapagain and Hoekstra, 2011).

This chapter aims to postulate the various issues associated with water usage in beef production. These include contributing factors to the water footprint of beef production and the effects it has on various aspects of both the environment and social wellbeing. This paper will further explore the various methods for assessing the water footprint of a product.

2.2 The South African Beef Industry

Beef production has a fundamental role in the socioeconomic status of South Africa (SA). The Department of Agriculture Forestry and Fisheries (DAFF) (DAFF, 2014) reported that, of the total cattle herds in SA, 80% contribution is from beef animals while the other 20% is made by dairy herds. It is the second fastest growing industry after the poultry industry in the agricultural sector of SA. This growth is driven by escalating demand for meat as the human population grows rapidly. The other drivers of this increasing demand include urbanization as well as improving the economic status of many households, which enables them to afford beef products. This tremendous increase in beef consumption was observed in the last decade and bares a large contribution to spawning revenue for the country. A gross value increase of 135% was observed during this period from R13 billion in 2006/07 to R30.6 billion in 2015/16, with an average of R19 billion per annum (DAFF, 2014).

2.3 Water Footprint of Beef Production

WF indicates how water utilization by livestock production systems impacts water resources (Hoekstra, et al., 2011). It estimates the amount of water utilized to produce a kilogram of meat. This water is measured along the production lifespan from input production to the stage, where the final product reaches the consumer (Chapagain and Hoekstra, 2004; Hoekstra et al., 2011). WF is mapped into green, blue, and grey categories. Green and blue water are both involved in food production, and grey water is involved in diluting polluted water.

2.3.1 Green water footprint

Green water footprint sustains global rain-fed agriculture, ecosystems, and ecosystem services. This is the water that infiltrates into the soil. It has both a productive role as transpiration and a non-productive role as evaporation in the biosphere (Chapagain and Hoekstra, 2004; Hoekstra et al., 2011; Molden, 2013). Green water has a direct correspondence to precipitation patterns, soil profile, as well as climatic conditions. It is accessible only to plants and cannot be directly manipulated by human management.

Green water reaching the soil surface is used by plants; recharges groundwater by filtration; or runs off towards surface water, lakes, and rivers. The water is also used for human activities in lakes, rivers, and groundwater. Some of the water is lost through evapotranspiration. Animals consume green water by feeding on grasses. To get a measure of the green water, the amount of feed and the amount of water in the feed consumed by animals must be quantified (Hoekstra et al., 2011). It can therefore be concluded that green water is roughly comparative to rainfall and crop yield.

2.3.2 Blue water footprint

Blue water footprint has a variety of uses. These include irrigation agriculture and industrial and domestic needs of society. These are sectors that compete for blue water supply, thereby exerting pressure on this limited resource (Zhuo at al., 2019). Blue water use has a higher opportunity cost in comparison to green water use. A 40% contribution to food production from irrigated agriculture was reported (Pastor et al., 2013). However, due to population increase projections by 2050 (Verlicchi and Grillini, 2020) that will result in increased demand for food, irrigation agriculture is expected to rise drastically to sustain these demands as will dietary shifts toward meat consumption due to income growth (Verlicchi and Grillini, 2020).

2.3.3 Grey water footprint

Grey water is calculated as the volume of water required to reduce pollutants to acceptable levels. This would enable the quality of ambient water to remain above defined water-quality standards (Zhao et al., 2019). According to Verlicchi and Grillini (2020), nitrogenous fertilizers in SA have the highest impact on water quality. They reported that only nitrites exceeded the acceptable limits. However, this may be affected by the type of fertilizers used in specific regions. Seasonal variations may also be observed (Marara and Paramuleni, 2020). Therefore, although nitrates are commonly considered of primary concern, the type of fertilizer and growing season need to be considered for a more realistic grey water assessment.

2.4 Effects of Water Footprint

2.4.1 Water scarcity

In 2016, an estimated four billion people globally were faced with severe water scarcity (Mekonnen and Hoekstra, 2016). This water scarcity is expected to intensify due to population increase (Mosase et al., 2019). A sharp increase has been observed since the 1960s (Kummu et al., 2020). Porkka et al. (2016) alluded that this sharp rise is due to the expansion of agricultural land to meet the escalating demands for food. Water scarcity is the condition presented by freshwater demands surpassing availability. Blue water scarcity relates to the direct insufficiency of water in rivers and aquifers (Falkenmark et al., 2007; Rosa et al., 2020). This is a major concern in the agricultural sector due to its reliance to a large extent on large amounts of water. South African river basins are already faced with moderate or severe water scarcity in most months of each year (Figure 1) (Molden, 2013; Pahlow et al., 2015). Fodder crops contribute the most to the blue water footprint, except for the Komati and Maputo river basins that sustain mostly the sugarcane plantations. This is a serious concern considering the predicted increases in world population that comes with escalated demands for more food. Pressure will intensify on agriculture to significantly increase its production to meet this demand (Falkenmark, M.; Rockström, 2004; Steinfeld et al., 2006). There are expected production and consumption increases of 2.5-4% annually in developing countries (Peden, 2007).

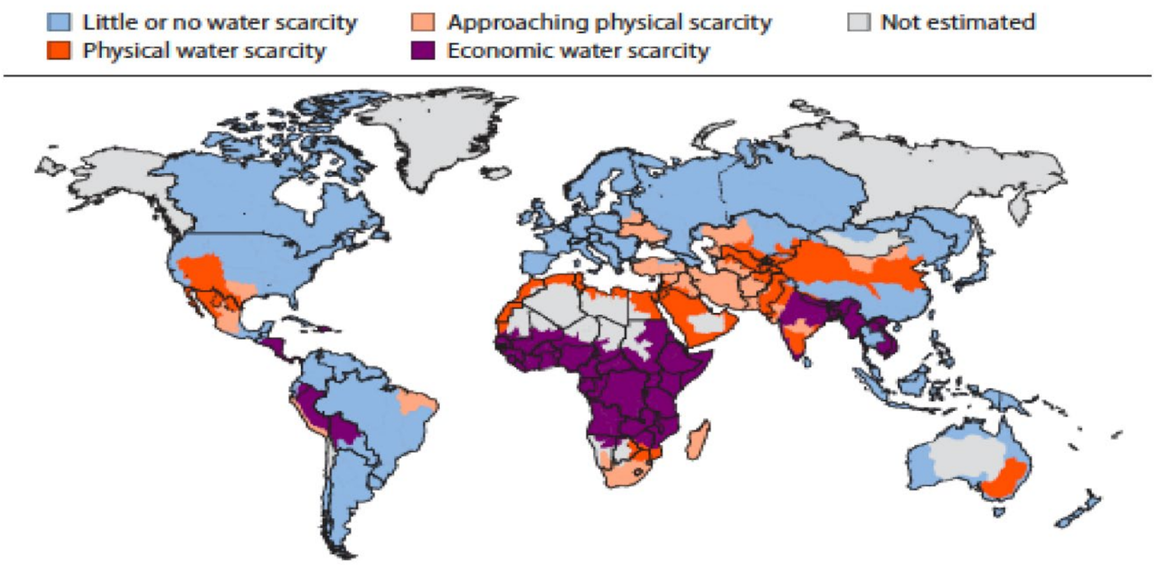

Figure 2.1. Map of water scarcity (Molden, 2013).

2.4.2 Water quality

Water quality is declining at a significant rate as seepage from mines, sewerage systems, and other sources are discharged casually due to ineffective effluent disposal policies. In the agriculture industry, effluent seepage is from abattoirs and dairy processing plants, which poses a major source of pollution to ground and surface water resources (Meissner, unknown)] and endangers the already stressed water supplies. For cattle fodder production, an intensive system uses nitrogen and phosphorus fertilizers on both crops used for cattle feeds and cultivated pastures to increase yields (Ololade, 2018). These fertilizers together with the use of pesticides contribute to the continuous degradation of water quality. The nutrient load in water encourages the growth of algae that negatively affects the drinking water quality and spoils recreational areas. The accumulation of these toxic compounds in water limits access to clean water for human consumption. They also contaminate and threaten the aquatic food web as they may accumulate in fish for human consumption. In the long run, there could be a decline in some indigenous fish species and a change or imbalance in aquatic species diversity.

2.4.3 Environmental effects

The amount of water required in livestock production systems has been well recognized; however, these amounts differ significantly with varying environmental conditions (Arias and Mader, 2011; Ahlberg et al., 2018). For example, heat stress may considerably increase the water requirements of various livestock species including beef cattle, while cold stress may decrease water intake. Environmental factors that vary momentously during hot and cold seasons include temperature, relative humidity, wind speed, solar radiation, and precipitation (Arias and Mader, 2011). Their variations or combination of environments may affect the water footprint significantly.

An increase in relative humidity reduces evaporative cooling effects, which may result in cattle drinking more water for body temperature regulation purposes. Wind speed contributes to evaporative cooling, which may increase the water requirements of cattle to maintain homeostasis. During cold seasons, it may result in cold stress that will significantly reduce water intake (Ahlberg et al., 2018). Solar radiation increases body temperature and thereafter water intake. Hide colour also plays an important role because cattle with different hide colours absorb solar radiation at different rates. Precipitation reduces water intake (Malan et al., 2020).

2.4.4 Social well-being

There are water-related basic human needs to be met continuously to deem the water footprint socially sustainable. Among these are basic needs for safe drinking water, cleaning and cooking services (U.N., 2015), as well as water for food production to ensure food security for all. Water availability affects mostly women, due to the responsibility imposed on them to collect water in the majority of developing countries (Sartori et al., 2014; Le Roux et al., 2018). Water also affects human health. Sartori et al. (2014) reported that 80% of illnesses in developing countries are the result of poor water quality and hygienic standards, while Hoekstra et al. (2011) identified rules of fairness that include freshwater availability. The first rule affects employment, particularly in fisheries where downstream fisheries might be affected by pollution from upstream fisheries. The second rule is the use of water as a public good whereby small-scale farmers neighbouring commercial farms may have limited access to freshwater due to big wells dug by commercial farms for irrigation.

2.4.5 Economic opportunity cost

The utilization of water for meat production should outweigh the costs associated with its water footprint. Hoekstra et al. (2011) described an economically unsustainable water footprint as the price of water being below its economic cost. Economic water productivity is used to measure the income generated per cubic meter of water used (Zhao et al., 2019; Chouchane et al., 2015). Such studies have been published on the dairy value chain in SA in 2017 (Owusu-Sekyere et al., 2017). These have taken into account economic water productivity for both milk and fodder crops. Their findings, as presented in Table 1, indicate economic water productivity measures of the main foodstuffs used in South African dairy feeds. These results indicate what foodstuff has lower economic water productivity (for example, maize silage in Table 2.1) to assist the farmer's decision on the continued use of the foodstuff particularly when its impact is minor on production, as observed in the percentage contribution to milk production. The results of Owusu-Skyere et al. (2017) show that the economic water productivity of different feedstuff is not directly related to other parameters of economic importance such as product value added and product yield. Ololade (2018) indicated that only blue water resources are accounted for in economic water productivity assessments because only blue water resources are considered of economic importance as the green water resources are not properly recognized.

Table 2. 1. Value addition and economic water productivity of main foodstuffs (Owusu-Sekyere et al., 2017).

Feedstuff	**Marginal Water Productivities (Kg/m^3)**	**% Contribution to Milk Yield**	**Value Added (Rand/Kg)**	**Economic Water Productivities ($Rand/m^3$)**
Lucerne hay	3.64	16.04	1.88	6.84
Oats silage	3.84	3.99	1.37	5.22
Sorghum silage	5.22	9.80	1.67	8.72
Maize silage	4.91	14.78	1.66	3.25
Maize meal	1.53	28.42	4.39	6.71
HPC	0.93	18.47	6.91	6.43

2.5 Factors Affecting Water Footprint

The predisposing factors of water usage in beef production are beef cattle breed, animal activity, diet type, feed consumption, water quality and temperature, as well as the ambient environment (Lardy et al., 2008). Fodder production makes up the largest amount of water used in beef production. This is increasing rapidly on a global scale to supply the demands of the growing population (Deutsch et al., 2010).

2.5.1 Types of livestock farming systems

There are two distinct types of production systems identified in SA: the extensive and intensive production systems. Extensive production system predominantly characterizes beef cattle production systems in SA, and are widely based on natural pastures (rangelands) (Du Toit et al., 2013).

2.5.1.1 Extensive production system

An extensive beef production system utilizes rainwater with no competition with runoff to water bodies like rivers, dams, and underground aquifers for industrial and domestic consumption. The authors (Chapagain and Hoekstra, 2004) calculated that agriculture accounts for 86% of global water consumption. However, crop production and natural pastures (rangelands) use only the water stored in the soil after precipitation. This water is referred to as green water because it is only utilized by green vegetation growing in the soil. This water is not available for use for any other purpose. Extensive beef production systems rely on green vegetation as a source of food that utilizes only green water.

Furthermore, extensive beef production is generally practiced on lands that cannot sustain crop production due to scarce rainfall and poor quality of soils (Meissner, unknown; Scholtz et al., 2013). In this production system, it is generally excluded when calculating water consumption. If not utilized for livestock or game, natural pastures would otherwise be unproductive. Its productivity is only toward beef and dairy production on extensive production systems grazing on natural pastures. An example of the KwaZulu Natal and Coastal Eastern Cape areas of South Africa. These extensive production systems are critically accountable for food security in such areas, which dominate almost all less developed countries. Natural pastures in these areas do not use “blue” water (SIWI, 2005; Falkenmark, M.; Rockström, 2006).

2.5.1.2 Intensive production system

Intensive production systems are characterized by high stocking densities per hectare. They are described as fairly efficient and comparatively high-productivity systems. Intensive systems heavily rely on total mixed rations (TMRs) with less than 10% of feed ingredients produced at the farm itself

(Du Toit et al., 2013; Scholtz et al., 2013). Contrary to semi-extensive and extensive production systems, intensive feedlot systems are practically committed to producing at an accelerated rate in response to the increasing demand for beef in urban areas. Feedlot cattle are largely dependent on high-energy diets that are composed of grains not produced locally on-farms. These high-energy diets are designed to speed up daily weight gain. The feedlot systems are big operations that are vertically integrated and fully industrialized. These production systems are therefore characterized by highly standardized technology and practices than semi-extensive and extensive production systems. However, the intensive feedlot systems are often linked to these semi-extensive or extensive production systems where they obtain their animals (weaner calves and yearlings) to fatten them till slaughter weight.

Globally, feedlot systems are currently holding about 2% of the cattle population with a contribution of about 7% to beef production (including animals sourced from semi-extensive and extensive production systems) (Figure 2.2) which means there will also be an increase in water requirements under such systems. In developed countries like the United States and Canada, feedlot systems are well advanced while in other countries like Asia and African countries are growing at an accelerated rate in response to the mounting demand for beef (Gerber et al., 2013).

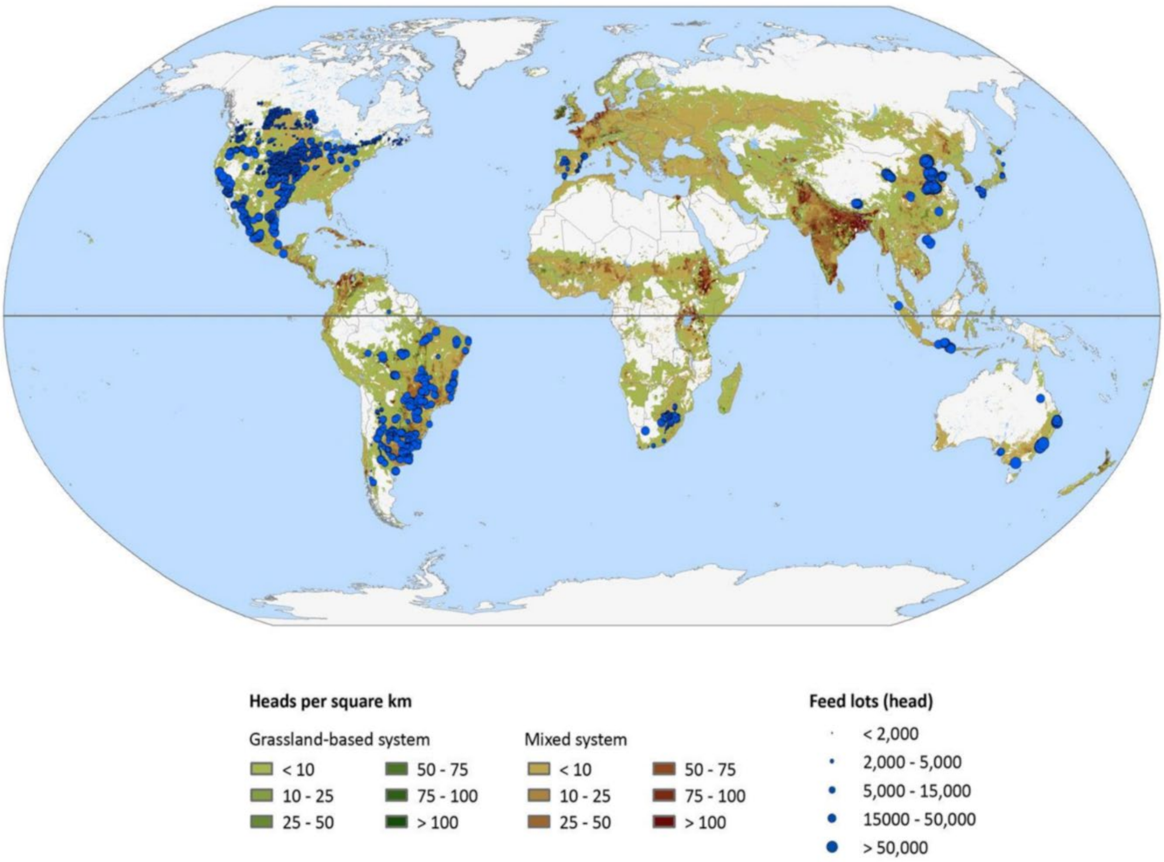

Figure 2.2. Estimated cattle population in grazing, mixed, and feedlot systems (Gerber et al., 2013).

Feedlot systems are well regulated to produce uniform carcasses as required in the retail sphere. They use in abundance the crop products as well as by-products like the oilcake meals and Dried

Distillers Grains with Solubles (DDGS). Their use of these natural resources is fairly efficient as depicted by their faster growth rates and efficient feed conversion ratios (Pelletier and Tyedmers, 2010; Capper et al., 2020), although in comparison are usually poorer than the intensive poultry and pig operations. Nevertheless, they are linked to high bearings on plummeting water supplies and air quality, mostly due to the geographical concentration of production units (Vasconcelos et al., 2007). Marẻ and Jordaan (2013), found that water use in the feedlot will differ according to cattle breed and diet type. They also found that green water has a significantly high percentage contribution to water footprint.

2.5.2 Feed composition

The amount of water (blue) withdrawn from rivers, lakes, and groundwater resources for food production on a global scale is enormous (Deutsch et al., 2010, Zhao et al., 2019). This also refers to the green water evaporating through vegetation (both crops and grazing plants) (Zimmer and Renault, 2003). The beef production industry utilizes green and blue water through water extractions for irrigation of fodder crops as well as the establishment of pastures and conversion of land use to beef farming operations that affect the shifts in water resource utilization as a consequence of changes in land use (Deutsch et al., 2010).

It is significantly important to understand that land used for livestock production is commonly unsuitable for other land use purposes like human settlements and/or crop production (Steinfeld et al., 2006). Steinfeld et al. (2006) further argued that, where these lands are not utilized for livestock production, they would otherwise be redundant. Therefore, green water associated with their use is somewhat irrelevant to be accounted for in production. However, Pimentel (1997) and Pimentel (2004) had earlier highlighted the importance of giving due consideration to evapotranspiration when calculating water flows and usage in agriculture at large. Falkenmark and Rockström (2004) further contribute to the disagreement by defending accounting for the evaporation from pasture lands only from vegetation component consumed by livestock while not accounting for the rest in terms of water requirement for livestock.

2.5.3 Feed origin

Beef production in South Africa is practiced under extensive and intensive production systems. The extensive system, which is the major contributor to beef production in SA (Meissner, unknown; Du Toit et al., 2013; Scholtz et al., 2013), feeds predominantly on rain-fed natural rangelands. The contrasting factor in the intensive production system is that their food predominantly originates from cultivated fodder crops that form the total mixed rations for feedlot animals and cultivated pastures that are fertilized and irrigated to encourage faster pasture development and basal cover. Fodder crops are the major consumers of blue water from the majority of the river basins in South Africa, with the Gamka River in the Western Cape utilizing a maximum of 62% (Pahlow et al., 2017). The impact that irrigated foodstuffs will have on the water footprint depends on the time of the year when it is planted and irrigated. For instance, feedstuffs planted in the summer months may theoretically have no impact on water scarcity. Table 2.2 illustrates South Africa is having severe water scarcity in most months of the year (Pahlow et al., 2017). This table shows that the biggest river basins in South Africa (Limpopo, Great Fish, Doring, and Great Kei) are facing severe water scarcity and depletion for most of the year. This is cause for concern and therefore warrants blue water accountability to raise awareness and to develop water conservation strategies.

Table 2. 2. Major river basins in South Africa (SA), their respective population, the number of months that a basin faces blue-water scarcity, and products with a significant contribution to WFblue (Pahlow et al., 2017).

River basin	Population	Number of Months per Year that A-Basin Faces Blue-Water Scarcity			Products with A Significant Contribution (≥3%) to WFblue in the Basin
		Moderate	Significant	Severe	(% contribution)
Limpopo	15,637,400	2	0	5	Fodder crops – 31%, sugarcane – 11%, seed cotton – 11%, wheat – 6%, domestic – 5%, maize – 4%, bananas – 3%
Orange	12,665,700	2	1	3	Fodder crops – 36%, wheat – 11%, maize – 8%, sugarcane – 7%, domestic – 5%, potatoes – 3%, grapes – 3%
Komati	2,416,140	1	0	3	Sugarcane – 33%, fodder crops – 28%, maize – 5%, domestic – 5%, –seed cotton – 4%, apples – 4%, bananas – 3%
Maputo	1,264,770	1	0	3	Sugarcane – 81%, fodder crops – 6%, domestic – 4%
Tugela	1,784,420	2	0	3	Fodder crops – 28%, maize – 16%, grapes – 12%, sugarcane – 6%, apple – 5%, wheat – 4%, bananas – 4%, domestic – 4%, pears – 3%
Great Fish	299,461	0	0	12	Fodder crops – 49%, sugarcane – 10%, apples – 6%, bananas – 5%, maize – 3%, pears – 3%
Doring	167,084	0	1	7	Fodder crops – 48%, wheat – 11%, sugarcane – 11%, grapes – 11%, potatoes – 3%
Gamka	278,648	2	1	1	Fodder crops – 62%, sugarcane – 10%, grapes – 7%, wheat – 6%
Great Kei	873,587	0	1	11	Fodder crops – 53%, domestic – 10%, sugarcane – 9%, apples – 4%, bananas – 3%

2.5.4 Ambient environment

The main environmental factors affecting animal water intake are ambient temperature, humidity, and wind velocity (Silanikove, 2000; Ololade 2018). High ambient temperatures increase water and ion losses of ruminants and thereby increase water requirements (Khelil-Arfa et al., 2012). This agrees with Scholtz et al. (2013), who reported increased perspiration and water intake due to high temperatures and solar radiation. Meyer et al. (2006) reported a 0.5 kg drinking water intake with every degree Celsius increase in ambient temperature (Table 2.3). However, the rise in humidity decreases the drinking water demand.

Table 2. 3. The mean, S.D., minimum and maximum values for the variables and the correlation coefficients (r) between water intake and the other variables (edited from Meyer et al., 2006).

Item	**Mean**	**S.D.**	**Min**	**Max**	***r***
Average ambient temperature (°C)	11.2	6.9	-8.6	26.0	0.295 *
Maximum ambient temperature (°C)	15.0	8.1	-5.9	33.8	0.282 *
Relative humidity (%)	79.8	11.9	48.0	100.0	-0.092 *
Water intake (kg/day)	17.8	6.7	0	78.7	

2.6 Water Use Efficiency in Beef Cattle

Water is the most vital nutrient required in the animal body. It constitutes above 70% of the animal's live weight (NRC, 2000). To maintain this enormous pool of water, animals acquire water through drinking, water from the food consumed, and metabolic water. However, not all this water is assimilated into the animal body. Some of the water is eliminated through urine, faeces, respiration, and perspiration (Khelil-Arfa et al., 2012; Meyer et al., 2000). Therefore, water use efficiency is defined as the ratio of the water assimilated in the animal body to the actual water consumed. Figure 2.3 illustrates the sources of water utilized by beef cattle as well as excretion flows.

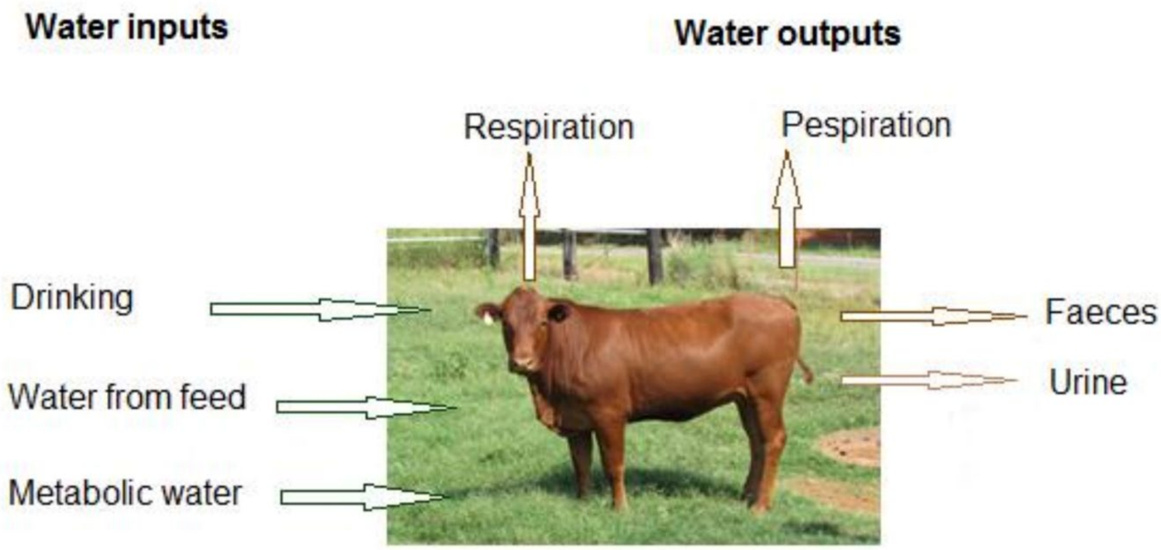

Figure 2.3. Water intake and excretion flows in beef cattle (Own illustration deduced from (Meyer et al., 2000)

2.7 Methods for Estimating Water Footprint

There are several approaches that can be employed to assess the water footprint of a product. Each detail explicit stage with emphasis on water resource management and impact assessment (Le Rou et al., 2018; Zhuo et al., 2019). Hoekstra et al. (2011) have outlined steps that measure the volume of fresh water that can be compared to total viable bounds within a limit to determine water scarcity on their water footprint network manual. There is also a Life Cycle Assessment (LCA) that is used to evaluate the potential environmental impacts of water utilization following the ISO 14046 standard.

2.7.1 Water footprint network

The water footprint assessment (WFA) approach considers freshwater resource allocation using a four-stage method comprising setting goals and scope, water footprint accounting, sustainability assessment, and response formulation (Hoekstra et al., 2011; Cosentino et al., 2015; Le Rou et al., 2018; Zhao et al., 2019). The accounting stage comprises quantification and mapping of freshwater use with three distinct types of water use: blue, grey and green water footprints. It is mainly intended to support better water management, including its use and allocation, and has played an important role in the awareness raising of water issues in the past decade.

2.7.2 Life cycle assessment

The LCA approach intends to quantify possible environmental affects spawned by human activity on an extensive range of environmental matters (climate change, air quality, land utilization, etc.) (Zhuo et al., 2019). Water utilization is among the possible effects. LCA, therefore, includes possible effects from depriving the human population and biomes of water supplies as well as specific possible affects from the emitted contaminants affecting water through different environmental impact pathways and indicators (mainly eutrophication, acidification, and toxicity to humans and ecosystems). The LCA methodology includes four phases: goal and scope, inventory accounting, impact assessment, and interpretation (Atzori et al., 2016; Zhuo et al., 2019). Quantitative impact indicators are at the core of the impact assessment phase.

2.7.3 Net water footprint

Vahnm and Bidoglio (2013) cited by Atzori et al. (2016) had identified limitations with the water footprint network (WFTN) of Zhuo et al. (2019). Atzori et al. (2016) identified limitations with the life cycle assessment (LCA) due to its focus on only blue water (Atzori et al. (2016; Zhuo et al., 2019). They developed a new concept of the generic framework (Zhuo et al., 2019, the net water footprint (WFTnet), or the generic framework as illustrated in Figure 2.4 (Vanham and Bidoglio, 2013; Pacetti et al., 2015; Atzori et al. (2016), with both the WFA and LCA playing complementary roles. This method was used by Pacetti et al. (2015), who also aimed to take advantage of the integration of these approaches to achieve a comprehensive assessment as it assessed both water use along with environmental, economic, and social effects.

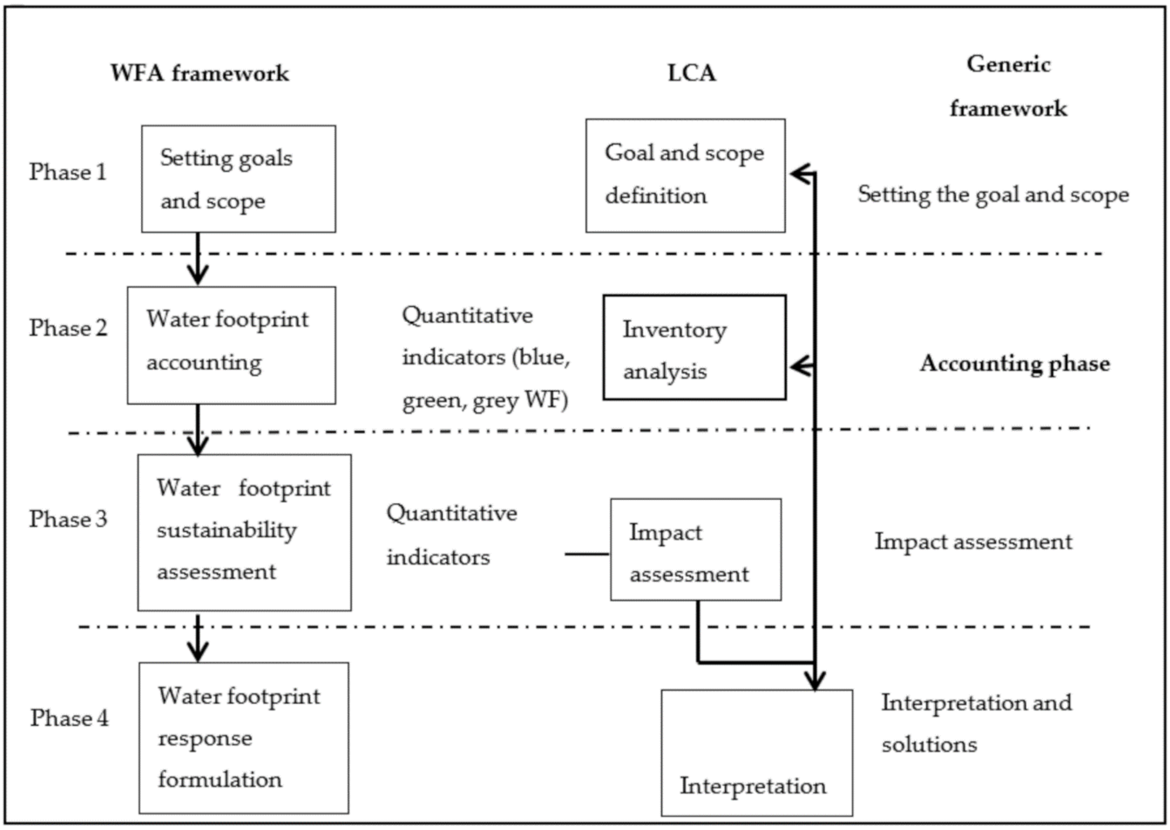

Figure 2.4. Comparison of LCA and WFA, illustrating the large similarity and the difference in quantitative indicators (Boulay et al., 2013).

2.8 Conclusions

It is evident that South Africa is at risk of water scarcity. All available data indicate that the country is fast approaching physical scarcity. Blue water resources are dry for most months of the year. Agriculture is the major contributor to the current state as this sector uses largely blue water for food production, for both crops and animal products (milk and meat). However, there is little research done to measure the water footprint due to beef production in SA. The country has been shown to be dominated by extensive beef production. There are no studies done to assess the water footprint in the extensive system. It can therefore not be concluded that beef production in South Africa plays the largest role in the water scarcity problem the country is facing without providing scientific evidence. Extensive beef production also consumes green water, occupying land that is not suitable for any other production. Current and future research activities need to focus on more efficient livestock production methods that reduce water footprint without compromising production. One of the ways to achieve a reduction in water footprint could be identifying and using breeds that do not require a lot of water per kilogram of meat produced.

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CHAPTER 3: WATER USE EFFICIENCY INDICATORS FOR POST-WEANING GROWTH PERFORMANCE IN THREE DIFFERENT FRAME SIZES OF SOUTH AFRICAN BEEF CATTLE

Abstract

The research was conducted to assess the water use efficiency for growth performance of three beef cattle frame sizes (small, medium and large farm size) in a feedlot. The specific objectives were (i) to determine water footprints for different body frame sizes of beef cattle under intensive production system in South Africa, and (ii) to assess the degree of variations in the volumetric water footprint indicator for post-weaning growth performance of beef cattle under intensive production system. The indicators of water use efficiency were water consumption efficiency (WCE) and water intake efficiency (WIE). In this study, productivity was defined as the weight gained per litre of water used. Thirty-three (33) beef cattle weaners of three different body frame sizes (small, medium, and large) (11 weaners of each frame size), representing three different breeds of similar age and body weight groups were obtained from stud breeders. At the end of the trial, the large frame size was significantly ($p<0.05$) the heaviest (406.14 kg) followed by the medium frame size (380.86 kg) and the small frame was the lightest (287.00 kg). The medium and large frame sizes had significantly ($p<0.05$) higher feed intake (667.34 and 651.73 kg), average daily gain (2.12 and 2.01 kg/day), water intake (1925.45 and 2018.64 L) and water-to-feed ratio (2.85 and 3.10 L) compared to the small frame size. The feed conversion ratio was similar ($p>0.05$) for the three frame sizes. Small frame size had significantly ($p<0.05$) lower weight gains (148.73 kg) than medium (177.86 kg) and large frame size breeds (168.59 kg). The WCE for the medium frame (0.09 kg/L) cattle was comparable ($p>0.05$) to large frame (0.08 kg/L), whilst that of the small frame (0.11 kg/L) cattle was higher ($p<0.05$) than that of the other frame sizes. The WIE of the small (10.56 L/kg) and medium (10.84 L/kg) frame sizes were not significantly ($p>0.05$) different, however, lower than that of the large frame size (12.04 L/kg). These results suggest that the small frame breed performed better than the medium and large frame breeds in terms of WCE for post-weaning growth performance under the intensive production system. However, studies are required to compare the water use efficiency of different frame sizes for other economic important traits such as carcass and meat characteristics. The notable outcome of this study is the effect of frame size on the use of water as a limiting natural resource, an effect that has not been quantified previously.

Keywords: Growth performance, water use, beef breeds, feedlot

3.1 Introduction

An intensive beef production system or feedlot is characterized by high stocking densities per hectare. Typically, it has fairly efficient and comparatively high animal productivity. This system heavily relies on total mixed rations (TMRs) with less than 10% of feed ingredients produced at the farm itself (du Toit et al., 2013; Scholtz et al., 2013). In contrast to mixed and pastoral production systems, feedlots are almost exclusively dedicated to food production, as a response to the growing demand for beef in urban areas. The vast majority of feedlot feed is purchased off-farm: beef cattle in feedlots are mostly fed on purchased grain, sometimes up to 95% in DM. Feedlots are also characterized by high energy rations and high daily weight gains. The operations are usually large in size, fully mechanized and vertically integrated. There is thus a greater uniformity of technology and practices than in mixed and grazing systems.

Feedlots are often attached to semi-extensive or extensive systems, from which they acquire young animals (weanlings or yearlings) for fattening until they reach a standard weight for slaughter (Broom, 2019). Today about 2% of the global cattle population is estimated to be held in feedlots and produces about 7% of the world's beef (the latter includes animals previously on other production systems). In Africa, driven by rising demand for meat in urban areas (Gerber et al., 2013), feedlots provide the kind of standardized carcasses requested by the retail sector and make use of relatively abundant crop products and co-products as well as by-products such as soybean cakes and Dried Distillers Grains with Solubles (DDGS). Feedlots usually have high animal performance levels in terms of daily weight gain and feed conversion ratio. This often results in relatively high levels of natural resource use efficiency (Capper, 2012; Pelletier et al., 2010), although typically lower than industrial poultry and pig operations. Feedlot operations are nevertheless associated with relatively high impacts on water resources and air quality, mostly due to the geographical concentration of production units (Vasconcelos et al., 2007).

Water is the most important nutrient required in the animal body. It constitutes above 70% of the animal's live weight (NRC, 2000). To maintain this enormous pool of water, animals acquire water through drinking, water from the food consumed and metabolic water. However, not all this water is assimilated into the animal's body. Some of the water is eliminated through urine, faeces, respiration and perspiration (Meyer et al., 2006; Khelil-Arfa et al., 2012). Therefore, water use efficiency is defined as the ratio of the water assimilated in the animal's body to the actual water consumed. The aim of this study was to evaluate the water use efficiency of three beef cattle frame sizes in a feedlot of South Africa. The specific objectives were (i) to determine water footprints for different body frame sizes of beef cattle under an intensive production system in South Africa, and (ii) to assess the degree of variations in the volumetric water footprint indicator for post-weaning growth performance of beef cattle under the intensive production system.

3.2 Materials and Methods

3.2.1 Study area

The study was conducted at the Animal Nutrition section of the Agricultural Research Council – Animal Production (ARC-AP) in Pretoria, Gauteng, South Africa (25º 53' 59.6" S and 28º 12' 51.6" E). The area is characterized by an ambient temperature range of 18 to 29 ºC during summer and between 5 and 20 ºC during winter. The experiment was conducted for 84 consecutive days (January to May 2022), with animals placed in single feeding pens.

3.2.2 Study design

Thirty-three (33) beef cattle weaners from three different breeds of similar age and body weight groups, representing three different body frame sizes (Large, Medium and Small) were obtained from stud breeders. The Simmental (n=11), Bonsmara (n=11) and Nguni (n=11) breeds were selected as representatives of the large, medium and small body frame-sized beef cattle breeds, respectively. On arrival at the farm, animals were tagged, weighed, dipped for tick control and vaccinated against respiratory diseases. The animals were randomly assigned to treatments in a Completely Randomised Design, i.e. eleven (11) animals per body frame size and each animal is a replicate unit. Animals were allowed 28 days adaptation period, followed by data collection. Feed and water were provided *ad libitum* to each animal**.**

3.2.3 Animal feeds

Thirty-three (33) animals (11 of each body frame size) were fed a total mixed ration (TMR). The diet composition of the TMR is presented in Table 3.1.

Table 3.1. Post-weaning diet of feedlot steers

Feed ingredient	**Composition (kg)**
Hominy chop	630
Grass hay (Eragrostis)	200
Soya oilcake	80
Molasses	60
Limestone	15
Urea	8
Salt	5
Vit/mineral premix	1.9
Nutrient	
Crude protein	120
ADF	84
NDF	159
Ca	11.6
P	3.6

3.2.4 Performance data

Animals were weighed using a platform electronic cattle-weighing scale at the start and at two-week intervals during the trial and at the end of the trial. The average daily gain (ADG) was determined by subtracting initial body weight from final body weight and dividing by the number of days of the experiment. Feed intake was recorded weekly by weighing feed offered to and refused by animals. The feed conversion ratio was computed as the ratio of live weight gain to dry matter intake. The feed conversion ratio (FCR, kg dry matter intake/kg weight gained) was estimated by dividing dry matter intake by the output of beef meat:

FCR = DMI / PO

where, DMI is the dry matter intake by an animal (kg dry matter/animal), and PO is the product output (kg meat) per animal.

3.2.5 Efficiency measures

Water intake (WI) of individual animals was measured daily at 08H00 in the morning before feeding. Water intake efficiency (WIE) was calculated as the ratio of water intake to the live weight gain of the animal (Ahlberg et al., 2019; Pereira et al., 2021).

WIE = WI / WG (L/kg)

Water consumption was measured by adding up water drunk and water in the feed. The moisture content of the feed was determined by the A.O.A.C method (AOAC, 2005) to determine the amount of water taken in from the feed by the animal. Water consumption efficiency (WCE) was calculated as the ratio of the live weight gain of the animal to the total volume of water consumed (kg weight gained per litres of water consumed) (Ahlberg et al., 2019; Pereira et al., 2021).

WCE = WG / WI (kg/L)

3.2.6 Statistical analysis

Data were analysed using repeated measures techniques of the MiniTab 17 (2017) in PROC MIXED considering the covariance structure of the observed data. The following statistical model was used:

$$Y_{ijk} = \mu + T_i + \varepsilon_{ij} + W_k + (TW)_{ik} + \varepsilon_{ijk}$$

Where Y_{ijk} = measurement of response (water intake, initial weight, weight gain, ADG, and FCR when the time was included as a classification variable) on the *j*th herd of the *i*th frame size treatment (small, medium and large) at the *k*th time (fortnights), μ = overall mean, T_i = fixed effect of beef frame size (small, medium and large), W_k = fixed effect of the *k*th time on measurements (k = 1, 2, …, 3), $(TW)_{ik}$ = interaction between *i*th frame sizes and *k*th time, ε_{ij} = random effect associated with the *j*th house on the *i*th breed group, ε_{ijk} = random error associated with the *k*th animal in the *i*th frame size at the *j*th time.

3.3 Results

The least-squares means (LSM) for different beef frame sizes for the growth performance traits and water efficiency measures when the time was modelled as a classification variable are presented in Table 2. The frame size of animal, time, and their interactions significantly ($p<0.05$) influenced the water in feed, drinking water, water consumption, WIE, WCE, water-to-feed ratio, feed intake, weight gain, ADG and the final weight. The FCR for the three frame sizes did not differ significantly ($p>0.05$). Furthermore, feed intake, ADG, weight gain, final weight, water in feed, water intake, water consumption, WIE and water-to-feed ratio were significantly higher ($p<0.05$) in large and medium frame beef cattle compared to the small frame size. The WCE for the medium-framed (0.09 kg/L) beef cattle was comparable ($p>0.05$ kg/L) to large frame (0.08 kg/L), whilst that of the small frame (0.11 kg/L) beef cattle was higher ($p<0.05$) than that of the other frame sizes.

Table 3.2. Least square means (LSM) and their standard errors (SE) for the growth performance traits and the water efficiency measures of different beef frame sizes, modelling time as a classification variable

Traits	Beef cattle frame size		
	Small	Medium	Large
Growth performance traits			
Start weight (kg)	138^{a}.27 ± 7.70	203.00^{b} ± 7.70	237.55^{c} ± 7.70
Final weight (kg)	287.00^{b} ± 9.75	380.86^{a} ± 9.75	406.14^{a} ± 9.75
Weight gain (kg)	148.73^{b} ± 5.63	177.86^{a} ± 5.63	168.59^{a} ± 5.63
Average daily gain (kg)	1.77^{b} ± 0.07	2.12^{a} ± 0.07	2.01^{a} ± 0.07
Feed intake (kg)	585.36^{b} ± 17.80	667.34^{a} ± 17.80	651.73^{a}± 17.80
Feed conversion ratio	4.00^{a} ± 0.13	3.81^{a} ± 0.13	3.89^{a} ± 0.13
Water use efficiency measures			
Water in Feed (L)	40.21^{b} ± 1.22	46.53^{a} ± 1.22	44.77^{a} ± 1.22
Drinking water (L)	1565.55^{b} ± 72.60	1925.45^{a} ± 72.60	2018.64^{a} ± 72.60
Water Consumption (L)	1605.76^{b} ± 73.40	1971.99^{a} ± 73.40	2063.41^{a} ± 73.40
WIE (L/kg)	10.56^{b} ± 0.39	10.84^{b} ± 0.39	12.04^{a} ± 0.39
WCE (kg/L)	0.11^{a} ± 0.00	0.09^{b} ± 0.00	0.08^{b} ± 0.00
Water-to-feed ratio (L/kg)	2.67^{b} ± 0.09	2.85^{ab} ± 0.09	3.10^{a} ± 0.09

a, b, c Row means with different superscripts differ significantly ($p<0.05$)

The WIE of the three South African beef cattle frame sizes breeds differed over time and are presented in Figure 3.1. The medium frame-sized breed had higher WIE in the first fortnight followed by the large frame size breed with the small frame-sized breed having the lowest. The WIE of the large frame-sized breed increased drastically towards the second fortnight followed by a sharp decline towards the third and fourth fortnights then a sharp increase towards the fifth fortnight and subsequently declined at the last fortnight. The medium frame-sized breed had WIE that was increasing at a slow rate from the second fortnight and started to decline after the fourth fortnight.

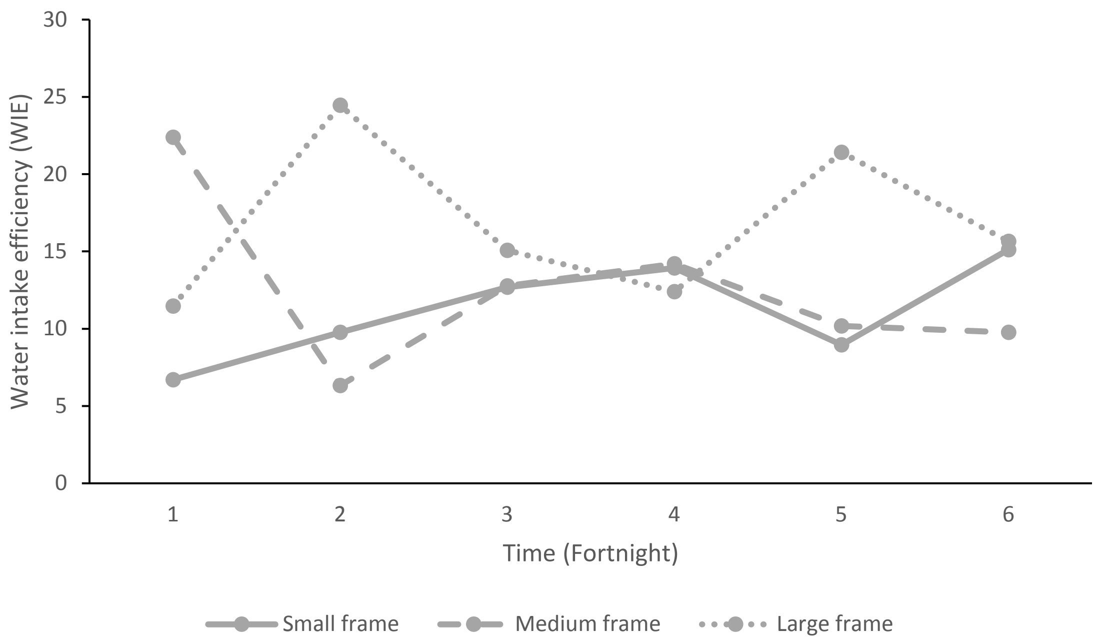

Figure 3.1. Water intake efficiency (WIE) of different South African beef frame sizes over time

The WCE of the three South African beef cattle frame sizes over time are presented in Figure 3.2. The large frame-sized breed had a sharp increase of WCE from the first fortnight to the second fortnight followed by a sharp decline in the third fortnight. All the breed frame sizes had similar WCE on the third and fourth fortnights that remained low for the large and medium frame-sized breeds. The small frame size had an increasing WCE in the fifth fortnight, then declined at the end of the sixth fortnight.

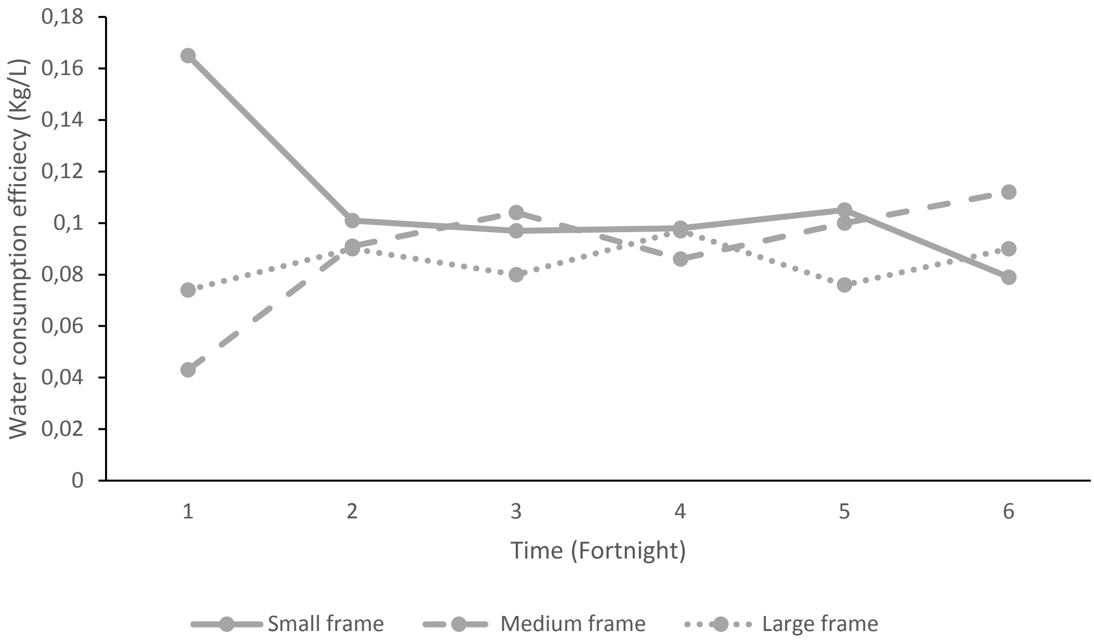

Figure 3.2. Water Consumption Efficiency (WCE) of different South African beef frame sizes over time

The WFR of medium frame breed was significantly higher ($p<0.05$) up to the third fortnight. Moreover, there was an increase in WFR for the large frame breed during the fourth fortnight and then increased sharply towards the fourth to the sixth fortnight (Figure 3.3). The pattern of the WFR between the small frame breed and medium frame breed was similar throughout the experimental period, wherein there was a decline from the third fortnight. Noteworthy, that of the small frame breed increased with time.

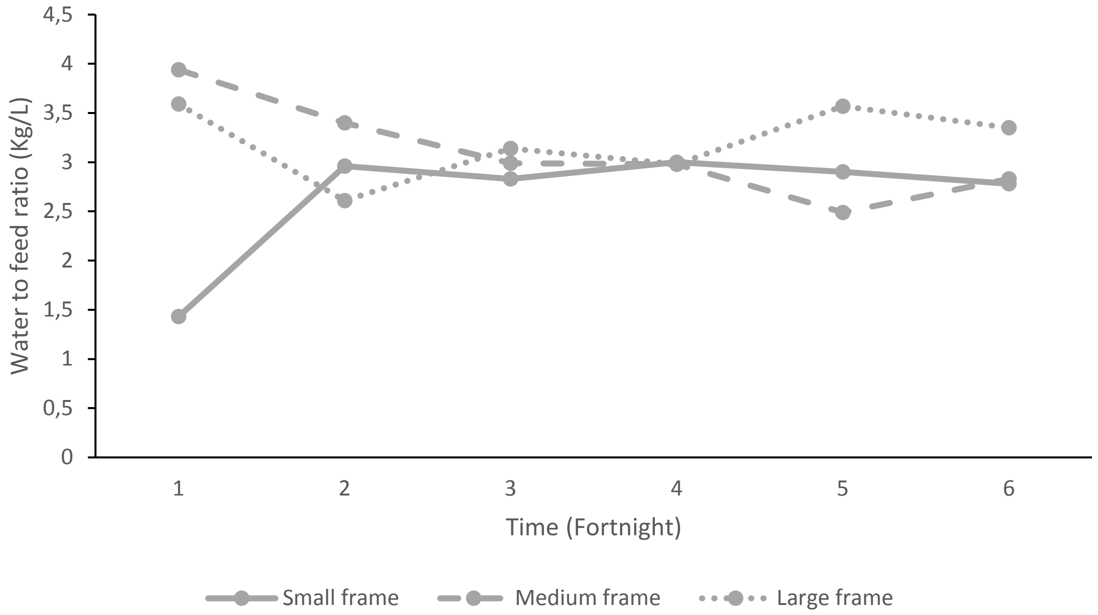

Figure 3.3. Water-to-feed ratio of different South African beef frame sizes over time

The FCR of the South African beef frame size between six fortnights is presented in Figure 3.4. The FCR of the medium frame and small frame in the first fortnight increased ($p<0.05$) from towards the second fortnight, then dropped in the third fortnight and then increased again in the fourth fortnight. However, from the fourth fortnight, that of the medium frame size breed declined with time till the end of the trial. On other hand, that of the large frame decreased in the second fortnight and then increased towards the third and fourth fortnight, then increased towards the fifth fortnight.

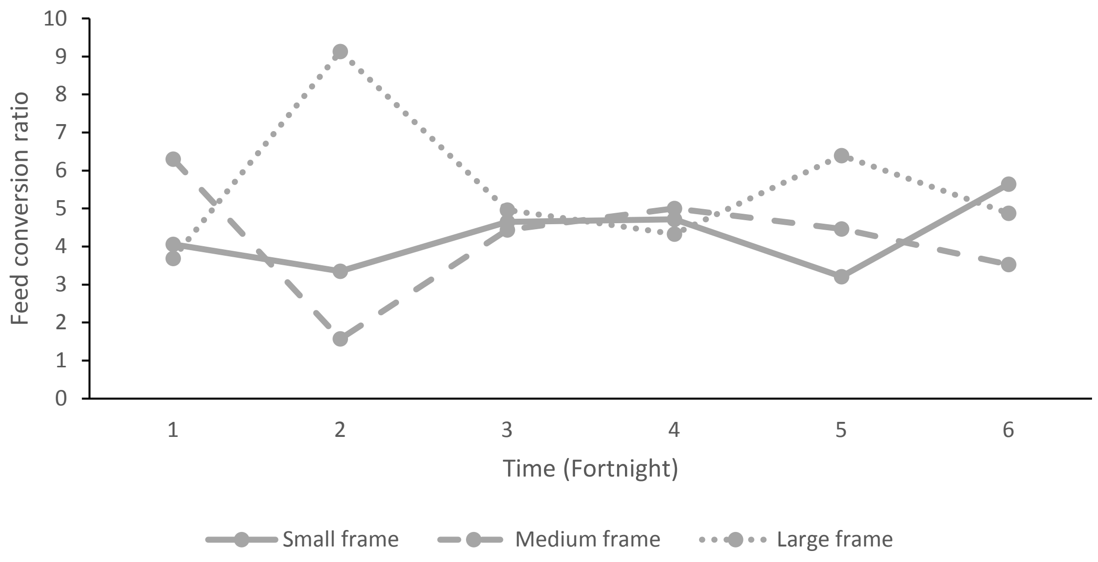

Figure 3.4. FCR of different South African beef frame sizes over time

The ADG of the different South African beef frame sizes over time is presented in Figure 3.5. The ADG of the larger frame-sized breed was slightly higher than that of the other frame sizes in the first fortnight and then declined till the third fortnight. In the second fortnight, all breeds had similar ADG, however, that of the small frame-sized breed decline towards the third fortnight and then increases till the fifth fortnight and then declined towards the sixth fortnight. The ADG of the large frame-sized breed increased drastically from the second to the third fortnight followed by another drastic decline towards the fourth fortnight and continued to decline. An increase in ADG was also observed for the medium frame-sized breed towards the third fortnight followed by a decline towards the fourth fortnight and then increased slightly towards the fifth fortnight till the last fortnight.

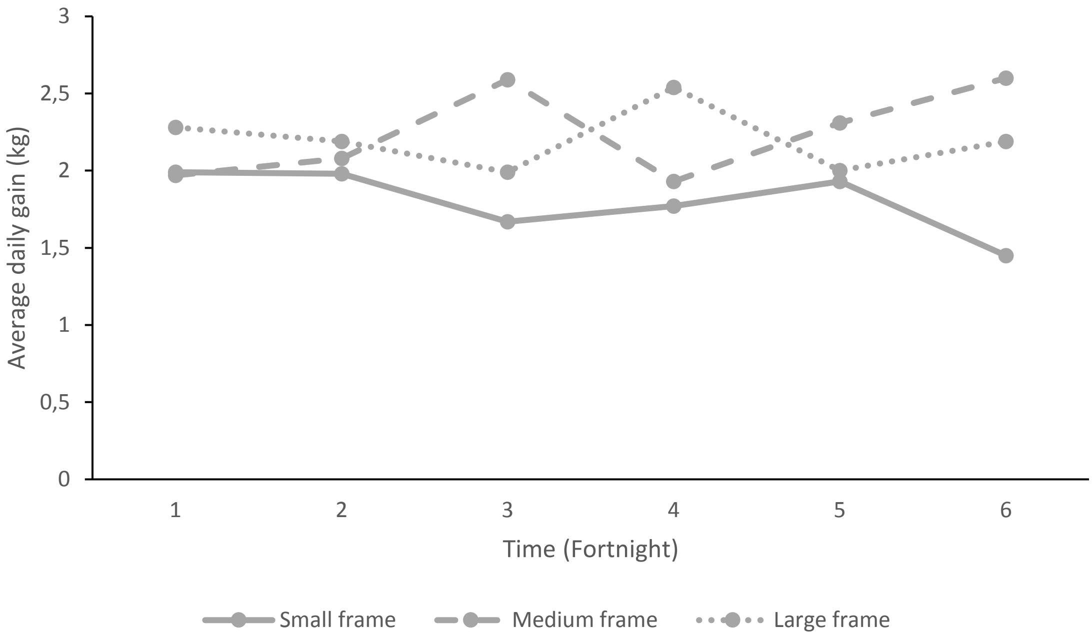

Figure 3.5. ADG of different South African beef frame sizes over time

The WI of the small and medium frames was of the same trend (Figure 3.6). However, it increased from the first to the second fortnight and then dropped towards the second fortnight till the fifth fortnight then sharply increased towards the sixth fortnight. On the other hand, that of the large frame breed was generally higher at the first fortnight and decreased slightly towards the second and third fortnight, and then sharply increased towards the till the fifth fortnight, and then sharply drops below that of the other frame sizes. Furthermore, that of small and medium was higher than that of large framed size breed on the last fortnight of the trial.

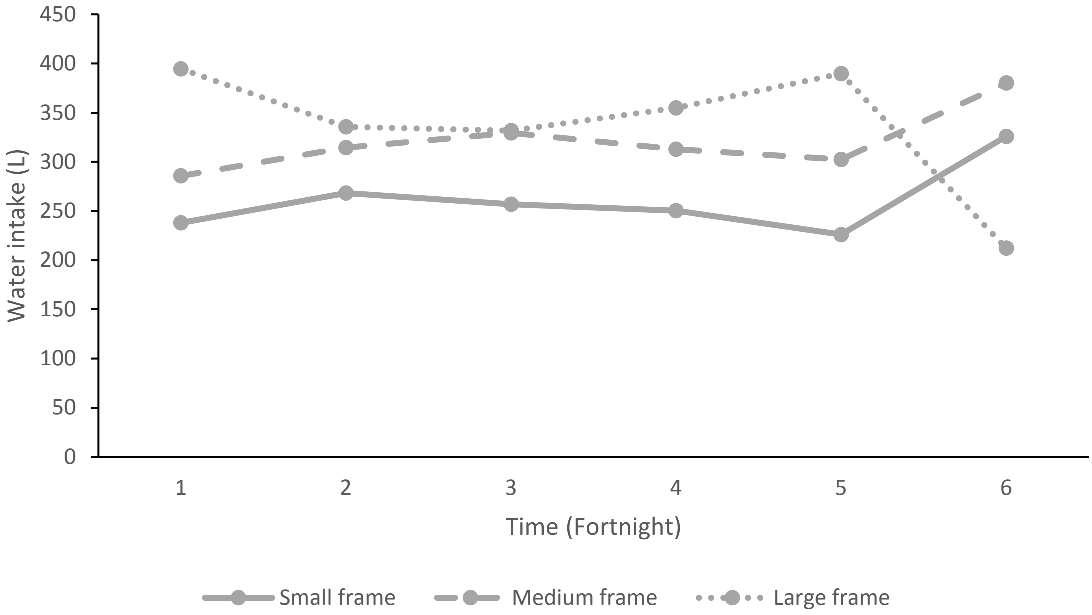

Figure 3.6. Water intake of different South African beef frame sizes over time

Feed intake of the three South African beef breed frame sizes differed and is presented in Figure 3.7. The large frame beef breed feed intake was higher in the first fortnight and then declined over time. The feed intake of medium frame size beef breed was generally lower during the first fortnight, then sharply increased towards the third fortnight and then declined towards the fourth fortnight, and then increased towards the last fortnight of the trial. On the other hand, the small-frame beef breed followed a similar pattern to that of the medium-frame beef breed. The feed intake of the Large frame started to decline sharply from the fourth fortnight till the end of the trial.

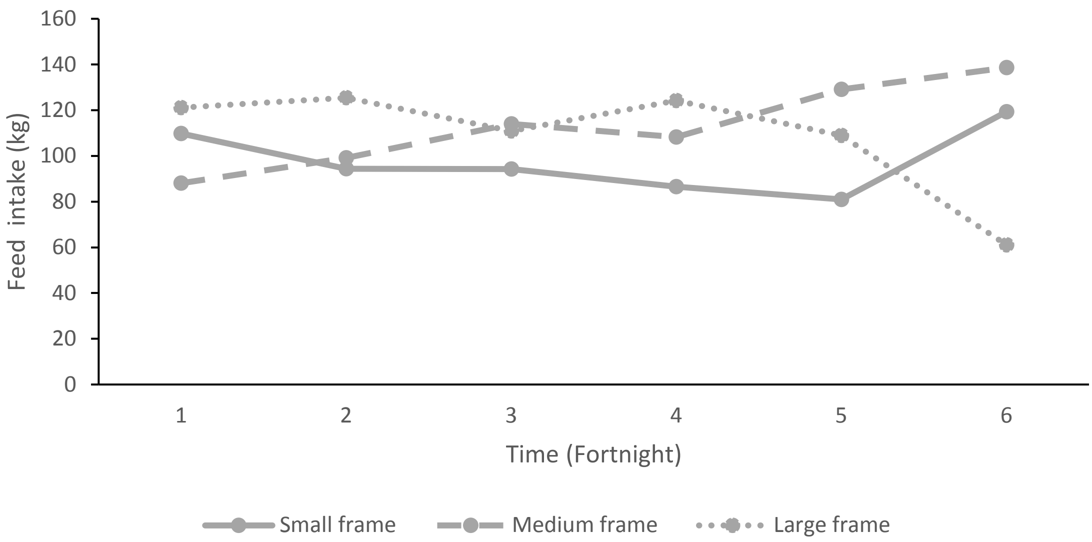

Figure 3.7. Feed intake of different South African beef frame sizes over time

The water consumption in feed and drinking water consumption of the three South African beef breed frame sizes differed and are presented in Figures 3.8 and 3.9, respectively. Notably, the water consumption in feed and drinking water consumption followed a similar pattern as the feed intake of the frame sizes under study. The large frame beef breed water consumption in feed and drinking water consumption was higher in the first fortnight and then declined over time. The water consumption in feed and drinking water consumption of medium frame beef breed was generally lower during the first fortnight, then sharply increased towards the third fortnight and then declined towards the fourth fortnight, and then increased towards the last fortnight of the trial. On the other hand, the small-frame beef breed followed a similar pattern to that of the medium-frame beef breed. The water consumption in the feed of the large frame started to decline sharply from the fourth fortnight till the end of the trial.

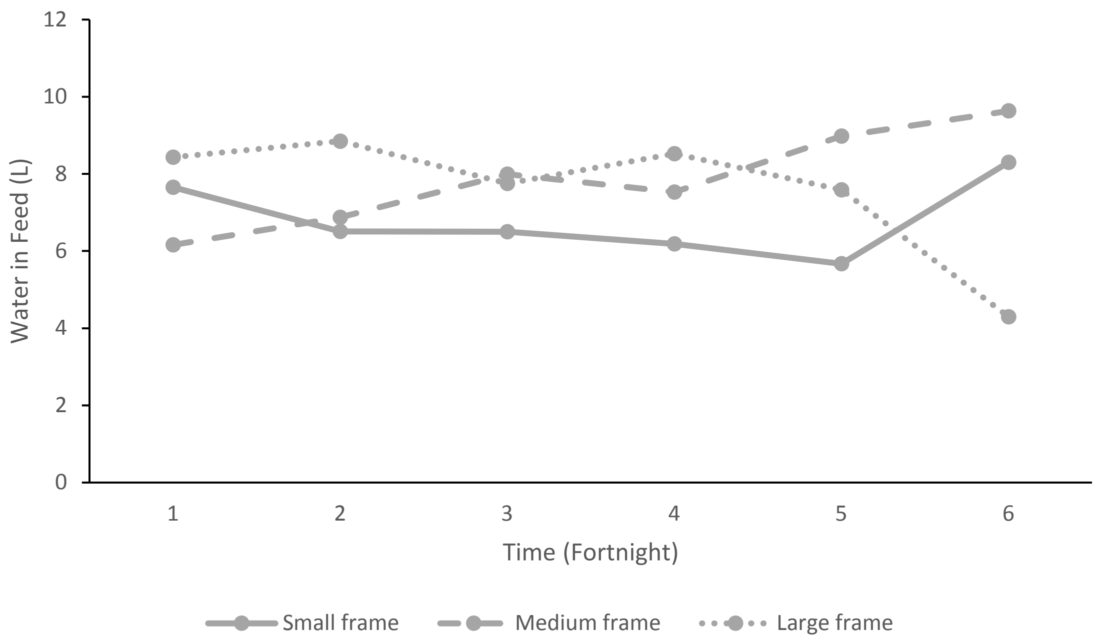

Figure 3.8. Water in feed intake of different South African beef frame sizes over time

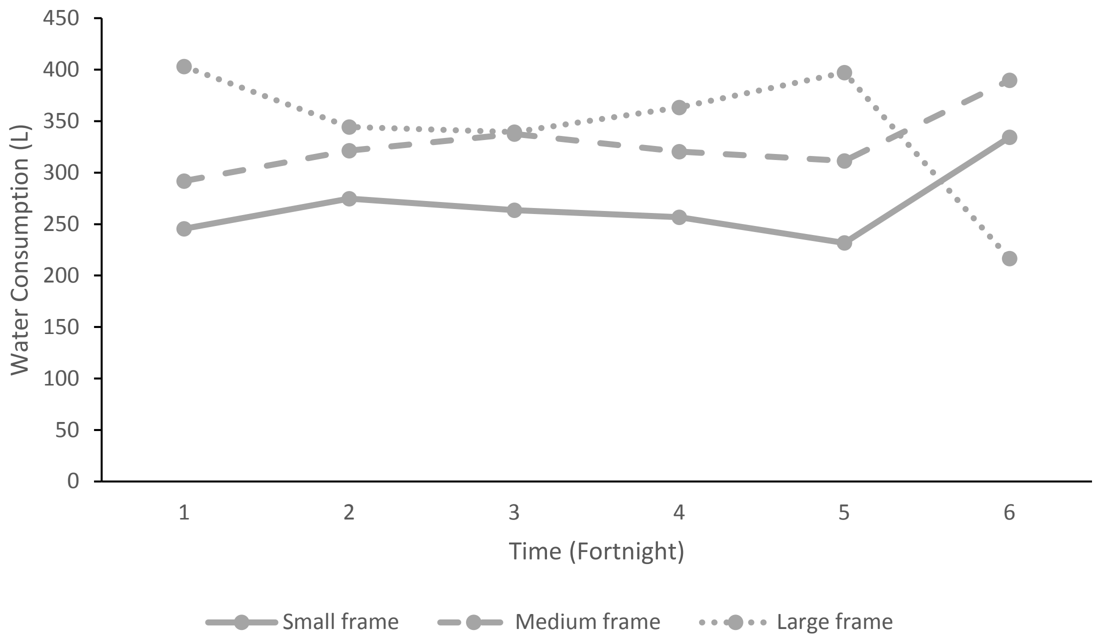

Figure 3.9. Water Consumption of different South African beef frame sizes over time

The WG of the South African beef frame sizes between six fortnights is presented in Figure 3.10. The WG of the small frame size breed declined from the first fortnight to the third fortnight then plateaued until the fifth fortnight. However, that of the large frame-sized breed was lower than the other frame sizes, however, it had a sharp increase until the third fortnight, and then had a drop in the fourth fortnight followed by a slight increase in the last fortnight. On the other hand, the weight gain of the medium frame sized breed had a smooth increase until the third fortnight then dropped towards the fourth fortnight but then sharply increased till the last fortnight of the trial.

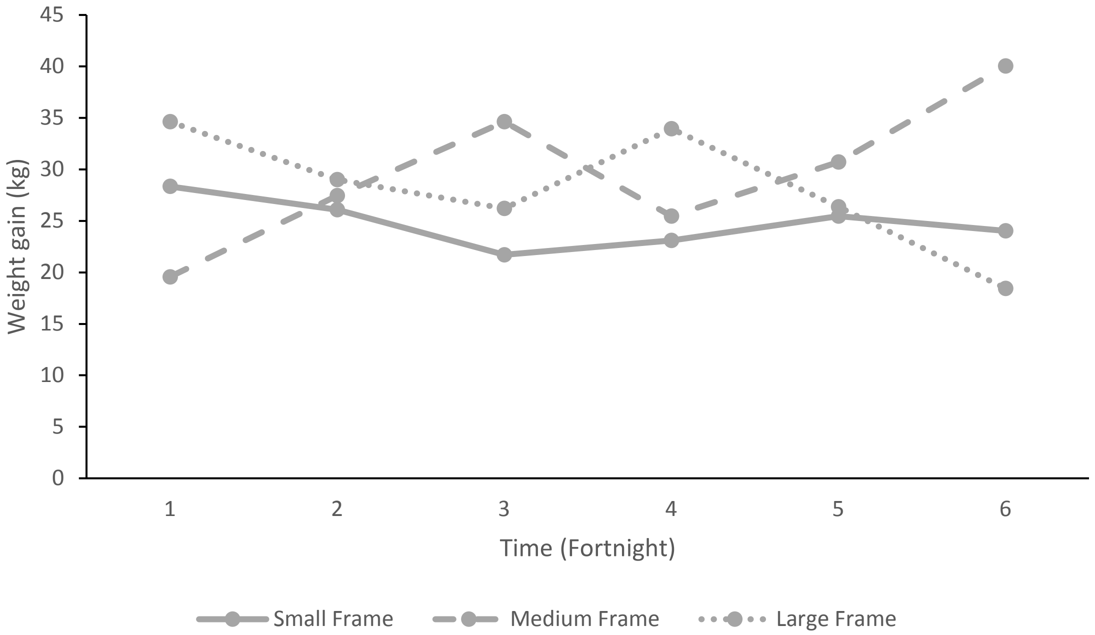

Figure 3.10. Weight gain of different South African beef frame sizes over time

3.4 Discussions

There is a general consensus in the literature that the daily feed intake of the large frame size is consistently higher than that of smaller breeds. Similar to our findings, (Vargas-Jurado et al., 2015) reported different dry matter feed intakes between beef breeds of different frame sizes, wherein the dry matter feed intake was consistently higher in larger than in smaller frame sizes. Our results showed variation in weight gain among the different breeds studied, which is also consistent with the literature (Maré and Jordaan, 2019). However, in contrast to other reports in the literature, we observed similar average FCR for all three different frame sizes and similar ADG for the large and medium frame sizes. Water is consumed during, shortly before, or after feeding events. The animals that had more water intake had significantly higher ADG, WG and body weight, a pattern that has been reported by several other researchers (Menezes et al., 2018; Ahlberg et al., 2019). More importantly, the low WI breed (small frame size) in the present study had lower average daily weight gains compared to the medium frame size breed.

Due to increasing concerns about water availability in the near future, it is critical to recognize the relationship between water intake and other economically important traits in beef production such as dry matter intake, FCR and average daily gain (ADG). The current study showed results of the water intake of different breeds following a similar trend over time. In all the frame sizes under study, water intake increased consistently from one fortnight to the next, until the end of the trial. This is consistent with the expectation that water intake increases with the growth of an animal (NRC, 2000). In agreement with other researchers (Mekonnen and Hoekstra, 2012; Mare, 2019), feed intake followed the same trend as water intake, which is according to expectation as the two variables are positively correlated.

The results from this study indicate that the medium and smaller breed utilizes water more efficiently for post-weaning growth performance as shown by their superior WIE and WCE. This indicates that the small frame-sized breed had a better gain per L of water consumed compared to the large frame-size animals. This concurs with the observation by Brew et al. (2011) and Ahlberg et al. (2019) that the animals with a low water intake utilize water more efficiently relative to their dry matter feed intake and body size. A study by Leeuw & Jiyana (2020) concluded that small frame-size cattle, such as Nguni, will be the breed of choice in the future due to their low water requirements. Leeuw & Jiyana (2020) also found that small frame size cattle have lower FCRs which means that they are more efficient in their use of feed. This is contrary to the findings in this study, whereby the average FCR was similar for all the frame sizes. Animals that have higher feed efficiency and low water intake and/or high-water use efficiency are desirable (Brew et al., 2011; Ahlberg et al., 2019). Furthermore, in dry areas where the water quality is also poor, it would be advantageous to rear cattle breeds that have both low water consumption and are efficient at utilizing available water resources efficiently.

3.5 Conclusions

These results suggest that the small frame-sized breed used in this study performed better than the medium and large frame-sized beef breeds in terms of WCE for post-weaning growth performance under the intensive production system. In the future, which seems to be threatened by water scarcity problems as a result of climate change, a small frame-sized beef breed would be desirable. However, studies are required to compare the water use efficiency indicators of the different frame sizes for other economically important traits such as carcass and meat characteristics. The notable outcome of this study is the effect of frame size on the use of water as a limiting natural resource, an effect that has not been quantified previously.

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CHAPTER 4: RELATIONSHIP BETWEEN VOLUMETRIC WATER FOOTPRINT AND CARCASS CHARACTERISTICS OF BEEF CATTLE UNDER INTENSIVE PRODUCTION SYSTEM

Abstract

The study was conducted to determine (1) the relationship between volumetric water footprint and carcass characteristics of beef cattle under intensive production system, and (2) the amount of water consumed per kilogram feed intake per breed. Thirty-three (33) beef cattle weaners from three different breeds of similar age and body weight groups, representing three different body frame sizes: small, medium and large (11 weaners of each frame size), were obtained from stud breeders. The animals were fed a total mixed ration and water *ad libitum*. Water intake (WI) of individual animals was measured daily at 08H00 in the morning before feeding. Water intake efficiency (WIE), water consumption efficiency (WCE), and water-to-feed ratio (WFR) were determined. The live animal carcass measurements were collected using ultrasound scanning to estimate carcass retail yield and meat quality. Animals were slaughtered when they had reached market weight, and the carcass characteristics were determined. The frame size of animal influenced ($p<0.05$) the water in feed, water intake, water consumption, WIE, WCE, water-to-feed ratio, service water and water footprint. Water in feed, drinking water, water consumption, WIE and the water-to-feed ratio was significantly higher ($p<0.05$) in large and medium frame size beef cattle compared to the small frame size. The WCE was comparable ($p>0.05$) for the medium-framed (0.09 kg/L) and large-framed (0.08 kg/L), beef cattle, and higher ($p<0.05$) than that of the small-framed beef breed (0.11 kg/L). The service water was significantly higher ($p<0.05$) for the large framed beef breed (3.55 l) than that of the small frame (2.45 l) and medium frame (2.64 l) beef breeds. Interestingly, the water footprint for the medium-framed beef breed (8.86 L/kg) was significantly lower ($p<0.05$) than that of the small-framed beef breed (9.88 L/kg) but similar ($p>0.05$) to that of the large-framed beef breed (9.02 L/kg). The frame size of the animal significantly ($p<0.05$) influenced warm and cold carcass mass, P8 fat and fat code. The small and medium frame beef breed yielded higher ($p<0.05$) P8 fat and fat code than the large frame size. The eye muscle area was higher for medium (50.36 mm) and large (46.70 mm) framed breeds compared to the small frame (40.24 mm). The results suggest that the medium frame size breed performed better in terms of water footprint whilst yielding comparable carcass characteristics to the large frame size in the intensive production system.

Keywords: Eye Muscle Area, Fat Thickness, Water Consumption Efficiency, Water Intake Efficiency, Water-to-Feed Ratio

4.1 Introduction

Food security is a challenge in rural and peri-urban areas of South Africa. The escalation of the high unemployment rate in rural areas further exacerbates the food security challenge (International Labour Office (ILO), 2012, p. 20). The anticipated growth in the world population assumes intensification of water-availability concerns as food demand escalates, particularly the demand for food of animal origin. This results in a shift from extensive animal production towards semi- and intensive production systems in an attempt to meet this escalating demand (Mpandeli et al., 2018). The expected environmental impacts of increased consumption of animal products (Pelletier and Tyedmers, 2010; Sutton et al., 2011; Godfray et al., 2018; Enahoro et al., 2019), and the pros and cons of intensive and extensive production systems have been researched extensively. Notably, incidents of drought resulting from climate change have severely impacted water-available resources (Mwendera and Atyosi, 2018). There is an undeniable impact on an increase in pressure exerted on water resources due to the intensification of animal production systems. From the South African national perspective, the National Development Plan (NDP) 2030 argues that climate change has the potential to reduce food production and availability of potable water, as a consequence of migration patterns and levels of conflicts. To that end, the NDP calls for intervention to ensure environmental sustainability and resilience, reduction in greenhouse gas emissions and improving energy efficiency, and protection of biodiversity and natural resources; to mention but a few.

Undoubtedly, water is the most important nutrient required in the animal body, constituting above 70% of the animal's live weight (NRC, 1996). To maintain this enormous pool of water, animals acquire water through drinking, water from the food consumed and metabolic water. However, not all this water is assimilated into the animal’s body (Meyer et al., 2004; Khelil-Arfa et al., 2012). Therefore, water use efficiency is defined as the ratio of the water assimilated into the animal’s body to the actual water consumed. Noticeably, water restriction reduces the water and dry matter intakes, body weight at slaughter and hot and cold carcass yields of animals (dos Santos et al., 2019) and carcass traits.

The ultrasound technology is commonly used in livestock for carcass trait measurements and is referred to as real-time ultrasound (RTU). Real-time ultrasound uses high-frequency sound waves (generally 2 to 10 MHz) to “see” under the animal’s hide while it is still alive. This is the same technology used for pregnancy diagnosis in both livestock and humans. A sound-emitting probe, or transducer, is placed snuggly on the animal’s back and the sound waves penetrate the tissues, reflecting off the boundaries between hide, fat and muscle layers. As the sound waves reflect back towards the probe, a cross-sectional image is created on the ultrasound machine monitor, which allows the measurement of the various carcass traits (Houghton and Turlington, 1992).

The live animal carcass ultrasound can be used to estimate carcass retail yield and meat quality. The potential of real-time ultrasound (RTU) has been well reported by many authors (Aiken et al., 2004; Greiner et al., 2004). The common traits include rib eye area (REA), backfat (BF), rump fat (RF) and percent intramuscular fat (PIMF). The rib eye area is measured between the 12th and 13th ribs and gives an estimate of the amount of muscle and lean product in the animal. Backfat is also measured between the 12th and 13th ribs and is an estimate of the external fat on the animal. This measurement is taken at a point three-fourths of the length of the rib eye from the end nearest the animal’s spine and is the most important factor affecting retail product yield. Rump fat is an additional measure of external fat on the animal. This measurement is taken along the rump of the animal between the hooks and pins. Percent intramuscular fat is an objective measurement of marbling in live cattle.

Marbling is the main trait used to determine quality grades, thus PIMF gives a good indication of the animal's meat quality (Strydom, 2011).

Beef production is recorded to use more of the water, therefore, to that end, it is important to quantify the volumetric water footprint, and compare different breeds. There is a paucity of information on the relationship between carcass characteristics and the volumetric water footprint of beef cattle in South Africa. This paper seeks to determine the relationships between volumetric water footprint and carcass characteristics of beef cattle under the intensive production system and to determine the amount of water consumed per kilogram feed intake per breed.

4.2 Materials and Methods

4.2.1 Study area

The study was conducted at the animal nutrition section of the Agricultural Research Council – Animal Production (ARC-AP) in Pretoria, Gauteng, South Africa (25º 53' 59.6" S and 28º 12' 51.6" E). The area is characterized by an ambient temperature range of 18 to 29 ºC during summer and between 5 and 20 ºC during winter. The experiment was conducted for 84 consecutive days (January to May 2022), with animals placed in single feeding pens.

4.2.2 Study design

Thirty-three (33) beef cattle weaners from three different breeds of similar age and body weight groups, representing three different body frame sizes (small, medium and large) were obtained from stud breeders. The Simmental (n=11), Bonsmara (n=11) and Nguni (n=11) breeds were selected as representatives of the large, medium and small body frame-sized beef cattle breeds, respectively. On arrival at the farm, animals were tagged, weighed, dipped for tick control and vaccinated against respiratory diseases. The animals were randomly assigned to treatments in a Completely Randomised Design, i.e. eleven (11) animals per body frame size and each animal is a replicate unit. Animals were allowed 28 days adaptation period, followed by data collection. Feed and water were provided *ad libitum* to each animal.

4.2.3 Animal feeds

Thirty-three (33) animals (11 of each body frame size) were fed a total mixed ration (TMR). The diet composition of the TMR is presented in Table 4.1.

Table 4.1. Post-weaning diet of feedlot steers

Feed ingredient	Composition (kg)
Hominy chop	630
Grass hay (Eragrostis)	200
Soya oilcake	80
Molasses	60
Limestone	15
Urea	8
Salt	5
Vit/mineral premix	1.9
Nutrient	
Crude protein	120
ADF	84
NDF	159
Ca	11.6
P	3.6

4.2.4 Carcass traits

The live animal carcass measurements were collected using ultrasound to estimate carcass retail yield and meat quality. Characteristics of the data structure include (P8: fat depth at P8 site, rib fat thickness: fat depth at 12/13th rib and eye-muscle area). Animals were slaughtered for the determination of carcass traits. Animals were weighed using a platform electronic cattle-weighing scale at the start and at two-week intervals during the trial and at the end of the trial. Prior to slaughter, animals were weighed.

Cattle were electrically stunned for 5 s at 200 volts, rendering them unconscious, after which they were slaughtered, skinned, and allowed to bleed for 5 min by suspension by both Achilles heels (Cloete et al., 2004). After bleeding, the head was cut at the neck point from the spinal column at the occipital-atlantal joint followed by the removal of the trotters at the joint from the metacarpus and the ulna of the forelimbs and the joint between the metatarsus and the fibula in the hind limbs. The offal was removed from the abdominal cavity during evisceration and was not included in this study. Eleven cattle were slaughtered per day, and all of the animals were slaughtered at the same abattoir under the same prescribed conditions.

Following evisceration, the head, trotters, and offal were removed from the carcass. Warm carcass weight (WCW) was measured one-hour post-mortem before the carcass was chilled by hanging it from both hind legs, and the carcass was immediately chilled at 4 °C. Cold carcass weight (CCW) was measured as the weight of chilled carcass 24 h post-mortem. The kidneys, kidney fat, and tail were removed after the carcass was chilled and were not used in this study. The fat code classification and distribution of the subcutaneous fat were performed by a visual appraisal of the carcass by a trained official who then assigned the carcasses a fat code (FC) according to the South African classification of red meat guidelines (http://www.samic.co.za/downloads/Redmeat.pdf (accessed on 10 October 2020). The fat codes for the studied beef cattle ranged from 0-2 and were in increments of 0.25.

4.2.5 Efficiency measures

Water intake (WI) of individual animals was measured daily at 08H00 in the morning before feeding. Water intake efficiency (WIE) was calculated as a ratio of water intake to the live weight gain of the animal (Ahlberg et al., 2019; Pereira et al., 2021).

WIE = WI / WG (L/kg)

Water consumption was measured by adding up water drunk and water in the feed. The moisture content of the feed was determined by the A.O.A.C method (AOAC, 2005) to determine the amount of water taken in from the feed by the animal. Water consumption efficiency (WCE) was calculated as the ratio of live weight gain of the animal to the total volume of water consumed (kg weight gained per litres of water consumed) (Ahlberg et al., 2019; Pereira et al., 2021).

WCE = WG / WI (kg/L)

. For this study, the water footprint excluded the water used in feed production and the pre-weaning period. The water footprint of an animal was determined using the following equation

$$WF_{animal} = WF_{feed} + WF_{drink} + WF_{serv}$$

Where, WF_{feed}, WF_{drink} and WF_{serv} represent the water footprints for feed, drinking water and service-water consumption, respectively.

4.2.6 Statistical analysis

The Carcass Measurements and water efficiency measures data were analysed using the General Linear Model (PROC GLM) of the MiniTab 17 (2017). The following statistical model was used:

$$Y_{ijk} = \mu + T_i + \ + \varepsilon_{ijk}$$

Where Y_{ijk} = measurement of response (fat thickness, P8 fat, warm carcass, cold carcass and fat code, water in feed, water intake, water consumption, WIE, WCE and water-to-feed ratio) on the *j*th herd of the *i*th frame size treatment (small, medium and large), μ = overall mean, T_i = fixed effect of beef frame size (small, medium and large), ε_{ijk} = random error associated with the *k*th animal in the *i*th frame size.

For the RTU scan data were analysed using repeated measures techniques of the MiniTab 17 (2017) in PROC MIXED considering the covariance structure of the observed data. The following statistical model was used:

$$Y_{ijk} = \mu + T_i + \varepsilon_{ij} + W_k + (TW)_{ik} + \varepsilon_{ijk}$$

Where Y_{ijk} = measurement of response (P8 fat, rib fat thickness, eye muscle area, Mar 1, Mar 2 and Mar 3 when the time was molded as a classification variable) on the *j*th herd of the *i*th frame size treatment (small, medium and large) at the *k*th time (fortnights), μ = overall mean, T_i = fixed effect of beef frame size (small, medium and large), W_k = fixed effect of the *k*th time on measurements (k = 1, 2, …, 3), $(TW)_{ik}$ = interaction between *i*th frame sizes and *k*th time, ε_{ij} = random effect associated with the *j*th house on the *i*th breed group, ε_{ijk} = random error associated with the *k*th animal in the *i*th frame size at the *j*th time.

4.3 Results

The least-squares means (LSM) for different beef frame sizes for RTU scans, carcass measurements and water use efficiency measures are presented in Table 4.2. The frame size of animal significantly ($p<0.05$) influenced warm and cold carcass mass, P8 fat and fat code. The medium and large frame beef cattle yielded similar ($p>0.05$) warm carcass and cold carcass mass. The small and medium frame beef cattle yielded higher P8 fat and fact code than the large frame size. The rib fat thickness for the three frame sizes did not differ ($p>0.05$) significantly. As for the RTU scans, all the frame sizes under study yielded similar ($p>0.05$) rib fat thickness, Mar 1, Mar 2 and Mar 3. However, the P8 fat and eye muscle under the RTU scans varied ($p<0.05$) across the frame sizes. The medium frame size yielded higher (3.64 mm) P8 fat, whereas the large frame size yielded the lowest (2.29 mm) P8 fat. The eye muscle was higher on medium (50.36 mm) and large (46.70 mm) framed breeds compared to the small frame (40.24 mm). The frame size of animal influenced ($p<0.05$) the water in feed, water intake, water consumption, WIE, WCE, water-to-feed ratio, service water and water footprint. Furthermore, water in feed, water intake, water consumption, WIE and the water-to-feed ratio was significantly higher ($p<0.05$) in large and medium frame beef cattle compared to the small frame size. The WCE for the medium-framed (0.89 kg/L) beef cattle was comparable ($p>0.05$) to that of the large frame (0.08 kg/L), whilst higher ($p<0.05$) than that of the small frame beef cattle (0.11 kg/L). The service water was significantly higher ($p<0.05$) in large beef cattle (3.55 L) than in the small-frame (2.45 L) and medium-frame (2.64 L) beef cattle. Noticeably, the water footprint for the medium-framed beef cattle (8.86 L/kg) was significantly lower ($p<0.05$) than that of small framed beef breed (9.88 L/kg) but comparable ($p>0.05$) to that of large-framed beef cattle (9.02 L/kg).

Table 4.2. Least square means (LSM) and their standard errors (SE) for RTU scans, carcass traits and water use efficiency measures

Traits	Frame size		
	Small	Medium	Large
RTU Scan traits			
P8 Fat (mm)	$3.26^{ab} \pm 0.45$	$3.64^{a} \pm 0.45$	$2.29^{b} \pm 0.45$
Rib fat thickness (mm)	$1.76^{a} \pm 0.29$	$2.16^{a} \pm 0.29$	$1.61^{a} \pm 0.29$
Eye-muscle area	$40.24^{b} \pm 2.01$	$50.36^{a} \pm 2.01$	$46.70^{a} \pm 2.01$
Mar 1	$0.59^{a} \pm 0.15$	$0.59^{a} \pm 0.15$	$0.57^{a} \pm 0.15$
Mar 2	$0.59^{a} \pm 0.15$	$0.60^{a} \pm 0.15$	$0.57^{a} \pm 0.15$
Mar 3	$0.61^{a} \pm 0.15$	$0.59^{a} \pm 0.15$	$0.57^{a} \pm 0.15$
Carcass traits			
Rib fat thickness (mm)	$3.95^{a} \pm 0.54$	$3.45^{a} \pm 0.54$	$2.52^{a} \pm 0.54$
P8 Fat (mm)	$5.55^{a} \pm 0.56$	$5.62^{a} \pm 0.56$	$2.61^{b} \pm 0.56$
Warm Carcass (kg)	$166.92^{b} \pm 6.24$	$229.02^{a} \pm 6.24$	$234.31^{a} \pm 6.24$
Cold Carcass (kg)	$163.03^{b} \pm 6.15$	$223.31^{a} \pm 6.15$	$229.48^{a} \pm 6.15$
Fat Code	$1.00^{a} \pm 0.56$	$1.11^{a} \pm 0.56$	$-1.11^{b} \pm 0.56$
Water use efficiency measures			
Water in Feed (L)	$40.21^{b} \pm 1.22$	$46.53^{a} \pm 1.22$	$44.77^{a} \pm 1.22$
Water Consumption (L)	$1565.55^{b} \pm 72.60$	$1925.45^{a} \pm 72.60$	$2018.64^{a} \pm 72.60$
Drinking water (L)	$1605.76^{b} \pm 73.40$	$1971.99^{a} \pm 73.40$	$2063.41^{a} \pm 73.40$
WIE (L/kg)	$10.56^{b} \pm 0.39$	$10.84^{b} \pm 0.39$	$12.04^{a} \pm 0.39$
WCE (kg/L)	$0.11^{a} \pm 0.00$	$0.09^{b} \pm 0.00$	$0.08^{b} \pm 0.00$
Water-to-feed ratio (L/kg)	$2.67^{b} \pm 0.09$	$2.85^{ab} \pm 0.09$	$3.10^{a} \pm 0.09$
Service water (L)*	$2.45^{c} \pm 0.00$	$2.64^{b} \pm 0.00$	$3.55^{a} \pm 0.00$
Water Footprint (L/kg)**	$9.88^{a} \pm 0.32$	$8.86^{b} \pm 0.32$	$9.02^{ab} \pm 0.32$

a, b, c Row means with different superscripts differs significantly ($p<0.05$); * Service water: water used during slaughtering process; **Water Footprint: excluded the water used in feed production and pre-weaning.

4.4 Discussion

The Longissimus muscle area has been used as an indicator of carcass muscling in many species. The high correlation between the longissimus muscle area and the weight of the hind leg indicates that this body dimension measurement may be an indication of carcass muscling. Results of the ultrasound scans show increasing fat deposition and muscle growth with time in all the breeds under study. The small frame and medium breeds were observed to be putting more rump fat than the large as indicated by higher P8 fat. Eye muscle area was highest ($p<0.05$) for the large frame. This is in line with the expectation that the larger breed will have more muscle than the smaller breeds. It may, however, indicate that large-frame breeds have a faster rate of muscling than small-framed breeds (Nqeno, 2008).

The variation in P8, rib fat thickness and eye-muscle area fat observed among the different frame sizes of beef cattle is consistent with results from the literature (Piao and Baik, 2015; Park et al., 2018). It is important to note that the low water intake cattle in the present study, that is medium frame, have higher P8 fat, rib fat thickness and eye muscle area. The days on feed could be shortened for these cattle and feed costs decreased if the market requires low-fat distribution in the carcass. Such shortening of the feedlot period can reduce water consumption, feed consumption, and thus profitability, of the farming enterprise.

Contrary to the present findings that medium and small frames have different eye muscle areas, Muchenje et al. (2008) reported that small frame-sized beef cattle such as Nguni and medium frame such as Bonsmara have similar eye muscle areas. This difference could be attributed to the difference in the production system, i.e. intensive *vs* extensive grazing system, of these two studies. The large frame and medium frame yielded better eye muscle area than that of the small frame size. This was expected as the literature (Keane et al., 1990; Chambaz et al., 2003) indicates that the eye muscle area tends to be higher in large framed than in small-framed beef breeds.

4.5 Conclusion

The results suggest that the medium frame size breed performed better in terms of water footprint whilst yielding comparable carcass characteristics to the large frame size in the intensive production system.

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CHAPTER 5: GENERAL CONCLUSIONS AND RECOMMENDATIONS

5.1 General Conclusions

From the literature, it is evident that South Africa is at risk of water scarcity. Available data indicate that the country is fast approaching physical scarcity. Blue water resources are dry for most months of the year. Agriculture is the major contributor to the current state as this sector uses largely blue water for food production, for both crops and animal production. However, there is little research done to measure the water footprint of beef production in South Africa. The country has been shown to be dominated by extensive beef production. There are no previous studies done to assess water footprint in the different production systems. It is, therefore, not clear how beef production in South Africa contributes to the country's water scarcity problem without providing scientific evidence. Extensive beef production also consumes green water, occupying land that is not suitable for any other form of agriculture. Current and future research activities need to focus on more efficient livestock production methods that reduce water footprint without compromising production. One of the ways to achieve a reduction of water footprint could be identifying and using breeds that require little water per kilogram of meat produced. From this study, productivity was defined as meat yield per litre of water used as opposed to feed conversion ratio that was similar for all different frame sizes.

These results suggest that the small frame-sized breed used in this study performed better than the medium and large frame-sized beef breeds in terms of WCE for post-weaning growth performance under intensive production system. As for carcass characteristics, the medium frame size breed performed better in terms of water footprint whilst yielding comparable carcass characteristics to the large frame size in the intensive production system. The notable outcome of this study is the effect of frame size on the water use as a limiting natural resource, an effect that has not been quantified previously.

The research contributes new knowledge and innovation towards the development of the indicators traits of water footprints for sustainable utilization of water in livestock production in South Africa. Currently, there are no indicators traits for livestock water footprint in livestock genetic improvement programmes in South Africa and many countries of the world. This research produced the baseline information on potential indicators traits (Water Intake Efficiency & Water Consumption Efficiency) to assess the livestock water footprints for the intensive production system in South Africa. The findings of this research are of importance to the livestock industry especially the feedlots, breeds associations, farmers and policymakers. The outcome of this study contributes toward global action to mitigate the impact of climate change (Goal 13: Climate Action – United Nations Sustainable Development Goals) and Goal 2 to "End hunger, achieve food security and improved nutrition and promote sustainable agriculture". The outcomes also align well with Africa Union Agenda 2063 as well as the National Development Plan (NDP) Vision 2030 Chapter 5 on Climate Change, and Chapter 6 on Modern Agriculture.

5.2 Recommendations

Noted below are some of the recommendations derived from the research:

- In view of water scarcity problems, and amid accelerated global warming (climate change), livestock breeding programmes should consider breeds or frame sizes that efficiently utilize water resources.
- The medium frame-sized beef breeds are recommended to be used in intensive production systems if producers are concerned about water use efficiency.
- There is a need to develop awareness and educational materials on water use efficiency for farmers and the public, as South Africa is a water-scarce country, and find ways to promote water use efficient beef breeds.

5.3 Future Work

Below are some of the recommendations for future work:

- Since this research focused only on the intensive production system, it would be worthwhile to also assess water use efficiency in the extensive system.
- The current study was conducted and completed in one season, future studies should compare results and trends across seasons.
- The current research was based on only three breeds as representatives of frame sizes, thus future research is needed to focus on identifying more efficient livestock production methods across breeds in order to reduce water footprint without compromising production.
- Previous studies elsewhere reported that the two indicator traits for water use efficiency studied are under genetic control, therefore, future studies to confirm this are required under the South African livestock population.
- Studies on the genetic basis underlying water use efficiency mechanisms and the possible genetic markers influencing water use efficiency are recommended.

6. APPENDICES

6.1 Research Outputs

6.1.1 Scientific publication

sustainability MDPI

Review

Sustainable Application of Livestock Water Footprints in Different Beef Production Systems of South Africa

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Abstract: There is an increase in requirement and competition for water, while water resources are decreasing at an accelerating rate. Agriculture is the biggest consumer of water and therefore has the largest water footprint, which is not yet known. The largest portion is acknowledged to be for producing animal products. Water footprints account for the amounts of water used to produce a commodity for consumption, measured along the commodity life cycle. Water withdrawals from surface and groundwater are accounted for when assessing the water footprint. The three identified major determinants of a water footprint of meat include feed conversion efficiency (FCE), feed composition, and feed origin, with the first two being influenced greatly by the animal production system. In South Africa (SA), the two distinct production systems are the intensive and extensive production systems. Intensifying beef animals improves FCE due to faster growths per kg feed consumed, reduced activity, and therefore reduced water footprint. Beef cattle in the extensive system consume a large component of roughages, while the intensive system has a high concentrate to roughage ratio. This theoretically increases the water footprint in the intensive system. The literature indicates large amounts of volumetric water footprint indicators of boneless beef in SA. Water footprint assessment is critical for enabling consumers to make well-informed and sound decisions when considering changes in their behavior due to the effect this has on social, economic, and environmental wellbeing. This paper aims to postulate the various issues associated with water usage in beef production. These include factors affecting the water footprint of beef production and the effects it has on various aspects of both the environment and social wellbeing. It further explores the various methods to assess the water footprint of a product.

Keywords: Water use; production system; animal feed; drinking water

1. Introduction

Incidents of drought resulting from climate change have severely impacted water-available resources [1]. The anticipated growth in the world population assumes intensification of water-availability concerns as food demand escalates, particularly the demand for food of animal origin. This results in a shift from extensive animal production towards semi- and intensive production systems in an attempt to meet this escalating demand [2]. The expected environmental impacts of increased consumption of animal products [3–6], and the pros and cons of intensive and extensive production systems [7,8] have been researched extensively. There is an undeniable impact on and increase in pressure exerted on water resources due to the intensification of animal production systems.

There are several other factors associated with this increase in water consumption from the intensive production system, such as low efficiency of rations [9]. Animals kept under the traditional extensive system generally utilize land that would not be suitable for either human settlement or other

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6.1.2 Conference proceeding

51st Congress of The South African Society for Animal Sciences 10-12 June 2019, University of Free State, Bloemfontein, South Africa. Summary of Poster Abstract, pp. 143.

The water footprint of South African beef production: a review

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Background: There is an increase in competition and water requirement while water resources are decreasing at an accelerating rate. Agriculture is the biggest consumer of water and therefore has the largest water footprint and yet not known. The largest proportion is acknowledged to be for producing animal products. The water footprint concept takes into account the volume of fresh water used to produce a product, measured along the entire value chain from the production of inputs to the final stage where the final product reaches the consumer

Aim: This study is aimed at quantifying the volumetric water footprint of beef production from weaning to slaughter.

Methodology: To enable to determine the water footprint both the water withdrawn from surface and groundwater and the use of soil should be accounted for. This water footprint is categorized into green (water used by plants), blue (water consumed from mixed feed, drinking and irrigation) and grey (water required to dilute pollutants to an acceptable level such that the quality of the ambient water is maintained). The largest water footprint of animal products such as beef meat relates to animal feeding. There are three identified major determining factors of water footprint of meat; these include feed conversion efficiency (FCE), feed composition and feed origin. The FCE and feed composition are influenced greatly by the animal production system. In South Africa, there are two distinct production systems; which are the intensive and extensive production systems. Intensifying beef animals improve their FCE due to faster growth rates per kg feed consumed and reduced activity, and therefore reduce water footprint. Beef cattle feed on a large component of roughage feed, particularly in the extensive system, while the intensive production system has a high concentrate to roughage ratio. This theoretically increases the water footprint in the intensive system due to the larger water footprint of concentrate feeds.

Results and Discussion: Literature indicates that the volumetric water footprint indicator of boneless beef in South Africa is 17 387 l/kg, compared with the global average of 15 414l/kg. The water requirement is claimed that approximately 15 500 L is needed to produce 1 kg beef, it is assumed that it takes three years to produce 200 kg of boneless beef.

Conclusion/recommendations: Water foot print assessment is critical to enable consumers to make well informed and sound decisions when considering changing their behaviour due to effect this have on both the social, economic and environmental impacts.

6.2 Capacity Development Report

6.2.1 Postgraduate students

The following students are attached to this project:

1. Noluthando Macamba: Registered with the Tshwane University of Technology for the degree Master of Agricultural Science (Animal Sciences) :
2. Ayanda Ngxumeshe: Registered with the Tshwane University of Technology for the degree Doctor of Philosophy in Science (Animal Production)

6.2.2 Institutional level

This work was and/or will be presented on institutional committees such as the Faculty of Science Committee of Postgraduate Studies, etc. and Faculty of Science Research Day.

This research has strengthened the collaboration between the Agricultural Research Council-Animal Production, Tshwane University of Technology, and Botswana University of Agriculture & Natural Resources Collaboration.

6.2.3 Knowledge dissemination

The dissemination of knowledge produced in this research will be disseminated through, (i) Conference proceedings, (ii) Scientific publications, (iii) popular publications such as Farmers Weekly, and (iv) Industry days subject to the availability of funds.