Comparing feed use efficiency and enteric gas production of Holstein and Jersey cows in a kikuyu pasture-based system using mathematical models

by

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Dissertation presented for the degree of
Doctor of Philosophy (Animal Sciences)

at
Stellenbosch University
Animal Sciences, Faculty of AgriSciences

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March 2020

Declaration

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated) that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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Summary

Feed use efficiency to synthesise maximum amounts of milk while ensuring responsible use and protection of the environment is of significance for sustainable milk production. The aim of this study was to compare factors affecting milk production, nutrient use and enteric gas production efficiencies of Holstein and Jersey cows that were reared under similar environmental conditions and management practices. Data used were lactation records of 122 Holstein and 99 Jersey cows, collected from 2005 to 2014. Records included cow birth date, calving date, lactation number, body weight (BW), kg milk yield (MY), % fat (MF) and % protein (Mprot). Cows were reared as one herd on kikuyu pasture and received on an as-fed basis 7 kg of concentrate containing 17% crude protein (CP) per day, fed in two equal portions after each milking. The total dry matter intake (DMI) was estimated using the National Research Council (NRC, 2001) method. Pasture intake was calculated as the difference between DMI and concentrate dry matter intake. The mean DMI, MY, kg MF and kg Mprot were higher in Holsteins while Jerseys had higher %MF and %Mprot. Jersey MY was 74% but when corrected to energy corrected milk (ECM), 85% that of Holsteins. Milk increase from primiparous to mature cows (parity ≥4) was 26.5% in Holsteins and 23.7% in Jerseys. Age at first calving (AFC) did not differ between breeds. The calving season (CS) did not affect mean test-date MY but cows that calved in summer had a flatter lactation curve. Mean lactation number was lower and the inter-calving period (ICP) longer in Holsteins than Jerseys. Cows with the ICP below 13 months tended to produce on average less 305-day milk yield. Jersey cows showed higher efficiency in DMI/kg BW, MF/kg DMI, Mprot/kg DMI, ECM/kg DMI, ECM/kg BW and MY/100 kg BW. Holsteins were efficient in MY/kg DMI. Both breeds were in negative energy balance (NEB) during the transition and early lactation stages, with Holsteins having longer and more intense NEB. The net energy intake (NEI)/kg ECM, NEI/kg metabolic BW ($BW^{0.75}$) and net energy for maintenance (NEm)/kg $BW^{0.75}$ were higher in Holsteins compared to Jerseys. However, after accounting for NEm, (NEI-NEm)/ECM, Holsteins had higher gross energy efficiency. Milk nitrogen (MN)/nitrogen intake (NI) was higher in Jerseys compared to Holsteins. The NI/kg $BW^{0.75}$ did not differ between breeds. Jerseys had higher faecal nitrogen (FN)/100 g NI but lower urinary nitrogen (UN)/100 g NI, protein requirements for scurf losses (SPA) and therefore lower manure nitrogen (ManN)/kg NI than Holsteins. Holsteins produced more kg carbon dioxide (CO_2)/day, but low CO_2/kg DMI and CO_2/100 kg BW than Jerseys. Breeds did not differ in CO_2/kg ECM. Holsteins emitted less methane

(CH_4) g/kg DMI and CH_4/100 kg BW, while Jersey emitted less CH_4/kg ECM. Mature cows produced on average 16% more CH_4 than their primiparous counterparts. With lactation stages, the highest CH_4 emissions were observed during mid-lactation with cows producing on average 28% more daily CH_4 when compared to the transition period. This indicates that accounting for production stages in estimating the methane emission factor (MEF, CH_4/head/year) will bring more accuracy and can therefore be recommended for regional and national inventories for SA dairy breeds. From this study, it can be concluded that neither of the breeds were overall more efficient regarding all traits, but Jersey cows showed higher efficiency in most measured traits.

Keywords: milk production, dry matter intake, parity, lactation stage, calving season, inter-calving period, age at first calving, energy, nitrogen, carbon dioxide and methane

Opsomming

Voerverbruik-doeltreffendheid om die maksimum hoeveelheid melk te sintetiseer, terwyl die verantwoordelike gebruik en beskerming van die omgewing is van belang vir volhoubare melkproduksie. Die doel van hierdie studie was om faktore wat melkproduksie, voedingstowwe en die doeltreffendheid van enteriese gasproduksie beïnvloed, te vergelyk tussen Holstein- en Jersey koeie wat onder soortgelyke omgewingstoestande en bestuurspraktyke grootgemaak is. Data wat gebruik is, het laktasierekords van 122 Holstein- en 99 Jersey-koeie onderskeidelik, wat van 2005 tot 2014 versamel is, ingesluit. Verslae het inligting oor die koeie se geboortedatum, kalwingsdatum, laktasienommer, liggaamsgewig (BW), kg melkopbrengs (MY), % vet (MF) en % proteïen (Mprot), ingesluit. Koeie is as een kudde op kikuju weiding grootgemaak en 'n 7 kg konsentraat wat 17% ru-proteïen (CP) per dag bevat, is in twee gelyke porsies na elke melking gevoer. Die totale droëmateriaal inname (DMI) is geskat volgens die NRC-metode. Weidingsinname is bereken as die verskil tussen DMI en konsentraat droëmateriaalinname. Die gemiddelde DMI, MY, kg MF en kg Mprot was hoër in Holsteins, terwyl die Jersey melk hoër MF en % Mprot gehad het. Jersey MY was 74%, maar as dit aangepas is vir energie-gekorrigeerde melk (ECM), was dit 85% van Holstein produksie. Melkverhoging van primêre en volwasse koeie (pariteit ≥4) was 26,5% in Holstein- en 23,7% in Jersey koeie. Ouderdom met eerste kalwing (AFC) het nie tussen die rasse verskil nie. Die kalfseisoen (CS) het nie die gemiddelde toetsdag MY beïnvloed nie, maar koeie wat in die somer gekalf het, het 'n vlakker laktasiekurwe gehad. Gemiddelde laktasie nommer was laer en die tussenkalfperiode (ICP) langer in Holstein- as in Jersey koeie. Koeie met die TKP onder 13 maande was geneig om gemiddeld minder melk op dag 305 te produseer. Jersey-koeie het ’n hoër doeltreffendheid getoon in DMI / kg BW, MF / kg DMI, Mprot / kg DMI, ECM / kg DMI, ECM / kg BW en MY / 100 kg BW. Holstein koeie was doeltreffend in terme van MY / kg DMI. Albei rasse het ’n negatiewe energiebalans (NEB) ervaar tydens die oorgangs- en vroeë laktasiefases, met Holsteins wat ’n langer en strawwer NEB ervaar het. Die netto energie-inname (NEI) / kg ECM, NEI / kg metaboliese BW ($BW^{0.75}$) en die netto energie vir onderhoud (NEm) / kg $BW^{0.75}$ was hoër in Holsteins in vergelyking met truie. Na die inagneming van NEm, (NEI-NEm) / ECM, het Holsteins egter ‘n hoër bruto energie-doeltreffendheid gehad. Melk stikstof (MN) / stikstofinname (NI) was hoër in die Jersey koeie in vergelyking met die Holsteins. Die NI / kg $BW^{0,75}$ het nie tussen rasse verskil nie. Die Jersey koeie het hoër fekale stikstof (FN) / 100 g NI, maar laer urien stikstof (VN) / 100 g NI, proteïenvereistes vir skurfverliese (SPA) en dus laer misstof stikstof (ManN) / kg NI as Holsteins gehad. Holstein koeie produseer meer kg koolstofdioksied (CO_2) / dag, maar het 'n laer CO_2 / kg DMI en CO_2 / 100 kg BW wanneer vergelyk met Jerseys. Rasse het nie verskil in terme van CO_2 / kg ECM nie. Holsteins het minder metaan (CH_4) g / kg DMI en CH_4 / 100 kg BW vrygestel, terwyl Jersey minder CH_4 / kg ECM vrygestel het. Volwasse koeie produseer gemiddeld 16% meer CH_4 as hul eweknieë. Met die laktasiefase is die hoogste CH_4-emissies waargeneem tydens mid-laktasie, met koeie wat gemiddeld 28% meer daaglikse CH_4 produseer in vergelyking met die oorgangstydperk. Dit dui daarop dat die berekening van die produksiefases in die beraming van die metaan-emissiefaktor (MEF, CH_4 / kop / jaar) meer akkuraatheid sal meebring, en dit kan dus aanbeveel word vir streeks- en nasionale voorrade vir SA suiwelrasse. Uit hierdie studie kan die gevolgtrekking gemaak word dat geen van die rasse in die algemeen doeltreffender was ten opsigte van alle eienskappe nie, maar dat Jersey-koeie hoër doeltreffendheid getoon het in die meeste gemete eienskappe showed higher efficiency in most measured traits.

Sleutelwoorde: melkproduksie, droëmateriaal inname, pariteit, laktasiefases, kalfseisoen, tussenkalfperiode, ouderdom met eerste kalwing, energie, stikstof, koolstofdioksied en metaan

Dedication

This dissertation is dedicated to the unsung hero, Mrs. Nomatile Angelina Nondzaba.

“Dingi, Thahla, Ntlanga enkulu kunazo zonke, this one is for you.”

Acknowledgements

I wish to express my sincere gratitude and appreciation to the following persons and institutions:

A big thank you to My Heavenly Father for carrying me through. “Every good and perfect gift is from above, coming down from the Father of the heavenly lights, who does not change like shifting shadows” (James 1:17).

My Supervisors: Prof. Kennedy Dzama, Dr. Carel Muller, Prof. Christiaan Cruywagen and Dr. Florence Nherera-Chokuda for your valuable inputs. Your different fields of expertise have shaped and sharpened this study, Thank you very much!

Western Cape Department of Agriculture, Animal Production Division for allowing me to use their data for this study.

Western Cape Agricultural Research Trust (WCART) for the financial support that made this research possible. A word of special thanks goes to Mrs. Gerty Mostert for the support and prompt response to requests and queries.

Agriculture Sector for Education and Training (AgriSETA) for financial support.

The Postgraduate Skills Development Division of the Stellenbosch University for the on-point capacity building workshops on research skills, soft skills and computer skills.

Dr. C. J. C. Muller and his wife, I don’t know where to begin. Your guidance, support and generosity with your time to see that this study comes to fruition is highly appreciated. Mrs. Muller, thank you very much for creating a welcoming atmosphere in your home. It is a true blessing to have known both of you.

Mr. J. A. Botha and Mr. N. Mnisi for keeping good records and availing yourselves to assist whenever I needed help.

Dr. Emiliano Raffrenato for linking me with the Nutritional Dynamic System Professional team (Team RUM&N) and their quick response in troubleshooting.

Mrs Gail Jordaan for helping with data analysis and general emotional support, highly appreciated.

Prof. Edward Imbayarwo-Chikosi for friendship and editing this document, your meticulous work at such a short notice, RESPECT!!!

Dr Helet Lambrechts for translating the summary of this document into Afrikaans.

Dr Bilungi Alain Useni, my brother from another mother, thank you very much for friendship and the skills you imparted on me.

My family, mom, brothers, nephews and nieces. A special thank you goes to my son Sonwabile Luzuko Bangani for the love, support, encouragement and believing in me, not forgetting my sisters Ntombekhaya, Ntombizandile, Nosakhele and Nosiseko. You were and are my rocks – mega love for you all.

Bongi, Nomama and Stando, it would be a major crime not to mention your names here. They say true friends are hard to find, thank you for being my friends, thank you very much for your prayers.

My cheerleaders: Ms. Thakane Motebang, Mr. Gerard Mamabolo and Mr. Fanny Phetla.

Colleagues for the support and friendship – you all are very special in your own special ways, thank you for the laughs, the help and everything, love you guys!

To everyone who has contributed to the success of this study, I might have not mentioned your name here, but rest assured, you are not forgotten.

If you get tired, learn to rest, not to quit (Banksy)

Preface

This dissertation is presented as a compilation of seven chapters. Each chapter is introduced separately and is written according to the style of the South African Journal of Animal Sciences.

Chapter 1 **General Introduction and project aims**

Chapter 2 **Literature review**

Chapter 3 **Research results**
Factors affecting milk production of Holstein and Jersey cows in a kikuyu pasture-based production system

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Estimating milk production and energetic efficiencies of Holstein and Jersey cows in a kikuyu pasture-based production system

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Chapter 7 **General conclusions, study limitations and recommendations**

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List of abbreviations

°C	Degree celsius
BW	Body weight
$BW^{0.75}$	Metabolic body weight
CH_4	Methane
CNCPS	Cornell Net Carbohydrate and Protein System
CO_2	Carbon dioxide
CP	Crude protein
DEI	Digestible energy intake
DEIMCF	Digestible energy methane conversion factor
DIM	Days in milk
DMI	Total dry matter intake
EB	Energy balance
ECM	Energy corrected milk
FN	Faecal nitrogen
GEI	Gross energy intake
GHG	Greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
ManN	Manure nitrogen
MCF	Methane conversion factor
MCP	Microbial protein
MEF	Methane emission factor
MEI	Metabolisable energy intake
MEpreg	Metabolisable energy for pregnancy
MF	Milk fat

MN	Milk nitrogen
MP	Metabolisable protein,
MPg	Metabolisable protein for growth
MPlact	Metabolisable protein for lactation
MPm	Metabolisable protein for maintenance
MPpreg	Metabolisable protein for pregnancy
Mprot	Milk protein
MS	Milk solids
MY	Milk yield
N	Nitrogen
NDS	Nutritional Dynamic System Professional
NE	Net energy
NEB	Negative energy balance
NEg	Net energy for growth
NEI	Net energy intake
NElact	Net energy for lactation
NEm	Net energy for maintenance
NH_3	Ammonia
NI	Nitrogen intake
NRC	National Research Council
NUE	Nitrogen use efficiency
RDP	Rumen degradable protein
RUP	Undegradable protein
SPA	Protein requirement for scurf losses
UN	Urinary nitrogen

Chapter 1
General introduction

1.1 Background

A study by the International Farm Comparison Network predicted an increase in demand for dairy products by 20 million tonnes per year globally (IFCN, 2014; Milk Producers' Organisation, MPO, 2018). Milk and milk products consumption in South Africa is also showing an increasing trend, associated with both the increase in population growth and per capita consumption (MPO, 2018). The estimated milk and milk products consumption in South Africa was 2 088 000 tons in the 2005/2006-year (Gertenbach, 2007) and increased to 3 245 000 tons in 2017 (MPO, 2017). This indicates an increase of about 55% in a period of 11 year. However, the escalating production costs, low milk prices, as well as unfavourable climatic conditions (MPO, 2017), all have a negative effect on the dairy farm business financial sustainability. Farmers are looking for practices that will achieve maximum milk production using the least possible inputs.

The effect of the dairy systems on the issue of rising greenhouse gas (GHG) emissions is also receiving more attention. According to the Food and Agriculture Organisation (FAO) of the United Nations (2019), the dairy sector needs to contribute effectively to the global effort of mitigating GHG emissions so as to avoid the dangers associated with climate change. This therefore makes it necessary for the producers to engage in practices that promote responsible use and protection of the environment (FAO, 2019). This will ensure that milk is produced in a sustainable way, and therefore benefit the country's GHG mitigation strategies and the overall dairy sector's public image.

As cows' milk comprises 83% of the total milk produced globally, a growing interest in comparing efficiencies between dairy cattle breeds in producing maximum milk yields while ensuring responsible management of the environment has been observed. There are at least seven breeds of cattle that are recognised as being dairy breeds in South Africa, namely: Holstein, Jersey, Guernsey, Ayrshire, SA Dairy-Swiss, Brown Swiss and Dairy Shorthorn (Gertenbach, 1995; Milk SA, 2014).

Holsteins and Jerseys constitute the highest proportion of all commercial dairy herds globally (Chiwome *et al.*, 2017), with Holsteins being by far the most popular breed (Gertenbach, 1995; Weigel and Barlass, 2003; Porter & Tebbit 2007; Heins *et al.*, 2008;

Chiwome *et al.*, 2017). The two breeds differ both in milk yield and composition. Jerseys produce lower volumes of milk at a higher solids content, while Holsteins produce higher volumes of milk at a lower solid content. On average, while South African Jersey cows produce 30% less milk, the MF and Mprot percentages are 32% and 18% higher, respectively, than that of Holstein cows (adapted from ICAR, 2015). Other than differences in milk production and composition, the two breeds differ in body weight. Mature South African Holstein cows weigh between 550 to 650 kg and Jersey cows between 380 to 450 kg (Gertenbach, 1995), suggesting that the South African Jersey cows weigh approximately 30% less than their Holstein counterparts. Because feed intake is positively related to animal size and production, Jerseys have a lower dry matter intake (DMI) than Holsteins due to their smaller body frame. Numerous authors have also reported a higher average daily DMI in Holsteins compared to Jerseys (Blake *et al.,* 1986; Palladino *et al.,* 2010; Kristensen *et al.,* 2015), attributable to their larger frame size. Because of the popularity of Holstein and Jersey cows, this study will focus on investigating and comparing performance efficiencies of these two dairy breeds, i.e., the proportion of product output vs. input, e.g., MY/kg DMI or MY/kg BW (Thomson *et al.,* 2001; Prendiville *et al.,* 2009; Ross *et al.,* 2015). Cows that use fewer inputs but produce greater outputs than their contemporaries are regarded as more efficient as this may contribute in reducing production costs.

1.2 Problem statement

Studies conducted on comparing the production efficiency of Holstein and Jersey cows (Muller & Botha, 1998; Thomson et al., 2001; Rastani *et al.,* 2001; Grainger & Goddard, 2004; Prendiville *et al.,* 2009; Palladino *et al.,* 2010; Capper & Cady, 2012; Kristensen *et al.,* 2015) are often short-term, or if long-term, breeds are mostly kept in different environmental and management systems. This is because most farmers tend to choose and produce milk using one breed type. As about 70% of productivity in cows is attributed to management and environmental factors (Campbell & Marshall, 2016), this results in wide variances in milk production levels even under similar environmental conditions but different management systems (Usman *et al.*, 2013). Although several short-term studies on comparing the two breeds have been conducted, in their meta-analysis, Phuong *et al.* (2013) concluded that short term studies are not sufficient to study the effect of animal factor in feed conversion efficiency, thus advocating for longitudinal measurements per animal. This maybe because short-term studies do not account for the influence of time on measured traits (Caruana *et al.*, 2015) e.g., production stages, and therefore fail to provide information on the consistency with which the trait is expressed. The results from short-term studies may also be confounded with carry-over effects from previous treatments (O'Connor *et al.*, 2014), and can therefore not be seen as a true reflection of efficiency.

1.3 Justification

Focusing on the efficient use of resources such as selecting a breed that can efficiently convert feed into suitable products is critical to profitability of the dairy farm business. Several authors reported that breeds differ in milk production, nutrient use (Mackle *et al.,* 1996; Kristensen *et al.,* 2015) and enteric gas production efficiencies (Capper & Cady, 2012; Dalla Riva *et al.,* 2014). The consistency and persistency of these variations in cows under similar environmental and management conditions needs to be investigated so as to substantiate the available literature. The dairy herd at the Elsenburg Research Station, Western Cape Department of Agriculture in South Africa is the most suitable herd on which this research can be conducted. This is because the farm was managed by the same person throughout the experimental years and the experimental animals received uniform treatment, i.e., reared and kept as one herd in pasture, received the same commercial concentrate, subjected to similar milking procedures, routine health assessments and care, and bred through artificial insemination with bulls selected using a computerised mating programme during all the experimental years using similar breeding objectives. Using records from this herd will provide information on trends across parity and lactation stages on breed performance efficiencies on milk production, nutrient use and enteric gas production that are not confounded with environmental, management and potential carry over effects from previous treatments.

1.4 Using mathematical models in this study

The records used in the study were compiled as part of the National Milk Recording and Improvement Scheme under the Animal Production Institute of the Agricultural Research Council (ARC) to estimate breeding values for sires, cows and heifers for a genetic profile of individual herds. Mathematical models were therefore used to predict input variables e.g. feed intake and its nutrient composition, animal requirements, as well as output variables, e.g. energy output in milk, nitrogen excreted and enteric gases emissions.

To simulate the nutrient composition of the feed, the Nutritional Dynamic System (NDS) Professional software package was used. The NDS Professional is a feed formulation software package developed to predict nutrient requirements and animal performance (output) based on management and environmental factors the animal is subjected to. This software uses the Cornell Net Carbohydrate and Protein System (CNCPS) biological model as a formulation and evaluation platform (NDS Professional, version 6.5, 2008 to 2018), making it suitable for these simulations.

Models used to predict animal requirements and output were from the National Research Council (NRC, 2001) and the CNCPS. The NRC (2001) models were chosen because of their empirical nature. Empirical models display the relationship between the process and influencing variables (Rickert *et al.,* 2000), e.g., relate the output to available data on animal characteristics and production data (Storm, 2012), and also account quantitatively for changes associated with different conditions (Lawson & Marion, 2008), e.g., the model for estimating DMI. The CNCPS models on the other hand, are mostly hybrid models. Hybrid models combine different mathematical models to produce a synergetic effect (Duarte & Saraiva, 2003). The CNCPS models combine mechanistic, deterministic, and static models in ruminant nutrition (Tedeschi *et.al,* 2005). Mechanistic models incorporate concepts about the underlying biological processes (Tedeschi *et al.,* 2005; Liberles *et al.,* 2013) e.g. rumen function and metabolism, deterministic models assign the outcome to cause and effect (Dzama, 1993) while static models explain the interaction and interconnections of the systems' components which remains constant during time under specific conditions (Torres & Santos, 2015). Moreover, both NRC and CNCPS models use equations from peer reviewed scientific articles (Fox *et al.,* 2004; Tedeschi *et al.,* 2014), making them suitable to use in this study.

1.5 Study aim

The aim of this study was to compare milk production, energy, nitrogen, and enteric gases production efficiency of Holstein and Jersey cows maintained under similar environmental conditions and management practices.

The objectives of the study were to:

- Determine the effect of calving season, age at first calving and inter-calving period in Holstein and Jersey cows in a pasture-based production system.

- Compare milk production efficiency of Holstein and Jersey cows maintained under similar environmental conditions and management practices.
- Using prediction models estimate and compare the efficiency of energy use for maintenance, production functions and body reserves mobilisation of Holstein and Jersey cows grazing in a kikuyu pasture-based system.
- Estimate nitrogen use efficiency using prediction models and compare performance efficiencies of Holstein and Jersey cows in a kikuyu pasture-based system.
- Predict daily enteric greenhouse gases (GHG), that is, carbon dioxide (CO_2) and methane (CH_4) emissions and GHG production efficiency of Holstein and Jersey cows in a kikuyu pasture-based system by parity and lactation stage.

1.6 Hypothesis

The hypotheses were proposed as follows:

- Holstein and Jersey cows do not differ in milk production efficiency
- Holstein and Jersey cows do not differ in energy use efficiency
- Holstein and Jersey cows do not differ in nitrogen use efficiency
- Holstein and Jersey cows do not differ in enteric gas production efficiency

1.7 Outline of the Dissertation

The Dissertation will be presented in seven separate chapters consisting of the following:

Chapter 1: General Introduction: provide background information, problem statement, justification, objectives and the outline of the dissertation.

Chapter 2: Literature Review: provide an overview of the dairy industry in South Africa, define efficiency measures and discusses breed effects on milk production, energy use, nitrogen use and enteric gas production efficiencies of Holstein and Jersey cows.

Chapter 3: Discusses factors affecting milk production potential of Holstein and Jersey cows. The factors include: age at first calving, lactation number, lactation stage, calving season, and inter-calving period.

Chapter 4: Estimates milk production efficiency as affected by breed, parity and stage of lactation with production efficiency estimated as output versus input. Milk was also standardised on an energy basis to energy corrected milk and the performance efficiencies of the two breeds compared. In this chapter, the estimation of energy use efficiency as the proportion of net energy intake utilised for maintenance, production and body reserves mobilisation is also discussed.

Chapter 5: Describes the estimation of nitrogen use efficiency as the proportion of nitrogen intake secreted in milk, proportion excreted in urine and faeces (manure nitrogen) and metabolisable protein balance.

Chapter 6: Describes the prediction of CH_4 and CO_2 production and estimation of GHG emission efficiency as a proportion of BW or kg milk produced.

Chapter 7: Provides General conclusion, limitations and recommendations.

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Chapter 2
Literature review

2.1 Introduction

The capacity to secrete milk is determined by the metabolic ability of the mammary tissues, but maximum rates of milk synthesis depend on the continuous supply of nutrients, their digestion and conversion efficiency for synthesis of the precursors for supply to the mammary tissue (Boyd & Kensinger, 1998). Insufficient supply of nutrients results in extensive use of body reserves and restricts production. Overfeeding increases feed costs, causes adverse health effects and excessive excretion of nutrients into the environment (NRC, 2001), resulting in wastage and environmental pollution.

Forage is the main feed source for dairy cows. This can be observed in the recommendation that the recommended inclusion rate of non-fibre carbohydrates in lactating dairy cows' diet is 30 to 45% on a dry matter (DM) basis (Batajoo & Shaver, 1994; Afzalzadeh *et al.*, 2010; Hall *et al.*, 2010), indicating that more than 55% of dairy cow diet is forage. Approximately 20 to 70% of cellulose may not be digestible (Varga & Kolver, 1997), resulting in a decrease in available nutrients for utilisation by the animal. The effects become more pronounced in grazing animals as the excess neutral detergent fibre in their diet limits voluntary feed intake because of physical fill in the rumen (Oba & Allen, 1999).

Pasture is also often associated with excess protein to what dairy cows require (Kolver *et al.*, 1998; Woodward *et al.*, 2011). The protein in pasture is generally highly degradable (NRC, 2001), while energy is the main limiting nutrient. This causes an imbalance between available energy and nitrogen in the rumen and, consequently, the inability of rumen microbes to fully utilise the available N. This constitutes both nitrogen and energy use inefficiency as there is a metabolic energy cost associated with excreting excess N with urine (Ishler, 2016).

Forages, especially poor quality forages, result in high CH_4 production, contributing to both greenhouse gas (GHG) concentrations in the atmosphere (Broucek, 2014), and energy loss (Hook *et al.*, 2010). The efficiency in digesting fibre and partitioning the available nutrients to maintenance and production is therefore of significance, especially in pasture-based animals. The objective of this literature review is therefore to provide a comparative presentation of Holstein and Jersey cows in milk production efficiency, nutrient use efficiency and enteric gas production efficiency. The causes or contributory causes to differences and their effect on production efficiency of the two breeds will also be explored.

2.2 Overview of the milk production industry in South Africa

Agricultural products contributed 2% to South Africa's gross domestic product value of almost R4 trillion in the 2015 financial year (Statistics South Africa, 2016). This shows a decline compared to the 2.5% contribution in 2014. The decline is attributed to the drought, viewed as climate change induced that severely affected the country in the third and fourth quarter of the 2015 financial year (Statistics South Africa, 2016).

According to the annual report by the South African Department of Agriculture, Forestry and Fisheries (DAFF, 2014), animal products have the highest gross value, contributing approximately 48% to the country's gross agricultural produce. Milk production is the fifth largest agricultural industry (Milk SA, 2014), contributing approximately 0.5% to the world milk production (DAFF, 2012; Milk Producers Organisation, MPO, 2018). The world's largest milk producer is India, contributing 16% to global production (FAO of the UN, 2015), followed by the United States of America, Pakistan, Brazil, Germany and China, respectively (FAO of the UN, 2015; MPO, 2018).

The milk production industry in South Africa is divided into a commercial and non-commercial sector. The non-commercial farmers, also known as subsistence farmers produce milk at a small-scale level, usually sufficient only to meet the needs of the farming family (MilkSA, 2014). When excess milk is produced, it is often sold in informal markets direct to consumers. Risk factors such as milk quality and safety form barriers for subsistence farmers to enter the formal market (MilkSA, 2014). Commercial dairy farmers generally operate on a large scale, using advanced technology which requires highly skilled workers. Cows receive proper nutrition and are maintained in good health so as to produce optimum amount of quality milk (Gertenbach, 2007). Because of smaller margins per cow, most commercial farmers have increased the number of cows so as to remain financially viable (Gertenbach, 2007). The average commercial dairy herd size in South Africa is 354 cows per herd, inclusive of both dry cows and cows in milk (IFCN 2017; MPO, 2018), making it the third largest dairy herd globally. The country with the largest dairy herd size is Saudi Arabia, followed by New Zealand, with 6924 and 419 cows per herd, respectively (IFCN 2017; MPO, 2018).

In South Africa, milk production varies by region, mainly due to climatic conditions. Most milk is produced in the coastal areas. This is evidenced by the survey conducted by MPO on total milk produced, where the top three milk producing provinces were the Eastern Cape, Western Cape and KwaZulu-Natal (MPO, 2015). The Eastern Cape and KwaZulu-Natal have good rainfalls resulting in good quality natural and cultivated pastures, while most farms in the Western Cape practice the total mixed ration (TMR) system (Gertenbach, 2007). The Western Cape has the second largest number of milk buyers (34 vs. 37 in Gauteng) (MPO, 2018), explaining the reason it is among the top milk producing provinces.

There are currently 1364 milk producers (MPO, 2018), employing approximately 40 000 farm workers in South Africa (Anonymous, 2017). Producer numbers are showing a steep decline annually since 2006 as many of them are struggling to maintain a profitable dairy farming operation (Erasmus, 2012). There were 4184 milk producers in 2006, declining to 3899, 3665, 3551, 2686, 2474, 1961, 1834, 1683,1593 from 2007 to 2017, respectively (MPO, 2018). Western Cape has the largest number of producers (419) followed by KwaZulu-Natal (221), Eastern Cape (212), Free State (206) and the remaining 306 producers are distributed over the other 5 provinces (MPO, 2018). Despite the decline in producer numbers, a steady increase in annual milk production is observed. This maybe because the remaining farmers are increasing their herds and are also using advanced technology to keep their businesses profitable (Gertenbach, 2007; Erasmus, 2012).

Using feeding systems, dairy production systems are classified into pasture-based and TMR systems (Gertenbach, 2007). Pasture-based cows produce less milk than those on TMR system. However, a marked shift in dairy herds to areas that are more pasture-based, e.g., Tsitsikama in the Eastern Cape Province of South Africa has been observed (Theron & Mostert, 2009). Growing interest to pasture-based system has also been reported in some parts of the United States, although the trend is not conclusive (Winsten *et al.,* 2010; Haan *et al.,* 2011). This is because the lower production costs on pastures that are managed efficiently (Alvarez *et al.,* 2008; Theron & Mostert, 2009) yield better net farm profit than that of the TMR system (McCarthy *et al.,* 2007; Theron & Mostert, 2009). In their different studies, Rust *et al.* (1995); Tucker *et al.* (2001); and White *et al.* (2002) found that although milk yield was lower with the pasture-based system, the net returns per cow were higher for pasture-based than TMR system due to reduced production costs. Moreover, the demand for organic milk has resulted in an increase in organic dairy farms

(Barkema *et al.,* 2015) which many of them are pasture-based. According to Gillepsie *et al.* (2009), in countries like the United States of America, consumers are willing to even pay more for milk from pasture-based systems even though it may not be organic.

Using data from 15277 registered and 12100 commercial Holstein cows participating in Logix Milk Recording (2015 – 2016), registered Holstein cows had on average 2.4 lactations, were on average 327 days in milk and produced 10765 kg milk containing 3.2% protein and 3.8% butterfat per annum, while commercial Holstein cows had average 2.7 lactations, 319 days in milk and produced 7937 kg milk containing 3.3% protein and 4% butterfat per annum. For 18655 and 8216 registered and commercial Jersey cows, the two herds had on average 3.0 and 3.2 lactations, 317 and 314 days in milk and produced 6451 kg and 5791 kg milk, respectively, with both herds producing 3.8% protein and 4.8% butterfat content (Logiχ Milk Annual Report, 2015 – 2016). As there is sufficient information on production potential of the two breeds, focus needs to be shifted towards investigating how efficiently they utilise the inputs to produce milk.

2.3 Defining efficiency

The concept “efficiency” was introduced by Koopmans (1951), defining it as a point where output is maximised given the inputs. In agreement, Farrel (1957) defined efficiency as the success in producing as large as possible of an output from a given set of inputs. Hubbard *et al.* (2014) also suggested the principle of obtaining maximum output achievable from a set of given inputs at the lowest possible cost, or producing the highest number of goods using the least amount of resources possible. As an extension to Koopmans’ (1951) definition, Cooper *et al.* (2007) stated that “the business unit is fully efficient if and only if it is not possible to improve any input or output without worsening some other input or output”. A producer is seen as efficient if they produced as much as possible with the inputs they have actually employed, and have produced that output at minimum cost (Greene, 1997).

In livestock production, “efficiency” was introduced by Dickerson in 1970 (Tess & Davis, 2002). According to Dickerson (1970), an efficient cow herd exhibits early sexual maturity, high rates of reproduction, low rates of dystocia, longer productive life, minimum maintenance energy requirements and the ability to convert feed into weight of weaned calves. The added benefit of efficiency is reduced environmental impact of production due to dilution of maintenance effect, e.g., with increased average milk yields, the cow emits less GHGs per unit of milk produced (Bell *et al.,* 2012; Bell & Tzimiropoulos, 2018).

In a dairy farm, feed efficiency is one of the biological traits that are referred to as traits of economic importance. Feed has a significant effect on production costs, as it constitutes more than 70% of the input costs in a dairy farm (Anonymous, 2017). According to Grainger & Goddard (2004), improvements in feed efficiency can be achieved if the cow achieves higher feed intake per unit liveweight, loses less energy in faeces, urine or methane (CH_4) for a given intake, has lower maintenance energy requirements, and partitions more metabolisable energy to milk than to body tissue. Weight loss should be for a short-term basis as long-term weight loss may result in undesirable outcomes (Grainger & Goddard, 2004) e.g., reproductive problems such as anoestrus resulting in long days open and long inter-calving periods.

Various factors such as inadequate or imbalances in nutrient supply, a decline in cow health and the genotype of the animal, affect the efficiency with which the nutrients are utilised. This results in excessive excretion of nutrients to the environment, contributing not only to wastage, but also to environmental pollution (Phuong *et al.*, 2013) as the nitrogen lost in faeces and urine, and CH_4 emitted during enteric fermentation contribute to global climate change. In this review, the efficiency with which feed is utilised by Holstein and Jersey cows will be discussed under the following measures:

- **Production efficiency:** This is product output vs. input, e.g., DMI per unit of body weight (BW), milk yield (MY) or milk solids (MS) per unit of DMI and MY or MS per unit of body weight (BW) (Mackle *et al.*, 1996; Muller & Botha, 1998; Thomson *et al.,* 2001; Grainger & Goddard, 2004; Prendiville *et al.*, 2009; Palladino *et al.*, 2010; Ross *et al.*, 2015). Animals using fewer inputs but have greater outputs in comparison to others are regarded as more efficient as they may improve the margins by contributing in reduction of production costs.
- **Energetic or energy use efficiency:** This is the efficiency of partitioning the available net energy intake (NEI) to maintenance and production functions. It is expressed as the proportion of NEI utilised for maintenance (NEm), lactation (NElact), or a proportion of NEI utilised to produce 1 kg energy corrected milk (ECM) after accounting for NEm (Blake *et al.*, 1986; Gallo *et al.*, 1996; Mackle *et al.*,

1996; Rastani *et al.*, 2001; Prendiville *et al.*, 2009; Olson *et al.*, 2010; Capper & Cady, 2012; Kristensen *et al.*, 2015).

- **Nitrogen use efficiency:** It is defined as grams milk N produced relative to N intake (Arndt *et al.*, 2015; Foskolos & Moorby, 2018) or nitrogen excreted in manure relative to nitrogen intake.
- **Enteric gas emission efficiency:** This is the proportion of carbon dioxide (CO_2) or methane (CH_4) produced per kg feed intake or per kg body weight. It can also be expressed as the amount of enteric GHG emitted per unit of product produced (Münger & Kreuzer, 2008; Capper *et al.*, 2009; Dalla Riva *et al.,* 2014; Hristov *et al.*, 2014; Olijhoek *et al.*, 2018).

2.4 Breed effect on performance efficiency

2.4.1 Milk production

Milk yield (MY), protein (Mprot) and butterfat (MF) contents of milk are production traits with the highest economic importance (Anonymous, 2017) and are positively correlated with efficiency (Meissner, 2015). A negative correlation between milk solids (MS) and yield has, however, been reported (Campbell & Marshall, 2016; Anonymous, 2017), with Anonymous (2017) reporting a correlation of -0.43 between milk yield and fat percentage. The heritability estimates for MY range between 0.21 to 0.47; MF, 0.19 to 0.43; and Mprot, 0.17 to 0.23 (Shadparvar & Yazdanshenas, 2005; Maiwashe *et al.*, 2008; Ulutas *et al.*, 2008; Erfani-Asl *et al.,* 2015; Anonymous, 2017), indicating that significant genetic improvement in these traits can be achieved through genetic selection.

Production traits are increasing linearly over time for both Holstein and Jersey cows. For Holstein and Jersey cows, respectively, Washburn *et al.* (2002) reported average milk yields of 6802 kg and 4753 kg containing 241 kg and 228 kg fat in the period 1976 to 1978, which increased to 8687 kg and 6375 kg milk yield containing 287 kg and 282 kg fat between the years 1997 to 1999. This indicates an average milk production increase of 25.4% and 19.1% fat in Jerseys while Holstein's milk increased by 21.7% and fat by 16.03%. In the Elsenburg Holstein herd in South Africa, Anonymous (2017) reported an increase in MY from 5112 kg to 8360 kg, MF from 189 to 293 kg and Mprot from 172 to 269 kg from the 1983/84 to 1997/98 milk recording years, mainly attributable to genetic progress. An increase in annual milk production from 2437 to 2817 million litres, despite a decrease of more than 50% (from 4184 to 1834) in producer numbers from 2006 to 2013 (MPO, 2015) was reported for the South African dairy herd. This maybe because the remaining farmers are increasing their herds and are also using advanced technology to keep their businesses profitable (Gertenbach, 2007; Erasmus, 2012).

The milk yield of dairy cows increases with parity, reaching peak at fourth or fifth lactation, followed by a decline thereafter (Bajwa *et al.,* 2004; Amimo *et al.*, 2007; Jingar *et al.*, 2014; Nyamushamba *et al.*, 2014; Meissner, 2015). The decline is associated with degeneration of the body systems over the recurring pregnancies (Nyamushamba *et al.*, 2014). The ability of the cow to stay in the milking herd for a minimum of at least four lactations without being involuntarily culled, may result in production of more milk and more calves during the cows' lifetime, and therefore a positive effect in the economic efficiency of the farm (Sawa *et al.*, 2013).

Breed effect on milk production parameters is also evident. Adapted from the International Committee for Animal Recording (ICAR, 2015) report, Table 2.1 shows differences in the average milk production, fat and protein percentage per lactation of Holstein and Jersey cows from a number of countries around the world including South Africa.

Table 2.1 Milk production parameters of Holstein and Jersey cows per lactation for some countries (Adapted from: ICAR, 2015)

Country	**MY (kg)**			**MF (%)**			**Mprot (%)**		
	H	**J**	**J/H**	**H**	**J**	**J/H**	**H**	**J**	**J/H**
United States	11321	8183	0.72	3.68	4.81	1.31	3.08	3.65	1.19
Denmark	10612	7300	0.69	4.09	5.96	1.46	3.42	4.16	1.22
Canada	10257	6699	0.65	3.90	5.002	1.29	3.20	3.80	1.19
Sweden	10133	6963	0.69	4.09	5.87	1.44	3.40	4.09	1.20
South Africa	9760	5718	0.59	3.82	4.78	1.25	3.19	3.71	1.16
United Kingdom	9752	6532	0.67	4.03	5.29	1.31	3.28	3.88	1.18
Switzerland	8589	5726	0.67	3.94	5.26	1.34	3.23	3.87	1.20
Poland	7950	6212	0. 78	4.07	5.04	1.24	3.35	3.85	1.15
Australia	7087	5168	0.73	3.93	4.84	1.23	3.27	3.72	1.14
New Zealand	6011	4306	0.72	4.27	5.49	1.29	3.59	4.05	1.13

MY: milk yield, **MF:** milk fat, **Mprot:** milk protein, **H:** Holstein, **J:** Jersey

Breed variability in production parameters between countries can be observed, indicating that research findings on comparing the performance efficiencies of Holstein and Jersey cows from different countries should not be applied directly to another country due to differences in production systems, available feeds and climatic conditions.

The production efficiency of Holstein and Jersey cows seem to vary in different studies. When expressed as DMI/kg body weight (BW), most authors reported higher DMI/kg BW in Jerseys compared to Holsteins (Muller & Botha, 1998; Thomson *et al.,* 2001; Grainger & Goddard, 2004; Anderson *et al.*, 2007; Prendiville *et al.*, 2009; Sneddon *et al.,* 2011; Kristensen *et al.*, 2015) (Table 2.2), indicating higher efficiency in Jerseys. These authors associated the high DMI/kg BW in Jerseys with the larger gastrointestinal tract (GIT) of this breed per kilogram BW. The differences in GIT size were confirmed by Beecher *et al.* (2014), who reported the proportions for the reticulo-rumen, omasum, abomasum and total GIT as 24.3 vs. 29.3, 29.2 vs. 33.9, 7.2 vs. 8.2 and 128.8 vs. 142.5 g/kg BW, in Holstein and Jersey cows, respectively. Aikman *et al.* (2008) associated the high DMI/kg BW in Jerseys with the high passage rate of digesta in this breed compared to Holsteins. In agreement, Ingvartsen & Weisberg (1993), observed a 21% higher passage rate in Danish Jerseys compared to Holsteins. Combining the two theories, the bigger GIT capacity per kilogram BW allows for high DMI and a larger surface area for attachment of rumen microbes for ease of fibre degradation, while the high passage rate of digesta suggests a faster rumen outflow, thus explaining the high DMI/kg BW in Jerseys. In contrast, (Rastani *et al.* (2001); Aikman *et al.* (2008); Knowlton *et al.* (2010) found no difference in DMI/kg BW between the Holstein and Jersey cows in New Zealand. This was attributed to the smaller difference in body size of Holstein cows in New Zealand.

Holsteins have been reported to be more efficient than Jerseys in converting DMI to MY (Muller & Botha, 1998; Thomson *et al.;* 2001; Palladino *et al.*, 2010) (Table 2.2). Jerseys, however, seem to have a higher feed efficiency for the production of MS than Holsteins (Grainger & Goddard, 2004; Prendiville *et al.*, 2009; Capper & Cady, 2012) (Table 2.2). According to Grainger & Goddard (2004), most of the extra solids in Jerseys milk is fat. A divergent price change developed between fat and protein prices in 2016 (MPO, 2018), resulting in MF being the most valuable milk component (Covington, 2017). This change was driven by the new research that was published in 2015 indicating that a low-carbohydrate-high-fat diet is beneficial for weight reduction or reducing the risk of lifestyle diseases such as type 2 diabetes and hypertension (Noakes, 2013; Bateman, 2015). The result was an increase in consumer demand for full-cream dairy products and butter, and consequently, a sharp increase in prices of high MF products (MPO, 2018).

Table 2.2 Studies comparing DMI/kg BW and milk production/kg DMI of Holstein (H) and Jersey (J) cows (s: significant, ns: not significant, p: probability)

Efficiency	H vs. J	Study duration	System	Significance	Reference
DMI/kg BW	3.4 vs. 4.0%	One summer season	TMR	S	Muller and Botha, 1998;
	30.8 vs. 31.2; 29.0 vs. 32.9; and 24.3 vs. 26.9g/kg	One month for each lactation stage (early, mid and late)	TMR and pasture	P<0.01	Thomson *et al.,* 2001
	14.2% more per 100 kg BW	Review (14 – 300 days)	TMR and pasture	S	Grainger & Goddard, 2004
	3.96 vs. 4.26%	One year	TMR	S	Anderson *et al.,* 2007
	3.36 vs. 3.99%;	One full lactation period	Pasture	P<0.01	Prendiville *et al.,* 2009
	3.42 vs. 3.90; and 2.91 vs. 3.22	Review (not specified)	TMR and pasture	S	Sneddon *et al.,* 2011
	3. 76 vs. 4. 56%.	6 months	TMR	P<0.05	Kristensen *et al.,* 2015
	0.033 vs. 0.036 kg	One early lactation	TMR	NS	Rastani *et al.,* 2001
	N/A	±6 months	TMR	NS (P = 0.955)	Aikman *et al.,* 2008
	3.55% vs. 3.90%	One lactation period	TMR	NS (P<0.16)	Knowlton *et al.,* 2010
MY/kg DMI	1.38 and 1.18 ℓ/kg DM	One summer season	TMR	S	Muller & Botha, 1998
	1.72 vs. 1.60; 1.24 vs. 0.98 and 0.79 vs. 0.63 ℓ/kg DM	One month for each lactation stage (early, mid and late)	TMR and pasture	P<0.01	Thomson *et al.,* 2001
MF/kg DMI	67 vs. 81 g/kg DMI	One full lactation period	Pasture	P<0.05	Mackle *et al.,* 1996
	71.4 vs. 100.9; 51.4 vs. 55.5 and 40.4 vs. 41.9 g/kg DMI	One month for each lactation stage	TMR and pasture	P<0.01	Thomson *et al.,* 2001
Mprot/kg DMI	58.9 vs. 65.8; 42.0 vs. 38.9 and 30.7 vs. 28.7 g/kg DMI	One month for each lactation stage (early, mid and late)	TMR and pasture	NS (P=0.6)	Thomson *et al.,* 2001
ECM/kg DMI	1.50 vs. 1.68 g/kg DMI	One full lactation period	Pasture	P<0.05	Mackle *et al.,* 1996
	1.35 vs. 1.46 g/kg DMI	6 months	TMR	P<0.05	Kristensen *et al.,* 2015
	1.51 vs. 1.55 g/kg DMI	One lactation, 187±39 post calving	TMR	NS (P = 0.51)	Olijhoek *et al.,* 2018

DMI: dry matter intake, **BW:** body weight, **MY:** milk yield, **MF:** milk fat, **Mprot:** milk protein**, ECM:** energy corrected milk, **TMR:** total mixed ration

In the literature reviewed, there is a lack of studies where production efficiency of MF or Mprot are measured individually, they are often presented as total solids, and this indicates a research need. When milk was corrected for its fat and protein content to energy corrected milk (ECM) per kg DMI, Jerseys were more efficient (Mackle *et al.,* 1996; Kristensen *et al.,* 2015). In contrast, Olijhoek *et al.* (2018), reported no difference between Holstein and Jersey cows (Table 2.2). Further investigation, using a longitudinal approach is needed to verify the available contradictory findings.

2.4.2 Energy use efficiency

Fibre and carbohydrates are the primary energy sources for ruminants. Other energy sources include protein and fats. Fat contains about 2.25 times more energy than carbohydrates or proteins (McDonald *et al.*, 2002). Types of fats include those that are degradable in the rumen and those that are protected against rumen microbial degradation, to be made available in the small intestines. The latter are referred to as “rumen inert” or “rumen bypass fats” (Aguilar-Pérez *et al.*, 2014). Total dietary fat must not exceed 7% of the feed dry matter (Eastridge & Firkins, 1991) as excessive intake results in depressed ruminal fermentation of structural carbohydrates and, consequently, increased excretion of fibre with faeces (Palmquist, 1994; Palmquist & Jenkins, 2017). The reduced fermentation activity is a result of either physical coating of the fibre or toxicity of unsaturated fatty acids against gram-positive bacteria (Jenkins & McGuire, 2006; De Marchi *et al.*, 2013).

The end-product of ruminal degradation of fibre, carbohydrates and deaminated proteins are volatile fatty acids (VFA), which are the main energy sources for rumen microbes. Acetate, propionate and butyrate are the predominant VFAs (Bergmen, 1990; Nagaraja *et al.,* 1997), with valerate occurring in small amounts of less than 5% (Bergmen, 1990). Fermentation of structural carbohydrates increases the molar proportion of acetate, while fermentation of starch or sugars favours the production of propionate (Dijkstra, 1994; Nagaraja *et al.,* 1997). Dijkstra (1994) reported acetate, propionate, and butyrate proportions of 65%, 16%, and 10% in diets containing more than 60% roughage while in the concentrate diets containing less than 40% roughage the proportions were 58%, 23% and 10%, respectively. Acetate is associated with increased milk fat concentration (Urrutia & Harvatine, 2017). Butyrate provides energy to the rumen wall and is used for fatty acid synthesis in adipose and mammary gland tissues (Ishler *et al.,* 2001). A pattern of decreased milk fat with a decrease in acetic and butyric acid concentrations in cows whose diet was changed to low hay was reported (Storry & Rook, 1966). High concentrations of propionic acid lead to increased lactic acid and glucose production, which stimulates insulin production thus reducing free fatty acid release from adipose tissue (Linn, 1988). Holsteins have been reported to have lower acetate concentrations than Jerseys, 63.2 vs.65.3% (Bangani, 2002); 57.7 vs.60.5% (McLean, 2015). The higher acetate concentration can be linked to the high %MF production in Jerseys. It is also suggestive of a higher concentration of fibrolytic bacteria in Jerseys, a possible reason Jerseys have been reported to be more efficient in digesting fibre compared to Holsteins. Several authors (Retief, 2000; Bangani, 2002; Aikman, 2008; Olijhoek *et al.,* 2018) reported greater effective neutral detergent fibre (NDF) degradability in Jerseys compared to Holsteins at all fractional outflow rates, suggesting a greater extraction of nutrients and a lower retention time of the digesta in Jerseys.

The amount of energy available to the cow and how it is partitioned between maintenance, milk production, pregnancy and growth is the main determinant of production efficiency. According to Bauman & Currie (1980), nutrient partitioning in dairy cows is regulated by homeorhetic controls, which are defined as “the orchestrated or coordinated changes in metabolism of body tissues necessary to support a physiological state”. Pregnancy and milk secretion are high priority functions for nutrient allocation (Bauman & Currie, 1980). After calving, there is a rapid energy demand for the initiation of milk synthesis, this is followed by the rapid increase in milk production that reaches peak yield in early lactation while the DMI is lagging behind (Drackley *et al.*, 2005), consequently predisposing the cow to negative energy balance (NEB). Metabolic disorders and hormonal imbalances associated with NEB cause poor reproductive performance e.g., longer inter-calving periods (Van Knegsel *et al.,* 2005). Primiparous cows are reported to experience less depletion and have faster recovery of body reserves than multi-parous cows (Gallo *et al.*, 1996; Lee & Kim, 2006; Friggens *et al.*, 2007), which can be associated with the faster cell growth and regeneration in younger animals compared to older ones.

With regard to breed differences, Rastani *et al.* (2001); and Friggens *et al.* (2007b) reported a shorter and less intense NEB in Jerseys compared to Holsteins that were fed TMR on an *ad libitum* basis. Washburn *et al.* (2002) observed higher condition scores in Jerseys than Holstein in both *ad libitum* TMR and pasture-based systems. With NEI/kg $BW^{0.75}$, no differences have been observed between Holstein and Jersey cows (Tyrrell *et* *al.*, 1991; Rastani *et al.*, 2001). The results on NEm/kg $BW^{0.75}$ are conflicting, Olson *et al.* (2010) reported no difference between breeds, and Capper & Cady (2012) observed a maintenance energy requirement of 54 MJ/day in mature Jersey cows weighing on average 454 kg, and 76 MJ/day in mature Holstein cows with an average weight of 680 kg. Expressed as NEm/kg $BW^{0.75}$, this becomes 0.57 and 0.55 MJ/kg $BW^{0.75}$ for Holstein and Jersey cows, respectively, which may suggest higher NEm/kg $BW^{0.75}$ requirements in Holstein cows. Jerseys have been reported to have a high efficiency in converting NEI to milk (Mackle *et al.*, 1996; Kristensen *et al.*, 2015), however, Blake *et al.* (1986) reported no difference in energy efficiency between Holstein and Jersey cows.

2.4.3 Nitrogen use efficiency (NUE)

Protein is one of the most expensive nutrients in animal diets. The low efficiency of nitrogen utilisation by ruminants compared to non-ruminants such as pigs and poultry (Calsamiglia *et al.*, 2010; Rius *et al.*, 2010) makes conditions more challenging. Nitrogen use efficiency is estimated to range between 13 and 45% (Baldwin, 1984; Haynes & Williams, 1993; Castillo *et al.*, 2000; Chase, 2004; Kohn *et al.*, 2005; Huhtanen & Hristov, 2009; Loor & Cohick, 2009; Calsamiglia *et al.*, 2010; Chase *et al.,* 2012; Giallongo *et al.*, 2016). The NUE range for grazing animals varies from 13% to 31% while that of animals receiving a total mixed ration under an intensive system may vary from 40% to 45% (Delagarde *et al.*, 1997; Vérité & Delaby, 2000; Keim & Anrique, 2011).

Feeding high levels of protein in diets, especially rumen degradable protein could result in large quantities of nitrogen being excreted to the environment, thus contributing to both wastage and pollution (VandeHaar & St-Pierre, 2006). This is because ammonia that is not utilised by rumen microbes is absorbed from the rumen by the liver, where it is converted to urea and excreted with urine via the kidneys (Harmeyer & Martens, 1990). Kauffman & St-Pierre (2001); Colmenero & Broderick (2006); Lee *et al.* (2011) and Mutsvangwa *et al.,* (2016) observed higher urinary output in cows fed high CP diets. According to Colmenero & Broderick (2006), the increased urinary output was required for excreting the excess nitrogen consumed. Urine and manure are the largest sources of ammonia (NH_3) emission (Braam *et al.*, 1997), a major air and water pollutant with harmful effects to the environment (Fenn *et al.*, 2003). Soil acidification and eutrophication of aquatic systems (Saggar *et al.*, 2004; Wang *et al.*, 2015), acid rain and nitrates found in drinking water are all related to NH_3 emissions (Steinfeld *et al.*, 2006). Although not a GHG, NH_3 contributes indirectly to nitrous oxide (N_2O) emissions (Fenn *et al.*, 2003; Steinfeld *et al.*, 2006), a GHG that has a global warming potential about 300 times that of CO_2 on a 100-year timescale (Griffis *et al.*, 2017). With excreting excess N in urine, there is a metabolic energy cost of 7.3 kcal (30.5 kJ) metabolisable energy for every gram of ammonia that is converted to urea in the liver (Tyrrell *et al.,* 1970; Ishler, 2016). This is the energy that could have been used to produce milk. Improving NUE results in higher conversion of feed nitrogen and energy into animal products (Powell *et al.*, 2010).

Research on improving NUE has mostly been on nutritional factors and diet manipulation to optimise rumen microbial fermentation and N flow to the small intestine (Marini & Van Amburgh, 2003; Reynal & Broderick, 2005; Colmenero & Broderick, 2006; Phuong *et al.*, 2013; Giallongo *et al.*, 2016) as rumen metabolism has been identified as the most important factor contributing to the NUE in ruminants (Tamminga, 1992; Calsamiglia *et al.*, 2010). According to Phuong *et al*. (2013), there are insufficient studies where detailed energy and nitrogen use of Holstein and Jersey cows have been compared. A study presenting a complete NUE of the two breeds is required to provide information on the comparative performance in the partitioning of total N intake as N output in milk, urine and faeces, pregnancy, and retained or mobilised N in Holstein and Jersey cows under similar environmental and management conditions.

Several authors reported no difference between Holstein and Jersey cows in milk nitrogen (MN) secreted as the proportion of NI (Blake *et al.*, 1986; Kauffman & St-Pierre, 2001; Knowlton *et al.*, 2010; Kristensen *et al.*, 2015).

2.4.4 Enteric gases emission efficiency

The rumen is inhabited by anaerobic microbes which digest the ingested crop residues and animal wastes through the process called enteric fermentation. Generated as natural by-products of enteric fermentation are carbon dioxide (CO_2) and methane (CH_4) (Hook *et al.*, 2010; Hristov *et al.*, 2014). Methanogens, the anaerobic bacteria responsible for methanogenesis, use hydrogen (H_2) and CO_2 produced from fermented feed to produce CH_4 (Hook *et al.*, 2010). Accumulation of H_2 has to be prevented as it reduces the rate of microbial growth, resulting in inhibition of ruminal fermentation, reduced carbohydrate and fibre degradation, and reduced microbial protein synthesis (Wolin, 1974; McAllister & Newbold, 2008; Knapp *et al.*, 2014).

Although methanogenesis is an essential process, the production of methane constitutes energetic inefficiency. Depending on feed composition and quality, methanogenesis represents a loss of about 2 to12 % of dietary gross energy consumed by the host animal (Johnson & Ward, 1996; Van Kessel & Russell, 1996; Hook *et al.*, 2010; Unger *et al.*, 2010; Medjekal *et al.*, 2018), with energy loss being approximately 6% in high producing lactating animals (Qiao *et al.*, 2014).

Enteric gases also contribute to GHG concentrations in the atmosphere that are linked to global climate change (Broucek, 2014). Agriculture is, however, not considered as an important global source of CO_2 (Dong *et al.,* 2006). It is viewed as part of a continuous biological cycle of fixation, utilisation, and exhalation (Dong *et al.,* 2006; Knapp *et al.,* 2014), resulting in the amount of CO_2 produced by ruminant animals being completely offset by uptake by natural carbon sinks (Steinfield *et al.,* 2006). Chianese *et al.* (2009), however, suggested the inclusion of CO_2 emissions when balancing for carbon flows in the farm to ensure that all sources of carbon emission are accounted for. There is still, however, very few studies where CO_2 emissions are estimated. Methane, on the other hand, has a global warming potential 25 times that of CO_2 (Broucek, 2014). Enteric CH_4 represents the greatest direct GHG released from the livestock sector (Caro *et al.*, 2016), accounting for about 32 – 40% (2.1 Gt CO_2 Eq/year) of agricultural CH_4 (Smith *et al.*, 2014). About 75% of enteric CH_4 is coming from cattle (Smith *et al.,* 2014). According to Moeletsi *et al.* (2017) dairy cattle contributed about 7% to the total annual CH_4 emissions in South Africa.

Alternative ways to reduce enteric CH_4 production through, e.g., dietary manipulation to redirect H_2 flow towards alternative electron acceptors such as propionate (Mirzaei-Aghsaghali & Maheri-Sis, 2011; Wang *et al.*, 2017) are energetically less favourable than the reduction of CO_2 to CH_4 by rumen microbes. Through a variety of adaptive mechanisms, the microbial ecology of the rumen system inherently reverts back to initial levels of CH_4 production (McAllister & Newbold, 2008). Non-suppression of CH_4 production associated with the development of resistance of methanogens to prolonged or repeated use of antibiotic or feed additives such as ionophores has also been reported (Mbanzamihigo *et al.*, 1996; Sauer *et al.*, 1998). The benefit of using feed additives is that even though enteric CH_4 may not be reduced, feed additives have improved animal performance in both dairy and beef cattle (McDougall *et al.*, 2004; Jouany & Morgavi, 2007), resulting in reduced enteric CH_4 when scaled as emissions per unit of product produced (Hristov *et al.*, 2014).

The Intergovernmental Panel on Climate Change (IPCC, 2006) is also encouraging the development of country-specific methane emission factors (kg CH_4/head/year) for different animal categories to enable close estimation of the country's emissions. According to Mangino *et al.* (2003), estimating emissions by sub-categories will bring better accuracy as herd population varies throughout the year. Overlooking the effects of the production stages assumes that individual animal characteristics remain constant throughout a given year (Mangino *et al.*, 2003). No literature could be found on the effect of production stages on enteric gas emissions. A study to determine the effect of production stage on enteric gas emissions is required. The results can form the basis for the development of dairy cow emission factors by lactation stage and parity that can be applied for regional and national inventories for South African dairy breeds.

Studies on breed comparison on enteric CH_4 emissions efficiency are conflicting on whether breed differences do exist. Capper & Cady (2012) reported a 20.5% reduction in carbon footprint when Jerseys were used to produce cheese compared to Holsteins despite the increase in the number of cows needed to produce the same volume of milk. Dalla Riva *et al.* (2014), reported greater CO_2 equivalent emissions with ECM production in Holstein compared to Jersey cows, and Kristensen *et al.* (2015), found that Jerseys produced less CH_4/kg ECM compared to Holsteins. In contrast, Olijhoek *et al.* (2018) reported no breed effect in CH_4/kg ECM. This therefore means that repeated studies need to be carried out for more accurate assessment.

On CO_2 emissions, no studies could be found on comparing the two breeds. In studies conducted on Holsteins using the Integrated Farm System Model (Chianese *et al.*, 2009), SF_6 tracer gas technique (Pinares-Patiño *et al.*, 2007; Aguerre *et al.*, 2011) and infrared gas analyser (Kinsman *et al.*, 1995), the CO_2 emitted by cows per day ranged between 8.5 and 18.7 kg.

2.5 Conclusion

The differences in milk yield parameters and efficiency of energy use, nitrogen use and enteric gas emissions in Holstein and Jersey cows were discussed. The literature reviewed indicated that Holsteins and Jerseys differ in production efficiency, although conflicting results were found regarding superiority of one breed. Many studies that were conducted were short term studies. Very few studies compared the efficiency of Holstein and Jersey cows on MF and Mprot production as individual components, the two components often being presented as total solids. The lack of information where detailed energy and nitrogen use efficiency of Holstein and Jersey cows have been compared was highlighted by some authors. Regarding enteric gas emissions, no study could be found on comparing CO_2 emissions of Holstein and Jersey cows. The suggestion by Chianese *et al.* (2009) on the inclusion of CO_2 emissions when balancing for carbon flows in the farm to ensure that all sources of carbon emission are accounted for needs to be explored. Studies on breed comparison on enteric CH_4 emission efficiency are conflicting on whether breed differences exist. Mangino *et al.* (2003) also expressed a need to consider the effect of production stages on enteric gas emissions as individual animal characteristics do not remain constant throughout a given year, there was also no study that could be found on comparing the effect of production stages on CH_4 production. This thesis will therefore focus on answering the gaps that have been identified in this literature review.

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Chapter 3

Factors affecting milk production parameters of Holstein and Jersey cows in a kikuyu pasture-based production system

3.1 Abstract

The aim of this study was to determine the effect of lactation stage, parity, calving season (CS), age at first calving (AFC) and inter-calving period (ICP) in milk production parameters of Holstein and Jersey cows maintained under similar management and environmental conditions for a 9-year period. Data were test-date lactation records of 122 Holstein and 99 Jersey cows varying from parity 1 to 6. Records were collected using standard milk recording procedures, i.e. 10 recording dates per year. This resulted in a total of 4576 test-date records, 2315 for Holsteins and 2261 for Jerseys. Cows were kept as one herd on kikuyu pasture and received on an as-fed basis 7 kg of concentrate containing 17% crude protein (CP) per day. The total dry matter intake (DMI) was estimated using the National Research Council method and pasture intake as the difference between DMI and concentrate DMI. The mean DMI was 17.8±2.6 vs. 14.4±2.1 kg/day, mature body weight 612±43 vs. 441±35 kg, milk yield (MY) 23.8±6.2 vs.17.9±4.4 kg/day containing 3.89±0.03 vs. 4.66±0.03% fat (MF) and 3.17±0.02 vs. 3.59±0.02% protein (Mprot) in Holstein and Jersey cows, respectively. Milk yield increase from primiparous to 4+ cows was 26.5% in Holsteins and 23.7% in Jerseys. Holsteins reached the peak daily MY between 31 and 65 days in milk (DIM) while transition and early lactation stage MY did not differ in Jerseys. Mean lactation number was lower in Holsteins than Jerseys, 2.5±0.15 vs. 3.0±0.17 lactations. Calving season had no effect on mean MY but cows calving down in summer had a lower peak MY resulting in higher persistency towards the end of the lactation period. The AFC also did not differ between breeds and it also did not affect the 305-day milk yield. Holsteins had a longer ICP than Jerseys, 13.9±0.18 vs 13.2±0.17 months and in both breeds, cows with the ICP below 13 months tended to produce on average less 305-day MY. These results indicate that lactation stage and parity are the major causes of variation in milk production performance, indicating the need for strategic feeding and longer productive life of dairy cows.

Keywords: lactation stage, parity, calving season, age at first calving, inter-calving period, similar environment, management practices, total dry matter intake

3.2 Introduction

Approximately 90% of income in a dairy farm is derived from milk sales, making milk production a major factor that drives dairy farm profitability (Muller & Botha 1998; Anonymous, 2017). The aim of a dairy farmer is therefore to produce large amount of milk that is of the highest quality at the least possible cost (Anonymous, 2017). Milk production depends on diet, environmental factors and genetic ability of the cow to utilise these inputs to produce milk (Blake & Custodio, 1984), i.e., the milk production potential of the cow is controlled by its genotype but the genetic expression is highly influenced by environmental factors the animal is subjected to (Kiplagat *et al.,* 2012).

Environmental factors include feeding system, age at first calving, lactation number, lactation stage, calving season, inter-calving period, days open (Bajwa *et al.,* 2004; Kunaka & Makuza, 2005; Pirzada, 2011; Nyamushamba *et al.,* 2014; Al-Samarai *et al.,* 2015), and prevention and control of health disorders (Fox & McSweeney, 1998; Cao *et al.,* 2010; Yang *et al.,* 2013). These factors have substantial effects on milk production traits, contributing approximately 70% in dairy cow productivity (Campbell & Marshall, 2016). Environmental factors are mostly management related and can be improved by adoption of good management practices.

The genetic effects are commonly referred to as intrinsic factors as they depend directly on the animal (Jimenez-Granado *et al.,* 2014). They include breed, feed intake, metabolism and its regulation, and functions of specific organs with emphasis on the mammary gland (Kronfeld, 1994). Because milk production is a factor of genotype-environment interactions (Kiplagat *et al.,* 2012), there is a need for environmental factors to be considered when comparing milk production of Holstein and Jersey cows. Very few studies compared the effect of environmental factors in Holstein and Jersey cows maintained under similar management and environment conditions over a long period of time. The aim of this study was therefore to investigate the trends and effects of these factors on milk production performance of Holstein and Jersey cows maintained under the same environmental conditions and management practices for a 9-year period.

The objectives were to determine:

- The effects of parity and stage of lactation on milk production parameters of Holsteins and Jersey cows in a kikuyu pasture-based system.

- Effects of calving season, age at first calving and calving interval on the production performance of Holsteins and Jersey cows in a kikuyu pasture-based system.

3.3 Materials and methods

3.3.1 Experimental area

The study was conducted at the Elsenburg Research Station, Western Cape Department of Agriculture in South Africa. The climate is typically Mediterranean with moist, cool winters and hot, dry summers. According to the monthly weather reports collected over the experimental period (January 2004 to December 2014) obtained from the Agricultural Research Council, the average rainfall at Elsenburg was 625 mm per annum. The highest precipitation was in May to August, ranging from an average of 85 to 115 mm per month and lowest was in December to March, between 13 and 19 mm per month (Figure 3.1). The average minimum temperatures were 7° C and 14° C, maximum temperatures 18° C and 30° C, and relative humidity 75% and 64% for winter and summer, respectively.

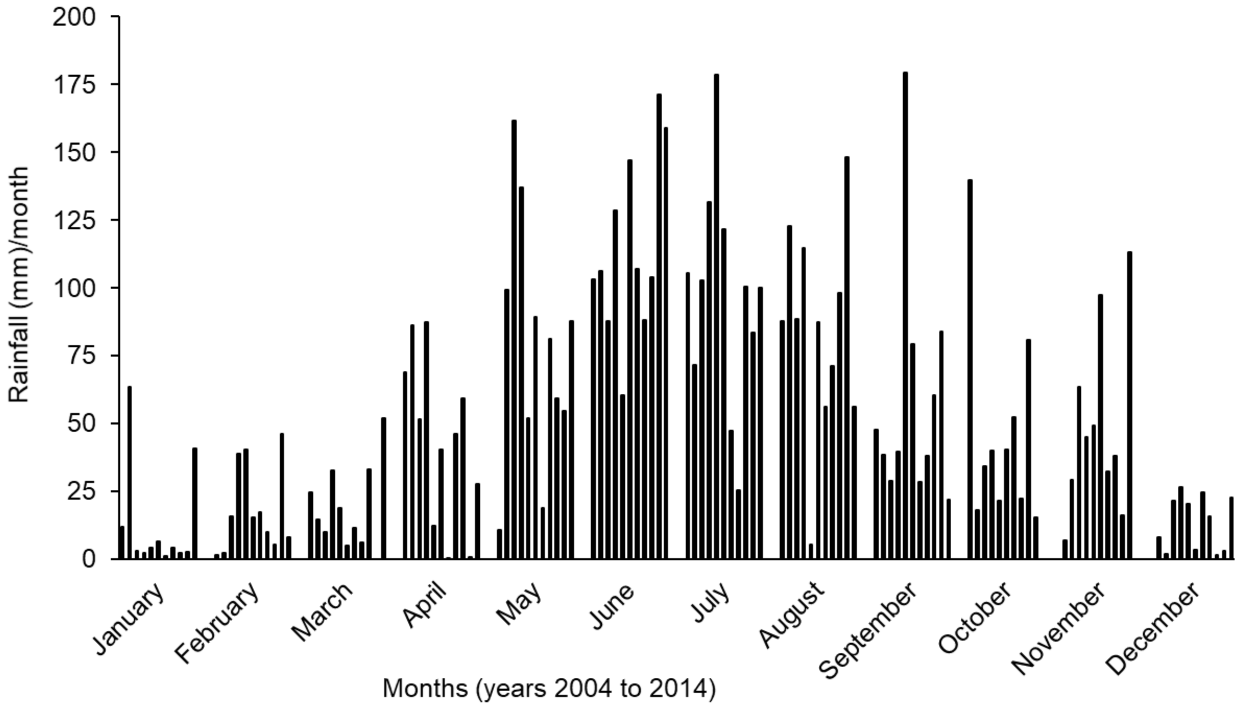


Figure 3.1 Monthly rainfall at Elsenburg from 2004 to 2014

3.3.2 Experimental animals

Data were lactation records of 122 Holstein and 99 Jersey cows, recorded from October 2005 to September 2014. Records collected included cow birth date, calving date, lactation number, BW, kg MY, %MF and %Mprot. Cows were kept as one herd under the same environmental conditions and management practices throughout the experimental period. After calving, cows were transferred to a fresh cow group for 10 days where they were assessed daily and treated when required for health and possible post-partum disorders such as retained placenta. Calving was year-round with a voluntary waiting period of about 60 days before first insemination. Heat detectors were put on cows following inspection of heat cycling by a veterinarian. Cows were inseminated 12 hours following first heat detection, i.e. according to the am-pm and pm-am rule. Cows observed in the morning was inseminated in late afternoon after milking and cows observed in the afternoon was inseminated the following morning after milking. Cows from both breeds were inseminated using imported semen from the United States of America. Bull selection for individual cows was based on commercial mating programme conducted by the AI company.

3.3.3 Milking and weighing of the cows

Cows were machine-milked twice a day. Milk recording procedures were according to the standard of the National Milk Recording Scheme, i.e. 10 recording dates per year. Milk yield per day was the sum of the morning and afternoon milking. Total lactation MY was adjusted to 305-days yield using the Test Interval Method (Sargent, 1968; ICAR, 2017) as follows:

$$MY = (I_0M_1 + I_1) \times ((M_1 + M_2)/2) + I_2 \times ((M_2 + M_3)/2) + I_n\text{-}1 \times ((M_n\text{-}1 + M_n)/2) + I_nM_n \text{.......eq 1}$$

Where: M_1, M_2, M_n = kg milk yield in the 24 hours of the recording day

I_1, I_2, I_{n-1} = intervals between recording dates in days

I_0 = interval between the lactation start date and the first recording date in days

I_n = interval between the last recording date and the end of the lactation period in days

Milk samples were collected for %MF and %Mprot analysis from each cow during the morning and afternoon milking on milk recording test-dates. The morning and afternoon milk samples for each cow were combined and analysed for %MF and %Mprot content using a Milko-Scan FT6000 (Foss, Hillerød Denmark). Weighing of the cows was also done in the morning of the milk test-dates using a calibrated electronic scale.

3.3.4 Lactation number (parity)

Lactation number varied from 1 to 7. As the 7th lactation observations were from only four cows, they were added to the 6th lactation observations and considered as lactation 6 so as to still include the full observations for that cow in the data. For each lactation period, BW, kg MY, %MF and %Mprot were recorded on milk recording test-dates. Data from cows with < 6 test-date records per lactation were removed and therefore excluded for further analyses. This resulted in a total of 4576 test-date records, that is, 2315 for Holstein cows and 2261 for Jersey cows.

3.3.5 Lactation stage

To determine the change in performance trends over a lactation period, lactation was divided into four stages by creating class intervals from the days in milk (DIM) as follows:

- Calving to 30 days: post-calving transition (“transition”),
- 31 to 100 days: early lactation stage,
- 101 to 200 days: mid-lactation stage, and
- More than 201 days: late lactation stage.

3.3.6 Calving season (CS) and age at first calving (AFC)

Calving was divided into two seasons, summer (October – March) and winter (April – September) and the lactation records were classified according to the two seasons so as to determine the effect of the calving season (CS) on milk production.

The AFC was calculated as the number of months from the date of birth of the cow to her first calving date. The AFC was divided into intervals to determine its effect on the subsequent 305-days milk yields. The intervals were as follows:

- < 23.0 months of age
- 23.1 – 25.0 months of age
- 25.1 – 29.0 months, and
- > 29.0 months

3.3.7 Inter-calving period (ICP)

Calving interval refers to the number of days between subsequent calving dates starting for each cow from lactation one. It combines the days open interval (calving date to conception date) and the gestation period of approximately 275-282 days. The ICP preceding the lactation was used to determine the effect of the length of the ICP on milk production in the subsequent lactation. The ICP ranges were created as follows:

- < 13.0 months,
- 13.1 - 15.0 months and
- > 15.0 months as prolonged inter-calving.

3.3.8 Diet

Cows were kept in a 45 hectares kikuyu pasture that was divided into camps throughout the experimental period. Cows grazed as one herd in one camp and were moved to the next when forage was insufficient so as to allow the camp to rest and recover before being grazed again. Pasture samples were collected monthly from 2011 to 2014 and proximate analysis conducted. Pasture analysis results were divided into summer and winter (Table 3.1) and the average results were used to estimate the nutrient intake of the cows in each season.

Lactating cows were also supplemented with a 7 kg commercial concentrate mixture containing 17% CP as fed (Table 3.2 & 3.3). The concentrate was split into two equal portions and offered to individual cows after each milking. Upon drying-off, cows were put on kikuyu pasture receiving no supplements. Three weeks before the expected calving date, a steam-up feeding programme for dry cows was started. Feeding consisted of *ad libitum* oats hay supplemented with a dry-cow concentrate mixture containing anionic salts to prevent the possibility of milk fever at calving. Cows were brought to the milking parlour once a day to be weighed and for concentrate feeding. Pregnant heifers were included in this group to familiarize them with the milking parlour environment. Concentrates were fed according to a step-up feeding system in which dry cows received one kg/day for the first week, two kg the second week and three kg the third week. After calving, the concentrate supplement was increased to 7 kg per cow per day.

As cows grazed as one herd, measuring individual cow / breed pasture intake was not done. The total dry matter intake (DMI) was therefore estimated using the National Research Council (NRC, 2001) formula. Although the DMI formula used was developed for Holstein cows (NRC, 2001), it was also used to estimate the DMI of Jersey cows in this study. This is because the NRC (2001) formula uses predictor variables that influence feed intake which apply to both breeds, e.g., body weight, lactation stage, and milk production that is corrected to account for the difference in milk composition between breeds. Pasture intake was estimated as the difference between DMI and concentrate DMI. Below is the NRC (2001) DMI equation for lactating dairy cows:

DMI (kg/day) = $((0.372\times4\%\ \text{FCM}) + (0.0968\times\text{BW}^{0.75})) \times (1-e^{(-0.192 \times (\text{WOL} + 3.67)})$……….eq 2

Where: FCM = 4% fat corrected milk (kg/day)

BW = body weight (kg)

WOL = week of lactation

$1\text{-}e^{(-0.192(\text{WOL}+3.67)}$ = adjustment for depressed DMI during early lactation.

The 4% FCM was calculated as: (15×kg MF) + (0.4×MY) (Gaines, 1928)……………......eq 3

Where: MY = milk yield (kg) and MF = milk fat (kg).

3.3.9 Statistical analysis

Statistical analyses were performed using the repeated measures techniques of the PROC MIXED procedure in the Statistical Analyses System (SAS) Software packages of SAS Enterprise Guide version 7.1. Cows functioned as experimental units where the response variables (body weight and milk production traits) were measured at fixed test-dates in each parity. To account for individual variation in experimental units, cow within breed was fitted as a random effect. The fixed effects were breed, lactation stage and parity, their interaction effects were breed × lactation stage, breed × parity, and breed × parity × test-date. The least squares means of the interaction effects of breed × parity × test-date for kg milk/day, kg BW and kg DMI/day obtained from different test-dates were regressed against parity and fitted in a curve to determine how these parameters respond to the predictor variables in each breed. A compound symmetry structure for the residuals was used as covariance structure for repeated measures over time within cows. In both breeds, DMI and milk production did not differ in parities 4, 5 and 6. The cows in these parities were then added together to make a group of mature cows (4+) in further statistical analysis for all measured traits. The equation used for statistical analysis for the effect of production stages was as follows:

$Y_{ijklm} = \mu + B_i + P_j + LS_k + TD_l + (B\times P)_{ij} + (B\times LS)_{ik} + (B\times P\times TD)_{ijl} + cow_m(B_i) + \varepsilon_{ijklm}$

Where:

Y_{ijklm} = dependent / response variable (milk production traits);
μ = overall mean;
B_i = fixed effect of the i^{th} breed (i =Holstein, Jersey);
P_j = fixed effect of the j^{th} parity (j = 1, 2, 3 and 4);
LS_k = fixed effect of the k^{th} lactation stage (k = transition, early lactation, mid-lactation and late lactation);
TD_l = fixed effect of the l^{th} test-date (l = 1 to 9);
$(B{\times}P)_{ij}$ = fixed interaction effect between breed and parity;
$(B{\times}LS)_{ik}$ = fixed interaction effect between breed and lactation stage;
$(B{\times}P{\times}TD)_{ijl}$ = fixed interaction effect between breed, parity and test-date;
$cow_m(B_i)$ = random effect of the m^{th} cow (m = 1 to 221) nested within the i^{th} breed $N \sim (0, \sigma^2_{cow(B)})$;
ε_{ijklm} = random error term $N \sim (0, \sigma^2_{\varepsilon})$.

The effects of calving season, AFC and ICP in milk production were also analysed to determine breed differences, production trends and to account for variations thereof. Their interaction effects were: breed × calving season, breed × calving season × lactation stage, breed × AFC, breed × AFC × parity, breed × ICP and breed × ICP × parity.

The equation used for statistical analysis for the effect of CS, AFC and ICP was as follows:

$Y_{ijklmno} = \mu + B_i + P_j + LS_k + CS_l + AFC_m + ICP_n + (B{\times}CS)_{il} + (B{\times}AFC)_{im} + (B{\times}ICP)_{in} + (B{\times}CS{\times}LS)_{ikl} + (B{\times}AFC{\times}P)_{ijm} + cow_o(B_i) + \varepsilon_{ijklmno}$

Where:

$Y_{ijklmno}$ = dependent variable (milk production);
μ = overall mean;
B_i = fixed effect of the i^{th} breed (i =Holstein, Jersey);
P_j =fixed effect of the j^{th} parity
LS_k =fixed effect of the k^{th} lactation stage
CS_l = fixed effect of the l^{th} calving season (l = winter and summer);
AFC_m = fixed effect of the m^{th} age at first calving (m = 1, 2, and 3);
ICP_n = fixed effect of the n^{th} inter-calving period (n = 1, 2 and 3);
$(B{\times}CS)_{il}$ = fixed interaction effect between breed and calving season;
$(B{\times}AFC)_{im}$ = fixed interaction effect between breed and age at first calving;
$(B{\times}ICP)_{in}$ = fixed interaction effect between breed and inter-calving period;

$(B \times CS \times LS)_{ikl}$ = fixed interaction effect between breed, calving season and lactation stage;

$(B \times AFC \times P)_{ijm}$ = fixed interaction effect between breed, age at first calving and parity;

$(B \times ICP \times P)_{ijn}$ = fixed interaction effect between breed, age at first calving and parity;

$cow_o(B_i)$ = random effect of the o^{th} cow (l = 1 to 221) nested within the i^{th} breed $N \sim (0, \sigma^2_{cow(B)})$;

$\varepsilon_{ijklmno}$ = random error term $N \sim (0, \sigma^2_{\varepsilon})$.

The between-breeds, between parity, lactation stage, calving season, AFC and ICP variations and their interactions were compared using the Bonferroni test and were declared different at P <0.05.

3.4 Results and discussion

Table 3.1 contains average nutrient composition of the Elsenburg pasture in summer and winter, 3.2 the ingredients and their inclusion levels in the concentrate mixture and 3.3 the nutrient composition of the concentrate mixture offered to lactating cows during the experimental period.

Table 3.1 Nutrient composition of the Elsenburg kikuyu pasture in different seasons

Average/month	DM	CP (%)	Fat (%)	NDF (%)	Ca	P	Ash (%)
October	22.2	16.8	3.3	53.8	0.5	0.4	9.5
November	21.9	18.4	3.2	54.4	0.5	0.4	9.5
December	21.9	18.3	3.2	55.4	0.5	0.4	10.0
January	21.5	18.0	3.1	55.9	0.5	0.5	10.4
February	21.9	17.5	2.9	55.4	0.4	0.4	10.6
March	21.4	17.8	3.1	53.7	0.4	0.5	9.6
Summer Average	**21.8**	**17.8**	**3.1**	**54.8**	**0.5**	**0.4**	**9.9**
April	21.2	19.2	3.4	53.8	0.4	0.5	9.8
May	20.7	18.3	3.1	53.1	0.4	0.4	10.7
June	19.4	19.7	3.3	53.0	0.5	0.4	11.2
July	18.4	20.7	3.6	53.0	0.5	0.6	11.5
August	19.8	18.7	3.4	53.5	0.4	0.5	10.8
September	20.8	17.0	3.3	54.2	0.5	0.4	10.3
Winter Average	**20.0**	**18.9**	**3.4**	**53.4**	**0.4**	**0.5**	**10.7**

DM: Dry matter intake, **CP:** Crude protein, **NDF:** Neutral detergent fibre, **Ca:** Calcium, **P:** Phosphorus

Table 3.2 Feed ingredients and inclusion quantities in the offered concentrate mixture

Ingredients	[1]DM	[1]CP	Inclusion	DM/ton	As fed	DM basis
	%	%	%	kg	kg	kg
Wheaten bran	88.3	17.8	10	88.3	0.70	0.62
Barley	89.7	11.3	10	89.7	0.70	0.63
Wheat	88.3	15.8	10	88.3	0.70	0.62
Maize	87.6	8.6	42	368.	2.94	2.58
COM	92.0	42.3	10	92.0	0.70	0.64
SOM	89.8	55.1	7.5	67.3	0.53	0.47
Fishmeal	90.0	72.0	1	9.0	0.07	0.06
Urea	99.0	281	0.6	5.9	0.04	0.04
Molasses 52%	75.5	4.1	4	30.2	0.28	0.21
Wheat Straw	92.0	4.8	3	27.6	0.21	0.19
Limestone	98.0	0.0	1	9.8	0.07	0.07
Salt	99.5	0.0	1	10.0	0.07	0.07
Total			**100**	**886.1**	**7.01**	**6.20**

DM: dry matter, **CP:** crude protein, **COM:** cotton oilcake meal, **SOM:** Soybean oilcake meal

[1]Formulated using the feed formulation package of the NDS Professional (2008 to 2018)

Table 3.3 Nutrient composition of the concentrate offered to lactating cows

Nutrient	**Units**	**As fed**	**Dry matter**
Dry matter	%	100	88.5
Crude protein	%	17.1	19.2
Rumen degradable protein[1]	%	53.1	60
Rumen undegradable protein[1]	%	35.4	40
Total carbohydrate[1]	%	64.0	72.3
Starch[1]	%	37.8	42.7
Physical effective neutral detergent fibre[1]	%	6.89	7.79
Acid detergent fibre[1]	%	7.42	8.38
Gross energy[1]	MJ/kg	16.2	18.3
Digestible energy[1]	MJ/kg	13.5	15.3
Metabolisable energy[1]	MJ/kg	10.8	12.2
Net energy[1]	MJ/kg	6.89	7.78
Total digestible nutrients[1]	%	70.7	79.8

[1]Formulated using the feed formulation package of the NDS Professional (2008 to 2018)

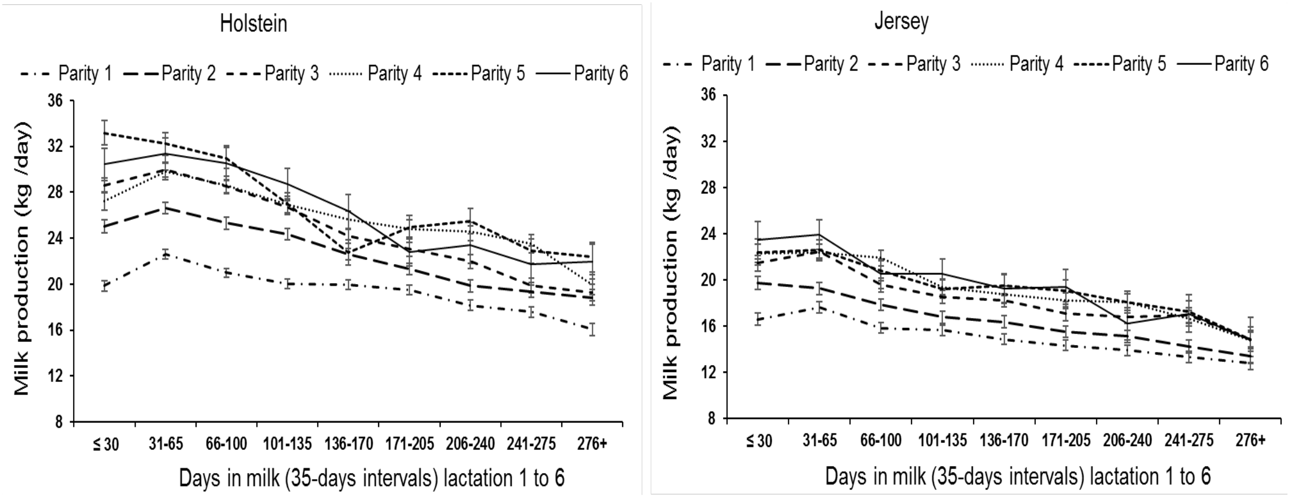
3.4.1 Milk yield and composition

3.4.1.1 Effect of parity and lactation stage

The overall test-dates means for kg MY, %MF and %Mprot of Holsteins was 23.8±0.22 kg, 3.89±0.03% and 3.17±0.02%, for Jerseys was 17.9±0.24 kg, 4.66±0.03% and 3.59±0.02%, respectively. When adjusted to a 305-days yield, Holsteins produced on average 7217±64.2 kg and Jerseys 5349±70.1 kg/cow/lactation, indicating that Jerseys produced on average 74.1% milk that of Holsteins. A comparable ratio (73%) was observed with the South African commercial herds (Logiχ Milk Annual Report, 2015 – 2016) where Holstein and Jersey cows were reported to produce 7937 kg and 5791 kg of milk/cow/lactation, respectively. The %MF and %Mprot contents of Holsteins were lower than that of Jerseys but when expressed as kg produced per day, Holsteins produced more MF (0.92±0.01 vs. 0.83±0.01 kg/day) and Mprot (0.75±0.01 vs. 0.64± kg/day), that is, 10% kg MF and 15% kg Mprot per day more than that of Jerseys.

The mean lactation number of Holsteins was lower than that of Jerseys (P=0.04), 2.5±0.15 and 3.0±0.17 lactations. These lactation numbers are comparable to those reported for the national herd of registered cows in South Africa, 2.4 for Holstein and 3.0 lactations for Jersey cows, but lower than the commercial herds, 2.7 for Holstein and 3.2 lactations for Jersey cows (Logiχ Milk Annual Report, 2015 – 2016).

In both breeds, milk production increased with parity, but parity had no effect from parity 4 to 6 (Figure 3.2). The increase in MY can be attributed to the increase in development and size of the udder of multiparous cows over that of the primiparous ones. Several studies (Bajwa *et al.*, 2004; Amimo *et al.*, 2007; Jingar *et al.*, 2014; Nyamushamba *et al.*, 2014) reported an increase in MY with parity, reaching peak at fourth or fifth lactation, followed by a decline thereafter. In South African dairy herds, Meissner (2015) observed a declining trend from the fourth lactation in Holsteins while Jersey cows peaked at the fourth lactation followed by a slow downward trend. With Holstein cows, Vijayakumar *et al.* (2017) also reported the highest MY in third lactation followed by a decline in fourth lactation. In both breeds, the decline is associated with degeneration of the body systems over the recurring pregnancies (Nyamushamba *et al.*, 2014). The absence of a declining trend in milk production in the fifth and sixth parities in this study can be associated with a decrease in the number of observations as parities progressed. Combined observations of parity 5 and 6 were 8.7% for Holstein and for Jerseys 10.7% of the total observations. The large standard error of means observed in parities 5 and 6 may be an indication that the sample size was small and therefore not representative of the true mean (Figure 3.2).



(a) **(b)**

Figure 3.2 Least squares means (±SE) of milk production of (a) Holstein and (b) Jersey cows as affected by parity and days in milk

The increase in MY in mature cows reached levels 26.5 and 23.7% higher than in first lactation for Holsteins and Jerseys, respectively. Comparable findings (25.2%) were reported by Jingar *et al.* (2014) in Holsteins but only on initial milk yield after calving, 11.8 kg for primiparous and 15.77 kg for combined parity 4 and above. This indicates that the ability of the cow to stay in the milking herd for a minimum of at least four lactations without being involuntarily culled can be an important aspect of production efficiency (De Vries, 2006; Sawa *et al.*, 2013) as the cow will give birth to more calves and also produce more milk during her lifetime.

In Holsteins, MY increased from transition and reached the peak in early lactation stage between day 31 and 65, followed by a decrease in subsequent stages (Figure 3.2). With Jerseys, transition and early lactation stage MY did not differ (Table 3.4), suggesting that Jersey cows reached peak MY in the first four weeks post-calving. According to the National Research Council (1989), milk production usually peaks 4 to 8 weeks post-calving. In mid to late lactation, partitioning of nutrients moves away from milk production so that body reserves are replenished for next calving (Garnsworthy, 1988).

In both breeds, %MF increased up to the second lactation, followed by a decline from third lactation. The %Mprot increased up to third parity in Jerseys and remained constant thereafter. In Holsteins, %Mprot did not differ in the first and second parity cows, it decreased in third parity levelling with that of mature cows. With the increase in MY with parity, a decrease in %MF and %Mprot was expected as MY and the percentage solid components are negatively correlated (Linn, 1988; Kunaka & Makuza, 2005; Sneddon *et al.,* 2015; Campbell & Marshall, 2016; Anonymous, 2017). The increase in MY, however, compensated for the decrease in % components, resulting in more kg MF and kg Mprot yield with advancing parity.

The lowest %MF and %Mprot produced was in early lactation stage, coinciding with the peak milk yield. With the decrease in MY, both traits increased from mid-lactation and reached the highest level in late lactation stage. Although the MY of Holsteins was slightly lower and that of Jerseys slightly higher during transition compared to that of early lactation, %MF and %Mprot were higher in transition period compared to early lactation stage. The higher %MF during the transition period is suggestive of the mobilisation of lipids in response to the high energy requirements of the fresh cow. Lipid mobilisation results in an increase in the concentration of non-esterified fatty acids (NEFA) in the blood stream. The NEFA may be utilised by peripheral tissues as a source of energy and by the mammary gland for MF synthesis (Block, 2010). The higher %Mprot can be attributed to colostrum that may still be present in the transition milk (Tsioulpas *et al.,* 2007). The result is therefore higher percentage of milk components in transition period, followed by a decline during the first two months of lactation, then a slow increase as lactation progresses (Linn, 1988). Due to the decrease in MY with progressing lactation stages, kg MF/day and kg Mprot/day also decreased with lactation stage (Table 3.4).

3.4.1.2 Effect of the calving season on MY

The calving season (P = 0.94) and the interaction effect of breed × calving season (P = 0.53) did not affect the mean test-dates MY, 21.2±0.28 vs. 21.3±0.28 kg/day in Holsteins, and 16.5±0.31 vs. 16.4±0.32 kg/day in Jerseys for summer and winter, respectively. The interaction effect of breed × calving season × days in milk (lactation stage) was, however, significant (P<0.01). In both breeds, cows that calved in winter showed an increasing MY from transition to early lactation, a more pronounced peak yield in early lactation followed by a steep decline till the cows were dried off (Figure 3.3). The decrease in MY from 31-65 days in milk (DIM) to 276+ DIM was 39% in both breeds, mean 26.2±0.44 to 16.0±0.53 kg/day in Holsteins and 20.0±0.48 to 12.2±0.58 kg/day in Jerseys. Summer calving cows tended to have a flatter lactation curve, showing a less decrease in MY after the peak lactation (Figure 3.3), indicative of lactation persistency. From 31-65 to 276+ DIM, Holstein MY decreased from 24.6±0.44 to 17.8±0.51 kg/day while Jerseys decreased from 19.3±0.45 to 14.0±0.50 kg/day, a 28% MY decrease in both breeds. Because high lactation persistency is associated with less stress during peak production (Tullo *et al.,* 2014) that results in lower susceptibility to nutritional disorders and possibly higher fertility in cows (Hickson *et al.,* 2006; Mostert *et al.,* 2008), summer can therefore be seen as an ideal calving season in the Western Cape.

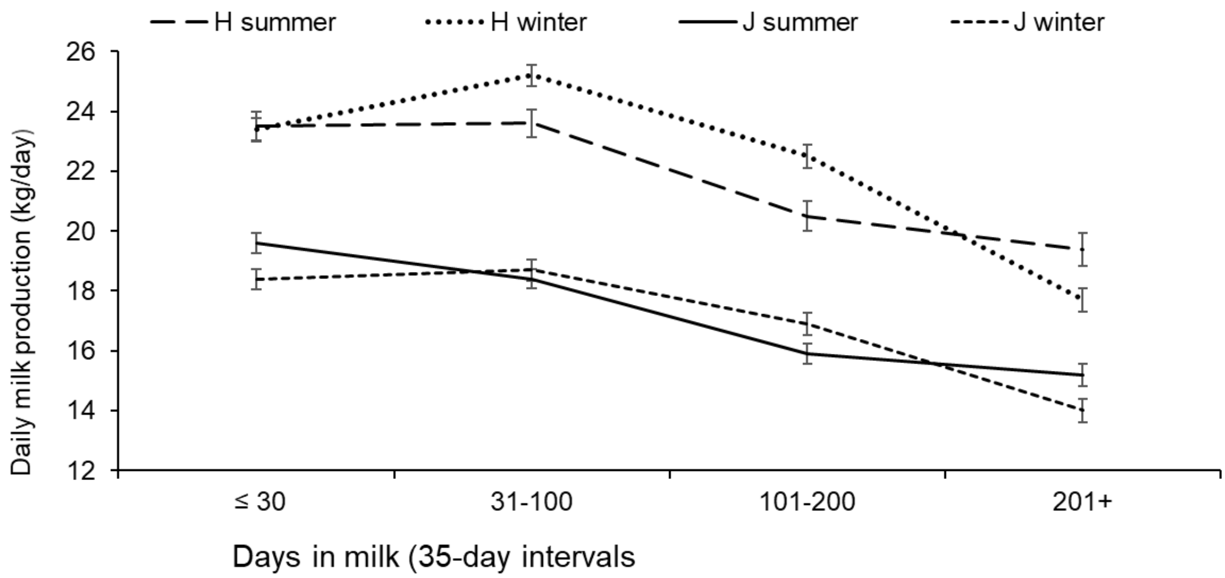


Figure 3.3 Least squares means (±SE) of daily milk production of Holstein and Jersey cows as affected by calving season and days in milk

3.4.1.3 Effect of AFC on MY

The AFC for Holstein and Jersey cows did not differ (P = 0.6) being 26.4±0.3 and 26.2±0.3 months respectively. In agreement, Beavers & Van Doormaal (2015) reported no difference in AFC of Holsteins and Jerseys, with both breeds calving for the first time at 25.8 months. Also, in South Africa, no differences were observed in AFC of registered Jersey and Holstein cows (26 months), but with commercial herds, Jerseys calved for the first time at 26 months and Holsteins at 28 months (Logiχ Milk Annual Report, 2015 – 2016). Dalla Riva *et al.* (2014) also observed an early AFC in Jerseys (26.0 months) compared to Holsteins (28.4 months).

Table 3.4 The mean (±SE) test-date production parameters and estimated daily feed intake of Holstein and Jersey cows by parity and lactation stage

	Parity										
	1		2		3		4+		P-values		Interactions
	H	J	H	J	H	J	H	J	Breed	P	B × P
No. of records	891	737	579	541	395	437	450	546			
BW (kg)	510^{d} ±4	372^{h} ±4	560^{c} ±4	404^{g} ±4	588^{b} ±4	427^{f} ±4	612^{a} ±4	441^{e} ±4	<.01	<.01	<.01
DMI (kg)	15.7^{d} ±0.1	12.9^{g} ±0.1	17.6^{c} ±0.1	14.0^{f} ±0.1	18.5^{b} ±0.1	15.1^{e} ±0.1	19.3^{a} ±0.1	15.7^{d} ±0.1	<.01	<.01	<.01
Milk (kg)	20.0^{d} ±0.2	15.7^{g} ±0.3	23.2^{c} ±0.3	17.1^{f} ±0.3	25.4^{b} ±0.3	19.1^{e} ±0.3	26.7^{a} ±0.3	19.9^{d} ±0.3	<.01	<.01	<.01
MF (%)	3.88^{e} ±0.03	4.58^{c} ±0.03	3.96^{d} ±0.03	4.71^{a} ±0.03	3.88^{e} ±0.04	4.68^{b} ±0.04	3.84^{f} ±0.04	4.67^{b} ±0.04	<.01	<.01	<.01
Mprot (%)	3.19^{d} ±0.02	3.51^{c} ±0.02	3.21^{d} ±0.02	3.59^{b} ±0.02	3.15^{e} ±0.02	3.63^{ab} ±0.02	3.14^{e} ±0.02	3.65^{a} ±0.02	<.01	<.01	<.01
MF (kg/d)	0.77^{g} ±0.01	0.71^{h} ±0.01	0.91^{d} ±0.01	0.80^{f} ±0.01	0.97^{b} ±0.01	0.89^{de} ±0.01	1.02^{a} ±0.01	0.93^{cd} ±0.01	<.01	<.01	<.01
Mprot (kg/d)	0.63^{e} ±0.01	0.55^{f} ±0.01	0.74^{c} ±0.01	0.61^{e} ±0.01	0.79^{b} ±0.01	0.69^{d} ±0.01	0.83^{a} ±0.01	0.72^{c} ±0.01	<.01	<.01	<.01
	Lactation stage (days in milk)										
	<30d		31-100		101-200		201+		P-values		Interactions
	H	J	H	J	H	J	H	J	Breed	LS	B × LS
No. of records	228	204	581	561	798	776	708	720			
BW (kg)	555^{c} ±3.8	407^{e} ±4.1	552^{c} ±3.6	399^{f} ±3.9	569^{b} ±3.54	410^{e} ±3.9	594^{a} ±3.6	429^{d} ±3.9	<.01	<.01	<.01
DMI (kg)	14.1^{f} ±0.15	11.7^{g} ±0.16	18.4^{c} ±0.12	14.8^{e} ±0.13	19.4^{a} ±0.12	15.7^{d} ±0.12	19.2^{b} ±0.12	15.5±^{d} 0.13	<.01	<.01	<.01
Milk (kg)	25.3^{b} ±0.3	19.9^{de} ±0.4	26.5^{a} ±0.3	19.5^{e} ±0.3	23.3^{c} ±0.3	17.1^{f} ±0.3	20.3^{d} ±0.3	15.3^{g} ±0.3	<.01	<.01	<.01
MF (%)	4.03^{d} ±0.04	4.57^{c} ±0.04	3.66^{f} ±0.03	4.50^{c} ±0.03	3.81^{e} ±0.03	4.70^{b} ±0.03	4.05^{d} ±0.03	4.88^{a} ±0.03	<.01	<.01	<.01
Mprot (%)	3.20^{e} ±0.02	3.51^{c} ±0.03	2.94^{f} ±0.02	3.40^{d} ±0.02	3.14^{e} ±0.02	3.64^{b} ±0.02	3.41^{d} ±0.02	3.83^{a} ±0.02	<.01	<.01	<.01
MF (kg/d)	1.01^{a} ±0.01	0.91^{c} ±0.02	0.97^{b} ±0.01	0.87^{d} ±0.01	0.88^{d} ±0.01	0.80^{a} ±0.01	0.81^{e} ±0.01	0.74^{f} ±0.01	<.01	<.01	0.39
Mprot (kg/d)	0.80^{a} ±0.01	0.70^{cd} ±0.01	0.78^{a} ±0.01	0.66^{e} ±0.01	0.73^{bc} ±0.01	0.62^{f} ±0.01	0.69^{d} ±0.01	0.58^{g} ±0.01	<.01	<.01	0.70

$^{a\text{-}h}$ Means within rows with different superscripts differ at P<0.05
BW: body weight, **DMI:** total dry matter intake, **MF:** milk fat, **Mprot:** milk protein

In both breeds, the 305-days milk yield was not affected by AFC (P = 0.47) (Figure 3.4). Early AFC can therefore be recommended because late AFC can be a constraint to profitability as it is a non-productive period with higher costs on maintenance without any income. Heifers that calve earlier reduce rearing costs for herd replacement and spend a greater proportion of their life producing milk, consequently, returning profit to a dairy farm business (Gröhn & Rajala-Schultz, 2000; Muller *et al.*, 2015).

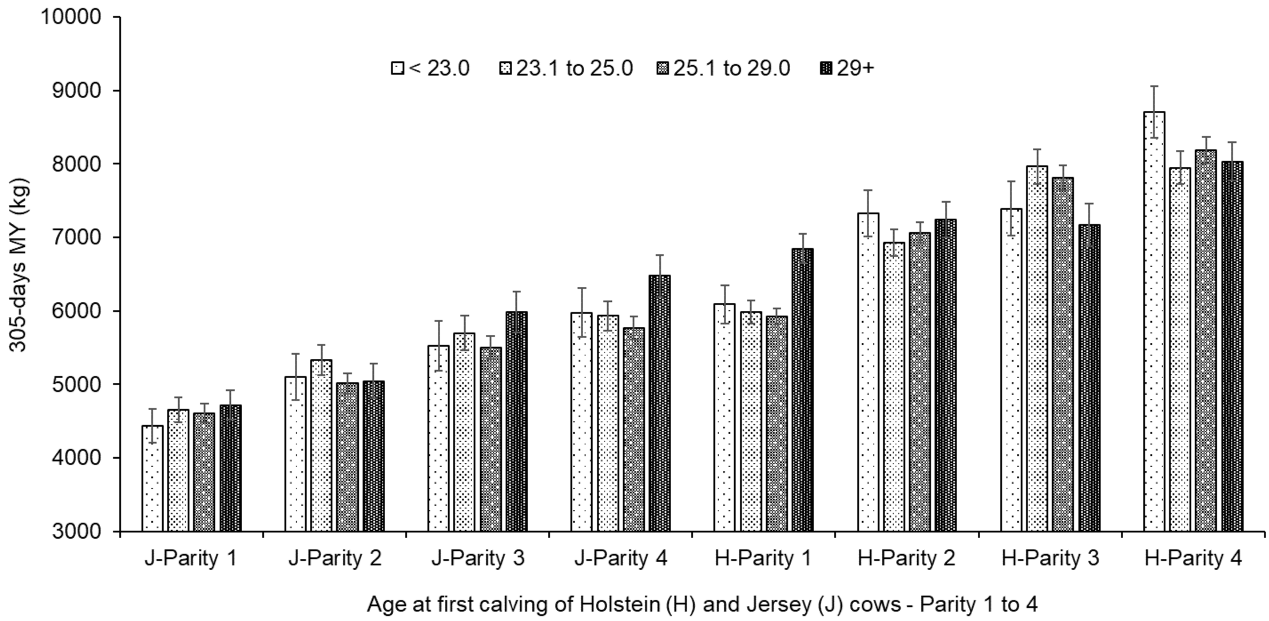


Figure 3.4 Least squares means (±SE) of 305-days milk production of Holstein and Jersey cows as affected by age at first calving and parity

3.4.1.4 Effect of ICP on MY

Holsteins had a longer ICP than Jerseys, 13.9±0.18 vs 13.2±0.17 months (P = 0.01). Parity did not have an effect on the length of ICP (P = 0.64). Numerous authors also reported a longer ICP in Holsteins compared to Jerseys: 14.1 versus 13.7 months (Capper & Cady, 2012); 432 days (14.3 months) versus 385 days (12.7 months) (Dalla Riva *et al.,* 2014). In cows participating in the National Dairy Animal Improvement Scheme in South Africa, Mostert *et al.* (2010) also reported lower ICP in Jerseys 389, 385 and 389 days compared to Holsteins 398, 394 and 395 days for all the first three calving intervals, respectively. Holsteins are often reported to have a longer and more intense negative energy balance (NEB) post-calving (Rastani *et al.,* 2001; Friggens *et al.,* 2007), excessive NEB is associated with delayed ovulation (Podpečan *et al.,* 2007), a possible reason for a longer ICP observed in this breed.

With Jerseys, no difference was observed in the 305-days milk yield with different ICP ranges although cows with the ICP below 13 months tended to produce less milk than those with the ICP range of 13 to 15 months (P = 0.08) and those above 15 months (P = 0.06). With Holsteins, cows with ICP longer than 13 months produced more milk than those with the ICP below 13 months (P<0.01) (Figure 3.5). The lower milk yield with shorter ICP can be assumed to be the result of insufficient accumulation of body reserves often associated with fewer days open or shorter dry period. An ICP of 13 months as recommended in most studies, can therefore be seen as the most suitable for both Holstein and Jersey cows.

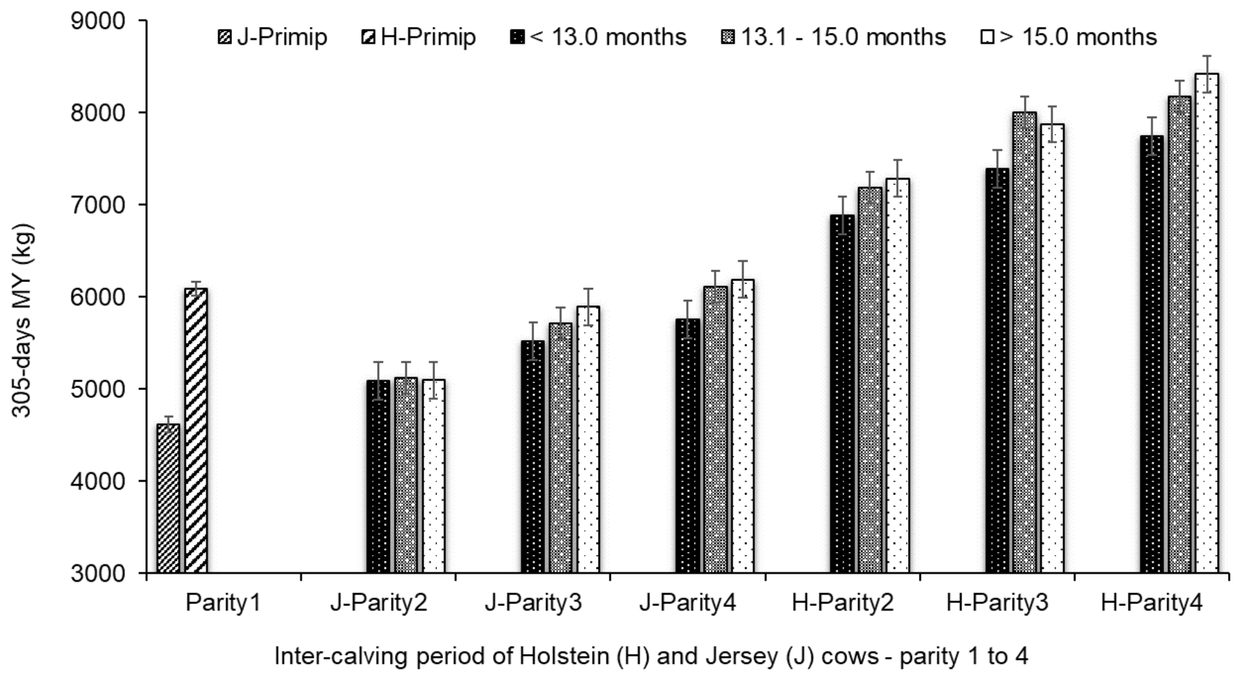


Figure 3.5 Least squares means (±SE) of 305-days milk production of Holstein and Jersey cows as affected by inter-calving period and parity

3.4.2 Body weight

The mean BW of Holstein and Jersey cows were 567±3.49 vs. 411±3.84 kg and mean mature weights 589±5.84 kg vs. 428±5.34 kg, respectively. This is in agreement with Gertenbach (1995) who reported mature weights that range between 550 to 650 kg for South African Holstein cows and 380 to 450 kg for Jersey cows. The BW increased with parity and lactation stage (Figure 3.6). Primiparous, second and third lactation Holstein cows weighed on average 83.3, 91.5, and 96.1% while Jerseys weighed 84.4, 91.6, and 96.8% of their mature BW, respectively. These results are comparable to the findings by Fox *et al.* (2004) that the target BW after first calving is 82 – 85%, second calving 92%, third calving 96% of the mature weight, with cows reaching mature BW at fourth calving. Body weight gain after maturity indicates excess energy consumed that is stored as body reserves while BW loss is indicative of the depletion of energy reserves to supplement for feed deficiencies (NRC, 2001; Fox *et al.*, 2004).

As expected, nadir BW in both breeds was in early lactation between 31 to 65 days in milk and the highest BW was achieved in late lactation stage (Figure 3.6, Table 3.4). In early lactation, cows lose body condition as they use their body reserves to meet the energy requirements for peak lactation while the DMI is still lagging behind (NRC, 2001). In late lactation, cows need to gain weight to have enough body reserves so as to minimise the effects of negative energy balance when they begin the next lactation (Poncheki *et al.,* 2015).

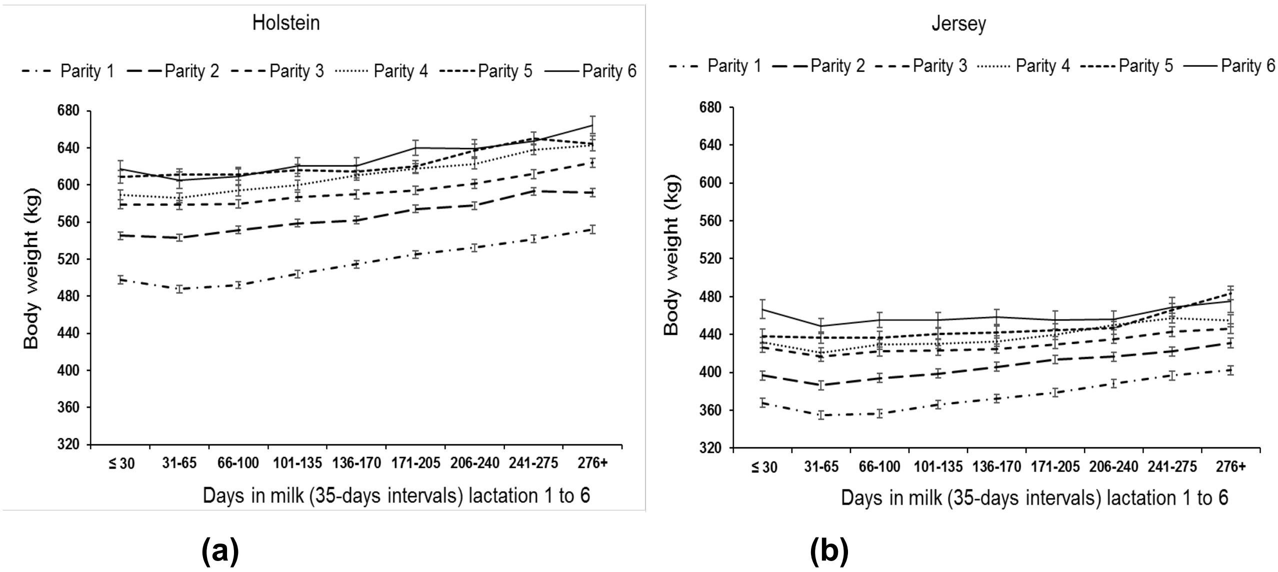
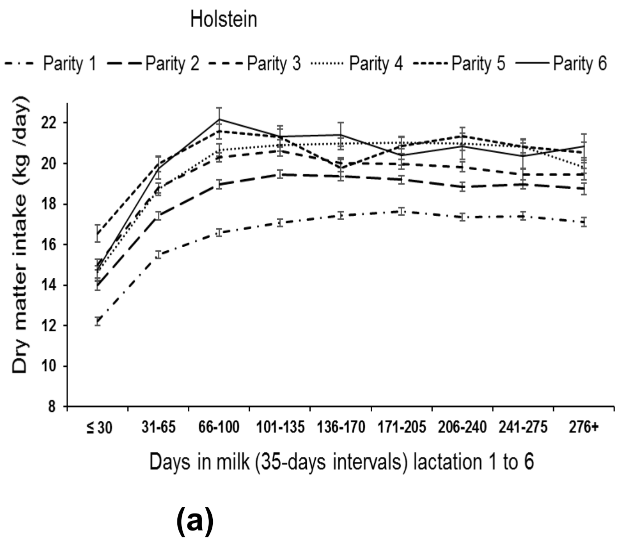


Figure 3.6 Least squares means (±SE) of body weights of (a) Holstein and (b) Jersey cows as affected by parity and days in milk

3.4.3 Dry matter intake

The mean estimated test-date DMI of Holsteins and Jerseys was 17.8±0.108 vs.14.4±0.116 kg/day respectively. As expected, DMI increased with parity and lactation stage because of increasing BW and milk yield in both Holstein and Jersey cows (Figure 3.7). In the current study, primiparous cows weighed on average 83% and produced approximately 75% milk that of mature cows, explaining the difference in proportion of DMI between the two parities.

The estimated DMI was lower during the transition period (Figure 3.7, Table 3.4) as the model adjusts for the week of lactation. Transition period is usually associated with physiological and hormonal changes that result in lower DMI in fresh cows. Dry matter intake increased curvilinearly from transition period reaching the peak in mid-lactation, followed by a decline in late lactation (Figure 3.7). In late lactation, the cows have fully regained their body condition as they are approaching the dry phase and milk production has decreased, a decline in DMI is therefore expected during this stage (Table 3.4).



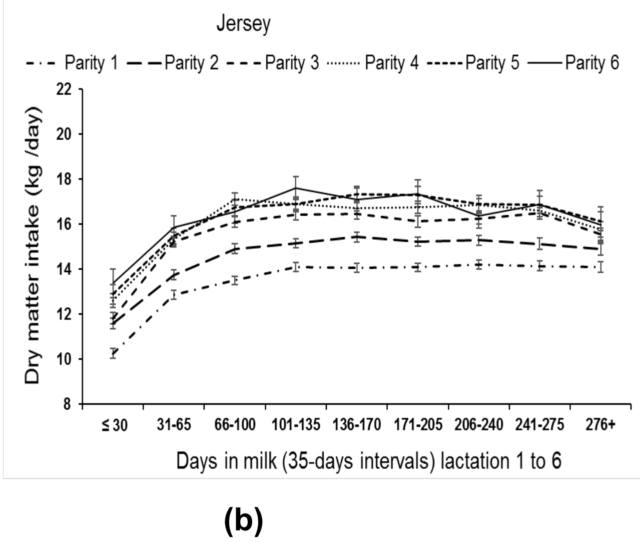


Figure 3.7 Least squares means (±SE) of the estimated dry matter intake of (a) Holstein and (b) Jersey cows as affected by parity and days in milk

3.5 Conclusion

Milk production of Holstein and Jersey cows in a pasture-based system is affected by lactation stage, parity, calving season, age at first calving and inter-calving period. The results indicate that lactation stage and parity are the major causes of variation in milk production performance and body weight of the cows. For improved productivity, it can be concluded that a longer productive life and strategic feeding to ensure that the cow is able to withstand increased nutritional demands required to sustain milk production in the next lactation are essential.

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Chapter 4

Estimating milk production and energetic efficiencies of Holstein and Jersey cows in a kikuyu pasture-based production system

4.1 Abstract

The aim of this study was to compare the milk production and energetic efficiencies of Holstein and Jersey cows kept under similar management and environmental conditions for a 9-year period. Data were lactation records of 122 Holstein and 99 Jersey cows collected from 2005 to 2014. Parities varied from 1 to 6. Cows grazed as one herd on kikuyu pasture and were supplemented with 7kg of concentrate containing 17% CP on an as fed basis daily for the entire lactation. Dietary energy was formulated using the feed formulation package of the Nutritional Dynamic System (NDS) Professional. Animal requirements were calculated using the National Research Council (NRC) and the Cornell Net Carbohydrate and Protein System (CNCPS) equations. Holsteins had a higher MY/kg DMI 1.36±0.01 vs. 1.27±0.01 kg than Jersey cows. Jersey cows had a higher DMI/kg BW being 3.51±0.02 vs. 3.13±0.02%, MF/kg DMI 52.4±0.3 vs. 58.4±0.4 g/kg, Mprot/kg DMI 42.7±0.3 vs. 45.1±0.3 g/kg, MY/100 kg BW 4.21±0.05 vs. 4.40±0.05%, energy corrected milk (ECM)/kg DMI 1.30±0.01 vs. 1.36±0.01 and ECM/kg BW 4.00±0.05 vs. 4.73±0.05 kg. Cows from both breeds were in negative energy balance (NEB) during the transition and early lactation stages. In Holsteins and Jerseys, respectively, the lowest NEB was -53.9 MJ vs. -39.7 MJ, it took 22.3±0.9 vs. 24.6±0.9 days to reach NEB nadir and the duration of NEB was 102.4±2.3 vs. 74.2±2.3 days. The net energy intake (NEI)/kg energy corrected milk (ECM) 5.52±0.04 vs. 5.35±0.04, NEI/100 g MF 13.7±0.10 vs. 12.5±0.10, NEI/100 g Mprot 16.7±0.14 vs. 16.2±0.15, NEI/kg metabolic BW ($BW^{0.75}$) 0.68±0.0002 vs. 0.67±0.0002 and net energy for maintenance (NEm)/kg $BW^{0.75}$ 0.46±0.002 vs. 0.43±0.002 were all lower in Jerseys compared to Holsteins. After accounting for NEm, (NEI-NEm)/ECM, Holsteins had higher gross energy efficiency than Jerseys, 1.82±0.01 vs. 1.98±0.01 MJ/kg ECM, suggesting the efficiency of Holsteins in utilising body reserves.

Keywords: long-term, similar management, parity, lactation stage, energy balance

4.2 Introduction

Milk producers select breeds based on profitability and market demand (Hunt, 2012). Because the genetic make-up of dairy cows affects milk yield and composition (Kiplagat *et al.,* 2012), differences between breeds in feed use efficiency may have economic consequences and requires investigation. This specifically applies to the Holstein and Jersey breeds as being the dominant dairy breeds in commercial herds (Gertenbach, 1995; Weigel & Barlass, 2003; Porter & Tebbit 2007; Heins *et al.,* 2008; Chiwome *et al.,* 2017).

In South Africa, milk prices are determined by the milk processors, resulting in different milk pricing structures (Anonymous, 2017). In most cases, milk prices are based on specific amounts for fat and protein. A new research indicating that low-carbohydrate-high-fat diet is beneficial for weight reduction or reducing the risk of lifestyle diseases such as type 2 diabetes and hypertension (Noakes, 2013; Bateman, 2015) was published in 2015. This resulted in an increase in consumer demand for full-cream dairy products and butter, and consequently, a sharp increase in prices of high MF products (MPO, 2018). Against this background, there is a need to compare the efficiency with which the two breeds produce MF and Mprot. In some instances, the two components are often combined as total solids or milk is standardised for its fat and protein content, e.g., fat corrected, solid corrected or energy corrected milk. This has resulted in a lack of literature showing the production efficiency of each component.

For milk synthesis, energy is the most essential nutrient, being responsible for regulating osmotic pressure in the mammary system and is therefore the major determinant of milk volume (Liu *et al.*, 2013; Lin *et al.*, 2016), precursor for MF (Gorewit, 1988; Rezaei *et al.,* 2016) and provision of energetic precursors for protein synthesis to manufacture milk protein (Mepham, 1982; Bionaz *et al.*, 2012). Despite being essential, energy is often the most limiting nutrient (VandeHaar *et al.,* 2016), especially for grazing animals. This is because the bulk of pasture grazed consists of cellulose, and approximately 20 to 70% of cellulose may not be digestible, resulting in only 10 to 35% of energy intake being captured as net energy (Varga *et al.,* 1997). Consequently, there is less available energy for maintenance and production functions such as milk production, growth and pregnancy. The efficiency in digesting fibre and partitioning the available net energy to maintenance and production is therefore of significance in cows in pasture-based production system.

The high energy demand for milk synthesis results in the altering of nutrient use by tissues to allow greater partitioning in support of lactation needs (Bauman & Currie, 1980; Boyd, 1998). According to Baumann and Currie (1980), pregnancy and milk secretion are high priority functions for nutrient allocation. The nutrient demand by the foetal calf and placenta in the last 3 weeks of pregnancy, followed by the rapid energy demand for the initiation of milk synthesis after calving and the rapid increase in milk production to reach peak yield in early lactation while the DMI is lagging behind (Drackley *et al.*, 2005) predispose the cow to negative energy balance (NEB). Metabolic disorders and hormonal imbalances associated with NEB result in less milk produced and reduced fertility (Wankhade *et al.,* 2017) e.g., longer days open as the animal is taking longer to regain its condition.

Holstein and Jersey cows vary in milk production and energy use efficiencies (Muller & Botha, 1998; Thomson *et al.,* 2001 Prendiville *et al.,* 2009; Kristensen *et al.,* 2015). There are, however, very few long-term studies comparing the two breeds under similar management and environmental conditions. Phuong *et al.* (2013) stated that most studies focus on nutritional effects and less on the effect of breed and production stages on nutrient use efficiency. The aim of this study was therefore to estimate and compare milk production and energy use efficiencies of Holstein and Jersey cows kept in a kikuyu pasture-based production system over a nine-year period. The objectives were to:

- Estimate and compare the efficiency of feed use (DMI) for milk, MF and Mprot production of Holsteins and Jersey cows in a kikuyu pasture-based system by parity and stage of lactation.
- Estimate the energy partitioning for maintenance, production functions, body reserves mobilisation and energy conversion efficiency to milk by Holstein and Jersey cows in a pasture-based system.

4.3 Materials and methods

4.3.1 Cow management during the experiment

Details of experimental animals, experimental area, diet and management of experimental animals are presented in Chapter 3, only a brief summary will be provided in this chapter. The study was conducted at Elsenburg Research Station, Western Cape Department of Agriculture in South Africa. Data were test-date lactation records of 122 Holstein and 99

Jersey cows that were collected from October 2005 to September 2014. Records included cow birth date, calving date, lactation number, BW, MY, %MF and %Mprot, and they were collected using the standard milk recording procedures, i.e. 10 recording dates per year. Parity varied from 1 to 6, resulting in a total of 4576 test-date records, 2315 for Holsteins and 2261 for Jerseys. Lactation period was divided into four stages: calving to 30 days in milk (DIM) (transition), 31 to 100 DIM as early lactation stage, 101 to 200 DIM as mid-lactation stage, and above 201 DIM as late lactation stage. Cows were kept as one herd on kikuyu pasture and received on an as-fed basis 7 kg of concentrate containing 17% crude protein (CP) per day, fed in two equal portions after each milking. The total dry matter intake (DMI) was estimated using the National Research Council (NRC, 2001) method, with pasture estimated as the difference between DMI and concentrate offered.

4.3.2 Production efficiency

Production efficiency was estimated as kg DMI/kg BW, kg MY/kg DMI, g MF/kg DMI and g Mprot/kg DMI. Milk was also corrected for its fat and protein content to energy-corrected milk (ECM) using the equation by Tyrell & Reid (1965):

ECM = (12.95×MF kg/day) + (7.65×True protein kg/day) + (0.327×MY kg/day).............eq 1

Where: true protein was calculated as: %Mprot × 0.93, (NRC, 2001)……………......eq 2

Production efficiency on ECM yield basis was similarly determined.

4.3.3 Estimating dietary energy

For the energy content of feed, formulation was done using the feed formulation package of the Nutritional Dynamic System (NDS) Professional (Table 4.2). The gross energy (GE) content and partitioned energy was estimated as the sum of energy contributions from the concentrate mixture offered and estimated pasture intake.

4.3.4 Estimating animal requirements

The energy requirements of the cows were calculated using the equations from the Cornell Net Carbohydrate and Protein System (CNCPS) and the National Research Council (NRC, 2001): net energy for maintenance (NEm) (NRC, 2001; Linn, 2003), net energy for growth (NEg) (NRC, 2001; Ross *et al.,* 2015); net energy for lactation (NElact) (NRC, 2001; Linn, 2003; Tylutki *et al.,* 2008) and metabolisable energy for pregnancy (MEpreg) (NRC, 2001;

Tylutki *et al.,* 2008). Below are the equations that were used for estimating animal requirements:

NEm (Mcal/day) = $0.08 \times BW^{0.75}$ + activity + grazing in good pasture…………………....eq 3

Where $BW^{0.75}$ = kg metabolic body weight

Activity = 10% NEm

Grazing in good pasture = 0.0012 Mcal/kg BW

NElact = kg MY × ((0.0929×MF) + (0.0547×Mprot) + (0.0395×ML))……….........…..eq 4

Where MF = milk fat (%)

Mprot = milk protein (%)

ML = milk lactose (%), a default ML value, 4.85% was used

MEpreg = ((2 × 0.00159 × days pregnant) - 0.0352) × (CBW/45) /0.14……..…….….…..eq 5

Where CBW = average birth weight of calves at Elsenburg Research Station

Days pregnant = DIM – estimated conception day

Estimated conception day = (ICP×30.5 days) – 280 days)

The length of pregnancy was assumed to be 280 days, as observed by Silva *et al.,* (1992), 280 vs. 278 days; and Norman *et al.* (2009) 279.5±5.3 vs. 279.9±4.9 days in Holstein and Jersey cows, respectively. Conception date was estimated as the difference between ICP (days) and the length of pregnancy. Pregnancy stage was then estimated as the difference between days in milk (DIM) at test dates and the estimated conception date. The birth weight of calves used was the average birth weight of calves at Elsenburg Research Station, 27.5 kg for Jersey (Goni *et al.,* 2016; Anonymous, 2017) and 38.0 kg for Holstein heifers (Metaxas, 2016).

NEg MJ/ day = $22.02 \times ((BW / 0.8 \times BW^{0.75}) \times ADG^{1.097}$ ……...……..…………………….eq 6

Where BW = body weight (kg)

$BW^{0.75}$ = metabolic body weight (kg)

ADG = average daily gain (kg), i.e., target weight / days ICP

Target weight = (Mature BW × adjustment for growth) – BW less conceptus weight

Adjustment for growth = 0.85 for primiparous cows, 0.92 for 2nd lactation, 0.96 for 3rd lactation and 1 for 4+ cows

Conceptus weight = (0.5556 × (18 + (days pregnant – 190) × 0.665))…...eq 7

4.3.5 Estimating energy balance

Energy balance (EB) was calculated as net energy intake (NEI) – (NEm + NElact + MEpreg + NEg). Cows whose estimated energy demands exceeded energy intake were declared to be in a negative energy balance (NEB) state. To determine the duration of NEB, the days in milk (DIM) in which the first positive EB was recorded was used to represent the number of days the cow was in NEB. For NEB magnitude, the NEB nadir was defined as the lowest NEB point achieved by the cow. The number of days to reach NEB nadir was the DIM in which the lowest NEB value was recorded.

4.3.6 Efficiency estimates for energy use

The partitioning of gross energy intake (GEI) was calculated as the proportion of digestible energy intake (DEI), metabolisable energy intake (MEI) and net energy intake (NEI) per GEI while NEI partitioning was computed as NEm/NEI, and NElact/NEI. The efficiency of NEI use was calculated as NEI/100 g MF, NEI/100 g Mprot, NEI/kg ECM, NEI/kg $BW^{0.75}$, NEm/$BW^{0.75}$, and gross efficiency calculated as estimated NEI utilised to produce 1 kg ECM after accounting for NEm (NEI-NEm)/ECM.

4.3.7 Statistical analysis

Data were analysed using the repeated measures methods available in the PROC MIXED procedure of SAS Enterprise Guide version 7.1. The fixed effects were breed, parity, lactation stage and test-dates. Their interaction effects were breed × lactation stage, breed × parity, and breed × parity × test-date. The cow was fitted as a random effect while the response variables were measured within a cow at every test-date in each parity. The least squares means of the interaction effects of breed × parity × test-date for kg DMI/ kg BW, MY/kg DMI, g MF/kg DMI, g Mprot/kg DMI, kg ECM/kg DMI, kg ECM/kg BW, NEm, NElact, EB, NEI/100 g MF, NEI/100 g Mprot and NEI/kg ECM were regressed against parity and fitted in a curve to determine how these parameters respond to the predictor variables in each breed. A compound symmetry structure for the residuals was used as covariance structure for repeated measures over time within cows. The between-breeds, between parity and between lactation stage variations and their interactions were compared using the Bonferroni test and were declared different at $P < 0.05$. Below is the equation that was used for statistical analysis:

$Y_{ijkl} = \mu + B_i + P_j + LS_k + TD_l + (B\times P)_{ij} + (B\times LS)_{ik} + (B\times P\times TD)_{ijl} + cow_m(B_i) + \varepsilon_{ijklm}$

Where:

Y_{ijklm}	= dependent / response variable (Milk production and energy efficiencies);
μ	= overall mean;
B_i	= fixed effect of the i^{th} breed (i =Holstein, Jersey);
P_j	= fixed effect of the j^{th} parity (j = 1, 2, 3 and 4);
LS_k	= fixed effect of the k^{th} lactation stage (l = 1, 2, 3, and 4);
TD_l	= fixed effect of the l^{th} test-date (l = 1 to 9);
$(B\times P)_{ij}$	= fixed interaction effect between breed and parity;
$(B\times LS)_{ik}$	= fixed interaction effect between breed and lactation stage;
$(B\times P\times TD)_{ijl}$	= fixed interaction effect between breed, parity and lactation stage;
$Cow_m(B_i)$	= random effect of the m^{th} cow (l = 1 to 221) nested within the i^{th} breed N ~ (0, $\sigma^2_{cow(B)}$);
ε_{ijklm}	= random error term N ~ (0, σ^2_{ε}).

4.4 Results and discussion

Table 4.1 shows the descriptive statistics of the least squares means and standard error of the variables that were used to estimate production efficiency of Holstein and Jersey cows. Table 4.2 is the energy content of the concentrate mixture. The energy content for the kikuyu pasture was as supplied in the feed formulation package of the Nutritional Dynamic System (NDS) Professional, GE = 4.59, DE = 2.89, ME= 2.34 and NEl= 1.47 MJ/kg.

Table 4.1 Mean (±SE) descriptive statistics for Holstein and Jersey cows in a kikuyu pasture-based production system

Parameters	Holsteins	Jerseys
No. of records	2315	2261
Milk (kg/day)	23.8±0.22	17.9±0.24
Milk fat (%)	3.89±0.03	4.66±0.03
Milk protein (%)	3.17±0.02	3.59±0.02
Body weight (kg)	567±3.49	411±3.84
Mature body weight	589±4.84	428±5.37
Total dry matter intake (kg)	17.8±1.08	14.4±0.116

Table 4.2 Estimated energy content of the concentrate mixture ([1]formulated using the NDS software)

Ingredients	% Inclusion	Ingredient energy content (MJ/kg)				Dietary inclusion (MJ/kg)			
		[1]GE	[1]DE	[1]ME	[1]NE	GE	DE	ME	NE
Wheaten bran	10	18.9	13.8	10.7	6.78	1.89	1.38	1.07	0.68
Barley	10	18.3	15.6	12.6	8.37	1.83	1.56	1.26	0.84
Wheat	10	18.9	16.6	13.4	8.62	1.89	1.66	1.34	0.86
Maize	42	18.5	16.2	13.2	8.52	7.77	6.80	5.55	3.58
COM	10	20.5	16.7	11.3	7.18	2.05	1.67	1.13	0.72
SOM	7.5	19.6	18.3	14.6	9.47	1.47	1.37	1.10	0.71
Fishmeal	1	18.8	15.5	14.0	9.16	0.19	0.15	0.14	0.09
Urea	0.6	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
Molasses	4	17.2	13.2	11.5	7.30	0.69	0.53	0.46	0.29
Wheat Straw	3	18.5	7.2	5.6	1.54	0.55	0.22	0.17	0.05
Limestone	1	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
Salt	1	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
Total	**100**					**18.3**	**15.4**	**12.2**	**7.81**

GE: gross energy, **DE:** digestible energy, **ME:** metabolisable energy, **NE:** net energy, **COM:** cottonseed oilcake meal, **SOM:** soybean oilcake meal

4.4.1 Milk and milk solids production efficiency

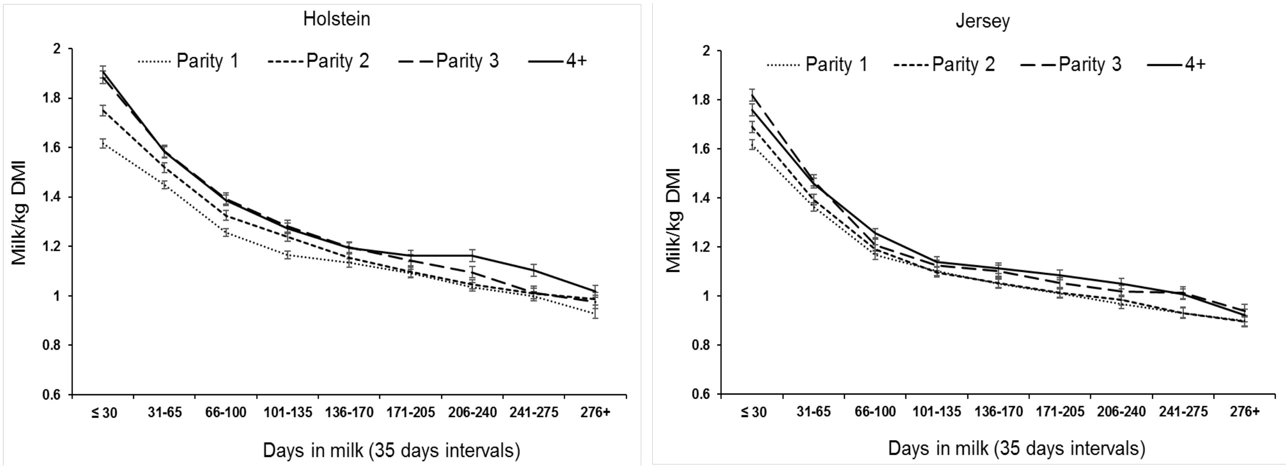
In all parities and lactation stages, the efficiency of converting DMI to MY was higher in Holstein than Jersey cows (Table 4.3, Figure 4.1). In agreement, Muller & Botha, (1998) observed higher efficiency of liquid milk production in primiparous Holstein compared to primiparous Jerseys, 1.38 and 1.18 kg MY/kg DMI. Thomson *et al.* (2001) also found higher production efficiency ratios in Holsteins compared to Jerseys, 1.72 vs. 1.60, 1.24 vs. 0.98 and 0.79 vs. 0.63 kg MY/kg DMI in early, mid and late lactation stages, respectively. Palladino *et al.* (2010) reported daily DMI of 18.4 kg vs. 15.3 kg and MY of 21.1 kg vs. 14.5 kg milk/day, which when expressed as output to input ratio can be translated to 1.15 vs. 0.95 kg milk/kg DMI in Holsteins and Jerseys, respectively, also suggesting higher milk production efficiency in Holsteins.

Jerseys produced more MF/kg DMI (Figure 4.2) and Mprot/kg DMI (Figure 4.3) than Holsteins in all production stages. In Holsteins and Jerseys, respectively, Mackle *et al.* (1996) observed MF of 67 vs. 79 g/kg DMI while Thomson *et al.* (2001) reported 71.4 vs. 100.9, 51.4 vs. 55.5 and 40.4 vs. 41.9 g MF/kg DMI in early, mid and late lactation stages, respectively. With Mprot/kg DMI, however, Thomson *et al.* (2001) reported no breed effect (P=0.6), the efficiency ratios being 58.9 vs. 65.8 in early, 42.0 vs. 38.9 mid lactation and

30.7 vs. 28.7 g/kg DMI in late lactation in Holsteins and Jerseys, respectively. The authors that combined MF and Mprot into total solids also reported higher efficiency in Jerseys, e.g., Mackle *et al.* (1996) reported a production efficiency of 115 vs. 129 g MS/kg DMI and Prendiville *et al.* (2009) 0.079 kg vs. 0.088 kg MS/kg DMI in Holsteins and Jerseys, respectively. Jerseys also had higher MS/kg BW (Table 4.3). In agreement, Grainger & Goddard (2004) observed a 23% more MS/LW in Jerseys compared to Holsteins (3.76 versus 3.06 g MS/LW); Prendiville *et al.* (2009) found that Holstein cows produced 0.27 kg and Jersey cows 0.35 kg MS/100 kg BW. These results indicate that Holsteins may be a more suitable breed for a volume-based pricing system and Jersey cows for component-based pricing system. With the introduction of component milk pricing system, crossbreeding Holstein cows with Jersey sires to exploit the hybrid vigour has been observed to yield beneficial results. Prendiville *et al.* (2009) reported that F_1 crosses (hybrids of the Holstein cows sired by Jersey bulls) tended to produce more daily milk solids, 1.41 kg/day compared to Holsteins and Jerseys,1.33 and 1.28 kg/day, respectively.

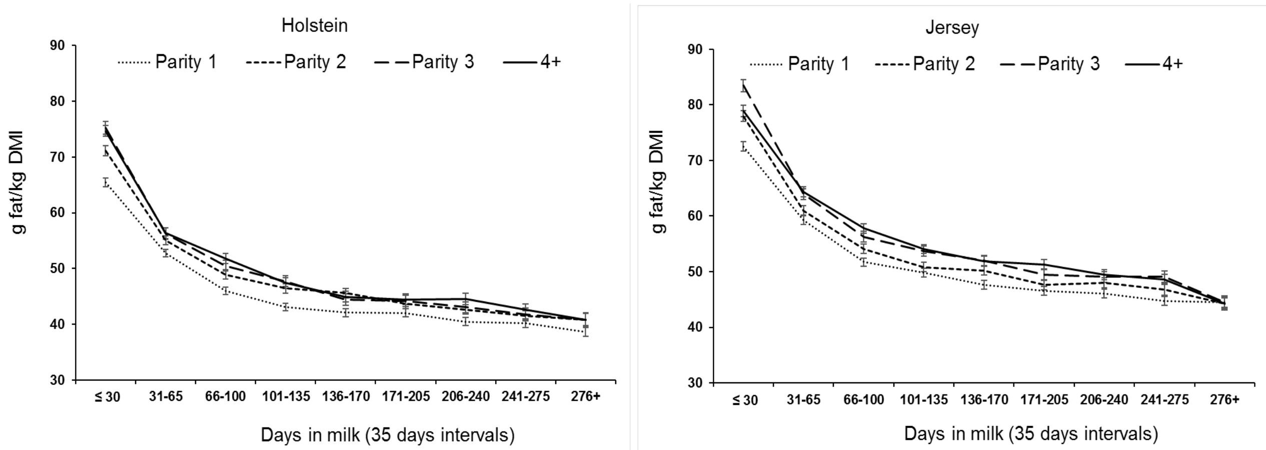
In both breeds, production parameters efficiencies (i.e., MY/kg DMI, g MF/kg DMI and g Mprot/kg DMI) increased with parity (Table 4.3). Older cows eat more, suggesting that the extra feed consumed above maintenance is partitioned toward milk production, resulting in increased productivity. Thus, having cows with a longer productive life will have a positive effect on overall production efficiency of the herd.

With advancing lactation, milk production efficiency followed a downward trend (Table 4.3). This can be associated with homeorhetic regulations. At the onset of lactation, nutrient use by tissues is altered to prioritise the demands of the mammary gland and secretion of high amount of milk, which is assumed to be the most critical role (Bauman & Bruce Currie, 1980). This results in high production efficiency during transition and early lactation stages although it happens at the expense of body reserves. In mid and late lactation stages, nutrient partitioning shifts towards building body reserves and supporting pregnancy in preparation for the next calving, and therefore a decrease in milk production efficiency. Strategic feeding of the cow in alignment with the lactation stage may be beneficial in improving her performance efficiency. According to (Gerloff (1988), the dry phase should be viewed as a preparatory phase where dairy cows are fed and managed to be able to make the transition from the dry period to the increased nutritional demands required to sustain milk production.



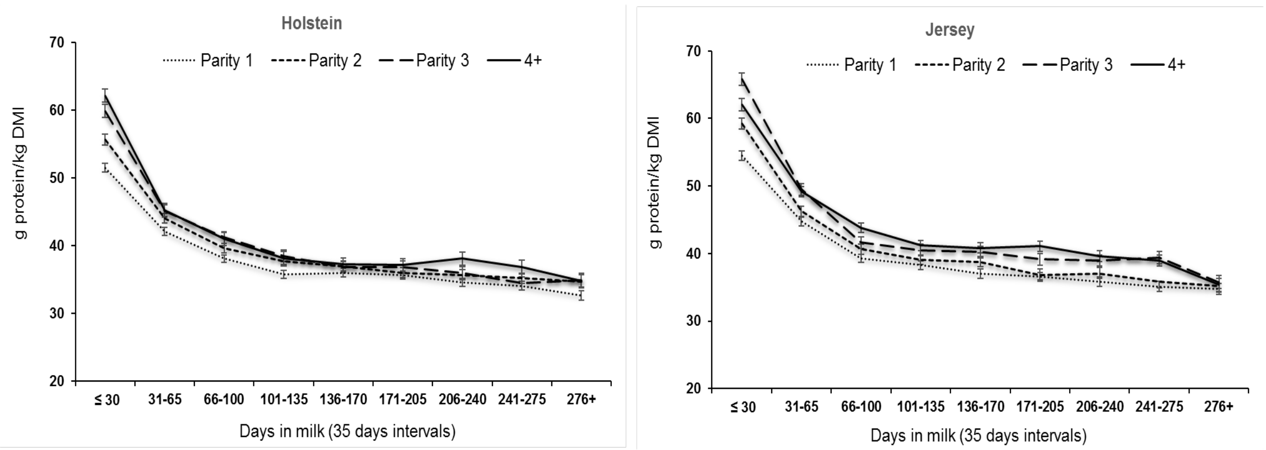
(a) (b)

Figure 4.1 Least squares means (±SE) of milk production efficiency (kg MY/kg DMI) of (a) Holstein and (b) Jersey cows as affected by parity and days in milk



(a) (b)

Figure 4.2 Least squares means (±SE) of milk fat efficiency (100 g MF/kg DMI) of (a) Holstein and (b) Jersey cows as affected by parity and days in milk



(a) (b)

Figure 4.3 Least squares means (±SE) of milk protein efficiency (100 g Mprot/kg DMI) of (a) Holstein and (b) Jersey cows as affected by parity and days in milk

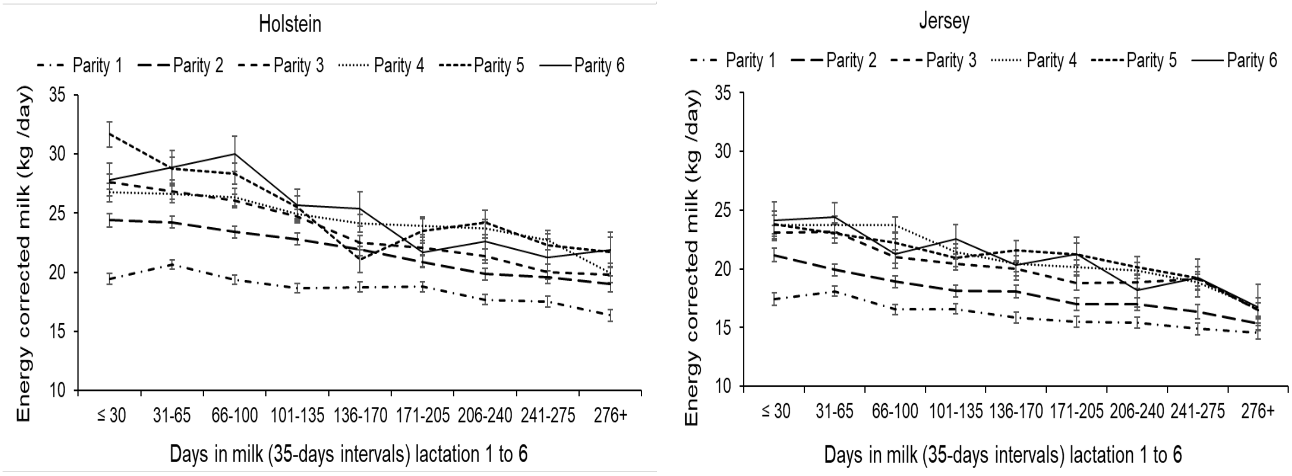
4.4.2 Energy corrected milk

After correcting milk for its fat and protein content, the ECM was 22.7±5.9 kg/day in Holsteins and 19.4±4.8 kg/day in Jerseys, indicating that Jersey cows produced on average 85.5% ECM that of Holstein cows, compared to 74% uncorrected milk observed in this study. Because of the higher solid content of Jersey cows' milk compared to that of Holstein cows, mature Jersey cows' ECM was similar to that of second lactation Holsteins (Table 4.3) whereas with uncorrected MY, mature Jersey cows MY was similar to that of primiparous Holsteins (Table 3.4). This suggests that MY, especially for Jersey cows, is not a good indicator of milk production efficiency as it does not account for the high fat and protein concentration in Jersey cows' milk. Similarly to MY, ECM increased with parity but decreased with lactation stage (Table 4.3, Figure 4.4).

Because of the higher milk solid content, Jerseys also produced more ECM/kg DMI (Figure 4.5) and ECM/kg BW (Figure 4.6) compared to Holsteins (Table 4.3). In agreement, Mackle *et al.* (1996) reported low DMI to solid corrected milk conversion efficiency in Holsteins, 1.49 vs. 1.63; Kristensen *et al.* (2015), ECM/kg DMI 1.35 vs. 1.46 kg and ECM/kg BW 5.06 vs. 6.65 kg compared to Jerseys. Olijhoek *et al.* (2018), however, reported no difference between breeds in ECM/kg DMI ($P = 0.51$). Because Jerseys in this study produced an overall ECM of 85% compared to 74% uncorrected milk yield that of Holsteins, Jersey cows were expected to perform better in ECM/kg DMI and ECM/kg BW. Both ECM/kg DMI and ECM/kg BW increased with parity but decreased with lactation stage. This was expected as milk production efficiency parameter (MY/kg DMI, g MF/kg DMI and g Mprot/kg DMI) increased with parity and decreased with lactation stage.

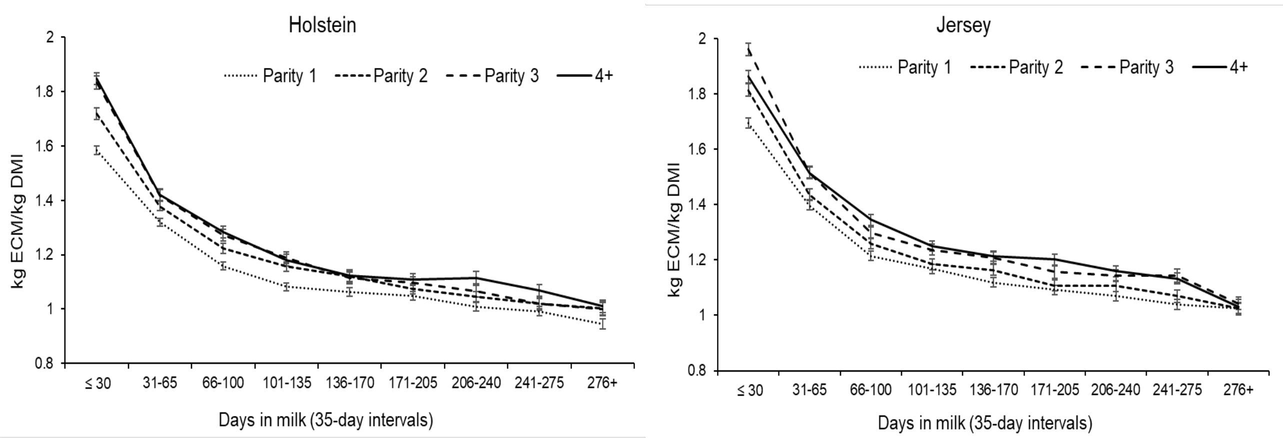
4.4.3 Efficiency of DMI (DMI/kg BW)

Holstein cows had lower DMI/kg BW than Jersey cows (Table 4.3, Figure 4.7). This is indicative of efficiency in Jersey cows as cows that eat more produce more. Moreover, higher DMI/kg BW is suggestive of higher energy intake which may provide better energy reserves, thus preventing excessive lipolysis and the effects of negative energy balance in cows. The higher DMI/kg BW may therefore be seen as a beneficial trait in grazing cows as energy in pasture is often limiting.



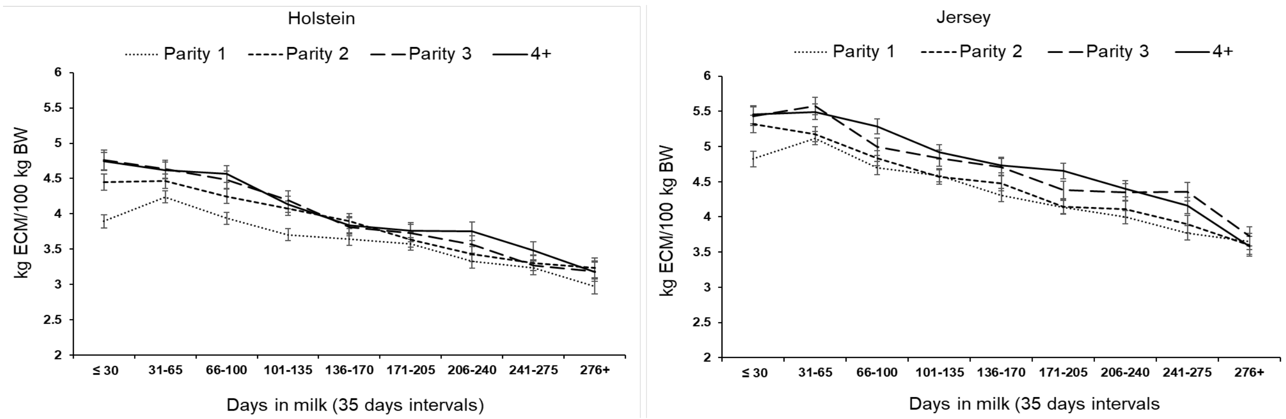
(a) **(b)**

Figure 4.4 Least squares means (±SE) of energy corrected milk of (a) Holstein and (b) Jersey cows as affected by parity and days in milk



(a) **(b)**

Figure 4.5 Least squares means (±SE) of energy corrected milk efficiency (kg ECM/kg DMI) of (a) Holstein and (b) Jersey cows as affected by parity and days in milk



(a) **(b)**

Figure 4.6 Least squares means (±SE) of energy corrected milk efficiency (kg ECM/kg BW) of (a) Holstein and (b) Jersey cows as affected by parity and days in milk

Table 4.3 The mean (±SE) test-date efficiency estimates of Holstein (H) and Jersey (J) cows as affected by parity and lactation stage

	Parity										
	1		2		3		4+		P-values		Interactions
	H	J	H	J	H	J	H	J	Breed	P	B × P
No. of records	891	737	579	541	395	437	450	546			
DMI/kg BW	3.09^{b} ±0.02	3.50^{a} ±0.02	3.14^{b} ±0.02	3.48^{a} ±0.02	3.15^{b} ±0.02	3.53^{a} ±0.02	3.14^{b} ±0.03	3.54^{a} ±0.03	<.01	0.06	0.10
Milk/kg DMI	1.29^{c} ±0.01	1.23^{d} ±0.01	1.34^{b} ±0.01	1.24^{d} ±0.01	1.39^{a} ±0.01	1.30^{c} ±0.01	1.41^{a} ±0.01	1.30^{c} ±0.01	<.01	<.01	<.01
Milk/100 kg BW	3.94^{f} ±0.05	4.25^{e} ±0.06	4.16^{e} ±0.06	4.28^{de} ±0.06	4.33^{cd} ±0.06	4.50^{ab} ±0.06	4.39^{bc} ±0.07	4.56^{a} ±0.06	<.01	<.01	0.02
g MF/kg DMI	49.7^{e} ±0.4	55.8^{c} ±0.4	52.6^{d} ±0.4	57.7^{b} ±0.4	53.4^{d} ±0.5	60.0^{a} ±0.5	53.9^{cd} ±0.5	60.1^{a} ±0.5	<.01	<.01	0.09
g Mprot/kg DMI	40.9^{f} ±0.3	42.8^{de} ±0.3	42.5^{e} ±0.4	44.1bc ±0.4	43.4^{cd} ±0.4	46.5^{a} ±0.4	44.1^{bc} ±0.4	46.8^{a} ±0.4	<.01	<.01	0.03
ECM	19.1^{e} ±0.2	16.7^{f} ±0.3	22.4^{c} ±0.3	18.5^{e} ±0.3	24.0^{b} ±0.3	20.7^{d} ±0.3	25.3^{a} ±0.3	21.6^{c} ±0.3	<.01	<.01	<.01
ECM/kg DMI	1.23^{e} ±0.01	1.31^{cd} ±0.01	1.29^{e} ±0.01	1.34^{b} ±0.01	1.32^{c} ±0.01	1.40^{a} ±0.01	1.34^{b} ±0.01	1.41^{a} ±0.01	<.01	<.01	0.11
ECM/100 kg BW	3.75^{d} ±0.05	4.52^{b} ±0.05	4.00^{c} ±0.06	4.62^{b} ±0.06	4.10^{c} ±0.06	4.87^{a} ±0.06	4.14^{c} ±0.06	4.92^{a} ±0.06	<.01	<.01	0.07
	Lactation stage (days in milk)										
	<30d		31-100		101-200		201+		P-values		Interactions
	H	J	H	J	H	J	H	J	Breed	LS	B × LS
No. of records	228	204	581	561	798	776	708	720			
DMI/kg BW	2.53^{h} ±0.03	2.87^{g} ±0.03	3.34^{e} ±0.02	3.73^{b} ±0.02	3.42^{d} ±0.02	3.83^{a} ±0.02	3.23^{f} ±0.02	3.63^{c} ±0.02	<.01	<.01	0.20
Milk/kg DMI	1.77^{a} ±0.01	1.71^{a} ±0.01	1.43^{b} ±0.01	1.31^{c} ±0.01	1.19^{d} ±0.01	1.08^{e} ±0.01	1.04^{e} ±0.01	0.97^{f} ±0.01	<.01	<.01	<.01
Milk/100 kg BW	4.53^{c} ±0.07	4.91^{a} ±0.07	4.79^{b} ±0.06	4.91^{a} ±0.06	4.09^{d} ±0.05	4.19^{d} ±0.06	3.41^{f}±0.05	3.58^{e}±0.06	<.01	<.01	0.015
g MF/kg DMI	70.8^{b} ±0.5	77.6^{a} ±0.6	52.1^{d} ±0.4	58.4^{c} ±0.4	44.8^{f} ±0.4	50.6^{d} ±04	41.8^{g} ±0.4	47.0^{e} ±0.4	<.01	<.01	0.08
g Mprot/kg DMI	56.4^{b} ±0.5	59.9^{a} ±0.5	42.0^{d} ±0.4	44.3^{c} ±0.4	37.1^{f} ±0.3	39.2^{e} ±0.3	35.4^{g} ±0.3	37.1^{f} ±0.3	<.01	<.01	0.08
ECM	24.5^{a} ±0.3	21.2^{bc} ±0.4	24.2^{a} ±0.3	20.4^{c} ±0.3	22.0^{b} ±0.2	18.6^{d} ±0.3	20.1^{c} ±0.3	17.2^{e} ±0.3	<.01	<.01	0.07
ECM/kg DMI	1.72^{b} ±0.01	1.82^{a} ±0.01	1.31^{d} ±0.01	1.37^{c} ±0.01	1.12^{f} ±0.01	1.18^{e} ±0.01	1.03^{g} ±0.01	1.09^{f} ±0.01	<.01	<.01	0.20
ECM/100 kg BW	4.39^{c} ±0.07	5.22^{a} ±0.07	4.37^{c} ±0.05	5.14^{a} ±0.06	3.86^{d} ±0.05	4.56^{b} ±0.05	3.37^{e} ±0.05	4.02^{d} ±0.05	<.01	<.01	0.13

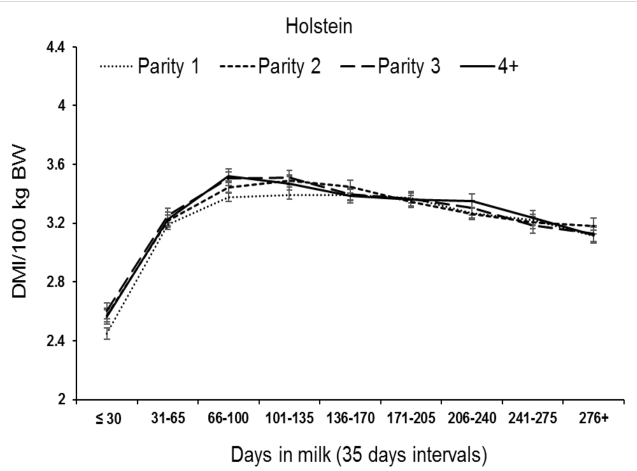
$^{a\text{-}h}$ Means within rows with different superscripts differ at P<0.05

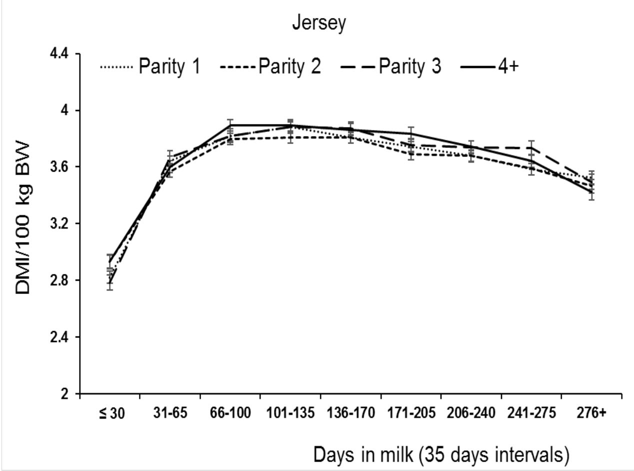
Several authors also observed higher DMI/kg BW in Jerseys compared to Holsteins, e.g., Mackle *et al.* (1996), reported a DMI of 2.55 vs. 2.66 kg per 100 kg BW/cow/day; Muller & Botha (1998), 3.4 vs. 4.0% of BW; Thomson *et al.* (2001), 28.0 vs. 30.8 g/kg liveweight; Anderson *et al.* (2007), 3.96% vs. 4.26% of BW; Prendiville *et al.* (2009), 3.36 vs. 3.99% of BW; Sneddon *et al.* (2011), 3.42 vs. 3.90 kg/100 kg BW on TMR and 2.91 vs. 3.22 kg/100 kg BW on a pasture; and Kristensen *et al.* (2015), 3. 76 vs. 4. 56% of BW. Ingvartsen & Weisberg (1993), reported a 19% greater DMI/100 kg BW while Grainger & Goddard (2004), reported 14.2% more DMI/100 kg BW in Jerseys compared to Holsteins. Although the following authors found no difference in DMI/kg BW between the two breeds: Rastani *et al.* (2001), 0.033 vs. 0.036 kg/kg BW; *(*Aikman *et al.* (2008), (P=0.955); Knowlton *et al.* (2010) 3.55% vs. 3.90% of BW (P<0.16), which they attributed to the smaller difference in body size of Holstein and Jersey cows in New Zealand, numerically, Jerseys appear to have a higher DMI/kg BW. Prendiville *et al.* (2010) reported no difference in DMI/kg BW between Holstein and Jersey cows during the dry period, and suggested that the higher DMI/kg BW often observed in Jerseys is predominantly driven by energy requirements for milk production.

To facilitate the higher DMI/kg BW, Jersey cows have been reported to have a bigger gastrointestinal tract (GIT)/kg BW compared to Holsteins (Smith & Baldwin, 1974; Prendiville *et al.;* 2009). Beecher *et al.* (2014), reported on the differences in GIT size of the two breeds where Holsteins and Jerseys had reticulorumen, omasum, abomasum and total GIT as 24.3 vs. 29.3, 29.2 vs. 33.9, 7.2 vs. 8.2 and 128.8 vs. 142.5 g/kg BW, respectively.

Aikman *et al.* (2008), associated the higher DMI/kg BW in Jerseys with the higher passage rate of digesta in this breed compared to Holsteins. In agreement, Ingvartsen and Weisberg (1993), observed a 21% higher passage rate in Danish Jerseys compared to Holsteins. Retief (2000) and Bangani (2002) reported higher effective dry matter and neutral detergent fibre degradability in Jerseys compared to Holsteins at all fractional outflow rates, suggesting a greater extraction of nutrients and low retention time of the digesta. The bigger GIT capacity per kilogram BW allows for higher DMI and greater attachment of rumen microbes for ease of fibre degradation while the higher passage rate of digesta indicates a faster rumen outflow, thus explaining the Jersey cows’ intrinsic mechanism for higher DMI/kg BW.

Parity had no effect on DMI/kg BW (Figure 4.7). Dry matter intake/kg BW, however, increased with lactation stage (P<0.05), reaching peak in mid-lactation thereby coinciding with the peak estimated DMI. The peak DMI/kg BW was followed by a decrease in the late lactation stage (Figure 4.7). The lower DMI/kg BW in late lactation stage is attributable to a decrease in DMI with decreasing milk production accompanied by an increase in BW as the cows had regained their body condition and some were pregnant.





(a) **(b)**

Figure 4.7 Least squares means (±SE) of DMI/100 kg BW of (a) Holstein and (b) Jersey cows as affected by parity and days in milk

4.4.4 Estimated partitioning of gross energy intake (GEI)

Holstein cows had a higher estimated GEI than Jersey cows in all parities and lactation stages (Table 4.4). As a proportion of estimated GEI, DEI was 67.6±0.06 vs. 69.5±0.07% and MEI 57.0±0.04 vs. 58.2±0.04% in Holstein and Jersey cows, respectively. This suggests that approximately 31% of GEI was excreted in faeces and 11% in urine and enteric gases, and therefore not available for animal use. According to the IPCC (2006), the percentage of GEI converted to methane in dairy cows is 6.5±1%, it can therefore be assumed that approximately 5% of GEI was lost in urine. Arndt *et al.* (2015) reported lower faecal energy losses, 28.6 vs. 25.9%, and urinary energy losses, 2.76 vs. 3.40% as proportion of GEI for high and low feed conversion efficiency cows that were housed in tie-stalls and received a TMR diet, respectively.

The estimated NEI/GEI in this study was 38.7±0.02 and 39.2±0.02% for Holsteins and Jerseys, respectively, suggesting that approximately 20% of GEI was lost in metabolic processes and heat production. As a proportion of MEI, the estimated energy lost in heat production was 32%. In agreement, Vandehaar (2011) reported that about a third of MEI is lost as heat associated with fermenting, digesting, and metabolising nutrients.

In both breeds, the estimated energy intake increased with parity and lactation stage. Mature Holstein and Jersey cows had GEI 18.2 vs. 16.8% and NEI 17.1 vs.15.9% higher than that of their primiparous counterparts, respectively. With lactation stages, the estimated GEI in transition cows was 25.7 vs. 23.9% and NEI 24.2 vs. 22.6% lower than that of late lactation cows for Holsteins and Jerseys, respectively. Because DMI in this study reached the peak in mid-lactation, peak energy intake was also achieved in mid-lactation, with no difference observed between mid and late lactation stages (Table 4.4).

4.4.5 Estimated partitioning of net energy intake (NEI)

The amount of energy available to the cow and how it is partitioned between maintenance, milk production, pregnancy and growth determines production efficiency. The overall mean estimated NEI for Holstein and Jersey cows was 120±0.7 vs. 99±0.7 MJ/day, respectively. The estimated maintenance and net lactation energy requirements comprised 79±0.4 vs. 61±0.4 MJ/day and 72±0.7 vs. 61±0.7 MJ/day in Holstein and Jersey cows, respectively.

As expected, in both breeds, the estimated NEI increased with parity and lactation stage, reaching peaks between 101 to 135 days in milk, and levelled thereafter (Figure 4.8). This is related to the increase in the estimated daily feed intake of cows. The NEm showed a decreasing trend post-calving, reaching the lowest point between 31 to 65 days in milk, coinciding with peak milk yield. The NEm thereafter increased and levelled from 241 days in milk as the cows were approaching the dry phase (Figure 4.9). Net energy requirements for lactation increased with parity but decreased as lactation stages progress (Figure 4.10), indicating a shift from prioritising lactation needs to improving body reserves and prioritising foetal demands as some of the cows were pregnant.

As a proportion of NEI, the estimated mean NEm was 67.5±0.3 vs. 63.4±0.3% and NElact 60.5±0.4 vs. 62.5±0.4% in Holsteins and Jerseys, respectively. Because NEm is proportional to BW, a greater proportion of estimated NEI was allocated to maintenance in Holsteins compared to Jerseys (Table 4.4). In agreement, Lopez-Villalobos *et al.,* (2000) reported that Jerseys required 5.5% less maintenance feed than Holsteins.

Table 4.4 The mean (±SE) energy partitioning parameters of Holstein and Jersey cows as affected by parity and lactation stage

	Parity										
	1		2		3		4+		P-values		Interactions
	H	J	H	J	H	J	H	J	Breed	Parity	BxP
No. of records	891	737	579	541	395	437	450	546			
GEI	275^{d} ±1.9	228^{g} ±2.1	307^{c} ±2.1	247^{f} ±2.2	323^{b} ±2.3	264^{e} ±2.3	336^{a} ±2.3	274^{d} ±2.3	<.01	<.01	<.01
DEI/GEI	69^{d}±0.1	71^{a}±0.1	68^{e}±0.1	70^{b}±0.01	67^{f}±0.1	69^{c}±0.1	67^{g}±0.1	69^{d}±0.1	<.01	<.01	0.02
MEI/GEI	57.6^{d} ±0.1	58.9^{a} ±0.1	57.0^{d} ±0.1	58.3^{b} ±0.1	56.7^{e} ±0.1	57.9^{c} ±0.1	56.5^{f} ±0.1	57.7^{d} ±0.1	<.01	<.01	0.02
NEI	107^{d} ±0.7	90^{g} ±0.8	119^{c} ±0.8	97^{f} ±0.8	125^{b} ±0.8	103^{e} ±0.8	129^{a} ±0.8	107^{d} ±0.8	<.01	<.01	<.01
NEI/GEI	39.0^{c} ±0.02	39.5^{a} ±0.02	38.7^{d} ±0.02	39.3^{b} ±0.02	38.6^{de} ±0.02	39.1^{c} ±0.02	38.5^{e} ±0.02	39.0^{c} ±0.02	<.01	<.01	0.02
NEm	73^{d} ±0.4	57^{h} ±0.4	78^{c} ±0.4	61^{g} ±0.4	81^{b} ±0.4	63^{f} ±0.5	84^{a} ±0.4	65^{e} ±0.5	<.01	<.01	<.01
NElact	61^{e} ±0.7	53^{f} ±0.8	71^{c} ±0.8	59^{e} ±0.9	76^{b} ±0.9	65^{d} ±0.9	80^{a} ±1.0	68^{c} ±0.9	<.01	<.01	0.01
EB	-10.1^{c} ±0.5	-4.9^{a} ±0.5	-14.7^{e} ±0.6	-6.2^{b} ±0.6	-17.3^{f} ±0.7	-9.6^{d} ±0.6	-19.4^{g} ±0.7	-10.3^{c} ±0.6	<.01	<.01	<.01

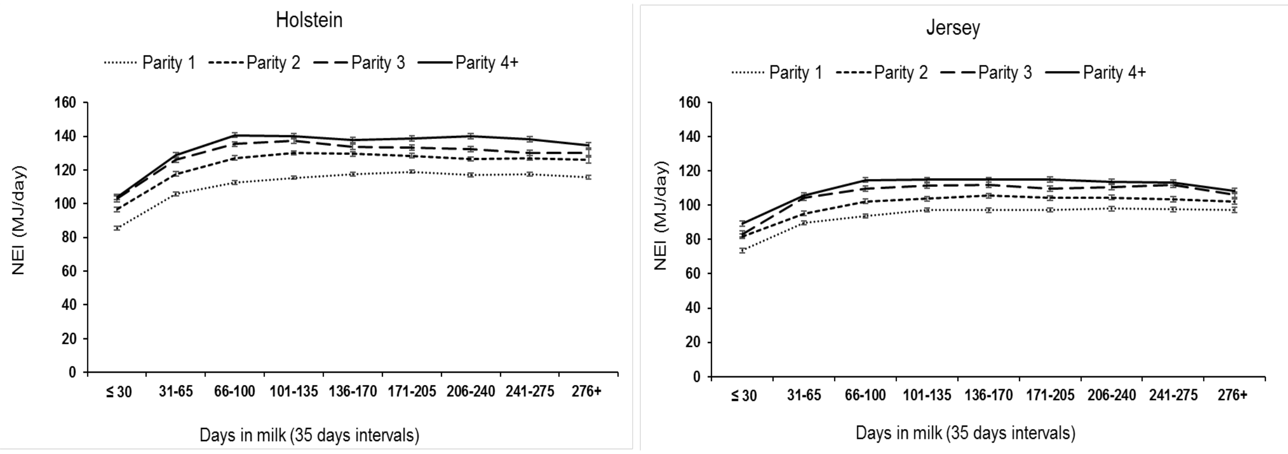
	Lactation stage (days in milk)										
	<30		31-100		101-200		201+		P-values		Interactions
	H	J	H	J	H	J	H	J	Breed	LS	BxLS
No. of records	228	204	581	561	798	776	708	720			
GEI	248^{e} ±2.5	207^{f} ±2.6	321^{b} ±2.0	261^{d} ±2.2	338^{a} ±2.0	275^{c} ±2.1	334^{a} ±2.0	272^{c} ±2.1	<.01	<.01	<.01
DEI/GEI	69.9^{a} ±0.1	71.9^{a} ±0.1	67.1^{e} ±0.1	69.0^{c} ±0.1	66.6^{f} ±0.1	68.4^{d} ±0.1	66.7^{f} ±0.1	68.5^{d} ±0.1	<.01	<.01	0.07
MEI/GEI	58.5^{b} ±0.1	59.8^{a} ±0.1	56.7^{e} ±0.1	57.9^{c} ±0.1	56.3^{f} ±0.1	57.5^{d} ±0.1	56.4^{f} ±0.1	57.6^{d} ±0.1	<.01	<.01	0.07
NEI	97^{f} ±0.9	82^{g} ±1.0	124^{c} ±0.7	102^{e} ±0.8	130^{a} ±0.7	107^{d} ±0.8	128^{b} ±0.7	106^{d} ±0.8	<.01	<.01	<.01
NEI/GEI	$39.3±0.02^{b}$	$39.9±0.02^{a}$	$38.6±0.02^{e}$	$39.1±0.02^{c}$	$38.4±0.02^{f}$	$38.9±0.02^{d}$	$38.5±0.02^{f}$	$39.0±0.02^{cd}$	<.01	<.01	0.07
NEm	78^{b} ±0.4	61^{f} ±0.5	77^{b} ±0.4	60^{g} ±0.4	79^{b} ±0.4	61^{f} ±0.4	82^{a} ±0.4	63^{e} ±0.4	<.01	<.01	<.01
NElact	78^{a} ±1.0	67^{c} ±1.1	77^{a} ±0.8	65^{d} ±0.9	70^{b} ±0.8	59^{e} ±0.8	64^{d} ±0.8	54^{e} ±0.8	<.01	<.01	0.07
EB	-53.9^{g} ±0.8	-39.7^{f} ±0.8	-17.5^{e} $±0.55^{e}$	-8.9^{d} ±0.6	2.2^{c} ±0.5	7.0^{b} ±0.5	7.6^{b} ±0.5	10.6^{a} ±0.53	<.01	<.01	<.01

$^{a-h}$ Means within rows with different superscripts differ at $P<0.05$

ECM: Energy corrected milk, **GEI:** MJ gross energy intake, **DEI:** digestible energy intake, **MEI:** metabolisable energy intake, **NEI:** net energy intake, **NEm:** net energy for maintenance, **NElact:** net energy for lactation, **EB:** energy balance

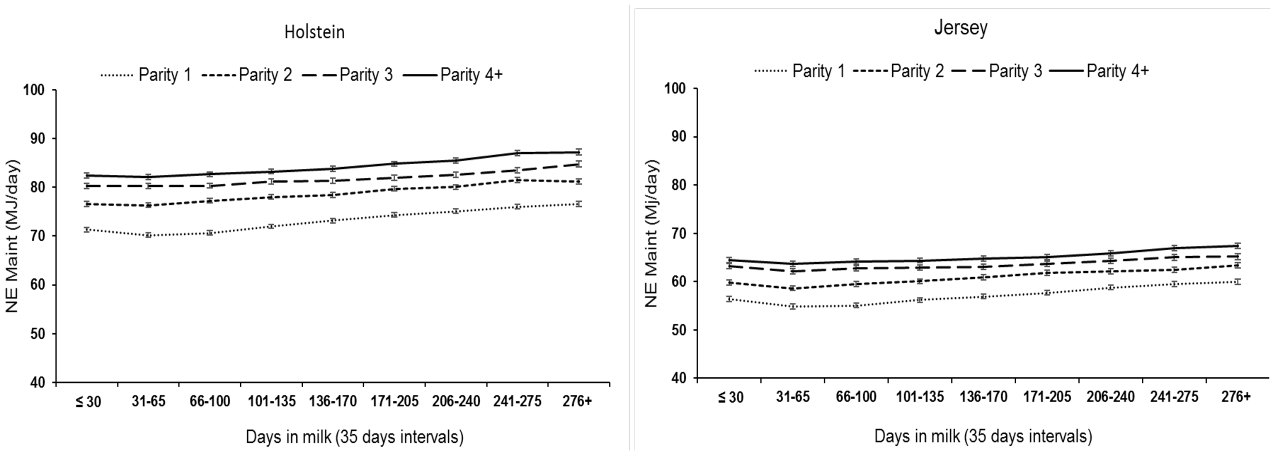
In contrast, Olson *et al.* (2010) reported no difference in maintenance energy allocation between the two breeds, 27.4 vs. 26.2% when expressed as a proportion of GEI. The high solid content (especially milk fat which is energy dense) of Jersey milk, can be associated with the estimated higher allocation of NEI to NElact in Jerseys compared to Holsteins (Table 4.4) despite their significantly lower MY.

Due to the bigger frame size and also the calf size at birth, the estimated energy requirements for growth, 9.4±3.0 vs. 2.6±2.1 MJ/day and pregnancy requirements, 15.7±0.14 vs. 10.3±0.09 MJ/day were higher in Holsteins compared to Jerseys. From these proportions, it can be observed that the estimated animal requirements exceeded the predicted energy intake, indicating that the deficit will have to be provided for by body reserves. The deficit, however, occurred only during transition and early lactation stages, most cows returned to positive energy balance in mid-lactation (Figure 4.11).



(a) (b)

Figure 4.8 Least squares means (±SE) of net energy intake of (a) Holstein and (b) Jersey cows as affected by parity and days in milk



(a) (b)

Figure 4.9 Least squares means (±SE) of net energy for maintenance of (a) Holstein and (b) Jersey cows as affected by parity and days in milk

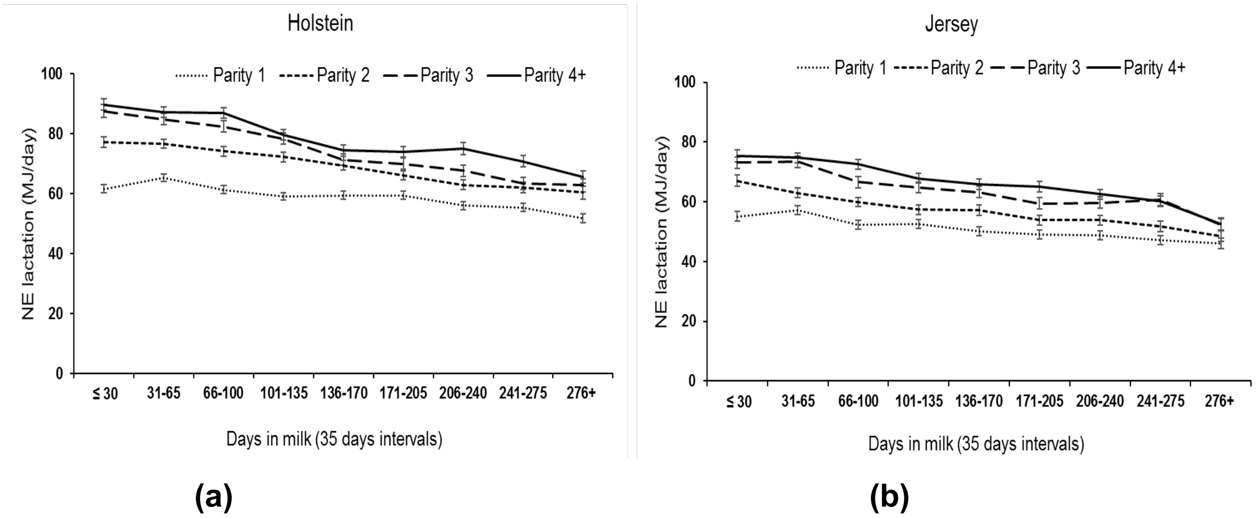
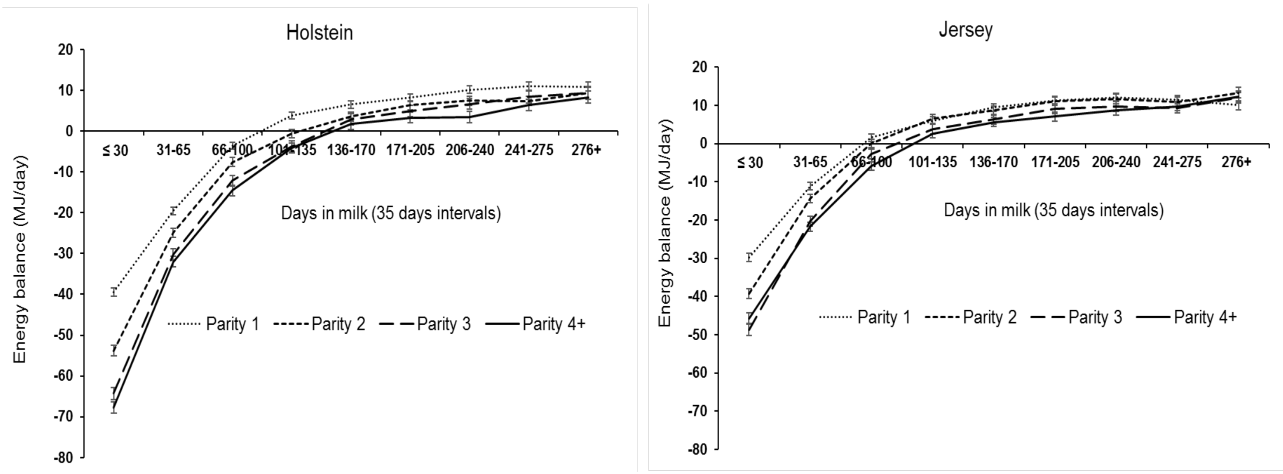


Figure 4.10 Least squares means (±SE) of net energy for lactation of (a) Holstein and (b) Jersey cows as affected by parity and days in milk

4.4.6 Estimated energy balance and mobilisation of body reserves

The estimated energy balance calculated imply that cows were in negative energy balance (NEB) in transition and early lactation stages (Table 4.4). This is in line with expectation as during the transition period, DMI is often lower in relation to nutrient requirements of the animal. The decline in DMI in the late dry period relative to the high energy requirements of the pregnant cow triggers the beginning of the NEB (Butler, 2003; Useni *et al.*, 2018). The rapid rise in nutrient requirements for the initiation of milk synthesis after calving, essentially doubling overnight (Drackley *et al.*, 2005) and the high milk productions peaking in early lactation while DMI is still lagging behind triggers homeorhetic regulations controls to alter nutrient use by tissues to support the changing priorities of lactation, resulting in NEB (Bauman & Currie, 1980). According to Bauman & Currie (1980), the lactation process is extensive, and in terms of nutrients and energy use, the cow should perhaps be viewed as an appendage to the mammary gland rather than vice versa.

The estimated NEB intensity was higher in Holsteins, reaching nadir at -53.9±0.8 MJ compared to -39.7±0.8 MJ in Jerseys (Table 4.5). This can be attributed to the lower DMI/kg BW in this breed, which may suggest lower energy intake. In agreement, Friggens *et al.* (2007) reported a shorter and less intense NEB in Jerseys compared to Holsteins. Washburn *et al.* (2002), reported lower body condition scores (which can be seen as a proxy for NEB intensity) in Holsteins compared to Jerseys that were kept both on pasture and under intensive systems.



(a) **(b)**

Figure 4.11 Least squares means (±SE) of energy balance of (a) Holstein and (b) Jersey cows as affected by parity and days in milk

NEB intensity also increased with parity in both breeds. Older cows produce more milk, suggesting that more energy is channelled to milk production than body reserves. In agreement, Gallo *et al.* (1996) reported less marked depletion and recovery of body reserves in primiparous cows compared to multi-parous ones. Friggens *et al.* (2007) found a lower energy mobilisation in primiparous cows compared to second and third parity cows while Lee & Kim (2006) reported an increase in loss (P<0.01) and delayed recovery of body condition with increase in parity (P<0.01).

The number of days it took to reach NEB nadir did not differ between breeds, 23.6±12.2 vs. 28.5±17.8 days, 24.0±13.3 vs. 24.8±13.4 days, 22.5±11.7 vs. 20.0±12.2 days and 19.2±10.0 vs. 24.8±12.8 days (P=0.076) from parity 1 to 4 in Holstein and Jersey cows, respectively. The duration of NEB was, however, longer in Holsteins than Jerseys (Table 4.5). In agreement, Rastani *et al.* (2001) reported a tissue energy balance nadir of −6.19 Mcal/day (-26 MJ/day) that occurred at week 1 of lactation and lasted for 7 weeks in Jerseys while with Holsteins was −12.9 Mcal/day (-54 MJ/day) occurring at week 2 and prolonged for 11 weeks.

NEB duration also increased with parity (P<0.01). The delayed recovery in body condition with parity can probably be attributed to slower cell growth and regeneration in older animals in comparison to younger cows. Moreover, older cows produce more milk, suggesting that they partition more energy to milk production instead of their body reserves. Lee & Kim (2006) reported increased risk of metabolic disorders with increasing parity, which they associated with increased milk yield and prolonged NEB.

The slower recovery can also be associated with changes in body composition. Energy deficit is provided for by the catabolism of body fat reserves and muscles. Growth comes with an increase in muscle mass and often a decrease in adipose tissue. Adipose tissue is the main site for lipid synthesis, storage and mobilisation (Wærp *et al.*, 2018) while the muscle fibre is composed mainly of protein. The catabolism of fat yields more than twice (about 2.25 times) energy per unit mass compared to protein or carbohydrates (McDonald *et al.*, 2002) suggesting another possible reason of delayed recovery with advancing parity.

4.4.7 Efficiency of energy use for milk production

The efficiency with which energy is used for lactation or milk production is a key driver of production efficiency (Xue *et al.*, 2011). Jersey cows used proportionally less mean test-date NEI to produce 100 g MF 13.7±0.10 vs. 12.5±0.10, 100 g Mprot 16.7±0.14 vs.16.2±0.15 and a kg ECM 5.52±0.04 vs. 5.35±0.04. In agreement, Mackle *et al.* (1996) reported a higher efficiency of converting MEI to milk energy output, 37 vs. 43% in Jerseys compared to Holsteins. Kristensen *et al.* (2015) also observed higher efficiency in Jerseys, producing 2.25 kg ECM/10 MJ of NEI while Holstein produced 2.09 kg ECM/kg/10 MJ of NEI. Using solids corrected milk as a proxy for ECM, however, Blake *et al.* (1986) reported no difference in energy efficiency between Holstein and Jersey cows.

In both breeds, NEI/100 g MF, NEI/100g Mprot and NEI/kg ECM decreased with parity, which can be seen as indicating higher efficiency with maturity. Except for during the transition period where the two breeds did not differ, Jersey cows showed higher efficiency in NEI/100 g MF (Table 4.5). With lactation stages, the two breeds did not differ in NEI/kg ECM during the transition and early lactation stages but in later stages, Jerseys used less NEI/kg ECM (Table 4.5). The NEI/kg ECM increased with lactation stages, suggesting that body reserves were used to meet lactation needs in the early stages.

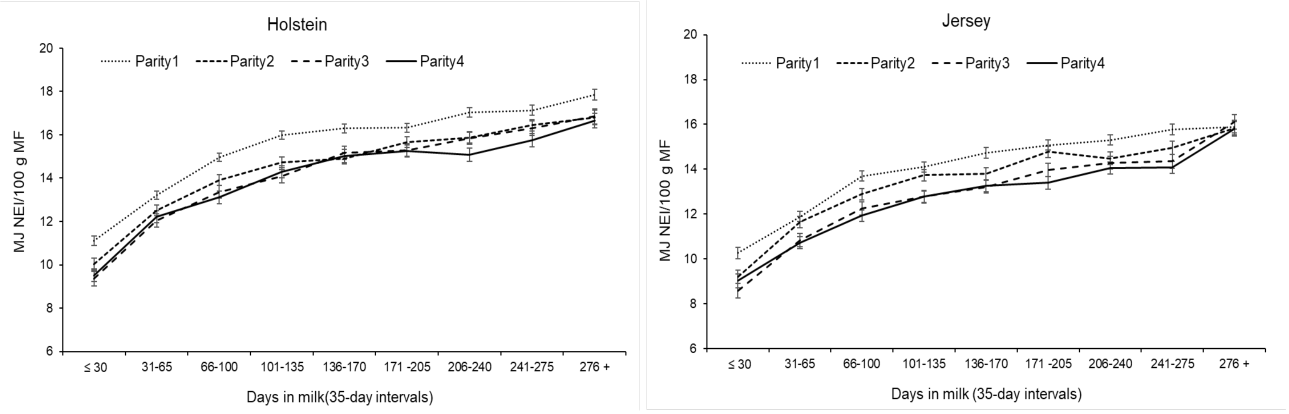
Blake and Custodio (1984) defined feed efficiency as the rate of converting dietary nutrients to milk after adjustment for nutrients supplied by catabolism (e.g., negative energy balance) or nutrients divert to replenish tissue reserves.

Table 4.5 The mean (±SE) energy efficiencies of Holstein and Jersey cows as affected by parity and lactation stage

	Parity										
	1		2		3		4+		P-values		
	H	J	H	J	H	J	H	J	Breed	Parity	B×P
Energy balance	-35.7^{b}±15.6	-23.4^{a}±13.7	-47.4^{c}±20.0	-33.1^{b}±15.6	-57.8^{d}±19.7	-44.3^{c}±14.1	-62.5^{d}±19.9	-40.4^{bc}±16.6	<.01	<.01	0.08
Days in NEB	83.7^{bc}±32.7	66.2^{d}±31.7	97.1^{a}±33.0	66.8^{d}±28.5	115.2^{a}±34.8	79.5^{cd}±28.0	113.6^{a}±32.2	84.6^{bc}±34.8	<.01	<.01	0.07
NElact/NEI	57.0^{e} ±0.4	59.2^{d} ±0.4	60.4^{d} ±0.5	61.3^{c} ±0.5	61.9^{bc} ±0.5	64.4^{a} ±0.5	62.9^{b} ±0.5	64.9^{a} ±0.5	<.01	<.01	0.09
NEm/NEI	69.1^{a} ±0.3	64.2^{c} ±0.3	67.5^{b} ±0.4	63.8^{cd} ±0.4	66.8^{b} ±0.4	63.0^{d} ±0.4	66.7^{b} ±0.4	62.4^{d} ±0.4	<.01	<.01	0.05
NEI/100gMF	14.7^{a}±0.11	13.3^{bc}±0.12	13.6^{b}±0.13	12.7^{c}±0.14	13.3^{bc}±0.15	12.1^{d}±0.15	13.2^{bc}±0.15	12.0^{d}±0.15	<.01	<.01	0.24
NEI/100gMprot	17.9^{a}±0.15	17.4^{ab}±0.17	16.8^{b}±0.18	16.6^{bc}±0.19	16.3^{bc}±0.21	15.5^{d}±0.20	16.0^{cd}±0.21	15.2^{d}±0.20	<.01	<.01	0.10
NEI/ECM	5.88^{a} ±0.04	5.67^{ab} ±0.05	5.52^{b} ±0.05	5.46^{b} ±0.05	5.38^{c} ±0.06	5.18^{de} ±0.06	5.29^{cd} ±0.06	5.09^{e} ±0.06	<.01	<.01	0.09
(NEI-NEm)/ECM	1.86^{d} ±0.01	2.05^{a} ±0.01	1.82^{e} ±0.01	1.99^{b} ±0.01	1.82^{e} ±0.01	1.94^{c} ±0.01	1.79^{e} ±0.01	1.93^{c} ±0.01	<.01	<.01	<.01
NEI/BW$^{0.75}$	0.68^{a} ±0.02	0.67^{b} ±0.02	0.68^{a} ±0.02	0.67^{b} ±0.02	0.68^{a} ±0.02	0.68^{a} ±0.02	0.68^{a} ±0.02	0.68^{a} ±0.02	<.01	<.03	0.04
NEm/BW$^{0.75}$	0.47^{a} ±0.02	0.43^{c} ±0.02	0.46^{b} ±0.02	0.43^{c} ±0.02	0.45^{b} ±0.03	0.42^{d} ±0.03	0.45^{b} ±0.03	0.42^{d} ±0.03	<.01	<.01	0.05
	Lactation stage (days in milk)										
	<30d		31-100		101-00		201+		Breed	LS	B×LS
Energy balance	-53.9^{g}±0.76	-39.7^{f}±0.80	-17.5^{e}±0.55	-8.9^{d}±0.56	2.2^{c}±0.50	7.0^{b}±0.52	7.6^{b}±0.53	10.6^{a}±0.53	<.01	<.01	<.01
NElact/NEI	78.9^{a} ±0.6	81.3^{a} ±0.6	61.4^{b} ±0.4	63.1^{b} ±0.5	52.9^{c} ±0.4	54.7^{c} ±0.4	48.9^{d} ±0.4	50.6^{d} ±0.4	<.01	<.01	0.84
NEm/NEI	81.9^{a} ±0.4	75.8^{b} ±0.5	63.0^{d} ±0.3	59.5^{f} ±0.4	61.3^{e} ±0.3	57.8^{g} ±0.3	64.0^{c} ±0.3	60.3^{f} ±0.3	<.01	<.01	<.01
NEI/100gMF	10.0^{f}±0.17	9.3^{f}±0.17	13.2^{d}±0.12	12.0^{e}±0.13	15.2^{b}±0.12	13.8^{c}±0.12	16.4^{a}±0.12	15.0^{b}±0.12	<.01	<.01	<.01
NEI/100gMprot	12.6^{d}±0.23	12.0^{d}±0.23	16.4^{c}±0.17	15.9^{c}±0.18	18.5^{b}±0.16	17.8^{b}±0.16	19.5^{a}±0.17	19.0^{ab}±0.17	<.01	<.01	0.59
NEI/ECM	4.11^{d} ±0.06	3.95^{d} ±0.07	5.24^{c} ±0.05	5.11^{c} ±0.05	6.09^{b} ±0.05	5.89^{b} ±0.05	6.63^{a} ±0.05	6.43^{a} ±0.05	<.01	<.01	0.69
(NEI-NEm)/ECM	0.71^{g} ±0.02	0.93^{f} ±0.02	1.92^{e} ±0.01	2.05^{d} ±0.01	2.32^{c} ±0.01	2.45^{b} ±0.01	2.34^{c} ±0.01	2.49^{a} ±0.01	<.01	<.01	<.01
NEI/BW$^{0.75}$	0.67^{b} ±0.03	0.67^{b} ±0.03	0.68^{a} ±0.02	0.68^{a} ±0.02	0.68^{a} ±0.02	0.68^{a} ±0.02	0.68^{a} ±0.02	0.68^{a} ±0.02	<.01	0.10	0.58
NEm/BW$^{0.75}$	0.55^{a} ±0.03	0.50^{b}±0.03	0.43^{d} ±0.02	0.40^{g} ±0.02	0.42^{e} ±0.02	0.39^{h} ±0.02	0.44^{c} ±0.02	0.41^{f} ±0.02	<.01	<.01	<.01

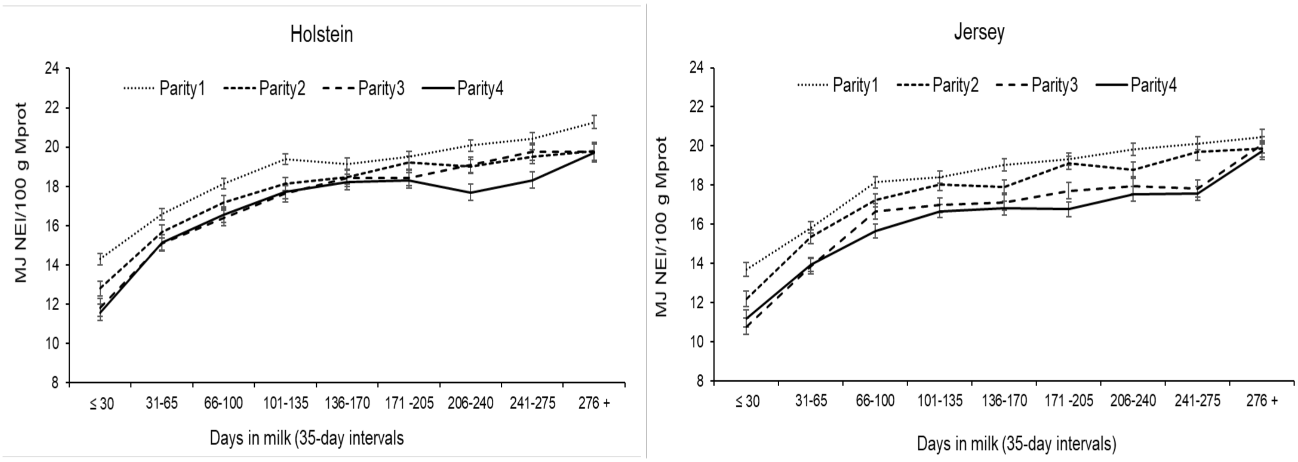
$^{a-h}$ Means within rows with different superscripts differ at $P<0.05$

ECM: Energy corrected milk, **NElact/NEI:** MJ net energy for lactation/MJ net energy intake, **NEm/NEI:** MJ net energy for maintenance/MJ net energy intake, **NEI/ECM:** Net energy intake/kg ECM, **NEI/BW$^{0.75}$:** MJ net energy intake/kg metabolic weight, **NEm/BW$^{0.75}$:** MJ net energy for maintenance/kg metabolic weight



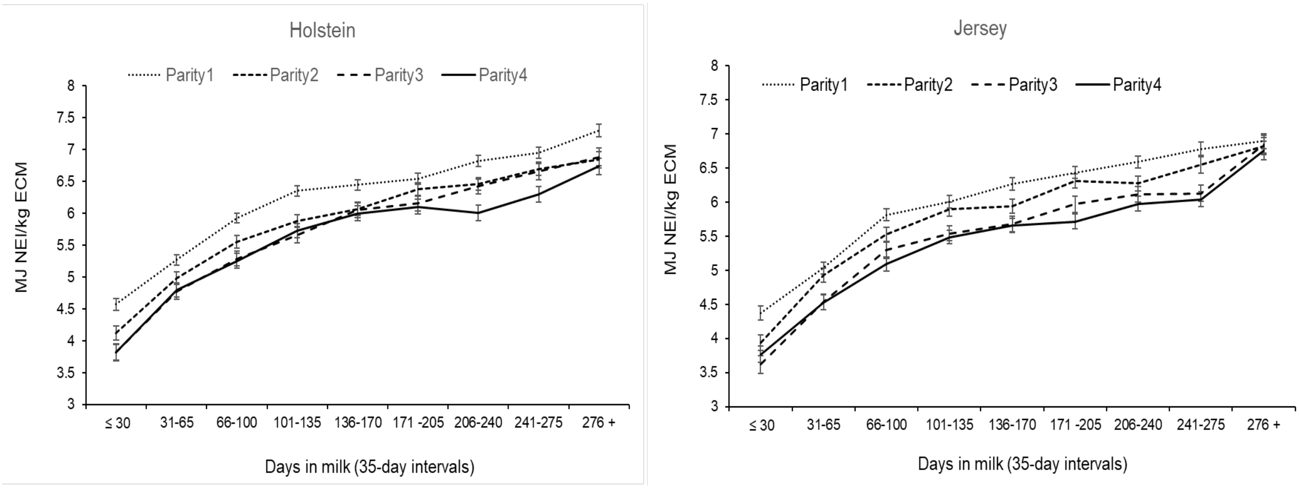
(a) **(b)**

Figure 4.12 Least squares means (±SE) of NEI/100g MF of (a) Holstein and (b) Jersey cows as affected by parity and days in milk



(a) **(b)**

Figure 4.13 Least squares means (±SE) of NEI/100g Mprot of (a) Holstein and (b) Jersey cows as affected by parity and days in milk



(a) **(b)**

Figure 4.14 Least squares means (±SE) of NEI/kg ECM of (a) Holstein and (b) Jersey cows as affected by parity and days in milk

The NEI utilised to produce 1 kg ECM after accounting for NEm, (NEI-NEm)/ECM (which can be seen as gross efficiency) was higher in Jerseys than Holstein in all parities and lactation stages (Table 4.4), indicating inefficiency in Jerseys. Rastani et al. (2001) also reported a higher gross efficiency in Holsteins (0.86 vs. 0.74) compared to Jerseys. The higher efficiency of Holsteins can be associated with the high rates of tissue mobilisation in this breed. Holsteins in this study had a longer and more intense NEB, indicating prioritising milk production over building body reserves.

4.4.8 Efficiency of energy use for body weight

The estimated test-date NEI/kg $BW^{0.75}$ was higher in Holsteins compared to Jerseys, 0.68 vs. 0.67 MJ/kg $BW^{0.75}$ ($P<0.01$), although only primiparous and second lactation Jerseys had high efficiency of NEI/kg$BW^{0.75}$, there was no breed effect in later parities (Table 4.5). Rastani *et al.* (2001) reported no breed effect in NEI/kg $BW^{0.75}$ ($P= 0.89$) and Tyrrell *et al.* (1991) also found no differences in milk energy output per kg $BW^{0.75}$ although Holsteins produced approximately 30% more milk than Jerseys. With lactation stages, both breeds showed higher efficiency in transition period which can be associated with mobilisation of body reserves (Figure 4.11). Breeds, however, did not differ (Table 4.5).

Holstein cows had higher NEm/kg $BW^{0.75}$ compared to Jersey cows, being 0.46±0.002 vs. 0.43±0.002 MJ/kg $BW^{0.75}$. Olson *et al.* (2010) reported no difference in NEm/kg $BW^{0.75}$ between the two breeds. Capper & Cady (2012) observed maintenance energy requirement of 54 MJ/day in mature Jersey cows that weighed on average 454 kg, and 76 MJ/day in mature Holsteins with the average weight of 680 kg. When expressed as NEm/kg $BW^{0.75}$, this was 0.57 and 0.55 MJ/kg $BW^{0.75}$ for Holsteins and Jerseys, respectively, suggesting higher NEm/kg $BW^{0.75}$ requirements and therefore lower efficiency in Holstein cows.

4.5 Conclusion

Holstein showed higher efficiency in MY/kg DMI, indicating that they can be considered to be more efficient in a volume-based pricing system. Jerseys' efficiency on MF/kg DMI, Mprot/kg DMI and ECM/kg DMI is indicative that they are more suitable for component-based pricing. Based on the market demand for higher solids, crossbreeding the two breeds to exploit heterosis can be seen as one of the strategies to improve production efficiency.

In both production and energy use, efficiency decreased with advancing lactation stages but increased with parity. In most measured energy use efficiency parameters, Jerseys showed higher efficiency but Holsteins, however, showed higher gross efficiency, that is, NEI use for milk production after accounting for NEm requirements indicating better efficiency of this breed in utilising its body reserves.

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Chapter 5

Estimating nitrogen use efficiency in Holstein and Jersey cows in a kikuyu pasture-based production system

5.1 Abstract

Research on improving nitrogen use efficiency (NUE) has mostly been on nutritional factors and diet manipulation to optimise rumen microbial fermentation as rumen metabolism has been identified as the most important factor contributing to NUE. This resulted in limited available literature on the effect of breed and production stages on NUE. The aim of this study was therefore to estimate NUE and compare performance efficiencies of Holstein and Jersey cows managed under similar environmental conditions. Data were lactation records of 122 Holstein and 99 Jersey cows that were collected from 2005 to 2014. Cows were kept as one herd in a kikuyu pasture-based production system and received on an as-fed basis 7kg of concentrate containing 17% crude protein daily. Dietary rumen degradable and undegradable protein were formulated using the feed formulation package of the Nutritional Dynamic System (NDS) Professional. Animal requirements were calculated using the National Research Council (NRC) and the Cornell Net Carbohydrate and Protein System (CNCPS) equations. The estimated metabolisable protein (MP) for maintenance (MPm), 672±3.9 and 543±4.2 g/day, growth (MPg), 47.9±2.25 vs. 36.3±2.2 g and for lactation (MPlact), 1038±10.3 vs. 888±10.8 g were higher in Holsteins while MP for pregnancy (MPpreg) did not differ between breeds, 40.4±3.2 vs. 45.5±2.4 g/day. Jerseys had higher milk nitrogen (MN)/nitrogen intake (NI) in all parities and lactation stages, mean, 16.8±0.1 vs. 18.2±0.1%. The NI/kg metabolic weight ($BW^{0.75}$) did not differ between breeds. Although Holsteins had higher faecal nitrogen (FN) per day, 219±1.4 vs. 175±1.5 g/day, FN/100 g NI was higher in Jerseys than Holsteins, 30.6±0.01 vs. 31.0±0.01 g. Holsteins, however, had higher urinary nitrogen (UN)/100 g NI, mean 51.7±0.11 vs. 49.7±0.12 g, protein requirement for scurf losses (SPA), 13±0.1 vs. 11±0.1 g and therefore high ManN/kg NI, 82.3±0.1 vs. 80.6±0.1% in all parities and lactation stages. The results from this study suggest a higher NUE in Jerseys compared to Holsteins as can be observed with higher estimated MN/NI and lower ManN/kg NI in Jerseys.

Keywords: similar environment, metabolisable protein, recycled nitrogen, parity, lactation stage, milk nitrogen, faecal nitrogen, urinary nitrogen, manure nitrogen

5.2 Introduction

Protein is on a per kg basis one of the most expensive nutrients in animal diets. However, nitrogen (N) utilisation is lower in ruminants than in non-ruminants such as pigs and poultry (Calsamiglia *et al.*, 2010; Rius *et al.*, 2010). Nitrogen efficiency, defined as gram milk N produced relative to N intake (Foskolos & Moorby, 2018) is estimated to range between 15 and 45% (Baldwin, 1984; Bruchem *et al.,* 1991; Haynes & Williams, 1993; Castillo *et al.*, 2000; Kohn *et al.*, 2005; Huhtanen & Hristov, 2009; Loor & Cohick, 2009; Calsamiglia *et al.*, 2010; Chase *et al.,* 2012; Giallongo *et al.*, 2016). The range is between 13% to 31% for grazing animals and 40% to 45% for animals receiving a total mixed ration under an intensive system (Delagarde *et al.*, 1997; Vérité & Delaby, 2000; Keim & Anrique, 2011).

The dietary N that does not appear in milk is either retained by the animal or excreted in urine and faeces (Dewhurst & Thomas, 1992). The excreted N contributes to pollution as well as wastage of both protein and energy. Urine and manure are the largest sources of ammonia (NH_3) emission (Braam *et al.*, 1997), a major air and water pollutant with harmful effects to the environment (Fenn *et al.*, 2003). The metabolic energy cost associated with excreting excess N in the urine is reported to be 7.3 kcal (30.5 kJ) metabolisable energy for every gram of NH_3 that is converted to urea in the liver (Tyrrell *et al.,* 1970; Ishler, 2016). This can result in lower milk yield (Ishler, 2016) as this is the energy that could have been used to produce milk. Improving nitrogen use efficiency (NUE) results in higher conversion of feed nitrogen and energy into animal products (Powell *et al.*, 2010) and reduced environmental footprint in dairy farming (Kebreab *et al.,* 2001).

Research on improving NUE has mostly been on nutritional factors and diet manipulation to optimise rumen microbial fermentation and N flow to the small intestine (Marini *et al.*, 2004; Reynal & Broderick, 2005; Colmenero & Broderick, 2006; Phuong *et al.*, 2013; Giallongo *et al.*, 2016) as rumen metabolism has been identified as the most important factor contributing to NUE in ruminants (Tamminga, 1992; Calsamiglia *et al.*, 2010). There is limited available literature on the effect of breed and production stages on NUE. In agreement, Phuong *et al*. (2013) reported on insufficiency of studies where detailed energy and nitrogen use of Holstein and Jersey cows have been compared. A study presenting NUE of the two breeds is required to provide information on the comparative performance in the partitioning of total N intake as N output in milk, urine and faeces, pregnancy, and retained or mobilised N in Holstein and Jersey cows under same environmental and management conditions.

Furthermore, most studies on NUE have been carried out only on Holsteins, with fewer studies conducted on Jerseys, especially in Southern Africa. With the consistently growing demand for cheese amongst all concentrated dairy products (Capper & Cady, 2012; MPO, 2019) and a shift towards milk component pricing (Prendiville *et al.,* 2009; Goni, 2014), there is a growing interest in crossbreeding Holstein cows with Jersey sires to improve milk solids production (Prendiville *et al.,* 2009). Results from this study will therefore contribute on the existing information on Jersey cows to help better understand their performance efficiency. The aim of this study was therefore to estimate NUE and compare performance efficiencies of Holstein and Jersey cows managed under the same environmental conditions over a 9-year period. The objectives were to:

- Estimate the effects of parity and stage of lactation on the efficiency of nitrogen conversion to milk in Holsteins and Jersey cows in a pasture-based system.
- Estimate the proportion of nitrogen excreted in urine, faeces and manure.
- Estimate the proportions of MP that are partitioned to maintenance and production functions in Holsteins and Jersey cows in a pasture-based system.

5.3 Materials and methods

5.3.1 Experimental animals and experimental design

Details of experimental animals, experimental area, diet and management of experimental animals are presented in Chapter 3, only a brief summary will be provided in this chapter. The study was conducted at Elsenburg Research Station, Western Cape Department of Agriculture in South Africa. Data were lactation records of 122 Holstein and 99 Jersey cows that were collected on fixed test-dates (10 test-dates per annum) from October 2005 to September 2014. Cows varied from parity 1 to 4+. This resulted in a total of 2315 observations for Holstein and 2261 for Jersey cows. Collected records included cow birth date, calving date, lactation number, BW, kg MY, %MF and %Mprot. Lactation period was divided into four stages: calving to 30 days as post-calving transition ("transition"), 31 to 100 days as early lactation stage, 101 to 200 days as mid-lactation stage, and above 201 days as late lactation stage. Cows grazed as one herd in a kikuyu pasture and were supplemented with a 7 kg commercial concentrate mixture containing 17% crude protein on as fed basis daily. The total dry matter intake (DMI) was estimated using the National Research Council (NRC, 2001) equation with pasture intake estimated as the difference between DMI and concentrate dry matter intake.

5.3.2 Estimating crude protein (CP) and N content of the diet

The pasture and commercial concentrate rumen degradable protein (RDP), rumen undegradable protein (RUP) and total digestible nutrient (TDN) contents were formulated using the feed formulation package of the Nutritional Dynamic System (NDS) Professional (version 6.5, 2008 to 2018). Total CP, RDP and RUP of the DMI were calculated as the sum of the contribution from the concentrate mixture offered and pasture assumed to be consumed. Based on the assumption that dietary protein contains on average 16% N, the nitrogen-to-protein conversion factor, 6.25 was used to convert CP to N.

5.3.3 Estimating metabolisable protein (MP) supply

Metabolisable protein supply was calculated as the sum of g RUP and microbial protein (MCP). The g RUP of the feed was estimated as g CP in feed × %RUP adjusted for TDN. The MCP yield was estimated as 130 g/kg of rumen fermentable organic matter (RFOM) adjusted for 64% availability and physical effective neutral detergent fibre (peNDF) factor (NRC, 2001; Fox *et al.*, 2004; Tedeschi *et al.*, 2015). The peNDF of the diet was above 20%. When the peNDF is 20% and above, the peNDF factor is equal to 1 (Fox *et al.*, 2004; Seo *et al.*, 2006), there was therefore no adjusting for peNDF. The RFOM was calculated using the equation by Ørskov & Mcdonald (1979) as follows:

RFOM = a + bc /(c + k)……………………………………………………………..………eq 1

Where a = the soluble fraction

b = insoluble but potentially rumen degradable fraction

c = insoluble fraction and

k = fractional outflow rate of feed ingredients.

The a, b and c fractions were obtained from Nutritional Dynamic System (NDS) Professional (version 6.5, 2008 to 2018) while the passage rate (k) for forage and concentrate were calculated using the equations by Seo *et al.* (2006):

K*p* concentrate = (1.169 + 0.1375 × FpBW + 0.1721 × CpBW) /100……………….…...eq 2

K*p* forage = (2.365 + 0.0214 × FpBW + 0.0734 × CpBW + 0.069 × FDMI)/100………...eq 3

Where FpBW = the forage DMI as a proportion of BW (g/kg BW)

CpBW = the concentrate DMI as a proportion of BW (g/kg BW) and

FDMI = the forage DMI, kg/day.

5.3.4 Estimating animal requirements

The metabolisable protein requirements for maintenance (MPm) were calculated using the equation by Tedeschi *et al.* (2015), lactation (MPlact) (NRC, 2001; Tylutki *et al.*, 2008), pregnancy (MPpreg) (NRC, 2001; Tylutki *et al.,* 2008), growth (MPg) and net protein for growth (NPg) (Fox *et al.*, 2004; Tedeschi *et al.*, 2015). Accounting for pregnancy started at 190 (Tylutki *et al.*, 2008) and mammogenesis at 259 days pregnant (VandeHaar, 1999; Bell *et al.*, 2000; Fox *et al.*, 2004). The MP balance was computed as the difference between MP supply and animal requirements. Below are the equations that were used:

$MPm = (2.75 \times SBW^{0.5})/0.67 + (0.20 \times SBW^{0.6})/0.67 + (0.09 \times IDM)$……………..…..………eq 4

Where SBW = shrunk body weight, i.e., (kg BW×0.96)

IDM = indigestible dry matter (g), i.e., ((100 – %TDN) × g DMI)

$MPlact = MY \times ((MTP / 100) / 0.67) \times 1000$………………….…………………………..….eq 5

Where MTP = milk true protein, i.e., %Mprot × 0.93

MY = milk yield (kg/day)

$MPpreg = ((0.69 \times t) - 69.2) \times (CBW / 45) / 0.33$……………………………………..…..….eq 6

Where t = days pregnant

CBW = average birth weight of calves at Elsenburg Research Station

$MPg = NPg / (0.834 - EqSBW \times 0.00114)$…………………….………...…………...…eq 7

Where EqSBW = equivalent shrunk body weight, i.e., (SBW × mature BW)/AFBW

AFBW = mature SBW, i.e., mature BW × 0.96

$NPg = SWG \times (268 - 29.4 \times RE/SWG)$…………………………..…………..……...eq 8

Where SWG = shrunk weight gain i.e., average daily gain

RE = retained energy, i.e., (DMI – DMI for maintenance) × NEm

5.3.5 Estimating N output

The N output in milk was estimated as: (g Milk/day × %Mprot)/6.38……..………………..eq 9

The faecal N (FN) and urinary N (UN) were estimated using the equations by Higgs *et al.* (2012) as follows:

FN g/day = [{[NI (g/kg OM) × (1–0.842)] + 4.3} × OMI (kg/d)] × 1.20……..…………….eq 10

Where FN = faecal nitrogen (g/day)

NI = nitrogen intake (g/day) and

OM = organic matter (kg/day), i.e., DMI – ash

UN g/day = NI − {FN + [(SPA + MPpreg + MPg)/6.25] + [(MY×Mprot×10) /6.38]}……..eq 11

Where UN = urinary nitrogen (g),

SPA = protein requirement for scurf losses, and

MP = metabolisable protein

SPA g/day = (0.20 × SBW$^{0.6}$)/0.67, (NRC, 2001; Fox *et al.,* 2004)……..……..………...eq 12

Where SBW = shrunk body weight (BW × 0.96), (Fox *et al.,* 2004)………...…...eq 13

Manure nitrogen g/day = FN + UN + SPA…………………………………………………eq 14

5.3.6 Efficiency estimates

Milk nitrogen (MN) efficiency was calculated as MN/NI and NUE for BW as NI/kg BW$^{0.75}$. For faecal, urine and manure N, efficiencies were computed as FN/NI, UN/NI, and (FN+UN+SPA)/NI, respectively.

5.3.7 Statistical analysis

Data were analysed using the repeated measures methods available in the PROC MIXED procedure of SAS Enterprise Guide version 7.1. The fixed effects were breed, parity, lactation stage and test-dates (days in milk). Their interaction effects were breed × lactation stage, breed × parity and breed × parity × test-dates. The cow was the experimental unit where the response variables were measured every test-date in each parity. To account for individual variation in experimental units, cow within breed was fitted as a random effect. The least squares means for the interaction effects of breed × parity × days in milk for MN/NI, FN/NI, UN/NI and (ManN) FN + UN + SPA)/NI obtained from different test-dates were regressed against parity and fitted in a curve to determine NUE in response to production stages. A compound symmetry structure for the residuals was used as covariance structure for repeated measures over time within cows. The between-breeds, between parity and between lactation stage variations and their interactions were compared using the Bonferroni test and were declared different at P<0.05. The following statistical equation was used for analysis:

$Y_{ijkl} = \mu + B_i + P_j + LS_k + (B\times P)_{ij} + (B\times LS)_{ik} + (B\times P\times LS)_{ijk} + cow_l(B_i) + \varepsilon_{ijkl}$

Where:

Y_{ijkl} = dependent / response variable (MPsupply, MPm, MPlact and efficiencies);

μ = overall mean;

B_i = fixed effect of the i^{th} breed (i =Holstein, Jersey);

P_j = fixed effect of the j^{th} parity (j = 1, 2, 3 and 4);

LS_k = fixed effect of the k^{th} lactation stage (l = transition, early, mid and late lactation stages);

$(B\times P)_{ij}$ = fixed interaction effect between breed and parity;

$(B\times LS)_{ik}$ = fixed interaction effect between breed and lactation stage;

$(B\times P\times LS)_{ijk}$ = fixed interaction effect between breed, parity and lactation stage;

$cow_l(B_i)$ = random effect of the l^{th} cow (l = 1 to 221) nested within the i^{th} breed $N \sim (0, \sigma^2_{cow(B)})$;

ε_{ijkl} = random error term $N \sim (0, \sigma^2_{\varepsilon})$.

5.4 Results and discussions

Table 5.1 Estimated RDP, UDP and TDN of the commercial concentrate

Ingredients	% inclusion in the diet	% CP[1] (ingred.)	% CP (conc.)	%RDP[1] (ingred.)	%RUP[1] (ingred.)	%RDP (conc.)	%RUP (conc.)	TDN (conc.)
Wheaten bran	10	17.8	1.78	65	35	1.15	0.62	7.12
Barley	10	11.3	1.13	63	37	0.71	0.42	8.94
Wheat	10	15.8	1.58	65	35	1.02	0.56	8.81
Maize	42	8.60	3.61	50	50	1.80	1.81	37.2
COM	10	42.3	4.23	50	50	2.13	2.10	6.98
SOM	7.5	55.0	4.13	62	38	2.55	1.57	6.29
Fishmeal	1	72.0	0.72	32	68	0.23	0.43	0.767
Urea	0.6	281	1.69	94	6	1.59	0.10	0.00
Molasses	4	4.10	0.16	81	19	0.13	0.03	2.74
Wheat Straw	3	4.80	0.14	55	45	0.08	0.07	0.68
Limestone	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salt	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.1		19.2			11.4	7.71	79.5

CP: crude protein, **RDP:** rumen degradable protein, **RUP:** rumen undegradable protein, **TDN:** total digestible nutrient, **COM:** cottonseed oilcake meal, **SOM:** soybean oilcake meal

[1]Formulated using the NDS Professional, (2008 to 2018)

Pasture CP was on average 18% (Table 3.1). The RDP, 65%, RUP, 35% and TDN, 62.9% used for kikuyu pasture were as supplied in the feed formulation package of the Nutritional Dynamic System (NDS) Professional.

5.4.1 Crude protein and NI

The mean daily CP (4482±30.6 vs. 3531±32.7 g/day) and NI (Table 5.2) of Holsteins was higher than that of Jerseys in all production stages. In both breeds, the estimated NI increased with parity, with NI of primiparous Holsteins being similar to that of mature Jerseys (Table 5.2). In lactation stages, NI increased from transition and reached peak in mid-lactation, followed by a decrease in late lactation (Table 5.2), following a similar trend to that which was observed in DMI. The increase was 30.4% and 29.1% from transition to mid-lactation in Holsteins and Jerseys, respectively.

5.4.2 Metabolisable protein

5.4.2.1 Estimated metabolisable protein supply

This represents the amount of protein that is absorbed in the small intestines and is available for animal use for maintenance and production functions. The estimated RUP was 1655±10.8 vs. 1320±11.5 g/day and MCP, 761±3.0 vs. 668±3.2 g/day. This resulted in a higher estimated MP supply in Holsteins than Jerseys, 2415±13.8 vs.1988±14.7 g/day, ($P<0.01$) with MCP contributing 32±0.1% and 34±0.1% to the total MP supply of Holstein and Jersey cows, respectively.

5.4.2.2 Partitioning of estimated MP to maintenance and production

The calculated MPm was 672±3.9 and 543±4.2 g/day ($P<0.01$) in Holsteins and Jerseys, respectively. As a proportion of NI, estimated MPm was higher in Holsteins compared to Jerseys (Figure 5.1). Because of the smaller BW, primiparous cows of both breeds had lower MPm/NI, thereafter, parity did not have an effect. The estimated MPm/NI was higher in transition cows, this was expected as cows in this stage are known to have a lower DMI and therefore lower NI relative to their nutrient requirements (Table 5.2).

The metabolisable protein requirement for lactation, 1038±10.3 vs. 888±10.8 g was also lower in Jerseys than in Holsteins as Jerseys produce less milk. In both breeds, MP for lactation increased with parity but decreased as lactation stage progressed (Table 5.2,

Figure 5.2). This is because older cows produced more milk, and milk production decreased with lactation stage resulting in less MP requirement for lactation.

Metabolisable protein requirements for growth, 47.9±2.3 vs. 36.3±2.2 g, was lower in Jerseys than in Holsteins as Jerseys are small framed animals. Metabolisable protein for pregnancy did not differ between breeds, 40.4±3.2 vs. 45.5±2.4 g/day (P=0.20). Holsteins were expected to have a higher MP requirement for pregnancy as they give birth to heavier calves. MP balance, 613±6.1 vs. 465±6.3 was positive in all parities and lactation stages suggesting that cows did not secrete milk at the expense of protein reserves.

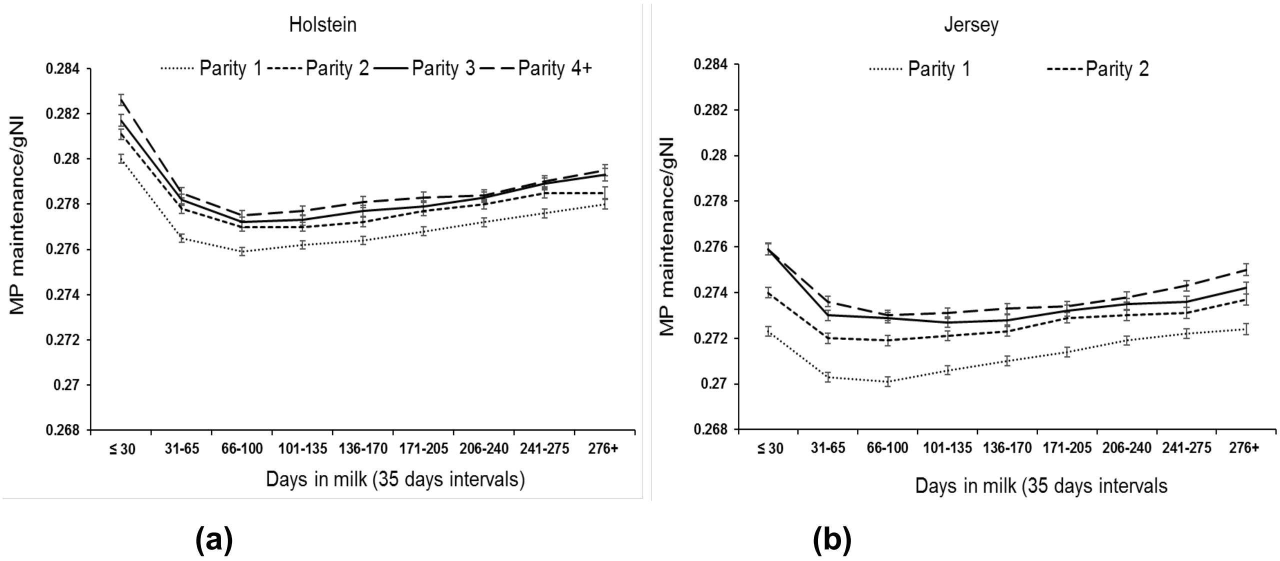


Figure 5.1 Least squares means (±SE) of metabolisable protein for maintenance/NI (MPm/NI) of (a) Holstein and (b) Jersey cows as affected by parity and days in milk

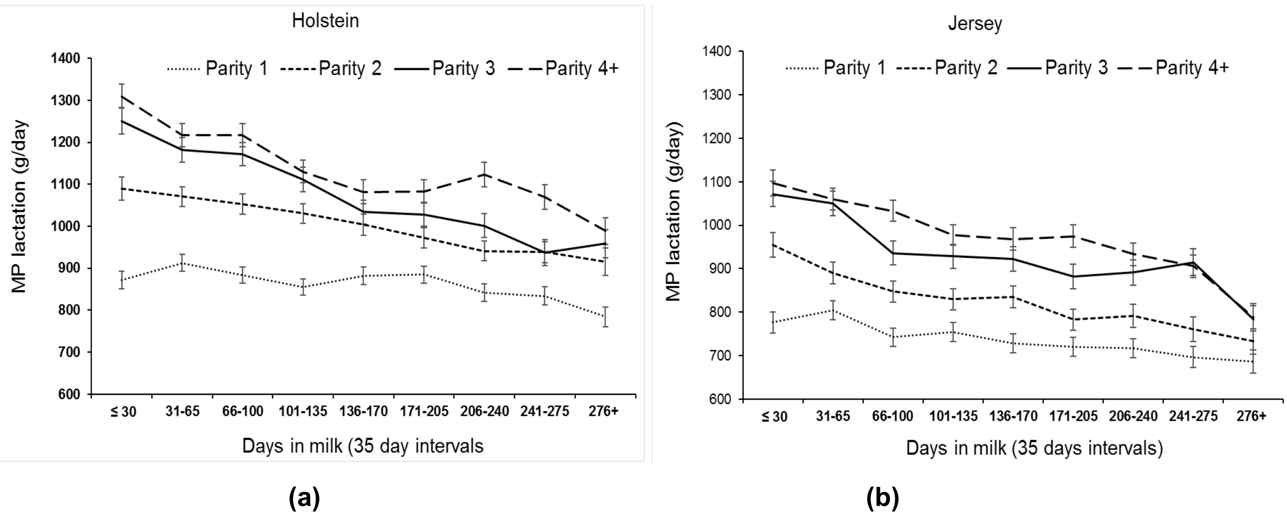


Figure 5.2 Least squares means (±SE) of metabolisable protein for lactation of (a) Holstein and (b) Jersey cows as affected by parity and days in milk

Table 5.2 Least squares means (±SE) of nitrogen intake, metabolisable protein supply and partitioning in Holstein and Jersey cows as affected by parity

	Parity										
	1		2		3		4+		P-values		Interaction
	H	J	H	J	H	J	H	J	Breed	P	B × P
No. of records	891	737	579	541	395	437	450	546			
CP (g)	3896^{d} ±31	3105^{g} ±34	4426^{c} ±35	3425^{f} ±37	4699^{b} ±38	3713^{e} ±39	4906^{a} ±39	3880^{d} ±39	<.01	<.01	<.01
NI (g)	623^{d} ±5	497^{g} ±6	708^{c} ±6	548^{f} ±6	752^{b} ±6	594^{e} ±6	785^{a} ±6	621^{d} ±6	<.01	<.01	<.01
RUP (g)	1449^{d} ±11	1170^{g} ±12	1635^{c} ±12	1283^{f} ±13	1731^{b} ±13	1384^{e} ±14	1804^{a} ±14	1443^{d} ±14	<.01	<.01	<.01
MCP (g)	703^{d} ±3	627^{g} ±3	755^{c} ±3	657^{f} ±4	782^{b} ±4	685^{e} ±4	802^{a} ±4	702^{d} ±4	<.01	<.01	<.01
MP supply (g)	2152^{d} ±14	1797^{g} ±16	2390^{c} ±16	1941^{f} ±17	2513^{b} ±17	2070^{e} ±17	2606^{a} ±17	2145^{d} ±17	<.01	<.01	<.01
MPm (g)	597^{d} ±4	488^{g} ±4	665^{c} ±4	530^{f} ±5	700^{b} ±5	566^{e} ±5	727^{a} ±5	588^{d} ±5	<.01	<.01	<.01
MPm/NI	27.8^{b} ±0.01	27.2^{d} ±0.02	27.9^{a} ±0.02	27.3^{cd} ±0.02	27.9^{a} ±0.02	27.4^{c} ±0.02	27.9^{a} ±0.02	27.4^{c} ±0.02	<.01	<.01	<.01
MP lactation (g)	881^{e} ±11	758^{f} ±12	1022^{c} ±12	846^{e} ±13	1095^{b} ±14	952^{d} ±14	1155^{a} ±14	996^{c} ±14	<.01	<.01	<.01
MP balance (g)	584^{b} ±7	458^{c} ±8	609^{ab} ±8	476^{c} ±8	626^{a} ±10	457^{c} ±9	633^{a} ±10	467^{c} ±9	<.01	<.01	<.01

$^{a\text{-}h}$ Means within rows with different superscripts differ at P<0.05

CP: crude protein, **NI:** nitrogen intake, **RUP:** rumen undegradable protein, **MCP:** microbial protein, **MP:** metabolisable protein, **MPm:** MP for maintenance

Table 5.3 Least squares means (±SE) of nitrogen intake, metabolisable protein supply and partitioning in Holstein and Jersey cows as affected by lactation stage

	Lactation stage (days in milk)										
	<30		31-100		101-200		201+		P-values		Interaction
	H	J	H	J	H	J	H	J	B	LS	B×LS
No. of records	228	204	581	561	798	776	708	720			
CP (g)	3445^{f} ±41	2750^{g} ±44	4658^{c} ±34	3649^{e} ±36	4950^{a} ±33	3882^{d} ±35	4873^{b} ±34	3841^{d} ±35	<.01	<.01	<.01
NI (g)	551^{f} ±7	440^{g} ±7	745^{c} ±5	584^{e} ±6	792^{a} ±5	621^{d} ±6	780^{b} ±5	615^{d} ±6	<.01	<.01	<.01
RUP (g)	1290^{g} ±14	1044^{h} ±15	1717^{c} ±12	1362^{f} ±13	1820^{a} ±12	1444^{d} ±12	1793^{b} ±12	1430^{e} ±12	<.01	<.01	<.01
MCP (g)	660^{f} ±4	593^{g} ±4	778^{c} ±3	679^{e} ±4	806^{a}±3	701^{d} ±3	799^{b} ±3	697^{d} ±3	<.01	<.01	<.01
MP supply (g)	1950^{f} ±18	1638^{g} ±20	2495^{c} ±15	2041^{e} ±16	2626^{a} ±15	2146^{d} ±16	2591^{b} ±15	2127^{d} ±16	<.01	<.01	<.01
MPm (g)	548^{a} ±5	450^{e} ±6	692^{b} ±4	556^{d} ±5	728^{a} ±4	585^{c} ±4	721^{a} ±4	582^{c} ±5	<.01	<.01	<.01
MPm/NI	28.1^{a} ±0.02	27.4^{c} ±0.02	27.7^{b} ±0.02	27.2^{d} ±0.02	27.7^{b} ±0.01	27.2^{d} ±0.02	27.8^{b} ±0.02	27.3^{d} ±0.02	<.01	<.01	<.01
MP lactation (g)	1107^{a} ±16	965^{bc} ±16	1079^{a} ±12	917^{d} ±13	1012^{b} ±11	861^{e} ±12	954^{cd} ±12	809^{f} ±12	<.01	<.01	0.70
MP balance (g)	125^{f} ±11	52^{g} ±12	699^{c} ±8	547^{e} ±8	865^{a} ±7	679^{c} ±7	763^{b} ±8	582^{d} ±8	<.01	<.01	<.01

$^{a-h}$ Means within rows with different superscripts differ at $P<0.05$

CP: crude protein, NI: nitrogen intake, RUP: rumen undegradable protein, MCP: microbial protein, MP: metabolisable protein, MPm: MP for maintenance

5.4.3 Milk nitrogen (MN)

The mean test-date MN of Holsteins was higher than that of Jerseys in all parities and lactation stages (Table 5.4 and 5.5). Holsteins in this study produced approximately 15% more Mprot (0.75±0.01 vs. 0.64± kg/day) than Jerseys. In both breeds, MN increased with parity, mature Jerseys had similar MN with Holsteins in second lactation (Table 5.4) suggesting a higher efficiency of Jerseys in converting NI to MN.

Although the estimated NI increased by 30.4% and 29.1% from transition to mid-lactation, MN decreased by 8.8% and 11.0% in Holsteins and Jerseys, respectively. This indicates that NI is not a good predictor of MN. Unlike MY which was at its peak in early lactation, MN tended to be higher during the transition period compared to early lactation stage, although the two stages did not differ (Table 5.5). This is because there was little difference in kg milk produced per test-date in Holsteins (25.3±0.33 vs. 26.5±0.26 kg) while with Jerseys (19.9±0.35 vs. 19.5±0.27 kg) there was no difference between transition and early lactation stages, respectively. Milk protein was also higher during the transition period than in early lactation, 3.2 vs. 2.94% in Holsteins and 3.51 vs. 3.4% in Jerseys. According to (Tsioulpas *et al.*, 2007) milk might still contain sufficient colostrum 15 days post-partum, suggesting that post-colostrum or transition milk still had higher casein and immunoglobulins concentrations compared to normal milk, hence the higher MN during the transition phase.

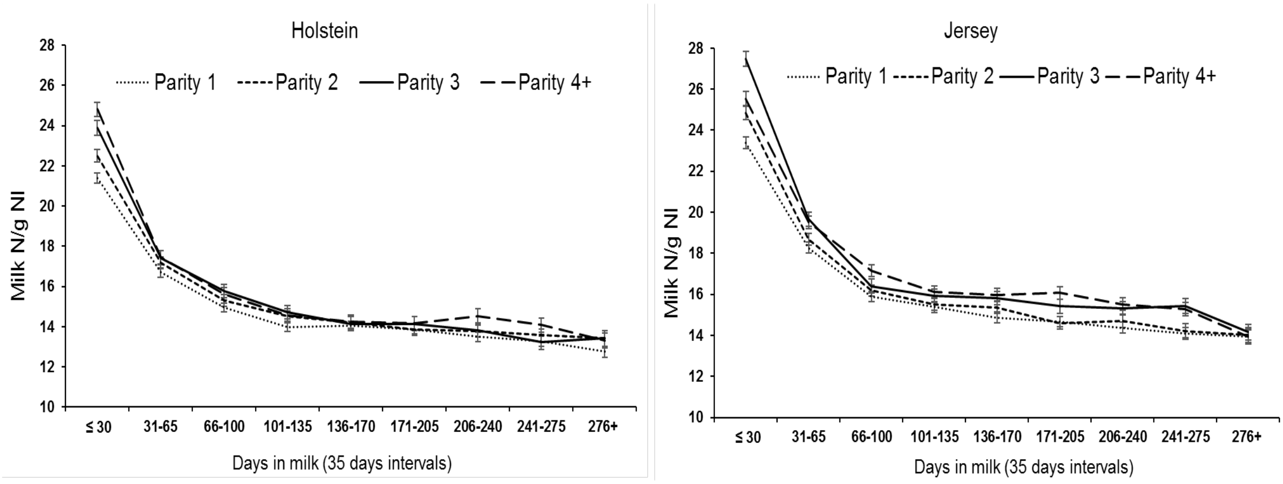
5.4.4 Estimated nitrogen use efficiency for milk production (MN/NI)

The proportion of NI secreted in milk (g MN/g NI) was higher in Jerseys than Holsteins in all parities and lactation stages (Tables 5.4 and 5.5), with the overall mean being 16.8±0.11 vs. 18.2±0.12% ($P<0.01$). In both breeds, NUE for milk production increased by approximately 6% from primiparous to mature cows while it decreased by 41% from transition to late lactation stage (Table 5.4 and 5.5). Although milk production increased with parity, the %Mprot in this study decreased with increasing parity, suggesting the reason for the small improvement in NUE with parity.

In contrast, several authors reported no difference between Holsteins and Jerseys in MN/NI. Blake *et al.* (1986) reported MN/NI of 28 ±8 vs. 30±8% in first trimester and 26±4% vs. 22±4% in the second trimester for Holsteins and Jerseys, respectively. Kauffman & St-Pierre (2001) reported MN/NI of 30.1 vs. 30.9%; Knowlton *et al.* (2010), 25.3 vs. 25.6%

(P=0.86); and Kristensen *et al.* (2015), 27.5 vs. 27.3%, all reporting no difference between Holstein and Jersey cows in MN/NI production. Jerseys in this study produced 85% ECM compared to 74% uncorrected milk yield, suggesting a reason for the higher MN/NI in Jerseys. The remaining N is assumed to have been excreted in urine and faeces.

The findings in this study are within the range often reported for overall utilisation of dietary N for milk synthesis in dairy cows. According to the following authors, the conversion rate of NI to MN in dairy cows is: 10 to 30% (Baldwin, 1984); 15 to 35% (Haynes & Williams, 1993); rarely exceed 0.30 (Bequette *et al.*, 1998); 25 to 30% (Loor & Cohick, 2009); and 16 to 36 % (Powell *et al.*, 2010). Bruchem *et al.* (1991) suggested MN/NI levels below 0.20 (20%) for European dairy cattle; Chase (2004) 28.8% in the United States and Gourley *et al.* (2012) a median value of 0.23 in Victorian herds and 0.26 in the Wisconsin dairy herds.



(a) **(b)**

Figure 5.3 Milk N/NI of (a) Holstein and (b) Jersey cows as affected by parity and days in milk

The NUE of the cows in this study falls under the level that Chase (2003) described as very low efficiency. According to this author, NUE values of less than 0.20 can be defined as very low; 0.20 – 0.25 is low; 0.25 – 0.30 is a typical range that encompasses most on-farm and some experimental feed NUE; 0.30 – 0.35 is above average; and greater than 0.35 is excellent. These results are, however, within the 13% to 31% NUE range for grazing animals suggested by Delagarde *et al.* (1997) and Vérité & Delaby (2000), and comparable to those reported by Woodward *et al.* (2011), NUE of 18.5% for low breeding and 22% for high breeding worth cows grazing on pasture. Cows in this study were in a pasture-based production system. Nitrogen use efficiency in pasture is generally lower than in intensive system (Powell *et al.*, 2010). This is because in pasture, protein usually exceeds animal requirements (Kolver *et al.*, 1998; Woodward *et al.*, 2011) and the protein is generally highly degradable (NRC, 2001) while energy is the main limiting nutrient. This results in imbalance between available energy and N in the rumen and consequently, inability of rumen microbes to fully utilise the available N.

5.4.5 Estimated nitrogen use efficiency for body weight

The NI/kg $BW^{0.75}$ did not differ between breeds (6.15±0.033 vs. 6.17±0.035, P=0.64). It, however, increased with parity (P<0.01) and lactation stage (P<0.01) but there were no interaction effects of breed by parity (P=0.05) and breed by lactation stage (P=0.86). These findings indicate that NI can better be explained by the level and stage of production rather than body weight.

5.4.6 Excreted nitrogen

5.4.6.1 Estimated faecal nitrogen and scurf losses

Faecal nitrogen (FN) losses were higher (P<0.05) in Holstein compared to Jersey cows, being 219±1.4 vs. 175±1.5 g/day due to higher estimated DMI in Holsteins. Marini & Van Amburgh (2005) reported a positive relationship between FN and DMI, that is, a constant increase or decrease in FN in relation to DMI. Peyraud *et al.* (1994) reported FN to be about 7.5 g/kg DMI in grazing dairy cows, Van Soest (1994) 0.6%, i.e., 6 g/kg of dietary DMI, while the NRC (1985); and Alderman *et al.* (2001) reported it to be 9% of indigestible DM. Because DMI increased with both parity and lactation stage, FN also increased with both production stages in both breeds.

The FN/100 g NI was, however, higher (P<0.05) in Jerseys than Holsteins in all production stages (Table 5.4 and 5.5; Figure 5.2). Primiparous cows had higher FN/100 g NI, showing a decreasing trend that levelled from third parity. Transition cows also had a higher FN/100 g NI, followed by a decline in early lactation but mid and late lactation stages did not differ. The group of cows that had higher FN/100 g NI had a lower DMI (Table 3.4) and therefore lower NI than their counterparts (Table 5.3). In the model used to estimate FN in this study, organic matter intake had a major contribution. The lower the DMI and NI, the higher the FN excreted as the proportion of NI. As the protein requirement for scurf losses (SPA) were estimated using the $BW^{0.75}$, SPA losses were higher in Holsteins compared to Jerseys, 13±0.05 vs. 11±0.06 (P<0.01).

Table 5.4 Least squares means (±SE) of nitrogen output in milk and excretions, and NUE of Holstein and Jersey cows as affected by parity

	Parity										
	1		2		3		4 +		P-values		Interactions
	H	J	H	J	H	J	H	J	Breed	P	B × P
No. of records	891	737	579	541	395	437	450	546			
Milk N (g)	99^{e} ±1.2	86^{f} ±1.3	115^{c} ±1.4	95^{d} ±1.5	124^{b} ±1.6	108^{d} ±1.6	130^{a} ±1.6	112^{c} ±1.6	<.01	<.01	0.01
Milk N/NI	16.3^{d} ±0.1	17.6^{b} ±0.1	16.7^{c} ±0.1	17.9^{b} ±0.2	16.9^{c} ±0.2	18.7^{a} ±0.2	17.2^{c} ±0.2	18.7^{a} ±0.2	<.01	<.01	0.05
NI/kg MetW	5.8^{e} ±0.04	5.9^{e} ±0.04	6.1^{d} ±0.04	6.1^{d} ±0.04	6.3^{c} ±0.05	6.3^{c} ±0.05	6.4^{ab}±0.05	6.4^{ab}±0.05	0.64	<.01	0.05
FN (g)	191^{d} ±1.4	155^{g} ±1.6	216^{c} ±1.6	170^{f} ±1.7	229^{b} ±1.8	183^{e} ±1.8	238^{a} ±1.8	191^{d} ±1.8	<.01	<.01	<.01
UN (g)	326^{d} ±2.6	250^{h} ±2.9	370^{c} ±2.9	277^{g} ±3.1	393^{b} ±3.2	298^{f} ±3.2	411^{a} ±3.2	311^{e} ±3.3	<.01	<.01	<.01
SPA (g)	12^{c} ±0.05	10^{e} ±0.06	13^{b} ±0.05	11^{d} ±0.06	13^{b} ±0.05	11^{d} ±0.06	14^{a} ±0.05	11^{a} ±0.06	<.01	<.01	<.01
ManN (g)	530^{d} ±4.1	415^{g} ±4.5	599^{c} ±4.5	457^{f} ±4.8	635^{b} ±4.9	492^{e} ±5.0	663^{a} ±5.0	513^{d} ±5.0	<.01	<.01	<.01
FN /100g NI	30.8^{c} ±0.01	31.2^{a} ±0.02	30.6^{d} ±0.02	31.0^{b} ±0.02	30.5^{d} ±0.02	30.9^{bc} ±0.02	30.5^{d}± 0.02	30.8^{c} ±0.02	<.01	<.01	0.01
UN /100g NI	53^{a} ±0.1	50^{b} ±0.1	52^{a} ±0.1	50^{b} ±0.2	52^{a} ±0.2	50^{b} ±0.2	52^{a} ±0.2	49^{b} ±0.2	<.01	0.02	0.22
ManureN/NI	85^{a} ±0.1	83^{c} ±0.1	84^{b} ±0.2	83^{c} ±0.2	84^{b} ±0.2	82^{d} ±0.2	84^{b} ±0.2	82^{d} ±0.2	<.01	<.01	0.12

$^{a\text{-}h}$ Means within rows with different superscripts differ at $P<0.05$

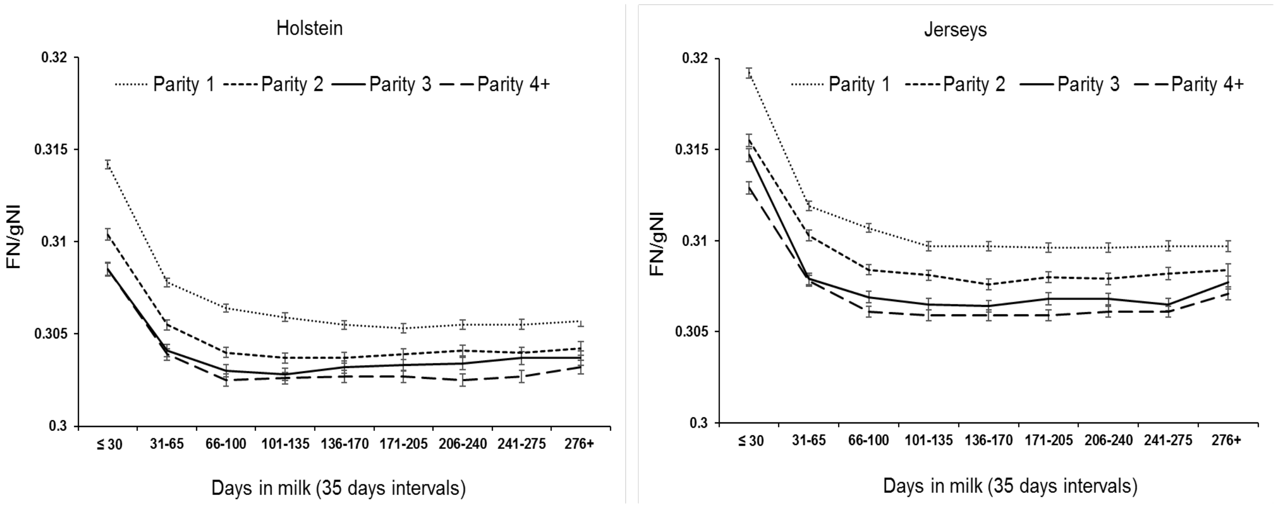
N: nitrogen, **NI:** nitrogen intake, **FN:** faecal nitrogen, **UN:** urinary nitrogen, **SPA:** protein requirement for scurf losses, **Man N:** manure nitrogen

Table 5.5 Least squares means (±SE) of nitrogen output in milk and excretions, and NUE of Holstein and Jersey cows as affected by lactation stage

	Lactation stage (days in milk)										
	<30		31-100		101-200		201+		P-values		Interactions
	H	J	H	J	H	J	H	J	Breed	LS	B × LS
No. of records	228	204	581	561	798	776	708	720			
Milk N (g)	125^{a} ±1.2	109^{bc} ±1.2	122^{a} ±1.4	104^{c} ±1.4	114^{b} ±1.3	97^{d} ±1.3	108^{c} ±1.3	91^{e} ±1.4	<.01	<.01	0.70
Milk N/NI	22.9^{b} ±0.2	25.1^{a} ±0.2	16.3^{d} ±0.1	17.7^{c} ±0.1	14.3^{f} ±0.1	15.5^{e} ±0.1	13.6^{g} ±0.1	14.7^{f} ±0.1	<.01	<.01	<.01
NI/kg MetW	4.8^{c} ±0.05	4.8^{c} ±0.06	6.5^{b} ±0.04	6.5^{b} ±0.04	6.8^{a} ±0.04	6.8^{a} ±0.04	6.5^{b} ±0.04	6.5^{b} ±0.04	<.01	<.01	0.86
FN (g)	171^{e} ±1.9	138^{f} ±2.0	227^{b} ±1.6	180^{d} ±1.7	240^{a} ±1.5	191^{c} ±1.6	237^{a} ±1.6	189^{c} ±1.6	<.01	<.01	<.01
UN (g)	250^{e} ±3.4	189^{f} ±3.7	391^{b} ±2.9	295^{d} ±3.0	432^{a} ±2.2	328^{c} ±2.9	426^{a} ±2.8	324^{c} ±3.0	<.01	<.01	<.01
SPA	13^{a} ±0.06	11^{b} ±0.06	13^{a} ±0.05	11^{b} ±0.06	13^{a} ±0.05	11^{b} ±0.06	13^{a} ±0.05	11^{b} ±0.06	<.01	<.01	<.01
ManN g/day	434^{e} ±5.3	338^{f} ±5.7	630^{b} ±4.4	485^{d} ±4.7	685^{a} ±4.3	529^{c} ±4.5	677^{a} ±4.4	524^{c} ±4.6	<.01	<.01	<.01
FN /100g NI	31.1^{b} ±0.02	31.6^{a} ±0.02	30.5^{e} ±0.02	30.9^{c} ±0.02	30.4^{f} ±0.02	30.8^{d} ±0.02	30.4^{f} ±0.02	30.8^{d}±0.02	<.01	<.01	<.01
UN /100g NI	45^{e} ±0.2	42^{f} ±0.20	52^{c} ±0.14	51^{d} ±0.15	55^{a} ±0.13	53^{b} ±0.14	55^{a} ±0.14	53^{b} ±0.14	<.01	<.01	0.02
ManureN/NI	79^{d} ±0.20	77^{e} ±0.21	85^{b} ±0.15	83^{c} ±0.15	87^{a} ±0.14	85^{b} ±0.14	87^{a} ±0.14	85^{b} ±0.14	<.01	<.01	0.06

$^{a-h}$ Means within rows with different superscripts differ at P<0.05

N: nitrogen, **NI:** nitrogen intake, **FN:** faecal nitrogen, **UN:** urinary nitrogen, **SPA:** protein requirement for scurf losses, **Man N:** manure nitrogen

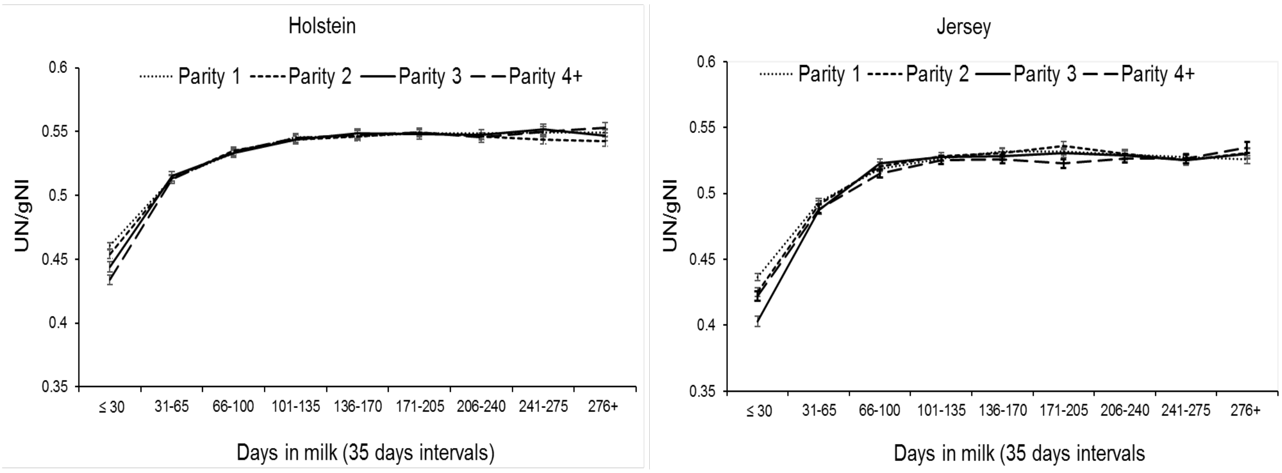


(a) (b)

Figure 5.4 Faecal nitrogen/100 g NI of (a) Holstein and (b) Jersey cows as affected by parity and days in milk

5.4.6.2 Estimated urinary nitrogen losses

Both estimated UN g/day and UN/100 g NI (Table 5.2) were higher in Holsteins compared to Jerseys in all parities (P<0.01) and lactation stages (P<0.01). Urinary N g/day increased with both parity and lactation stage due to increase in NI as the two production stages progressed (Table 5.4 and 5.5). An increase in UN/100 g NI from transition to early lactation stage, which started levelling in mid-lactation was observed (Figure 5.5).



(a) (b)

Figure 5.5 Urinary Nitrogen/100 g NI of (a) Holstein and (b) Jersey cows as affected by stage of lactation and lactation number

Parity, however, did not have an effect on UN/100 g NI (P=0.22). Urinary nitrogen is reported to have a linear relationship with NI (Marini & Van Amburgh, 2005; Jardstedt *et al.*, 2017). Several authors reported no breed effect on UN/NI. Kauffman & St-Pierre

(2001) reported 27.1% vs. 28.5% UN/NI; Aikman *et al.* (2008) reported that breeds did not differ in UN excreted as a proportion of apparently digested N (P=0.634) and Knowlton *et al.* (2010), (P=0.19). Urinary nitrogen is the major route for N excretion, Holsteins in this study had lower MN/NI in all parities and lactation stages, suggesting that the excess NI that was not utilised for milk production was excreted as UN.

5.4.6.3 Estimated manure nitrogen excretion

The calculated total manure excretion, which was the sum of FN, UN and SPA losses was higher in Holsteins compared to Jerseys, 613±6.11 vs. 465±6.28 g/day (P<0.01). Because FN and UN increased with parity and lactation stage, manure N losses also increased with both production stages. Increases from primiparous to mature cows averaged 20% for both breeds while mid-lactation cows excreted approximately 37% more ManN than transition cows (Table 5.3). Bockmann *et al.* (1996) and Kristensen *et al.* (1998) also reported differences in N excretion with cows in different phases of lactation.

The estimated ManN/kg NI was also higher in Holsteins compared to Jerseys, 82.3±0.11 vs. 80.6±0.12% (P<0.01). This is because more N was excreted as UN than as FN, and Holsteins had a higher UN than Jerseys. According to Bruchem *et al.* (1991), nitrogen excretion in faeces and urine may approach 80% of daily consumption depending on different feed sources. Primiparous Holsteins had higher ManN/kg NI, which levelled from second lactation while with Jerseys, the ManN/kg NI was high in both primiparous and second lactation cows, levelling in third lactation. In contrast to the findings in this study, Blake *et al.* (1986) reported no difference between breeds. This author attributed differences in N excretion of Holstein and Jersey cows to tissue balance and DMI to meet breed potentials in milk production rather than difference in post-absorptive nutrient utilisation. Arndt *et al.* (2015) reported higher FN/DMI and lower UN/DMI in efficient cows. The lower ManN/kg NI in Jerseys in this study suggest a higher efficiency of this breed in nitrogen use.

5.5 Conclusion

This study compared the NUE of Holstein and Jersey cows by parity and lactation stage. The increase in estimated MN/NI with parity while ManN/NI decreased is indicative of better NUE in older cows. Breeds differed with Jerseys having higher estimated MN/NI but lower ManN/NI compared to Holsteins, suggesting higher NUE in Jerseys.

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Chapter 6

Estimating enteric carbon dioxide and methane emissions of Holstein and Jersey cows in a kikuyu pasture-based production system

6.1 Abstract

The production of carbon dioxide (CO_2) and methane (CH_4) in ruminants constitutes energetic inefficiency and contributes to greenhouse gas (GHG) concentrations that are linked to global climate change. The aim of this study was to estimate and compare enteric CO_2 and CH_4 production of Holstein and Jersey cows by parity and lactation stage. Data were lactation records of 122 Holstein and 99 Jersey cows collected using standard milk recording procedures, i.e. 10 recording dates per year. Cows were kept in a in kikuyu pasture-based production system and received on an as-fed basis 7 kg of concentrate containing 17% crude protein (CP) daily. CO_2 and CH_4 emissions were calculated using the Cornell Net Carbohydrate and Protein System (CNCPS) equations. Holstein cows emitted higher kg CO_2/day but lower kg CO_2/kg DMI and kg CO_2/100 kg BW compared to Jersey cows. The emitted kg CO_2/kg DMI was higher during the transition stage and levelled from early lactation while kg CO_2/100 kg BW increased up to mid-lactation, followed by a decline in late lactation. The kg CO_2/kg ECM did not differ between breeds, it decreased by 14% from primiparous to mature cows and increased by 35% from transition to late lactation stage. CH_4 emission increase from primiparous to mature cows was ±16% and from transition to mid-lactation was ±28%. Holstein cows emitted less g CH_4/kg DMI and g CH_4/100 kg BW than Jersey cows. Jersey cows, however, emitted less g CH_4/kg ECM than Holstein cows. The emission of CH_4/kg BW decreased with parity while CH_4/kg ECM increased from primiparous to second lactation, followed by a decrease in third lactation and mature cows. It can therefore be concluded that Holstein cows emitted less CO_2 and CH_4 per kg DMI and kg BW while Jerseys emitted less CH_4/kg ECM. Both parity and lactation stage affected enteric GHG emissions of Holstein and Jersey cows, indicating that accounting for production stages will bring better accuracy in estimating the methane emission factor (MEF, CH_4/cow/year).

Keywords: breed efficiency, enteric emissions, lactation stage, parity

6.2 Introduction

Carbon dioxide (CO_2) and methane (CH_4) are generated as natural by-products of enteric fermentation (Hook *et al.*, 2010; Hristov *et al.*, 2014). Methane is produced by methanogens, the anaerobic bacteria that belong to the domain *Archaea*, phylum *Euryarchaeota* (Hook *et al.*, 2010). The methanogens combine the CO_2 generated by bacteria, protozoa and fungi from the fibre degradation activity (Wang *et al.*, 2017b; Medjekal *et al.*, 2018) with the hydrogen (H_2) released from the oxidation reactions required to obtain energy (Mirzaei-Aghsaghali & Maheri-Sis, 2011) to produce CH_4 through the process called methanogenesis.

Methanogenesis is an essential process as unremoved H_2 accumulates leading to acidosis and reduced rate of microbial growth (Chianese *et al.,* 2009b), and consequently, inhibition of ruminal fermentation, reduced fibre degradation and microbial protein synthesis (Wolin, 1974; McAllister & Newbold, 2008; Knapp *et al.*, 2014). The production of CH_4, however, constitutes energetic inefficiency. Depending on feed composition and quality, methanogenesis represents a loss of about 2 to12 % of dietary energy consumed by the host animal (Johnson & Ward, 1996; Van Kessel & Russell, 1996; Hook *et al.*, 2010; Unger *et al.*, 2010; Medjekal *et al.*, 2018), with high-producing lactating animals lose at least 6% (Qiao *et al.*, 2014).

Enteric gases also contribute to greenhouse gas (GHG) concentrations in the atmosphere that are linked to global climate change (Broucek, 2014). Livestock production is, however, not considered as an important global source of CO_2 emissions (Chase *et al.,* 2011). This is because the CO_2 emitted by livestock is viewed as part of a continuous biological cycle of fixation, utilisation, and exhalation (Dong *et al.,* 2006; Knapp *et al.*, 2014), resulting in the amount of CO_2 produced by ruminant animals being completely offset by uptake by natural carbon sinks (Steinfeld *et al.*, 2006). Chianese *et al.* (2009), however, suggested the inclusion of CO_2 emissions when balancing for carbon flows in the farm to ensure that all sources of carbon emission are accounted for. Methane, on the other hand, has a global warming potential 25 times that of CO_2 (Broucek, 2014). Enteric CH_4 represents the greatest direct GHG released by livestock (Caro *et al.*, 2016), accounting for about 32–40% (2 .1 Gt CO_2 Eq/year) of agricultural CH_4 (Smith *et al.*, 2014). About 75% of enteric CH_4 is produced by cattle (Smith *et al.*, 2014). Moeletsi *et al.* (2017), reported annual average CH_4 emissions of 1227.96 Gg in South Africa, 7% of which was from dairy cattle.

Several studies on strategies to reduce enteric CH_4 production have been conducted, e.g., dietary manipulation to redirect H_2 flow towards alternative electron acceptors such as propionate (Mirzaei-Aghsaghali & Maheri-Sis, 2011; Wang *et al.*, 2017a). The flow of H_2 to the alternative electron acceptors has been found to be energetically less favourable than the reduction of CO_2 to CH_4, through a variety of adaptive mechanisms, the microbial ecology of the rumen system inherently reverts back to initial levels of CH_4 production (McAllister & Newbold, 2008). With the use of antibiotics or feed additives such as ionophores, non-suppression of CH_4 production associated with the development of resistance of methanogens to prolonged or repeated use have been reported (Mbanzamihigo *et al.*, 1996; Sauer *et al.*, 1998). Breed comparison on enteric CH_4 emissions per unit of DMI or kg product produced is one of the strategies that are drawing more attention. With the studies conducted to compare Holstein and Jersey cows, (Münger & Kreuzer, 2006; King *et al.*, 2011; Capper & Cady, 2012; Broucek, 2014; Dalla Riva *et al.,* 2014; Olijhoek *et al.*, 2018) the results are conflicting on whether breed differences exist, indicating a need for repeated studies for more accurate assessment.

Furthermore, the Intergovernmental Panel on Climate Change (IPCC, 2006) is encouraging the development of country-specific methane emission factors (MEF, kg CH_4/head/year) for different animal categories to enable close estimation of the country's emissions. According to Mangino *et al.* (2003), estimating emissions by sub-categories will bring better accuracy as herd population vary throughout the year. Overlooking the effects of the production stages assumes that individual animal characteristics remain constant throughout a given year (Mangino *et al.,* 2003). No literature could be found on the effect of production stages on enteric gas emissions. The aim of this study was therefore to estimate enteric CO_2 and CH_4 production of Holstein and Jersey cows by parity and lactation stage. The results from this study can also form the basis for the development of dairy cow emission factors by lactation stage and parity that can be applied for regional and national inventories for South African dairy breeds. The objectives of the study were:

- To predict daily enteric CO_2 and CH_4 emissions and compare enteric gases emission efficiencies of Holstein and Jersey cows in a pasture-based system by parity and lactation stage
- To estimate MEF (CH_4/kg/head/year) of Holstein and Jersey cows kept in a pasture-based system.

6.3 Materials and methods

6.3.1 Experimental animals and experimental design

Details of experimental animals, experimental area, diet and management of experimental animals are presented in Chapter 3, only a brief summary will be provided in this chapter. The study was conducted at Elsenburg Research Station, Western Cape Department of Agriculture in South Africa. Data were lactation records of 122 Holstein and 99 Jersey cows, parity 1 to 4+ that were collected from October 2005 to September 2014 using standard milk recording procedures, i.e. 10 recording dates per year. Collected records included cow birth date, calving date, lactation number, BW, kg MY, %MF and %Mprot. The total number of observations for Holsteins was 2315 and 2261 Jerseys. Lactation period was divided into four stages: calving to 30 days as post-calving transition, 31 to 100 days as early lactation stage, 101 to 200 days as mid-lactation stage, and above 201 days as late lactation. Cows grazed as one herd in a kikuyu pasture and were supplemented with a commercial concentrate mixture containing 17% crude protein on as fed basis. The total dry matter intake (DMI) was estimated using the National Research Council (NRC, 2001) equation with pasture intake estimated as the difference between DMI and concentrate DMI.

6.3.2 Estimating emitted CO_2 (kg/day) and CH_4 (kg/day)

Carbon dioxide (kg/day) and CH_4 MJ/day were estimated using the equations from the Cornell Net Carbohydrate and Protein System (CNCPS). These models were chosen because they use the principles of rumen fermentation and equations from peer reviewed scientific articles (Fox *et al.*, 2004; Tedeschi *et al.*, 2014), making them practical tools to use for these simulations. The equations were as follows:

CO_2 kg/d = [821.3 + (126.0 × DMI) – (1.18 × milk)] /0.27……………………………….eq 1

Where DMI is kg dry matter intake per day and

Milk is kg/day (Casper & Mertens, 2010; Van Amburgh *et al.*, 2015).

CH_4 MJ/d = $45.98 - (45.98e^{-1 \times [(-0.0011 \times \text{starch/ADF}) + 0.0045 \times \text{ME intake}]})$…………………………eq 2

Where Starch and ADF are kg intake per day and

Metabolisable energy intake (MEI) as MJ/day. (Mills *et al.*, 2003; Van Amburgh *et al.*, 2015).

To convert CH_4 MJ/d to kg CH_4/day = CH_4 MJ/day / 55.65 MJ/kg ……….....................eq 3

Where The factor 55.65 MJ is the energy content of a kg CH_4 (IPCC, 2006).

The MEF (kg CH_4/head/year) = daily kg CH_4 × 365 days……………………..….............eq 4

Two other methods were also used to estimate MEF, that is, IPCC (2006) and Liu *et al.* (2017) equations:

Tier 2, IPCC: MEF = (GEI × 0.065 × 365)/55.65…………………..…………………….…eq 5

Where GEI = gross energy intake, MJ/head/day

0.065 = default CH_4 conversion factor (MCF) for dairy cows (6.5±1%) (i.e., the percentage of GEI converted to CH_4) (IPCC, 2006).

Liu *et al.* (2017) suggested the use of digestible energy intake (DEI) MCF (DEIMCF) as an alternative approach to express MCF as DEI can better represent the large variation among diets than GEI. The equation used to determine MEF for this method was adapted by combining Liu *et al.* (2017) DEIMCF and IPCC Tier 2 equations. The default MCF in the IPCC (2006) equation was replaced with DEIMCF and GEI with DEI. The DEIMCF was calculated using the equation by Liu *et al.* (2017) as follows:

DEIMCF = 40.69 - 43.84 (DEI) - 4.870 (EIL) + 6.368 (DEI x EIL)……………..…………eq 6

Where DEIMCF = the percentage of DEI converted to CH_4

DEI = the energy digestibility of feed (ranging from 0.33 to 0.84) and

EIL = energy intake level of cattle (measured as the ratio of DEI to the energy requirement for maintenance of cattle, ranging from 0.89 to 7.47).

DEIMEF: MEF = (DEI × DEIMCF × 365)/55.65…………………………………………..…eq 7

The MEFs from the CNCPS, IPCC (2006) and Liu *et al.* (2017) methods were then compared against each other to determine differences in MEF as a way of confirming the consistency of the findings.

6.3.3 Estimating enteric gases emission efficiency

Cows were classified by breed, parity and stage of lactation. Kilogram CO_2/day, kg CH_4/day and MEF were then compared according to these classes. Efficiency estimates were calculated as CO_2 or CH_4/kg DMI, CO_2 or CH_4/kg BW and CO_2 or CH_4/kg ECM using only the CNCPS model results.

6.3.4 Statistical analysis

Statistical analyses were performed using the repeated measure methods available in the PROC MIXED procedure of SAS Enterprise Guide version 7.1 to test main effects and interaction effects between them in a repeated measures design. The fixed effects were breed, parity and stage of lactation. The interaction effects were breed × parity, breed × lactation stage and breed × parity × lactation stage. The least squares means of the interaction effects of breed × parity × lactation stage for g CH_4 were fitted in a curve to determine how this parameter respond to the predictor variables in each breed. The cow was an experimental unit where the response variables (CH_4, CO_2, and their efficiency measures) were measured in each lactation stage during the lactation period. To account for individual variation in experimental units, cow within breed was fitted as a random effect. A compound symmetry structure for the residuals was used as covariance structure for repeated measures over time within cows. The between-breeds, between parity and between lactation stage variations and their interactions were compared using the Bonferroni test and were declared different at $P < 0.05$. The statistical model used to analyse was as follows:

$$Y_{ijkl} = \mu + B_i + P_j + LS_k + (B\times P)_{ij} + (B\times LS)_{ik} + (B\times P\times LS)_{ijk} + cow_l(B_i) + \varepsilon_{ijkl}$$

Where:

Y_{ijkl} = dependent / response variable (CH_4, CO_2, and their efficiency measures);

μ = overall mean;

B_i = fixed effect of the i^{th} breed (i =Holstein, Jersey);

P_j = fixed effect of the j^{th} parity (j = 1, 2, 3 and 4);

LS_k = fixed effect of the k^{th} lactation stage (l = 1 to 4);

$(B\times P)_{ij}$ = fixed interaction effect between breed and parity;

$(B\times LS)_{ik}$ = fixed interaction effect between breed and lactation stage;

$(B\times P\times LS)_{ijk}$ = fixed interaction effect between breed, parity and lactation stage;

$cow_l(B_i)$ = random effect of the l^{th} cow (l = 1 to 221) nested within the i^{th} breed $N \sim (0, \sigma^2_{cow(B)})$;

ε_{ijkl} = random error term $N \sim (0, \sigma^2_{\varepsilon})$.

To test for the differences in methods (CNCPS, DEIMCF and IPCC), One Way ANOVA was performed. The means were compared using Bartlett's test and Levene's test and declared significant at $P < 0.05$. The statistical model used to analyse was:

$$Y_i = \mu + Met_i + e_{ij}$$

Where:

Y_i = dependent / response variable (MEF);

μ = overall mean;

Met_i = fixed effect of the i^{th} method (i =CNCPS, IPCC, DEIMCF).

e_{ij} = random error term

6.4 Results and discussion

Below (Table 6.1) is the descriptive statistics showing the mean and the standard deviation (SD) values of the animal traits and feed characteristics that were used as inputs in the models to estimate enteric CO_2 and CH_4 emissions of Holstein and Jersey cows.

Table 6.1 The descriptive statistics of animal traits and feed characteristics used as model inputs.

Parameters		Holsteins (n = 2315)		Jerseys (n = 2261)	
	Units	Mean	SD	Mean	SD
Milk	kg/day	23.8	6.2	17.8	4.4
Body weight	kg	567	64.5	412	46.9
Dry matter intake	kg	18	2.9	15	2.2
[1]Starch	kg	2.65	0.05	2.60	0.04
[1]Acid detergent fibre	kg	3.54	0.74	2.70	0.56
[1]Gross energy intake	MJ/day	318.3	49.57	261.6	37.88
[1]Digestible energy intake	MJ/day	213.2	29.06	180.0	22.21
[1]Metabolisable energy intake	MJ/day	180.1	25.3	151.1	19.4

[1] Formulated using the NDS Professional, 2008 to 2018)

6.4.1 Estimated enteric carbon dioxide emissions

The mean estimated CO_2 produced per day was higher in Holstein cows than Jersey cows (Table 6.2). The range was 6.54 to 15.8 kg/day in Holstein cows and 6.3 to 14.1 kg/day in Jersey cows. Although no studies could be found on comparing the two breeds, the range of CO_2/day for Holstein and Jersey cows in this study is comparable to those that have been reported for Holstein cows on pasture by Pinares-Patiño *et al.* (2007), being 8.8 to 10.5 kg/day and Lee *et al.* (2017), being 11.4 kg/d to 16.8 kg/day. A comparable CO_2/day range but for Holstein cows on TMR was also reported by Kinsman *et al.* (1995), being 9.9 to 14.68 kg/day and Liu *et al.* (2012), 12.8 to 16.3 g/day. Aguerre *et al.* (2011), however, observed higher values compared to those in this study, 17.97 to 18.65 kg/day in Holstein cows receiving a TMR with different forage-to-concentrate ratios.

The CO_2/day increased both with parity and lactation stage (Table 6.2). The increase from primiparous to mature cows was 14% and 12% while that from transition to late lactation was 20% and 18% for Holstein and Jersey cows, respectively. The increase in CO_2 emissions with production stages can be associated with increased DMI as production stages progressed. Arthur *et al.* (2018) reported a positive relationship between CO_2 emission rate and DMI (r=0.82).

Although Holstein cows had higher CO_2 emissions per day compared to Jersey cows, they produced less kg CO_2/kg DMI and kg CO_2/100 kg BW (Table 6.2). As DMI has a major contribution in the model used to estimate CO_2/day, this can be attributed to the lower DMI/kg BW in Holsteins compared to Jerseys. With parity, CO_2/kg DMI decreased from primiparous to second lactation and levelled thereafter, while with lactation stage CO_2/kg DMI was higher in transition stage followed by a decline that levelled from early lactation. The CO_2/100 kg BW increased up to mid-lactation, followed by a decline in late lactation stage, while it decreased as parities advanced. These findings indicate that the higher DMI and heavier BW of multi-parous and later lactation stage cows had a diluting effect on CO_2 emitted, resulting in lower CO_2/kg DMI and CO_2/kg BW as production stages advanced.

Breed did not have an effect on kg CO_2/kg ECM (P>0.05). The CO_2/kg ECM, however, decreased by 14% from primiparous to mature cows and increased by 35% from transition to late lactation stage in both breeds (Table 6.2). The 35% increase in CO_2/kg ECM can be related to the decrease in ECM/kg DMI with advancing lactation stages which was associated with a shift in nutrient partitioning in mid and late lactation towards supporting pregnancy and building body reserves in preparation for the next calving.

6.4.2 Estimated enteric methane emissions

6.4.2.1 Methane conversion factor (MCF)

The MCF is a key parameter in determining the methane emission factor (MEF). The MCF values obtained in this study, 6.91±0.007 vs. 6.95±0.007 (P<0.01) in Holsteins and Jerseys, respectively, were within the default range, 6.5±1% for dairy cows as suggested by the IPCC (2006). Olijhoek *et al.* (2018) also reported higher CH_4/GEI in Jerseys than Holsteins (P=0.01). In contrast, no differences in MCF between Holstein and Jersey cows were observed by Hellwing *et al.* (2016), being 6.11% for both breeds; and Liu *et al.* (2017), 5.3±1.6% vs. 5.6±3% (P=0.67) in Holstein and Jersey cows, respectively. A negative relationship between MCF and the level of feed intake has been reported by numerous authors (Johnson & Johnson, 1995; Sauvant & Giger-Reverdin, 2009; McGeough *et al.*, 2010; Ramin & Huhtanen, 2013; Hellwing *et al.*, 2016), explaining the reason for lower MCF in Holsteins compared to Jerseys.

Determining MCF based on GEI is criticised by most authors (Hristov *et al.*, 2013b; Hellwing *et al.*, 2016; Liu *et al.*, 2017) for not fully reflecting the effects of diet quality and composition as it includes the part of feed that is not available to the animal. For example, inasmuch as concentrates and forage can have similar GE, they differ in digestibility or energy availability. According to those authors, DEI and energy intake level are the two factors that have a significant effect on enteric CH_4 production. Liu *et al.* (2017) therefore expanded the Tier 2 method (IPCC, 2006) to develop MCF based on DEI and proposed that DEIMCF be considered as an alternative approach to express MCF.

The mean DEIMCF in this study was 9.7±0.02 vs. 9.2±0.02% (P<0.01) in Holsteins and Jerseys, respectively. This is comparable to the findings of Kennedy & Charmley (2012) who reported a mean DEIMCF that ranged between 8.6–13.4% in cattle that were fed grass diets. Increasing energy intake level and energy digestibility of feed reduced DEIMCF for both effects (Kennedy & Charmley, 2012; Liu *et al.*, 2017).

6.4.2.2 Comparing models for methane emission factor (MEF)

Using the CNCPS, IPCC and DEIMCF methods, respectively, the mean MEFs in Holsteins were 142.2±0.4, 135.7±0.4 and 137.3±0.4 kg/head/year; while for Jerseys they were 119.0±0.4, 111.5±0.4 and 110.7±0.4 kg/head/year. The IPCC and DEIMCF MEFs did not differ, Holsteins (P=0.15) and Jerseys (P=0.18), and both methods predicted lower MEF than CNCPS (P<0.01).

Even though the estimated MEF differed in these models, their mean values were all comparable to the available literature. For the South African dairy herds, the Department of Environmental Affairs (DEA, 2015) reported MEF values of 127 and 132 kg CH_4/head/year for lactating cows on pasture and TMR, respectively. Lower MEF values for the South African dairy herds were, however, reported by Du Toit *et al.* (2013), being 76.4 kg CH_4/head/year for concentrate fed and 71.8 kg CH_4/head/year for pasture-based production systems. Moeletsi *et al.* (2017) also reported lower values, 83.70 kg, 112.36 kg and 108.53 kg of CH_4/head/year for cows on TMR, pasture-based system and mixture of TMR and pasture systems, respectively. In the study by Du Toit *et al.* (2013), the average milk production of the cows was 10.5 kg/day while Moeletsi *et al.* (2017) used data that was obtained from the National Department of Agriculture (also in South Africa), which probably included low producing cows. With a decrease in milk production, DMI also decreases. There is a positive correlation between DMI and CH_4 production, suggesting the reason for lower MEF observed by the two authors. In this study, milk production (ECM) was 22.7±5.9 kg/day in Holsteins and 19.4±4.8 kg/day in Jerseys, suggesting higher DMI and hence the higher MEF values compared to the two South African studies.

The IPCC (2006) recommended a MEF of 46 kg/head/year for dairy cows in the African continent producing milk averaging 475 kg/head/year. Cows in this study produced higher milk volume, 8700 and 6552 kg/head/year (calculated as mean daily MY × 365) for Holsteins and Jerseys, respectively. Extrapolating from IPCC (2006), dairy cows that produce 8400 kg and 6000 kg milk/head/year have MEFs of 128 and 117 kg/head/year, respectively, which is comparable to the estimates obtained in this study (Table 6.2). Also comparable to the findings in this study, Sonessen *et al.* (2009) stated that a dairy cow that produces an annual average of 9000 kg milk is estimated to have a MEF of approximately 120 to 130 kg/head/year. In agreement, Hristov *et al.* (2013b) suggested a MEF of 128 kg/head/year for high producing dairy cows while Chase (2015) reported an average CH_4 production of 373 to 509 g/day (translating into a MEF of 136.2 to 185.8 kg/cow/year) in Holstein cows depending on the level of milk production.

6.4.2.3 Estimated daily enteric CH_4 production and emission efficiency

As expected, Holsteins produced more CH_4 than Jerseys, 379±2.1 vs. 314±2.3 CH_4 g/day. Heavier animals have a higher feed intake and therefore produce more CH_4 (Negussie *et al.*, 2017). Herd *et al.* (2014) also reported a positive correlation between CH_4 production and DMI, i.e. 0.65±0.02 in beef cattle. Lima *et al.* (2016) reported a linear decrease in daily CH_4 produced as the level of feed intake decreased. In both breeds, daily CH_4 produced increased as parity and lactation stage progressed (Table 6.2). Mature Holstein cows produced 15.6% and Jersey cows 17.1% more CH_4 than their primiparous counterparts. Mature Jerseys and primiparous Holsteins did not differ in CH_4 production (Table 6.2).

Table 6.2 The mean (±SE) enteric emissions and their efficiencies of Holstein and Jersey cows as affected by parity and lactation stage

	Parity										
	Parity 1		Parity 2		Parity 3		Parity 4+		P-values		Interactions
	H	J	H	J	H	J	H	J	Breed	P	BxP
No. of records	891	737	579	541	395	437	450	546			
CO_2/day	10.2^{d} ±0.05	8.9^{g} ±0.06	11.0^{c} ±0.06	9.4^{g} ±0.06	11.5^{b} ±0.06	9.9^{e} ±0.06	11.8^{a} ±0.06	10.1^{d} ±0.06	<.01	<.01	<.01
CO_2/DMI	0.65^{c} ±0.001	0.69^{a} ±0.001	0.63^{d} ±0.002	0.68^{b} ±0.002	0.62^{e} ±0.002	0.66^{c} ±0.002	0.62^{e} ±0.002	0.66^{c} ±0.002	<.01	<.01	0.02
CO_2/BW	2.01^{e} ±0.01	2.42^{a} ±0.01	1.97^{f} ±0.01	2.34^{b} ±0.01	1.95^{g} ±0.01	2.32^{c} ±0.02	1.92^{h} ±0.01	2.31^{d} ±0.02	<.01	<.01	0.01
CO_2/ECM	0.56^{a} ±0.01	0.56^{a} ±0.01	0.51^{b} ±0.01	0.53^{b} ±0.01	0.50^{c} ±0.01	0.50^{c} ±0.01	0.48^{d} ±0.01	0.49^{d} ±0.01	0.38	<.01	0.08
CH_4/day	342^{d} ±2.1	281^{g} ±2.4	377^{c} ±2.4	307^{f} ±2.5	393^{b} ±2.6	327^{e} ±2.7	405^{a} ±2.7	339^{d} ±2.7	<.01	<.01	<.01
CH_4/kg DMI	21.7^{a} ±0.03	21.6^{b} ±0.03	21.4^{c} ±0.03	21.7^{a} ±0.03	21.2^{d} ±0.04	21.7^{a} ±0.04	21.1^{e} ±0.04	21.6^{b} ±0.04	<.01	<.01	<.01
CH_4/kg BW	67.4^{b} ±0.4	76.3^{a} ±0.5	67.2^{b} ±0.5	76.0^{a} ±0.5	66.8^{bc} ±0.5	76.6^{a} ±0.5	66.0^{c} ±0.5	76.7^{a} ±0.5	<.01	0.41	<.01
CH_4/ECM	18.7^{a} ±0.1	17.6^{b} ±0.2	17.5^{b} ±0.2	17.2^{bc} ±0.2	17.0^{c} ±0.2	16.4^{de} ±0.2	16.6^{cd} ±0.2	16.1^{e} ±0.2	0.01	0.01	<.01
	Lactation stage (days in milk)										
	<30		31-100		101-200		201+		P		
	H	J	H	J	H	J	H	J	Breed	LS	BxLS
No. of records	228	204	581	561	798	776	708	720			
CO_2/day	9.4^{e} ±0.07	8.3^{f} ±0.07	11.4^{b} ±0.05	9.8^{d} ±0.06	11.9^{a} ±0.05	10.2^{c} ±0.06	11.8^{a} ±0.05	10.1^{c} ±0.06	<.01	<.01	<.01
CO_2/DMI	0.68^{b} ±0.002	0.72^{a} ±0.002	0.62^{e} ±0.001	0.66^{c} ±0.002	0.61^{e} ±0.001	0.65^{d} ±0.002	0.62^{e} ±0.001	0.65^{d} ±0.002	<.01	<.01	0.03
CO_2/BW	1.70^{h} ±0.02	2.06^{f} ±0.02	2.07^{e} ±0.01	2.47^{b} ±0.01	2.09^{d} ±0.01	2.49^{a} ±0.01	1.99^{g} ±0.01	2.38^{c} ±0.01	<.01	<.01	0.06
CO_2/ECM	0.40^{d} ±0.01	0.40^{d} ±0.01	0.48^{c} ±0.01	0.49^{c} ±0.01	0.56^{b} ±0.01	0.56^{b} ±0.01	0.61^{a} ±0.01	0.62^{a} ±0.01	0.38	<.01	0.85
CH_4/day	304^{e} ±2.8	244^{f} ±3.0	393^{b} ±2.3	326^{d} ±2. 5	412^{a} ±2.3	344^{c} ±2.4	408^{a} ±2.3	341^{c} ±2.4	<.01	<.01	0.12
CH_4/kg DMI	21.5^{b} ±0.04	20.7^{d} ±0.05	21.5^{b} ±0.03	22.0^{a} ±0.03	21.2^{c} ±0.03	22.0^{a} ±0.03	21.3^{c} ±0.03	22.0^{a} ±0.03	<.01	<.01	<.01
CH_4/kg BW	54.5^{g} ±0.6	59.8^{f} ±0.6	71.4^{d} ±0.5	81.9^{b} ±0.5	72.5^{d} ±0.4	84.0^{a} ±0.	68.9^{e} ±0.5	79.9^{c} ±0.5	<.01	<.01	<.01
CH_4/ECM	12.7^{d} ±0.2	11.4^{e} ±0.2	16.7^{c} ±0.2	16.3^{c} ±0.2	19.4^{b} ±0.2	19.0^{b} ±0.2	21.1^{a} ±0.2	20.7^{a} ±0.2	<.01	<.01	0.02

[a-h] Means within rows with different superscripts differ at P<0.05

CO_2: carbon dioxide, **CH_4:** methane, **DMI:** dry matter intake, **BW:** body weight, **ECM:** energy corrected milk

With lactation stages, the highest CH_4 emissions were observed during mid-lactation, corresponding with the peak DMI. When compared to the transition period, daily CH_4 produced during mid-lactation was 26.2% and 29.1% higher in Holsteins and Jerseys, respectively. This indicates that accounting for production stages will bring more accuracy in estimating MEF.

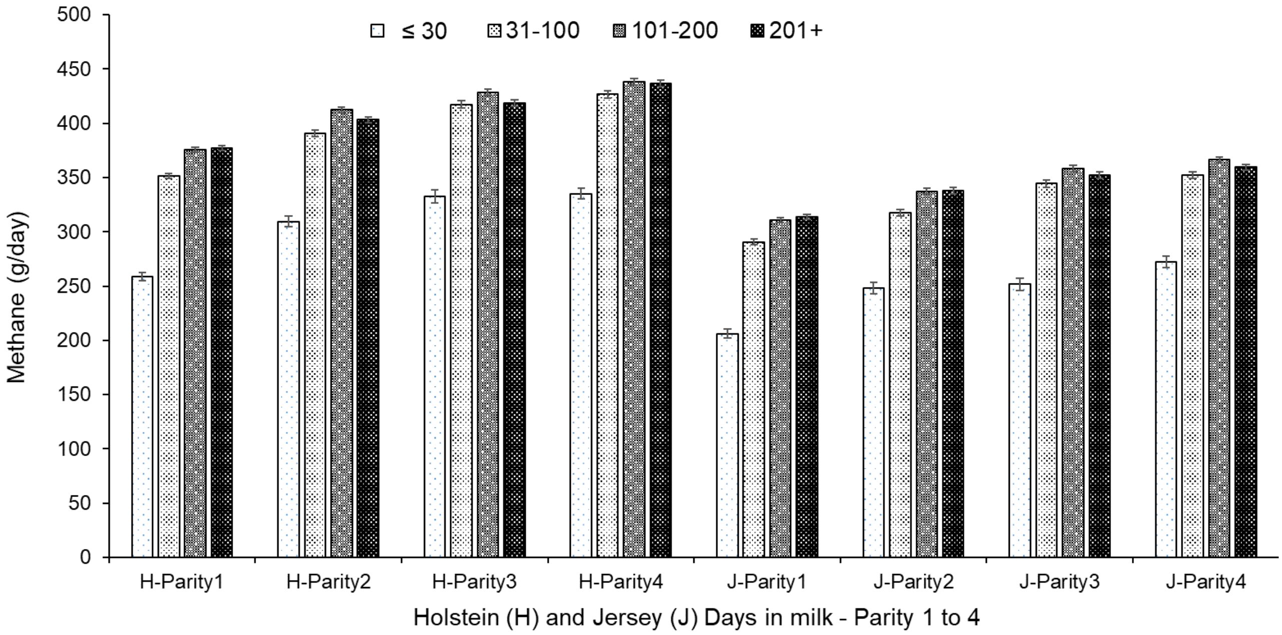

Figure 6.1 Mean daily methane emissions of (a) Holstein and (b) Jersey cows as affected by stage of lactation and lactation number

Except for primiparous cows, Holsteins emitted less CH_4/kg DMI than Jerseys (Table 6.2). In agreement, Olijhoek *et al.* (2018) observed lower CH_4/kg DMI in Holstein cows than Jersey cows that were on high forage concentrate, 31.6 vs. 32.6 CH_4/kg DMI. Münger & Kreuzer (2008) also found lower emissions in Holsteins compared to Jerseys, emissions being 24.6 g, 25.3 g and 25.6 g of CH_4/kg DMI in Holsteins, Simmentaler and Jerseys respectively. Jerseys had a higher DMI/kg BW, suggesting a higher amount of substrate available for fermentation and hence higher CH_4/kg DMI.

Holsteins produced less CH_4/100 kg BW than Jerseys, average 66.8±0.40 vs. 76.4±0.42 (P=0.01) in all parities and lactation stages (Table 6.2). According to Yan *et al.* (2010), CH_4 is negatively related to BW, suggesting the reason for low CH_4/kg BW in Holsteins. CH_4/100 kg BW increased with lactation stage up to mid-lactation, followed by a decline in late lactation stage. Although CH_4 produced per day increased with parity, parity did not have an effect on CH_4/100 kg BW (Table 6.2). The heavier body weight of older cows diluted the increasing amount of CH_4 produced per day.

Jerseys, however, produced less CH_4/kg ECM, 17.5±0.1 vs. 16.8±0.1 (P = 0.0011) in all parities (Table 6.2). In agreement, Capper & Cady (2012) reported a 20.5% reduction in carbon footprint when Jersey cows were used to produce cheese compared to Holsteins despite the increase in the number of cows needed to produce the same volume of milk. Dalla Riva *et al.* (2014) also observed greater CO_2 equivalent emissions with ECM production in Holsteins compared to Jerseys, 0.96 kg vs. 0.80kg CO_2 equivalent/kg ECM, and Kristensen *et al.* (2015) observed a production of more ECM/MJ CH_4 in Jerseys compared to Holsteins, 1.12 vs. 1.26. In contrast, Olijhoek *et al.* (2018), reported no breed effect in CH_4/kg ECM. Jerseys in this study produced more ECM/kg DMI, this therefore diluted the amount of CH_4/kg ECM produced. According to Hristov *et al.* (2014) improving productivity in dairy herds minimises the amount GHG produced when expressed as emissions per unit of product produced.

6.5 Conclusion

Efficiency of enteric emissions differed between breeds, with Holsteins emitting less CH_4/kg DMI and CH_4/kg BW while Jerseys produced less CH_4/kg ECM. Both lactation stage and parity affect the amount of enteric gases produced. Looking at the observed major variations in GHG emissions with parity and lactation stages, it can be concluded that accounting for production stages will bring more accuracy in estimating MEF.

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Chapter 7

General conclusions, study limitations and recommendations

7.1 General conclusions

In this study the production performance of Holstein and Jersey cows in a kikuyu pasture-based production system was compared using records that were compiled as part of the National Milk Recording and Improvement Scheme for estimating the breeding values of the herds. Using mathematical models from the National Research Council (NRC, 2001) and the Cornell Net Carbohydrate and Protein System (CNCPS), these records were used to estimate energy use, nitrogen use and enteric gas production efficiencies of Holstein and Jersey cows. Production parameters and estimated production efficiencies were compared by breed, lactation stage and parity. Factors affecting milk yield and composition included breed, parity, lactation stage and inter-calving period. While season of calving did not affect milk yield per lactation, it affected the shape of the lactation curve with cows that calved in summer having lower peak milk yields and higher persistency of production after peak.

Based on the estimation of the DMI of cows, Jersey cows had a higher DMI/kg BW in comparison to Holstein cows. The higher DMI/kg BW may be beneficial for grazing cows as energy in pasture is often limiting. Higher DMI/kg BW may result in higher energy intake which would reduce excessive lipolysis thus reducing the effects of the negative energy balance in Jersey cows. This may suggest that Jersey cows would be more suitable for pasture production systems in comparison to Holstein cows.

While the milk yield of Jersey cows was 74% of the milk yield of Holsteins produced, their ECM yield was 85.5% that of Holstein cows, indicating that milk yield *per se* may not be a suitable indicator of production efficiency because the higher fat and protein percentages in Jersey milk are not taken in account. When accounting for the fat and protein content in milk, Jersey cows showed higher efficiency in ECM/kg DMI and ECM/kg BW.

Breeds differed in milk yield and milk composition resulting in differences between efficiency measures. As expected, Holstein cows showed a higher efficiency in MY/kg DMI while Jerseys in milk components per kg DMI. These results indicate that Holsteins may be a more suitable breed for volume-based pricing system and Jersey cows for component-based pricing systems.

Milk yield increased with parity being approximately 25% higher in mature cows than their primiparous counterparts. The increase in MY/kg DMI, MF/kg DMI and Mprot/kg DMI are indications of the importance of longevity in dairy cows. A longer productive life to at least four parities is recommended as this would increase both the number of progeny born and lifetime milk production during the cow's lifetime. With lactation stages, the transition period was observed as the stage with high production efficiency as characterised by higher MY/kg DMI, MF/kg DMI, Mprot/kg DMI and ECM/kg DMI. Putting in place good management practices such as strategic feeding, genetic improvement, provision of shelter and, diseases prevention and control is recommended so as to improve cow productivity and longevity.

As a proportion of net energy intake (NEI), Holstein cows allocated more energy to maintenance due to the bigger frame compared to Jersey cows. Jersey cows showed a higher efficiency in converting NEI to MF, Mprot and therefore ECM while efficiency measures NEI/BW$^{0.75}$and NEm/BW$^{0.75}$ were lower. The high gross efficiency, that is, NEI use for milk production after accounting for NEm requirements, as well as longer more intense NEB in Holstein compared to Jerseys is an indication of high efficiency of Holsteins in utilising its body reserves compared to Jerseys.

Overall results regarding MN/NI were comparable to the 13% to 31% NUE in terms of milk yield that has been suggested for grazing animals. Jerseys showed high NUE as indicated by high MN/NI and low ManN/NI compared to Holsteins. Very little improvement in MN/NI with advancing parities (6%) was observed. This was expected as the percentage milk protein showed a decreasing trend with advancing parities. These findings can also be seen as confirming what has been reported by most researchers, a negative correlation between milk yield and its solid components. Lactation stage, however, resulted in a 41% decrease in MN/NI from transition to late lactation stages, indicating the shifting of nutrient use from milk production to body tissue as lactation stages progress.

Emitted enteric CO_2/kg ECM decreased by 14% from primiparous to mature cows and increased by 35% from transition to late lactation in both breeds. Enteric CO_2 emission is an area that needs further investigation as there were no other studies to support these findings. Holsteins showed efficiency in emitted CH_4/kg DMI and CH_4/kg BW than Jersey cows. Jerseys, however, produced less CH_4/kg ECM, confirming that improving productivity in dairy herds minimises the amount GHG produced per unit of product produced. The CH_4 production increased with parity, mature cows produced on average 16% more CH_4 than their primiparous counterparts. When compared to the transition period, approximately 27% more daily CH_4 was produced by cows during mid-lactation. The large variations because of parity and lactation stage should be considered when estimating MEF.

7.2 Study limitations

The study used records that were compiled for the National Milk Recording and Improvement Scheme for the estimation of genetic profiles of individual herds. Pasture intake was not directly measured as cows from both breeds grazed as one herd. Models were used to estimate total DMI and pasture intake was estimated as the difference between calculated DMI and offered concentrate. It is proposed that for similar studies, cows may be kept as a single herd while using the n-alkane method to estimate the DMI of individual cows.

The concentrate offered to cows was bought from a commercial company. Due to company policy on confidentiality, nutrient composition, e.g. the energy content, rumen degradable and undegradable protein contents could not be obtained from the supplier. To estimate the nutrient composition, a feed formulation software was used. Nutrient use efficiency and enteric gases production was therefore estimated using the nutrient composition data produced from the formulation software package. For future research, taking random samples of the concentrate for analysis on delivery is proposed so as to build a database of the concentrate nutrient content.

The DMI formula used was developed for Holstein cows (NRC, 2001), but it was also used to estimate the DMI of Jersey cows in this study.

7.3 Recommendation for further studies

The study does not include the overall economic efficiency of cows within standard commercial production systems. Further studies on other traits of economic importance need to be conducted for a well-informed conclusion. Below are some recommendations:

- Conduct feeding trials to determine the DMI of Jersey cows towards the development of a DMI model for Jersey breed;
- A detailed economic efficiency study comparing the two breeds which includes the lifetime milk income of cows, the value of progeny and beef as secondary sources of income, and
- Estimating heritability and repeatability of milk production traits to determine the extent to which the differences observed between and within breeds can be associated with additive genetic variance.